" A Survey of the Fishes, Aquatic Invertebrates and Aquatic Plants of the Colorado River and Selected Tributaries from Lee Ferry to Separation Rapids"

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CHAPTER 1

INTRODUCTION

The Colorado River and its tributaries between Lee Ferry and Separation Rapids, a distance of 389 km (see Appendix 1-1 for metric conversions) has been relatively unexplored by terrestrial and aquatic ecologists. Basic ecological investigations have only been initiated in the last decade due to the harsh environmental conditions and general lifficulty of access. Recent investigations include surveys of fish (Holden and Stalnaker 1970, Miller and Smith 1968, Minckley 1978, Minckley and Blinn 1976, Suttkus et al. 1976), aquatic invertebrates (Cole and Kubly 1976, Gaufin et al. 1960, Minckley 1978), aquatic plants (Czarnecki et al. 1976, Sommerfeld et al. 1976), bacteriological studies (Slawson and Everett 1974, Sommerfeld et al. 1976), physico-chemical studies (Cole and Kubly 1976, 1977, Sommerfeld et al. 1976), and riparian investigations (Carothers et al. 1976).

Historically, the primitive Colorado represented a unique aquatic habitat, ranging from a swift-flowing, turbid river to a system characterized by long periods of low flows during droughts. Water temperatures fluctuated seasonally with the water being warmer in spring and summer, and cooler during fall and winter. Physico-chemical regimes varied with the flow regimes, i. e., spring run-off, summer flooding, or conversely, summer drought. It was within this system that one of the most unique North American fish faunas developed, a faunal assemblage which had one of the highest rates of endemism of any river basin in North America (Miller 1958). This fauna included the bizarre appearing humpback chub (Gila cvnha) and razorback sucker (Xvrauchen texanus) as well as the roundtail chub (Gila robusta), speckled .dace (Rhinichthvs osculus), flannelmouth sucker (Catostomus latipinnis) and bluehead sucker (Catostomus discobolus).

Currently, the Colorado River is drastically different from its original state due to the construction of numerous hydroelectric dams, which have stabilized the riverine environment. The turbidity has decreased and scouring flows have ceased to exist. Physico-chemical factors, which fluctuated dramatically in pre-dam years, are also less variable due to the Glen Canyon Dam. Water temperatures, which)nce varied seasonally are now cold and change very little throughout the year. A diurnal tidal fluctuation, coincident with hydroelectric demand, has markedly affected the riparian zone and fish and invertebrate productivity in the various tributaries.

As a result of these changes and the introduction of exotic fish, the number of native fish species has declined. The Colorado squawfish, bonytail and roundtail chub can be considered extinct within Grand Canyon. The flannelmouth and bluehead suckers are apparently thriving in the dam-altered regimen; the speckled dace is well represented in tributary areas and less common in the mainstream; the humpback chub is generally restricted to the Little Colorado River area, and the razorback sucker is extant in Grand Canyon based on the capture of one specimen in 1978 (Minckley and Carothers 1980). These native species now share the river and its tributaries with at least 18 exotic or introduced species.

The present investigation was conducted to expand the available base-line information on the aquatic resources of this region, with major emphasis being placed on fish, aquatic invertebrates and plants. This study was conducted within the Colorado River and selected tributaries, from Lee Ferry (R. M. 688.6) to Separation Rapids (R. M. 650.6) during 1977 - 1979.

The field data and collections were gathered during six river expeditions (Nov. - Dec. 1977, Jan., May, June, August and Oct. - Nov. 1979) and four helicopter fly-in surveys. The river expeditions (July and Sept. 1977; July and Oct. 1978) lasted from 12 to 18 days and represent approximately 1440 field person days of effort. The helicopter fly-in surveys were all in the vicinity of the Little Colorado River Gorge. Approximately 40 person-days of field effort were expended in this area studying the status and distribution of the endangered humpback chub.

The ichthyofauna were studied in order to better understand their life hisotry, ecology and interrelationships, especially with exotic species. This entailed gathering data on distribution, movement, relative abundance, age and growth, food habits and reproductive cycles for all possible species. Condition factors and length-weight relationships were also determined for all gamefish. Data pertaining to angler use of the area, fish introductions and ectoparasites were also collected. The status of protected endemic species, and any restoration efforts pertaining to them, are examined and discussed relative to the major habitat changes, along with the reasons for their decline.

Aquatic invertebrate communities were studied in order to determine what aquatic groups are present, their distribution, abundance, diversity and biomass. Factors affecting invertebrates, such as fluctuating water levels and substrate differences were examined and related to seasonal and biotic influences.

Aquatic plant communities were examined in order to determine what species are present, their abundance and seasonal variations along the mainstream and in selected tributaries. All known man-made or natural discharges were determined, along with their effects on the Colorado River.

These data and information from the literature were then integrated to provide an overview of the aquatic ecosystem within Grand Canyon National Park. This study will provide a baseline for further investigations of a more directed nature, as well as data to assess trends in the distribution and abundance of, especially, endangered fish species.

CHAPTER 2

MATERIALS AND METHODS

Investigations were conducted on the Colorado River and selected tributaries from Lee Ferry (R. M. 689) to Separation Rapids (R. M. 450.6) during 1977 - 1979.

The major river trips varied from 14 to 19 days in length with the respective trip dates being 21 November - 8 December, 1977 (winter); 22 January - 6 February (winter), 12 - 29 May (spring), 29 July - 14 August (summer), and 30 September - 18 October, 1978 (fall). One additional Colorado River trip was made from 22 - 23 February, 1978, between Diamond Creek and Pierce Ferry. The Paria River was sampled the day prior to each Colorado River trip, with the exception of the first sampling trip, which was made on the 26 - 27 of October, 1977. The winter trips ended at Diamond Creek (R. M. 463), while the remaining trips ended at Pierce Ferry (R. M. 404). Designated river miles follow the Pacific Southwest Interagency Committee, Water Management Subcommittee (1978).

Due to technical and logistical problems, many of the sampling procedures were perfected during the course of the first winter river trip. Consequently the data from this trip were largely used to supplement data from the second winter trip. An additional Colorado River trip from 9 - 22 June, 1978, was used to supplement summer data pertaining to fish distribution, movement, growth and age, and records of uncommon fish. For two days beginning on 6 July, 1978, we made fish collections 20.8 km and 8.0 km upstream from the Little Colorado River confluence, at Blue Springs and Big Canyon Creek, respectively. Little Colorado River collections were supplemented by data from a September 1977 trip (Minckley 1977). Flooding in this system prevented further trips.

During the five major river trips, we carried out a sampling program to assess seasonal changes in fish, aquatic invertebrates and aquatic plants (Table 2-1). The mainstream was sampled at least every 32 km, while the tributaries were sampled at their confluences and approximately 200 m upstream from the confluences.

<u>Physico-Chemical Parameters</u>

Physico-chemical measurements of specific conductance, pH and water temperature were taken routinely as part of our sampling program. Water temperature (^{o}C) was measured in the River and at the confluence and upstream stations of all tributaries using mercury-filled glass thermometers. Specific conductance, a measure of total dissolved salts (Czarnecki 1978), was measured with a Hach Conductivity Meter (Model 17250) referred to 25^{o}C. Hydrogen ion concentration (pH) was determined by two methods. The first method utilized a Hach wide range pH indicator. This indicator, used during November - December, 1977, January - February and May, 1978, appears to have malfunctioned in that it consistently gave readings of 9.0 for all tributaries. Consequently, the data collected by this particular method have been omitted from Appendix 3-3. A pH meter (Hach model 17200) was used during the October 1977, Paria sampling and for all tributaries during July - August and Spetember - October, 1978. Problems in keeping these meters dry and functioning during the trips were the cause for data to be occasionally missing. These data were supplemented with literature values for the ranges of major ions and plant nutrients in the mainstream and selected tributaries (Cole and Kubly 1976, 1977).

Table 2-1. Dates and types of sampling of primary, secondary tributaries,and springs within the study area. Types of sampling: A = fishes, B = aquatic plants, C = aquatic invertebrates.

	River Miles WPRS	River Miles USGS	Winter 1977	Winter 1978	Spring	Summer	Fall
PRIMARY TRIBUTARIES:							
Paria R.	688.4	1.0R	B, C		A, B, C	A, B, C	A, B, C
L. Colorado R. (confl.)	627.4	61.1L	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
L. Colorado R.** (20.8 km upstr.)	627.4	61.1L				A, B, C	
L. Colorado R., Big Canyon**						A, B, C	
Bright Angel Crk.	601.3	87.9R	A, B, C	A, B, C	B, C	A, B, C	A, B, C
Shinumo Crk.	580.7	108.9R	A, B, C	A, B, C	B, C	A, B, C	A, B, C
Tapeats Crk.	555.8	133.5R	A, B, C	A, B, C	B, C	A, B, C	A, B, C
Deer Crk.	553.2	136.1R	A, B, C	A, B, C	B, C	A, B, C	A, B, C
Kanab Crk.	546.1	143.5R	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
Havasu Crk.	533.0	156.9L	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
SECONDARY TRIBUTARIES:							
Buckfarm Crk.	647.9	41.0R	B, C			A, B, C	A, B[1]
Nankoweap Crk.	636.4	52.0R	A, B, C	--		--	--
Unkar Crk.	616.5	73.0R	--	A, B, C	--		--
Clear Crk.	604.9	84.0R	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
Pipe Crk.	600.2	89.0L	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
Hermit Crk.	594.4	95.0L	B, C	A	A, B, C	A, B, C	A, B, C
Crystal Crk.	590.8	98.5R	B, C	A, B, C	A, B, C	A, B, C	A, B, C
Stone Crk.	557.7	131.0R	A, B, C	--	A, B, C	A, B, C	--
155 Mile Cyn.	539.7	155.0R	--	--	B, C	--	
National Cyn.	523.3	166.8L	B, C	B, C	--	C	
Three Spring Cyn.	474.4	215.5L		B, C	B, C		B, C
219 Mile Cyn.	470.8	219.0R	B, C	B, C	--		--
Diamond Crk.	464.4	226.0R	B, C	A, B, C	A, B, C	A, B, C	A, B, C
SPRINGS:							
Vasey's Paradise	688.1	31.9R	B, C	B, C	B, C	B, C	B, C
Elves Chasm	572.8	116.5L	B, C	--	B, C	A, B, C	A, B, C
Lava Falls Spr.	510.6	179.0R	B	B	B, C	--	--

(continued)

Table 2-1 (cont.). Dates and types of sampling of primary, secondary tributaries, and springs within the study area. Types of sampling: A = fishes, B = aquatic plants, C = aquatic invertebrates.

	River Miles WPRS	River Miles USGS	Winter 1977	Winter 1978	Spring	Summer	Fall
SPRINGS (cont.):							
Travertine Falls	459.7	229.2L		A, B, C		A, B, C	A, B, C
Bridge Cyn. City	455.1	235.0L		A, B* C	B, C		A, B, C
INCIDENTAL COLLECTIONS:							
Phantom Crk.			B	--	A		
190.5 Mile Cyn.	497.5	190.5L		B, C	--		
Spring Cyn.	485.1	203R		B, C	B, C	--	B, C
Travertine Cyn.	459.1	229L		A, B, C	A, B, C	A	

* Bridge Canyon, not Bridge Canyon City was sampled on this date.

[1] Sampled at confluence only

** Collection dates 6 - 7 July, 1978

The data presented on the area of drainage basins, origins and discharge fluctuations were drawn primarily from the literature (Dolan et al. 1978; Hamblin and Rigby 1968; Huntoon 1968, 1970; Johnson and Sanderson 1968; Leopold 1969; U.S.G.S. 1954a, b, 1957 a, b, 1962a-c). Flow measurements were taken on the Paria River during October, 1977.

Aquatic Plants

Aquatic plants (periphyton and aquatic macrophytes) were sampled seasonally during 1977 - 1978 in the mainstream of the Colorado River and selected tributaries.

Aquatic Macrophytes. The aquatic macrophytes were sampled by two methods. A list of macrophytes and their general abundance and phenology was developed for the mainstream and each tributary. Representative specimens were collected and pressed to verify field identifications and to serve as voucher specimens.

The second aquatic macrophyte sampling technique involved sampling transects in several stands of emergent vegetation (e. g., bulrush, *Scirpus* spp.) near the Paria River, Little Colorado River, and Bright Angel Creek. The density, frequency and percent cover of each species were determined using 0.25 m^2 to 0.5 m^2 quadrats that were spaced equidistant along the transects. Density measurements were made by counting the number of individuals of a species within a quadrat (Daubenmire 1968). Cover was estimated visually for each species within a quadrat following the classification system of Daubenmire (1968). 7Āequency was determined as the percentage of occurrence of a species within each quadrat. The importance value of each species was calculated (Curtis and McIntosh 1950), with 300 being the maximum possible value. Transect length, quadrat size and spacing were maintained in subsequent samples once established within a particular stand.

Taxonomic references utilized to identify aquatic macrophytes included Correll and Correll (1975), Hermann (1970, 1975), Gould (1973), Kearney and Peebles (1964) and McDougall (1973). Specimens of aquatic macrophytes collected during this study were deposited in the herbaria of the Museum of Northern Arizona and Northern Arizona University.

Lists of plant species collected from the Grand Canyon (Bennett 1978, Carothers and Aitchison 1976) were compared with those in Correll and Correll (1975). A new plant species list was made which was a combination of those species common to both lists and species added to the Grand Canyon flora as a result of this study.

Periphyton. Collections of periphyton were made in two ways. Samples of approximately equal size were taken in habitats where quantitative sampling was not feasible (e. g., Vasey's Paradise with solid rock substrate).

Quantitative periphyton samples were taken by brushing a 7.6 cm^2 area of rock substrate or removing a 5 cc volume of surface sediment using a plastic syringe with the end removed (Douglas 1958).

Quantitative periphyton transects, utilizing a combination of the brush and syringe techniques, were run near the invertebrate transects (confluence and 200 m up the tributary) at all tributaries. Water temperature, specific conductance and pH were measured in conjunction with periphyton samples.

Diatom slides of the preserved specimens were made by placing 0.5 ml of a homogenized sample on a 22 mm x 22 mm glass cover slip and mounting in Hyrax (Rand et al. 1976). Identification and enumeration of diatoms were made by examining twelve strips (.067 mm x 22 mm) at 12500 x magnification under a Zeiss phase-contrast optical system. The number of diatoms/cm^2 of substrate was calculated for each taxon and for entire sample.

Taxonomic references used for identification of diatoms include Hustedt (1930), Patrick and Reimer (1966, 1975) and Czarnecki and Blinn (1977, 1978). Algal samples were placed in the collections of the Museum of Northern Arizona and Northern Arizona University.

Aquatic Invertebrates

Collections of aquatic invertebrates were made from tributaries and springs within the study area. Sampling of the mainstream Colorado River was restricted to side pools and eddies due to difficulties caused by the swift current and rocky substrate (Woodbury et al. 1959), with dredges being taken approximately every 32 km along the River. Qualitative samples of benthic invertebrates were taken by hand in many side pools and gravel bars exposed at low water levels. Consequently, mainstream collections emphasized qualitative rather than quantitative sampling. Intermittent streams and springs were sampled qualitatively, except when circumstances permitted the collection of quantified data.

Transects located at the confluence of each tributary with the Colorado River and 200 m upstream were established at most of the tributaries and two of the springs. The exact position of the confluence transect varied with the mainstream water level at the time of sampling, with the samples being taken further up the tributary at high mainstream water levels than at lower mainstream water levels. In all cases, confluent transects were established at the lowest point possible for sampling and remained stationary during this study.

A few exceptions wera made to the above procedure. The upstream transect on the Paria River was located 8.0 km from the confluence, and upstream transects on the Little Colorado River were located at Blue Springs and Big Canyon, 20.9 km and 11.3 km from the confluence, respectively. A 200 m transect on the Little Colorado River was established during the final sampling trip in October. The 200 m transect at Hermit Creek, established in December, was changed in August when flash flooding caused a channel change in the stream. A similar situation occurred in May at Diamond Creek when road grading moved the stream channel from the downstream side of the road to the upstream side.

The number of samples taken at each transect was determined by the width of the tributary. A maximum of eight collections comprising four duplicate samples (two marginals and two at stream center) were taken at the larger tributaries, and a minimum of two samples (one duplicate) were taken at the smaller tributaries. One additional sample was taken at each 200 m transect for the Museum of Northern Arizona invertebrate collections. Many invertebrates obtained from fish seining were also collected.

The surber-type stream bottom sampler, with a mesh size of ten threads/cm and a sampling area of 929 cm^2, was used in fast flowing, shallow water (less than 30 cm in depth), with sand, gravel and rubble substrates. A mini-Ponar grab with a sampling area of 232 cm^2 was used where the depth exceeded 30 cm, and silt and sand substrates predominated.

The width and maximum depth of the stream as well as substrate type were also assessed. Substrate configuration was estimated visually using Cummins' (1962) scale of particle sizes. Biological parameters such as algal cover, detrital accumulations and surrounding aquatic and terrestrial vegetation were assessed when present.

Benthic samples were washed through a #30 U. S. standard sieve before preservation in 10% formalin. Laboratory processing of the samples followed procedures outlined by Lind (1974), Welch (1948) and Weber (1973). All invertebrates were stored in 95% isopropyl alcohol for later identification.

Identifications were made to the family or genus (where possible) with the exception of the earthworms (Annelida) which were only identified to class. Aquatic invertebrates were identified with the aid of keys from Edmondson (1959), Johannsen (1934, 1935, 1937a, b), Pennak (1953), Ross (1944) and Usinger (1956).

Each taxon was counted to obtain density values, then dried in an oven at 100 C for four hours. Dry weights for biomass data were obtained using a Sartorius Analytical Balance. Case-dwelling larvae and pupae were weighed without their cases. Members of the broad-shoulder water striders (Veliidae), water striders (Gerridae), and water treaders (Mesoveliidae) were not considered true benthic invertebrates, and consequently were not included in the calculations.

All samples from each transect were combined to reduce error resulting from sample size. Biomass, diversity (Shannon and Weaver 1963) and evenness (Pielou 1975) were calculated for each transect. Percent density, biomass, and density and biomass per unit substrate area were calculated on a seasonal basis for each transect. Community similarity indices (C) were calculated using the number of individuals in each taxon for comparing confluent and upstream invertebrate communities as well as those from different tributaries (Onsting 1956).

Fish

Fish samples were taken using trammel, gill and fyke nets, and by seining and electrofishing. Two trammel nets, 91.5 m x 2.5 m with a 4 cm outer wall and a 3.8 cm inner wall, were set in the River near each night's camp. Fyke nets were placed at the confluence of the tributaries during the winter and fall trips and in the mainstream during the initial winter trip. This practice was discontinued in later trips as it proved ineffective. Experimental gill nets, 45.7 m x 1.5 m with mesh sizes of 2.5, 3.8, 5.0 and 6.4 cm were used primarily during the helicopter-based operation into the Little Colorado River, and in collecting activities at its mouth.

Seining collections were made using one or a combination of the following seines: a 30.9 m x 2.5 m x 1.8 cm bag seine, 6.1 m x 1.9 m x 3 mm and 1.9 m x 1.9 m x 3 mm minnow seines.

Tributaries were sampled by seining the lower 200 m of the stream. Additional collections were made 0.8 to 1.6 km upstream along most tributaries to document the occurrence of fish in these areas. The mainstream Colorado River was seined sporadically during the summer and fall river trips.

Data recorded from each seine haul included an estimate of the area seined and the number and types of fish collected. This information was used to estimate the relative density of fish within a given system.

Electrofishing was initially conducted using a 120 volt AC generator directly connected to two electrodes. This proved unsatisfactory and modifications were made in order to imporve galvanonarcosis and galvanotaxis, for reducing harmful effects to the fish and improving the safety of the crew. These modifications included incorporating electromagnetic and solid state devices in such a manner that the electrofishing system was converted to DC which is continuously variable from 0 to 600 volts.

Electrofishing was conducted throughout the mainstream, with all likely areas of fish concentrations being examined. The majority of fish were released after being recorded and tagged. Electrofishing of the tributaries using a back pack shocker was discontinued due to malfunctions in the equipment and the swiftness of the tributaries.

In all cases, a subsample of fish taken by these various methods was preserved in 10 percent formalin and returned to the laboratory for analysis of food habits, fecundity and growth and age studies.

Distribution and relative densities of fish within the mainstream Colorado River were determined from electrofishing and trammel net data. Relative densities are presented on a seasonal basis for each river section. Trammel net data are also presented for each river section and are expressed as the number of fish collected per net night, in a standard trammel net set which is defined as a 12 hour overnight set of one net having the dimensions of 91.5 m x 2.4 m. Trammel net data for Little Colorado River collections are based on 12 hours of daytime sampling. Gill net sets are presented in a similar manner (i. e., daytime or nighttime), with a standard gill net set representing one 12 hour set using a net 45.7 m x 1.2 m. Gill net data are also presented as meters drifted.

Movement data were determined by tagging operations, started during the January - February trip. Exotic and nonendangered native fishes over 15 cm in total length were tagged using Floy Anchor Tags, Model FD-68C. These tags were 5 cm in length, numbered sequentially, and color coded for the various trips. Anchor tags were attached to the body, below the dorsal fin, and were placed so that the interneural rays of the dorsal fin held them in place. All tags were inscribed with the following legend, "MAIL TO DEPT BIOL MNA RT 4 BOX 720 86001."

Humpback chubs were tagged using Floy Fingerling Tags, with dimensions of 9 mm x 3 mm. These tags were attached immediately behind the dorsal fin by running vinyl thread through the skin dorsally and secured with a double overhand knot. Excess string was then clipped off and the puncture sites were treated with 1% potassium permanganate. All tagged fish were weighed and measured prior to release.

Food habits were determined by stomach content analysis. This was accomplished either by removing stomachs to the pyloric sphincter or by removing the digestive tract and examining one fourth of its contents. The latter method was used to assess the diets of those species with poorly defined stomachs (i. e., carp, flannelmouth suckers and bluehead suckers). Food organisms were identified to family when possible (Barror and DeLong 1964, Ware and Whipple 1959) under an Olympus 40x binocular dissecting microscope. Fish and reptile remains were identified by comparing body parts to whole specimens from the study area.

A number of procedures have been developed to quantitatively assess the food habits of fish (Hynes 1950, Lagler 1956, Ricker 1958). During this study, the mass or weight method was employed. In this procedure each food item was dried at 100 C for four hours, allowed to cool at room temperature (25 C), and weighed on a Sartorious analytical balance to the nearest 0.1 mg. Feeding selectivity was calculated using Ivlev's (1961) Electivity Indices. Kulczynski's Similarity Index (Oosting 1956) was used as an indication of interspecific dietary overlap. Values of mass derived from items classified as detritus and invertebrate remains were excluded from statistical comparisons, as these dietary elements do not represent specific taxonomic categories.

For purposes of discussion, food habit data were divided into three areas, 1) the Colorado River (R. M. 689 - 449), 2) the northern tributaries (Paria River, Bright Angel, Shinumo, Tapeats, Deer, Clear and Crystal Creeks) and 3) the southern tributaries (Little Colorado River, Havasu, Pipe and Hermit Creeks, and Elves Chasm).

The age structure of the common Colorado River fishes was determined by several commonly accepted techniques including the scale (Hatch 1973, Lagler 1956, Minckley 1972), opercle (LeCren 1947, McConnel 1951) and pectoral spine (Sneed 1951) methods. The scale method (Van Oosten 1929) was used for the rainbow trout and the speckled dace. Several other species showed a high frequency of damaged or regenerated scales which made the scale method unacceptable. For this reason and due to ease of application (Nilsson 1921), the opercle method was utilized for humpback chub, flannelmouth suckers, bluehead suckers, and carp. Pectoral spines were utilized for age determinations in the channel catfish since this species has no scales and a complex opercular structure. Due to an insufficient sample size (N = 20), no length-frequency distribution was constructed for channel catfish.

Age class designations followed the procedure outlined by Tesch (1968) whereby each fish is assigned to an age class based on the number of annuli observed, rather than being attributed a certain number of years. Back calculation of growth was computed using the "N Annuli" Program on file in the Arizona State University computer which utilizes the Dahl-Lea Direct-Proportion method (Lagler 1956). Sexual differences in growth rate were analyzed by a t-test. Reproductive condition was determined by field observations and by computing the gonadal somatic index (Carlander 1969). Fecundity estimates were made by determining the number of eggs present in a subsample of the ovaries. Condition factors, which provide a measure of the well being or "plumpness" of a fish, were computed for all gamefish collected (Carlander 1969, Lagler 1956). The values of this [illegible] ran[illegible] from zero to three with three being considered the ideal condition. Length-weight relationships are a means of determining the length or weight of a fish from a given population when only one of these parameters is available.

The number of ectoparasites and the species of fish on which they occurred were recorded after visual examination.

A Creel Census of Bright Angel Creek, Coconino County, Arizona was conducted from November 1977 through March 1978. The study area extended from the confluence of Bright Angel Creek and the Colorado River to the Clear Creek Trailhead, a distance of approximately three kilometers. This reach of Bright Angel Creek was broken into six sites from which to monitor angler use. The sites are as follows: 1) Confluence (confluence of Bright Angel Creek and the Colorado River), 2) Lower End (area between the Confluence and the Bridge), 3) The Bridge (area under and just upstream of the Bridge, 4) Campground (the portion of stream directly adjacent to Bright Angel Campground, 5) Phantom Ranch (the portion of stream adjacent to and just downstream of Phantom Ranger Station and Phantom Ranch and 6) Upper End (Bright Angel Creek between Phantom Ranch and the Clear Creek Trailhead) (Figure 2-1).

Five census days were expended each month except in December 1977, and March 1978, when three and two days were expended, respectively. Overall, a total of 20 census days were expended. Shoreline interviews were conducted during the morning and afternoon of each day with the data being recorded on standard Arizona Game and Fish Commission (AGF) Creel Census forms. Although the total number of successful and unsuccessful

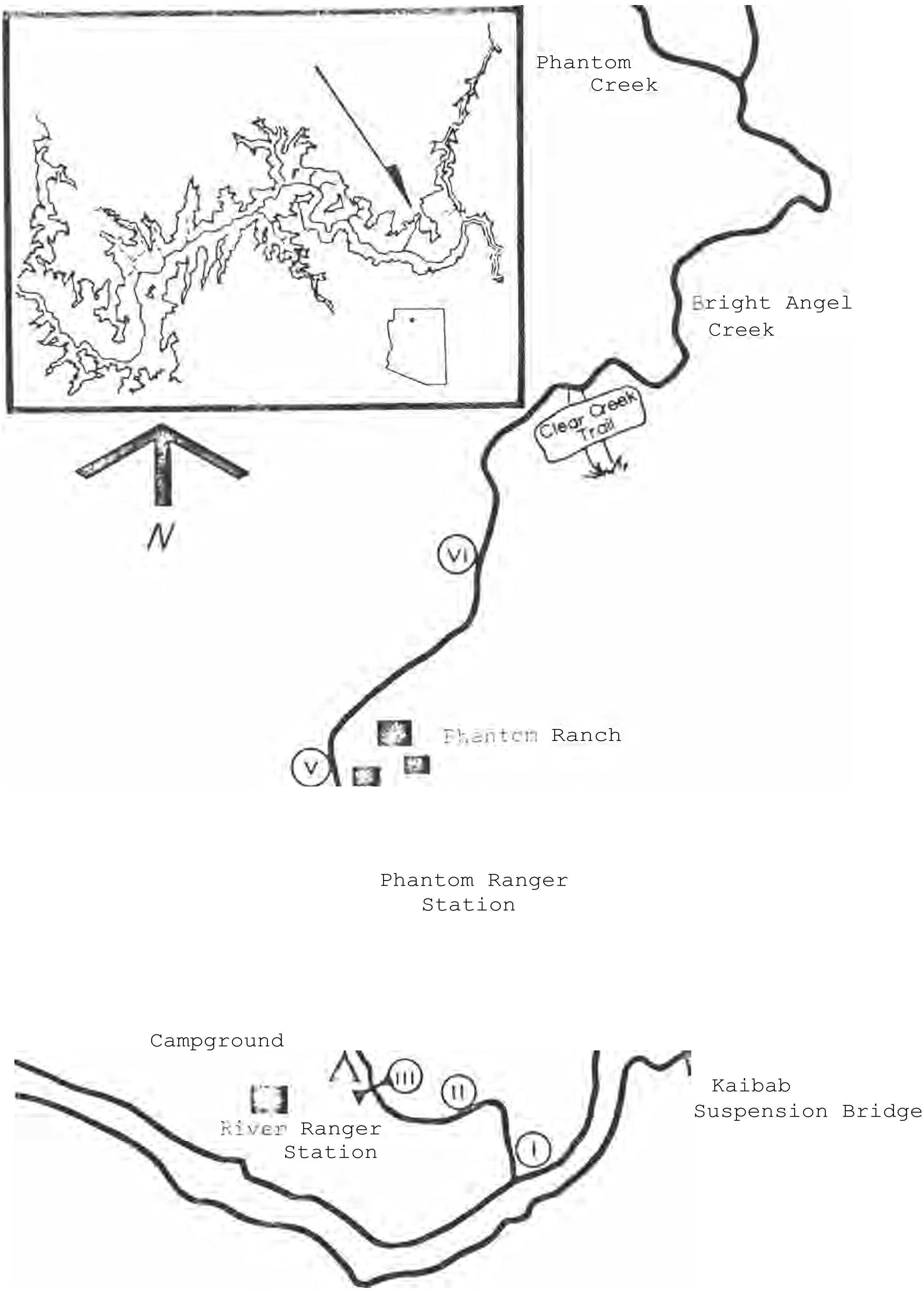

Figure 2-1 Location of study area, Bright Angel Creek, Grand Canyon National Park, Coconino County, Arizona.

anglers were recorded each day, only successful anglers were interviewed during this survey.

The following information was collected from each successful angler party: number in party, angler sex and residence, fishing method and technique, length of time spent fishing, location in the study area, number of successful anglers in the party, number and species of catch, and length and weight of each fish. Lengths of creeled fish were reasured to the nearest millimeter, and uncleaned fish were weighed to the nearest tenth kilogram. Fish stomachs were removed, placed in whirlpacks, preserved in 10% formalin, and returned to the laboratory for dietary analysis.

Several of the angler statistics were estimated (Appendix 2-1) since only successful anglers were interviewed. Angler Use was calculated as monthly means and percentages. Angler Pressure was calculated on a mouthly basis and as a percent of annual visitation.

A Creel Census of the 24 km reach of river between Glen Canyon Dam and Lee Ferry was conducted by Arizona Game and Fish between Jul 1977, and June 1978. Both boat and shore anglers were interviewed, as well as some anglers returning to Lee Ferry at the end of the day. Data collected were the same as those in the Bright Angel Creek Census, with only the angler location being omitted. All fish measurements were recorded in standard English units.

The National Park Service (NPS) at Lee Ferry has been conducting daily counts of fishermen and boat days, and compiling them into monthly visitor and special use studies. The number of fishermen per day is determined by a count of boat trailers at the Lee Ferry parking lot, multiplied by a constant (m) to deternine the number of boat fishermen, which is then added to a count of shore fishermen at Lee Ferry proper, resulting in a total fishermen per day (boat trailers x m) + shore fishermen = total fishermen . The number of boat days is determined by adding the boat trailer count to the number of boat rentals for that day. Trailer counts were conducted at approximately 2:00 PM each afternoon and angler counts at approximately 8:30 AM each morning (C. Dilts, N National Park Service, pers. comm.).

Angler use of Diamond Creek at its confluence with the Colorado River is controlled by the Hualapai Tribal Council through the Office of Hualapai Wildlife and Outdoor Recreation (HWLOR). Permits can be obtained by interested parties from that office. HWLOR was contacted to obtain data concerning the number of permits issued and the extent of general visitation at Diamond Creek and its confluence with the Colorado River. Records were requested for the study period (November 1977 - March 1979) as well as annual records for the previous six years (1972 - 1977). An estimate of angler pressure during commercial raft trips (Appendix 2-2) was calculated based on the responses of the 14 outfitters returning an angler use questionnaire.

Chapter 3

DESCRIPTION OF THE STUDY AREA

the study area included the mainstream Colorado River and 27 tributaries and springs between Lee Ferry (River Mile 688.6) and Separation Rapids (R. M. 450.6) (Table 3-1, Figure 3-1). Throughout the report, the Water and Power Resources Service (WPRS) river mile designations R. M. are used to locate study sites. Conversions of these river miles to the system used by Belknap (1969) and the National Park Service in Grand Canyon are in Table 3-1. For the purposes of consistently sampling various portions of the River during this study, the mainstream was partitioned into 12 (I - XII) river sections, each approximately 32 km in length (Table 3-1, Figure 3-2).

Colorado River

The Colorado River originates on the west slope of the Continental Divide near Mount Richthofen, Rocky Mountain National Park, at an elevation of 3965 m. Following a southwesterly course through Colorado and Utah before entering northeastern Arizona, the River traverses approximately 885 km and drops 942 m in elevation by the time it reaches Lee Ferry in Arizona (Iorns et al. 1965). Twenty-four kilometers upstream from Lee Ferry, the River is impounded by the 216 m high Glen Canyon Dam, forming Lake Powell.

The downstream portion of the River has been considerably affected since the Dam's completion in 1963. Prior to 1963, the River exhibited a completely different rogimen in terms of seasonal discharge, sediment load

Table 3-1. Key to river section and tributary numbers.

Tributary	Map Key (Figure 3-1)	*River Mile Belknap	River Miles Section (Figure 3-2)	River Mile W.P.R.S.
Lee Ferry		0.0	I	688.6
Paria River	A	1.0		688.4
Mile 20		20.0		668.6
Vasey's Paradise (spr.)	1	31.9	II	658.1
Mile 40		40.0		648.6
Buck Farm	2	41.0	III	647.9
Nankoweap	3	52.0		636.4
Mile 60		60.0		628.6
L. Colorado River	B	61.1	IV	627.4
Unkar	4	73.0		616.5
Mile 80		80.0		608.6
Clear Creek	5	84.0	V	604.9
Bright Angel Creek	C	87.9		601.3
Pipe Creek	6	89.0		600.2
Hermit Creek	7	95.0		594.4
Crystal Creek	8	98.5		590.8
Mile 100		100.0		588.6
Shinumo Creek	D	108.9	VI	580.7
Elves Chasm	9	116.5		572.8
Mile 120		120.0		568.6
Stone Creek	10	131.0	VII	557.7
Tapeats Creek	E	133.5		555.8
Deer Creek	F	136.1		553.2
Mile 140		140.0		548.6
Kanab Creek	G	143.5	VIII	546.1
155 Mile Canyon	11	155.0		539.7
Havasu Creek	H	156.9		533.0
Mile 160		160.0		528.6
National Canyon	12	166.8	IX	523.3
Lava Falls Spring (spr.)	13	179.0		510.6
Mile 180		180.0	X	508.6
Mile 200		200.0		488.6
Three Springs Canyon	14	215.5	XI	474.4
219 Mile Canyon	15	219.0		470.8
Mile 220		220.0		468.6
Diamond Creek	16	226.0	XII	464.4
Travertine Falls (spr.)	17	229.2		459.7
Bridge Canyon (spr.)	18	235.0		455.1
Separation Canyon	19	239.5		450.6

KEY: spr. - spring
W.P.R.S. - Water and Power Resources Service
* see Belknap (1969).

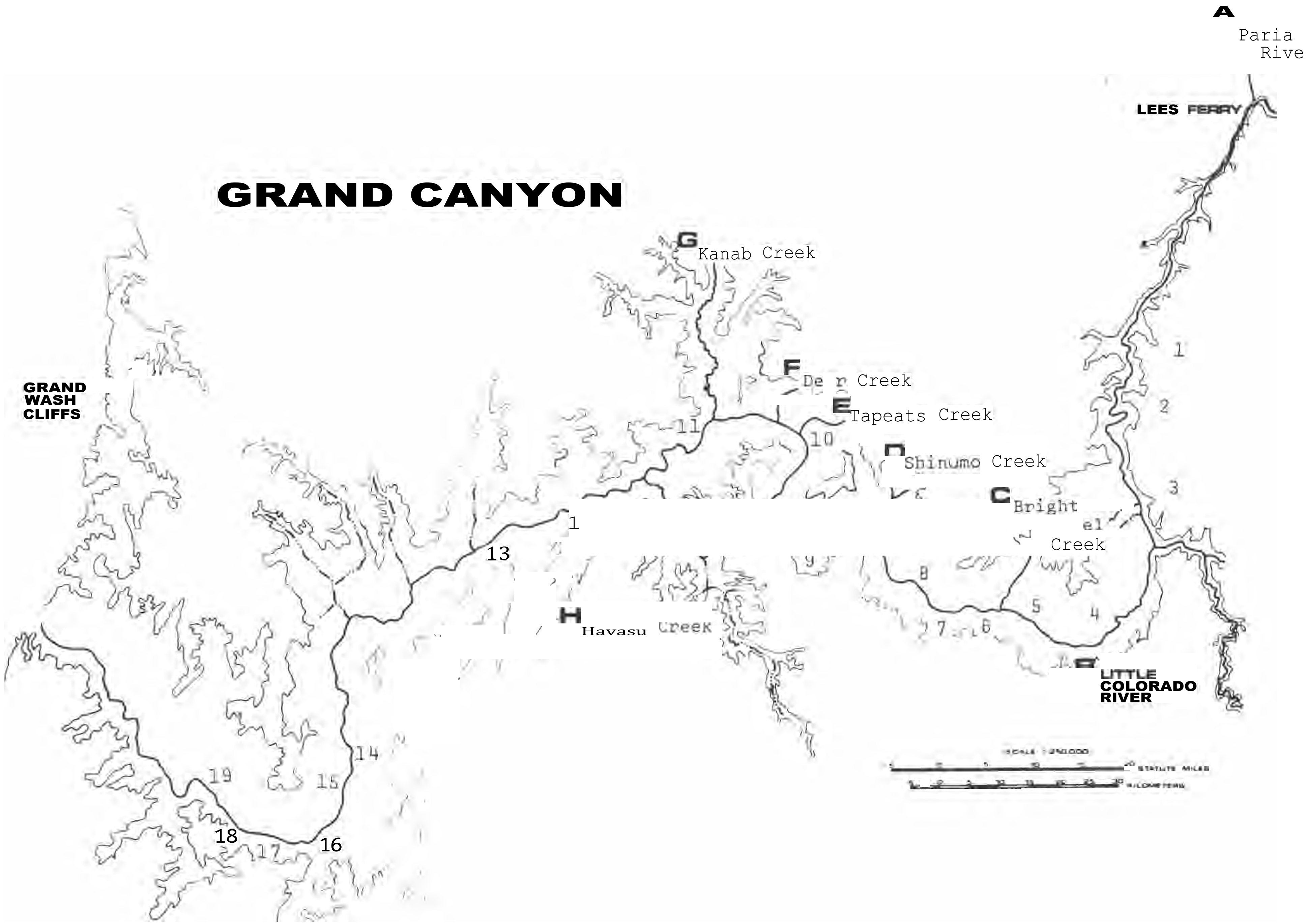

Figure 3-1. Map of the study area showing tributaries A through H (most heavily sampled), and 1 through 19, respectively.

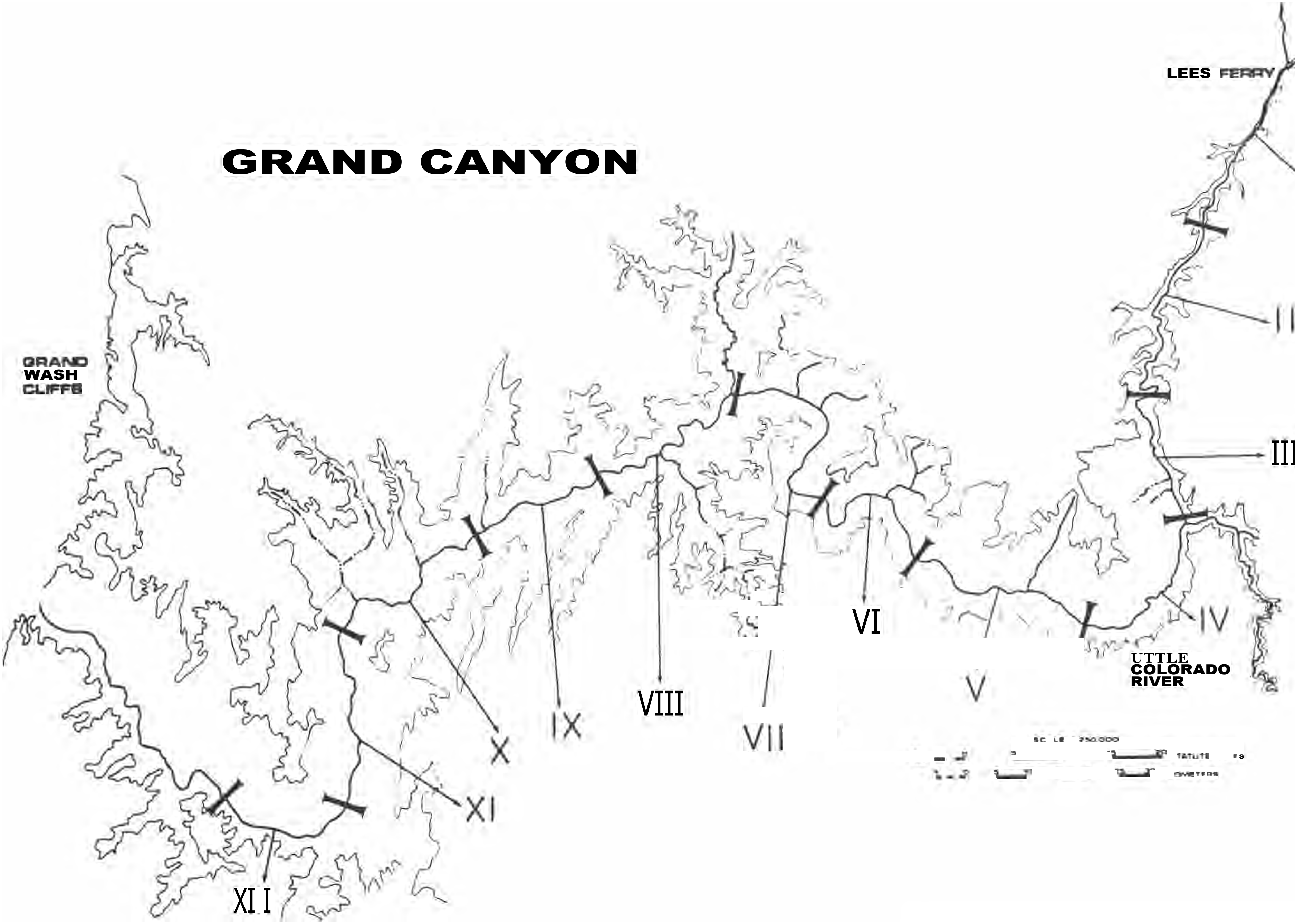

Figure 3-2. Map of the study area showing river mile sections I through XII.

and water temperature. Spring snowmelt from the headwaters of the Colorado River used to result in peak flows during May and June, followed by a gradual decline during the remainder of the year. Flash flooding would frequently cause a second peak in late summer. During periods of high flow, the River transported substantial amounts of sediment through the Canyon, thus scouring the channel. As waters receded in the summer, sand and silt were deposited along the River margins. This alternating erosion and deposition produced a time-varying fluvial terrace morphology (Dolan et al. 1974). Most of the pre-Dam terraces were deposited along the River in areas with reduced velocity, such as in alcoves along the banks, in the mouths of tributaries and on point bars in wide sections of the River. Terraces were also built up as narrow deposits bordering wide, straight stretches of the River. By far the most common point of deposition was in the eddies occurring above and below the rapids (Dolan et al. 1974).

Pre-Dam flooding often reached 2,434 m^3/s, with discharges of 2,830 cms occurring every few years. A maximum discharge of 5,660 cms was recorded in 1921 at the Phantom Ranch (R. M. 601.3) gauging station. Sediment load averaged 374 metric tons/day. A maximum of 27,164 metric tons/day was recorded in 1927 with a discharge of 3538 cms (Dolan et al. 1974). Pre-Dam seasonal water temperature extremes of the River ranged from 0 to 27 C.

Vegetation patterns along the River margins have been substantially altered by Glen Canyon Dam. Prior to the operation of the Dam, the zone closest to the River was subject to annual flooding. The vegetation in this zone was composed of several ephemeral plant species and a few mesophytic woody plants such as seep willow (Baccharis salicifolia), desert broom (Baccharis spp.) and true willows (Salix spp.) that became established during periods between floods. Above this ephemeral zone was an area of vegetation whose lower boundary was delineated by the high water mark of the major floods. Species within this zone included Apache plume (Fallugia paradoxa), redbud (Cercis occidentalis), hackberry (Celtis reticulata), mesquite (Prosopis juliflora) and acacia (Acacia greggii). Desert species i. e., brittle bush (Encelia farinosa), various cacti (Opuntia spp.), creosote bush (Larrea divaricata) Mormon tea (Ephedra spp.) which are not affected by the River (Carothers et al. 1976) live on the talus slopes above this zone.

A new riparian community is now established from Lee Ferry to Separation Rapids, in the ephemeral zone once inundated by seasonal flooding. The lower boundary of this new community is the present-day high water mark. Vegetation in this zone is composed primarily of salt-cedar (Tamarix spp.), arrowweed (Tessaria sericea), coyote willow (Salix exiqua), desert broom (Baccharis sarothroides) and seep willow. Above this community and below the old pre-Dam high water mark, exists an unstable beach community characterized by red brome (Bromus rubens), tansy mustard (Descurainia pinnata), fescue (Festuca octoflora), Chaengctis fremontii, Russian thistle (Salsola kali) and camelthorn (Alhagi camelorum) (Carothers et al. 1976). Additionally, algae (Cladophora glomerata) has become established along the river bed as a result of increased light penetration and greater stability of the riverbed (Dolan et al. 1974).

Since the construction of Glen Canyon Dam, seasonal extremes in discharge, sediment load and temperature may have been eliminated. Discharge from the Dam is now regualted by regional power demands. The mean daily maximum discharge is about 566 cms and the daily minimum is 130 cms with extremes ranging from 28 to 764 cms. Since water is released from penstock gates, far below the level of sunlight penetration (hypolimnion; up to 61 m below the surface depending on the level of the lake) and long after most of the sediment has been deposited in the upper reaches of Lake Powell, the water entering the River below the Dam is clear and perpetually cold. Water temperatures range from 6 to 15^{o} C and vary little throughout the year. Thus, the River is cooler in the summer and warmer in the winter than in pre-Dam days (Cole and Kubly 1976) (Table 3-2).

Sediment load has been drastically reduced as well. Between the Dam and the Little Colorado River, there is very little sediment input (except on occasion from the Paria River), causing this part of the River to be clear throughout most of the year (Cole and Kubly 1976). Median sediment load at Lee Ferry has been reduced by a factor of about 200 (from 1500 ppm to 7 ppm). The reduction in sediment load is less substantial further downstream due to sediment input from tributaries and the erosion of pre-Dam fluvial terraces. Sediment load at Phantom Ranch has been reduced by a factor of only 3.5 (from 1250 to 350 ppm) (Dolan et al. 1974). Currently, the Little Colorado River contributes the majority of sediment to the Colorado River between Lee Ferry and Lake Mead (Cole and Kubly 1976).

The marked alterations in seasonal flow patterns have changed the alluvial morphology of the River. Pre-Dam terrace deposits of sand and silt have been eroded by the River. In many locations, erosion no longer occurs because coarser sediments of large gravel and rubble have been exposed and cannot be dislodged under present flow regimes (Dolan et al. 1974). This process, referred to as armoring, is especially evident in the area between the Dam and Lee Ferry (Pemberton 1976). Areas were armoring does not occur reach an equilibrium when erosion and deposition are roughly balanced (Dolan et al. 1974). This situation is probably more common in the stretch between the Little Colorado River and Lake

Table 3-2. Physico-chemical data for the mainstream of the Colorado River for November 1977, January - February 1978, May 1978, July - August 1978, and October 1978.

Date	River Mile *(Belknap)	River Mile (W.P.R.S.)	Time	pH	Specific Conductance (umho/cm)	Water Temperature (°C)
11/21/77	7	681.6	1515	7.5	910	6.0
11/22/77	27	661.6	1700	7.1	900	6.8
11/23/77	38	650.6	1900	-	830	6.5
1/21/78	7	681.6	1730	8.5	895	8.9
1/22/78	27	661.6	1700	-	850	8.5
1/23/78	33	655.6	1630	8.5	850	8.0
1/25/78	58	630.6	1100	8.5	860	8.0
1/26/78	72	615.5	0830	9.0	950	6.5
1/29/78	99	589.6	0730	9.3	880	7.5
1/29/78	108	580.6		9.0	1100	8.5
2/1/78	136	553.3		9.0	840	8.0
2/2/78	145	544.1		8.5	1100	-
2/3/78	145	544.1		9.0	930	7.0
2/4/78	166	522.6		9.0	910	9.5
2/5/78	180	508.6		9.0	1000	-
2/6/78	196	492.6		-	1000	
5/12/78	1.5	687.9		-	860	9.0
5/15/78	18	670.6	--	-	870	10.0
5/15/78	32	656.6	1630	-	1200	8.0
5/17/78	80	608.6	1430	-	1200	11.0
5/20/78	103	585.6	--	-	1200	11.5
5/21/78	118	570.6		-	920	12.5
7/30/78	27	661.6		7.8	1200	12.5
7/31/78	38	650.6		7.6	990	14.0
7/31/78	57	631.6		7.6	1200	14.0
8/4/78	98	590.6		7.5	1200	15.0
8/5/78	109	579.6		7.6	1250	15.0
8/8/78	166	522.6		7.9	1190	15.0
8/10/78	179	507.6		7.8	1100	15.0
10/2/78	32	656.6	--	7.7	1425	12.0
10/4/78	--		0917	7.4	1400	11.5
10/6/78	88	601.2	1715	7.8	1600	13.5

KEY: W.P.R.S. - Water and Power Resource Service
* see Belknap (1969).

Mead than between the Dam and the Little Colorado River, since the lower River has a greater sediment input (Cole and Kubly 1976).

Between Lee Ferry and Separation Rapids, the Colorado River exhibits a typical pool-rapid morphology with the River dropping approximately 677 m over the 384 km distance. The rapids are constrictions in the stream channel resulting from deposition of debris and are typically areas of accelerated flow and high gradients. Velocities of 3 to 5 m/s and gradients of 0.5 to 2 m/100 m are typical of many rapids in the Canyon (Dolan et al. 1978, Leopold 1969). Fifty percent of the 677 m elevational change occurs in the 161 rapids, that constitute about 9% of the total distance.

The pools separating the sequence of rapids are areas of greater width, slower velocity and more shallow gradients. In these areas velocities of 0.3 to 0.6 m/s and gradients of 0.5 m/100 m are normal (Leopold 1969).

River width and depth vary with discharge. Under the present flow regimes, the average width is about 200 m with a range from approximately 80 to 320 m. The average depth of the River is about 10 to 12 m, though the longitudinal profile is highly irregular. The majority of deep pools (20 m or greater) occur immediately below major repids where the water flow emerges as a jet directed toward the riverbed. The resultant scouring of the riverbed forms the pools. The deepest pool measured was 35 m and had a discharge of about 450 cms. In general, shallow portions of the River occur upstream of rapids or in areas where the river channel is wider (Dolan et al. 1978).

Where the stream channel is constricted (i. e., in the vicinity of rapids and riffles), a large portion of the downstream flow is directed against one bank, resulting in a strong upstream surface against the opposite bank. At times, these backwaters or eddies may form half the total width of the River. Eddies are often areas of sediment deposition and erosion since they typically have a lower velocity (Leopold 1969).

In its course through Marble and Grand canyons, the Colorado River cuts along a number of distinct geologic strata, ranging in age from 180 million (Jurassic) to 1.5 billion years (Precambrian). The Canyon is narrow or wide depending on the thickness and resistance to erosion of the various rock formations. In Marble Canyon (Lee Ferry to approximately R.M. 642), the Colorado River cuts through late Paleozoic and Mesozoic Formations, the majority of which are highly resistant to erosion. Steep walls of Redwall Limestone form a narrow canyon in this section of river. Between R.M. 642 and 614.5, the Canyon widens as the River cuts through less resistant early Paleozoic and late Precambrian strata. This area consists primarily of Mauv Limestone and Bright Angel Shale as well as the Grand Canyon Series of which the Dox Formation is the most prominent (Hamblin and Rigby 1968).

Between R. M. 614.5 and R. M. 430, the Canyon is separated into five natural subdivisions as seen from the Colorado River: an Upper, Middle and Lower Granite Gorge, and two intervening sections where early Paleozoic rocks form vertical cliffs at river level. Upper Gorge is approximately 45 km long and extends from R. M. 614.5 to R. M. 583. This area is characterized by steep walls of highly resistant Precambrian granites and schists and a narrow (80 m) swiftly moving channel.

Near R. M. 573, the Precambrian rock disappears below river level and steep vertical cliffs of the Paleozoic Redwall Limestone again predominate. The Middle Granite Gorge begins at R. M. 563. Its walls are less pronounced than those of the Upper Groge and have only a limited thickness exposed at river level. The Canyon narrows again near R. M. 550, due to the Precambrian rock at river level being replaced by the early Paleozoic strata. This section of the River is similar to Marble Canyon. Lower Granite Gorge begins at R. M. 477 and extends downstream to R. M. 430. A relatively large proportion of Lower Gorge's Precambrian rock is exposed at river level, forming a steep V-shaped canyon similar to that in Upper Gorge (Hamblin and Rigby 1968).

During this study, water temperatures of the Colorado River ranged from 6 to 15 C (Table 3-2). Generally, temperatures increased downstream and during the summer months. During 1975 - 1976, the mainstream temperatures varied from 7.0 to 17.2 C (Cole and Kubly 1976, 1977). In contrast, pre-Dam temperature extremes differed by 29.5 C (Cole and Kubly 1976).

Specific conductance (corrected to 25° C) varied from 830 to 16,000 micromhos/cm during 1977 - 1978 (Table 3-2). Pre-Dam conductance extremes ranged from 318 to 2430 micromhos/cm at Lee Ferry and up to at least 2900 micromhos/cm in stretches downstream of the Little Colorado River (Cole and Kubly 1976).

During this study, the pH of the mainstream varied from 7.1 to 7.9 (Table 3-2). Cole and Kubly (1976) recorded a pH range of from 7.4 to 8.2.

The ranking of the major anions within the mainstream were $SO_4 > CO_3 > Cl$. Their concentrations changed little from Lee Ferry to Diamond Creek. The ranking of the major cations within the mainstream were Na > Ca^{++} > Mg > K^{+} (Cole and Kubly 1976) (for ranges in plant nutrients see Table 3-3).

Table 3-3. Range of plant nutrients from the mainstream and selected tributaries during April 1975 - March 1976. Silica and phosphate in mg/liter; P and N in mg/liter. N = sum of NO_3 - N and NO_2 - N. P = orthophosphate - P (adapted from Cole and Kuble 1976).

	SiO_2	PO_4^-			N/P
Mainstream	5.9-10.5	0.03-0.72	9.8-234.7	90-600	1:5-34:8
Paria	8.5-11.0	0.1-1.19	35.3-387.9	550-650	1:3-18:4
Vasey's Paradise	6.4-10.8	0.06-0.17	19.6-55.4	120-950	2:2-36:5
Little Colorado	8.0-11.0	0.04-0.08	13.0-19.5	180-460	9:2-28:3
Bright Angel Creek	5.0-7.0	0.03-0.19	9.8-61.9	0-120	0-4:6
Shinumo Creek	5.0-7.5	0.06-0.70	19.6-228.0	0-100	0-5:1
Elves Chasm	9.0-13.0	0.04-0.06	13.0-19.5	340-510	26:1-36:8
Tapeats Creek	5.5-9.0	0.08-0.22	26.1-71.7	10-170	0:2-6:5
Deer Creek	6.4-8.5	0.08-0.16	26.1-52.1	140-260	2:9-7:7
Kanab Creek	6.5-15.0	0.04-1.10	13-358.3	80-320	0:6-8:2
Havasu Creek	7.5-21.0	0.02-0.14	45.6-6.5	120-210	4:6-18:4
Diamond Creek	13.6-22.5	0.10-0.25	32.6-81.5	100-620	2:2-12:8

Tributaries

Certain tributaries were sampled more regularly than others. Only those tributaries with abundant data will be discussed in terms of physico-chemical parameters.

Paria River

The Paria River enters the Colorado from the north, 0.9 km downstream from Lee Ferry. Originating near the southern part of the Escalante Mountains at an elevation of approximately 1983 m in southern Utah, it flows in a southeastward direction for approximately 88 km before it joins the Colorado River. Most of the elevational change occurs in the first 48 km as the Paria River drops off the Pausaugunt and Paria Plateaus. In the remaining 40 km to its confluence with the Colorado, the Paria assumes a low gradient. The average gradient of the River is 12 m/km (Gregory and Moore 1931).

The Paria River drains an estimated 3652 km^2 in the Escalante Mountains and Paria Plateau. Its average discharge over the past 54 years is 0.8 cms, with extremes of zero and 456 cms (U. S. G. S. 1977).

Near Lee Ferry, the Paria cuts along the Chinle, Shinarump Conglomerate and Moenkopi Formations. Although the Shinarump Conglomerate is a resistant formation, it is relatively thin in cross section. Both the Chinle and Moenkopi Formations are thicker in cross section and consist primarily of shales and siltstones. These formations form an open valley near the confluence (Gregory and Moore 1931).

Marginal vegetation near the confluence includes salt cedar, coyote willow and Russian olive (*Eleagnus angustifolia*). Within the flood plain upstream, there are stands of arrowweed, Goodding willow (*Salix gooddingii*) and Fremont cottonwood (*Populus fremontii*).

The anions of the Paria River are dominated by sulfate, with their proportions resembling those in the mainstream (Cole and Kubly 1976). It had the highest nitrogen value and relatively high phosphorous values among the 11 tributaries sampled. The Paria has been called "...probably ...one of the largest sediment carriers of its size in the world"; it has a mean discharge-weighted suspended-sediment concentration of 114,000 ppm near its mouth. The Paria River is a major source of suspended sediment in the mainstream during periods of peak discharge.

During this study, the water temperature at the confluence of the Paria with the mainstream Colorado River ranged from 13 to 22.5 C (Table 3-2). Specific conductance varied widely at the confluence (315 to 1120 micromhos/cm) and at the station 8 km upstream (375 to 1140 micromhos/cm) (Table 3-4). The pH at the mouth of the Paria varied 0.9 (8.1 to 9.0), while 8 km upstream, it had a variation of 0.2 (8.2 to 8.4).

All physical and chemical parameters of the Paria vary widely as does the discharge level. Similar fluctuations were reported for the main river prior to the construction of Glen Canyon Dam (Cole and Kubly 1976).

Little Colorado River

The Little Colorado River drains 141,155 km^2 in eastern and northern Arizona. It travels 412 km northwestward from its source in the White Mountains to its confluence with the Colorado River at R. M. 627. In this distance, the River drops 1922 m in elevation. About 1068 m of this drop occurs in the first 87 km, with the average gradient being 12 m/km. The River has a much more shallow profile over the remainder of its course (3 m/km) (NACOG 1978a).

Table 3-4. Temperature, conductivity and pH values for Colorado River mainstream and tributaries during November - December 1977, January - February 1978, May 1978, July - August 1978, and October 1978. Temperatures are in degrees Celsius, conductivity in micromhos/cm.

	Winter 1977						Winter 1978						Spring 1978					
	Confluence			200 m			Confluence			200 m			Confluence			200 m		
Tributaries			pH	T	C	pH			pH	T	C	pH		C	pH	T	C	pH
Paria River	15	1120	8.1	14	1140	8.4							16°	315		22°	375	
Vasey's Paradise	9	310	7.9				10	280					15	300				
Buck Farm	-	-		11	-		-											
Nankoweap	4	745		4.5	690	-		-										
L. Colorado River	14.7°	4100					8.5	935					12	950		21	4150	
Unkar Creek	-	-					-	-		11	965	-		-	-	-	-	
Clear Creek	12	350		12.5°	370	-	8°	440	-	8	442	-	11	170		11	100	
Bright Angel Creek	8.8	335	-	11	340	-	7.5	340	-	7	320	-	14°	220	-	16	200	
Pipe Creek	10°	460	-	10	455	-	11	590	-	11	600	-	16	-	-	17.5	-	
Hermit Creek	12	690	-	12	710	-	-	-					23	920	-	23	940	
Crystal Creek	5.8°	2600	-	6	2500	-	7.5	2400		7.5	2400	-	22.5	450	-	22.5°	459	
Shinumo Creek	9	340	-	9	330	-	8°	405	-	9	415	-	11.5	180	-	-	-	
Elves Chasm	8.5°	740	-	8.5	670	-	-	-					17.5°	425		17	525	
Stone Creek	9	140	-	9	240	-							20			25°		
Tapeats Creek	11	300	-	12	340	-	12	360		-	-		11.5		-	-		
Deer Creek	12°	350					12.5°	380		15	380	-	12.5		-	13.5°	-	
Kanab Creek	9	1100	-	9	1300	-	11	1120	-	11	1120	-	21		-	19	-	
Mile 539.7							-		-	-	-		21.5					
Havasu Creek	14	660		14	660	-				14	660	-	16.5			17		
National Canyon	-		-	-					-	9	1900	-						
Lava Springs			-	-					-	-	-							
Mile 498.6			-	-	-	-				-	-							
Three Springs							15	695		17	710	-	22°					
Mile 470.8		-					-	-	-	9	1200	-						
Diamond Creek	12	680	-	13	680	-	10.5	800	-	12	850	-	27°			27.5	-	
Travertine Canyon			-	-	-	-	-	-					22.5					
*Travertine Falls			-	-	-	-	12°	1600		8.5	1350	-						
*Bridge Canyon Bridge City			-	-			-	-	-	14°	725	-						

(continued)

Table 3-4(cont.). Temperature, conductivity and pH values for Colorado River mainstream and tributaries during November - December 1977, January - February 1978, May 1978, July - August 1978, and October 1978. Temperatures are in degrees Celsius, conductivity in micromhos/cm.

Tributaries	Summer 1978 Confluence T	C	pH	200 m T	C	pH	Fall 1978 Confluence T	C	pH	200 m T	C	pH
Paria River	22.5°	550	8.1	33.5°	–	8.3	13°	595	9	25.5°	580	8.2
Vasey's Paradise	18°	410	8.4	–	–	–	18.5°	420	8.4	–	–	–
Buck Farm	–	–	–	30°	550	7.9	–	–	–	–	–	–
Nankoweap	–	–	–	–	–	–	–	–	–	–	–	–
L. Colorado R.	11.5°	1100	7.9	15°	5400	7.8	13.8°	2200	7.8	23°	6100	7.8
Unkar Creek	–	–	–	–	–	–	–	–	–	–	–	–
Clear Creek	22.5°	395	8.1	23°	420	8.0	22°	495	8.6	22°	480	8.5
Bright Angel Creek	22°	370	8.2	23°	330	8.7	15.5°	450	8.0	16°	440	7.9
Pipe Creek	30.5°	490	8.0	30.5°	480	8.0	19.5°	430	8.7	19°	500	8.6
Hermit Creek	28°	970	8.0	28.5°	940	8.2	21.5°	850	8.0	21°	860	8.0
Crystal Creek	22°	940	8.0	22°	940	7.9	15.5°	2000	8.1	16°	2000	7.9
Shinumo Creek	20°	360	7.8	19.5°	345	7.8	20°	370	8.5	19.5°	370	8.6
Elves Chasm	17°	975	8.1	21°	835	8.2	17	1200	8.2	17°	940	8.2
Stone Creek	25°	475	7.8	26°	420	7.7	–	–	–	–	–	–
Tapeats Creek	14°	355	8.2	15°	365	8.2	15°	410	8.2	14°	380	7.8
Deer Creek	19°	400	8.3	18°	420	8.2	14.2°	442	8.3	15.5°	440	8.2
Kanab Creek	24°	1300	8.0	24°	1450	8.0	18°	1900	7.9	18°	1900	7.7
Mile 539.7	–	–	–	–	–	–	–	–	–	–	–	–
Havasu Creek	23.5°	710	9.0	23°	640	8.8	18°	740	8.3	19°	795	8.0
National Canyon	–	–	–	–	–	–	–	–	–	–	–	–
Lava Springs	–	–	–	–	–	–	–	–	–			
Mile 498.6	–	–	–	–	–	–	–	–				
Three Springs	–	–	–	–	–	–		–	–			
Mile 470.8	–	–	–	–	–	–	–	–	–	–	–	–
Diamond Creek	27°	630	8.4	27	730	8.4	23°	470	–	22	410	
Travertine Canyon	–	–	–	–	–	–	–	–	–	–	–	
*Travertine Falls	23°	1500	8.2	–	–	–	–	–				
Bridge Canyon	–	–	–	–	–	–	–	–				
Bridge City	–	–	–	–	940	7.4	–	–				

Table 3-4 (cont.). Temperature, conductivity and pH values for Colorado River mainstream and tributaries during November - December 1977, January - February 1978, May 1978, July - August 1978, and October 1978. Temperatures are in degrees Celsius, conductivity in micromhos/cm.

KEY:

200 m   Sample taken 200 m upstream from confluence with Colorado River

- Temperature

- Conductivity

- Samples taken during 2/21/78 and 2/22/78

Between 5 and 21 km upstream from its confluence, numerous springs enter the Little Colorado River. The largest of these, Blue Springs, is located 21 km upstream. Blue Springs issues water from the Redwall Limestone formation, and together with the smaller springs found downstream, drains about 72,520 km^2 in the Black Mesa Basin. The combined discharge of these springs ranges from 6 to 7 cms (Johnson and Sanderson 1968). Measurements taken 51 km upstream from Blue Springs near Cameron, Arizona indicate that at this point, discharges for the Little Colorado River range from zero to 705 cms. For the year 1977, the mean discharge was 2.6 cms with a minimum of no flow for many days and a maximum of 93 cms on August 20 (U. S. G. S. 1977). At certain times of the year, Blue Springs provides the only water flow into this stream as the Little Colorado River above Blue Springs ceases to flow.

Near its confluence, the Little Colorado River is bordered by early Paleozoic strata, most of which are thick in cross section and highly resistant to erosion (i. e., Kaibab, Toroweap, Coconino, Supai and Redwall). These strata form a narrow, deep canyon extending from 21 km upstream to the confluence itself. Along the margins and in the river channel, deposits of travertine form a series of dams and pools. Stands of salt cedar and coyote willow occur near the confluence, while further upstream, stands of salt cedar and some sparse stands of common reed (*Phragmites australis*) are found along the margins of the River. The Little Colorado River is a popular stop for many of the commercial river trips, and although the River is not readily accessible by hiking, the confluence is visited by a large number of people during the summer months.

The Little Colorado River is unique within the Colorado River system in that it is the only major tributary of the saline sodium chloride type.

In addition to raising the conductivity of the mainstream, the Little Colorado is, at certain times, its major contributor of suspended particulate matter.

Water temperature at the confluence of the Little Colorado River ranged from 8.5 to 14.5° C during this study (Table 3-4). Two hundred meters upstream of the confluence, the water temperatures ranged from 15 to 23 C. The specific conductance of the Little Colorado at its mouth ranged from 935 to 4100 micromhos/cm, while upstream, a difference of 1950 micromhos/cm (4150 to 6100 micromhos/cm) was measured (Table 3-4). These differences depended upon the extent of mixing that occurs between the mainstream and tributary at the confluence, and on whether or not the Little Colorado was flowing above Blue Springs. When the Little Colorado is flowing above Blue Springs, the water in Blue Springs is diluted and the conductivity is lowered.

The pH (Table 3-4) displayed little variation between the confluence and the 200 m station upstream, ranging only 0.1 pH unit (7.8 to 7.9).

Overall, the most striking differences between the Blue Springs area and the confluence are the lower pH values and the higher temperatures (Tables 3-5).

Bright Angel Creek

Bright Angel Creek enters the Colorado River from the North Rim at R. M. 601.3. The source of the Creek is Angel Springs, located 19 km upstream from the Creek's confluence. The spring issues water from solution tubes near the top of the Muav Limestone at an elevation of approximately 1830 m. From here, the Creek flows southward to the Colorado River, dropping 1068 m in elevation, with an average gradient

Table 3-5. Physico-chemical data collected in the Blue Springs area of the Little Colorado River, 5 - 7 July, 1978.

Locality	pH	Specific Conductance (umho/cm)	Temperature (°C)
Blue Springs	6.1	4200	21
Spring 2	7.4	6800	21
Spring 3	6.3	4200	21
Spring 4	6.4	4000	21
Spring 5	7.1	5600	21
LCR at Big Canyon	7.3	5100	21
Big Canyon	7.2	7400	21

of 55 m/km. The only recorded discharge for the springs contributing to the flow of Bright Angel Creek is 0.4 cms, made in July 1969 (Huntoon 1970).

A number of other springs contribute to the flow of Bright Angel Creek, the largest of which is Roaring Springs, located 16 km upstream from the mouth of the Creek. The spring contributes most of the base flow to Roaring Springs Creek, a major source of inflow to Bright Angel Creek (Johnson and Sanderson 1968). Discharge measurements for the spring during July 1969 ranged from 0.2 to 0.7 cms. Currently, Roaring Springs provides water for facilities on the North and South Rims (Huntoon 1970).

Phantom Creek enters Bright Angel Creek 1.9 km above its confluence with the Colorado River. Discharge from Phantom Creek is derived primarily from Haunted and Phantom Springs. In July 1969, these springs had a combined discharge of slightly more than .03 cms (Huntoon 1970).

The Bright Angel watershed drains 262 km^2 of the southern portion of the Kaibab Plateau through a series of karstic ground water systems (Huntoon 1970). The average discharge for Bright Angel Creek (based on 47 years of records) is 1.0 cms. A maximum discharge of 125 cms was recorded in 1936, and a mimimum discharge of 0.3 cms was recorded in 1961 (U. S. G. S. 1975).

Bright Angel Creek is bordered by high, steep walls of granite and schist from approximately 6 km upstream to the confluence. Near its confluence the canyon widens as the stream flows over a debris fan consisting of riverine deposits of gravel cobble. At the mouth of the stream, salt cedar, coyote willow, arrowweed and alkali golden bush (Haplopappus acredenius) occur in low densities. Approximately 198 m upstream from the mouth, cottonwoods grow along the stream margins.

Bright Angel Creek is easily accessible from both the North and South Rims by way of the Kaibab and Bright Angel trails, and a large number of people visit the Creek and surrounding areas annually. Phantom Ranch is located 2 km upstream from the mouth of the Creek and provides lodging for hikers and fishermen throughout the year. In the spring of 1967, Bright Angel Creek flooded its banks, breaking water lines leading to the South Rim and damaging buildings at Phantom Ranch. As a preventive measure, a reach of the Creek was channeled near its mouth.

Bright Angel Creek is one of at least eight dilute dolomitic tributaries (Cole and Kubly 1977). All these tributaries receive their waters from the Kaibab Plateau, and their chemical nature may be attributed to the Kaibab Limestone. These waters are strong carbonate waters containing calcium and magnesium and low amounts of sulfate, chloride and sodium.

During this study, water temperatures at the confluence and upstream sampling station displayed similar seasonal variations. The confluence ranged from 7.5 to 22 C and upstream ranged from 7 to 23 C. The specific conductance of Bright Angel Creek is relatively low and varied from 220 to 450 micromhos/cm at the mouth, while 200 m upstream, this variation was 320 to 440 micromhos/cm. The pH of the Creek was quite stable at its confluence, varying only 0.2 (8.0 to 8.2), while it varied 0.8 (7.9 to 8.7) at the upstream station (Table 3-4).

Shinumo Creek

Shinumo Creek enters the Colorado River from the northwest at R. M. 580.7. Its source is South Big Springs located 19 km upstream from the mouth of the Creek at an elevation of 2318 m. The Creek flows southwestward from the Springs to the Colorado River with an average gradient of approximately 85 m/km. A number of springs enter the Creek along its course, the largest of which is Shinumo Springs, located about 13 km from the mouth of the Creek. In July 1969, a single discharge measurement of 0.1 cms was made.

White Creek enters Shinumo Creek from the northwest approximately 5 km from the mouth. This creek is spring fed and perennial. Near the mouth of Shinumo Creek, the combined discharge of White and Shinumo Creeks ranged from 0.1 to 0.4 cms for the months of September and June (Johnson and Sanderson 1968).

Near its confluence, the stream is bordered on one side by a large debris fan of riverine deposits consisting of boulders, cobbles and sand. The opposite side of the Creek is bordered by a steep wall of vishnu schist and granite. Seep willow and satintail (_Imperata brevifolia_) occur along the margins of the stream. Upstream, the canyon narrows considerably and vegetation becomes scarce. Approximately 200 m from the mouth of the Creek, a small waterfall empties into a deep, large pool.

Shinumo Creek is not readily accessible by hiking, though it is a popular stop for commercial river trips during the summer months. People arriving at the Creek walk up through the stream to the water fall and swim in the pool at its base.

Shinumo Creek is also a dilute tributary. All dilute dolomitic streams except Vasey's Paradise displayed low N/P ratios (Cole and Kubly 1976, 1977).

Water temperatures recorded at the mouth of Shinumo Creek during this study, spanned 12 degrees (8° to 20° C). Near the base of the waterfall, the temperatures varied 10.5 degrees (9 to 19.5° C).

Specific conductance at the Creek's confluence ranged from 180 to 405 micromhos/cm (Table 3-4), while upstream this fluctuation was less pronounced (330 to 415 micromhos/cm). The pH of Shinumo Creek displayed moderate fluctuations during the study period, but there was little difference between the confluence (7.8 to 8.5) and the upstream station (7.8 to 8.6).

Tapeats Creek

Tapeats Creek enters the Colorado River from the North Rim at R. M. 555.8. Its source is a series of springs located in the Tapeats Amphitheater. The largest of these is Tapeats Springs, located approximately 10.5 km from the confluence of the Creek at an elevation of approximately 1129 m (Huntoon 1968). Measured discharge from Tapeats Springs ranged from 1.1 to 4.4 cms between April and September. Minimal flow rates well below 1.1 cms have been known to occur in the winter months (Huntoon 1968). By the time it reaches the Colorado River, the Creek has dropped approximately 519 m in elevation, with an average gradient of 48 m/km.

To the southeast of Tapeats Springs, Thunder Springs flows from the Muav Limestone at an elevation of 1068 m. This spring provides the base flow for Thunder River which joins Tapeats Creek about 3 km above its confluence (Johnson and Sanderson 1968). Discharge measurements from Thunder Springs ranged from 0.4 to 3.6 cms between April and September. Together, Thunder and Tapeats Springs drain a large portion of the southwest Kaibab Plateau. Tapeats Creek contributes the largest discharge into the Colorado River from the north side of the Grand Canyon (Huntoon 1968), ranging from 1 to 8 cms (Johnson and Sanderson 1968).

A debris fan consisting of boulders, cobbles and gravel is located near the confluence of Tapeats Creek with the Colorado. This area is relatively open and vegetation consists primarily of a scattered overstory of seep willow and coyote willow. Along the stream margins, scouring rush (*Equisetum hiemale*), jointed rush (*Juncus articulatis*), cardinal monkey flower (*Mimulus cardinalis*) and water speedwell (*Veronica aquatica*) are found. Upstream from the mouth, the canyon narrows and is bordered by high walls of Tapeats Sandstone. Further upstream, the canyon narrows even more and only an occasional seep willow or maidenhair fern (*Adiantum cappilus-veneris*) is encountered.

Tapeats Creek is another in the series of dilute, dolomitic tributaries listed by Cole and Kubly (1976, 1977). The water temperature of Tapeats Creek at its confluence ranged from 11^{o} to 15^{o}C during this study (Table 3-4). Five hundred meters upstream, the seasonal fluctuation in tributary temperature was similar (12^{o} to 15^{o} C). Seasonal variation in specific conductance at the Creek's confluence (300 to 400 micromhos/cm) was greater than at the upstream station (340 to 380 micromhos/cm).

A pH of 8.2 was recorded twice from the confluence, whereas this parameter was variable at the upstream station (7.5 to 8.2).

Deer Creek

Deer Creek enters the Colorado River from the north at R. M. 553.2. Its source is a number of springs that drain the southern part of the Kaibab Plateau, the largest of which are Vaughen and Deer Springs. Vaughen Springs is located approximately 5 km upstream from the mouth of Deer Creek where it issues from the Muav Limestone at an elevation of 854 m. This spring occasionally dries up during periods of low runoff (Huntoon 1968).

Deer Springs is a perennial spring located about 2 km from the mouth of the Creek at an elevation of 824 m in the Muav Limestone (Huntoon 1968). The combined flow rate for Vaughen and Deer Springs has been measured for the months of June and September when it ranged from 0.15 to 0.23 cms (Johnson and Sanderson 1968). The average gradient of the Creek is approximately 171 m/km. The majority of the elevational change occurs at Deer Falls near the confluence of the Creek where it drops about 76 m from the Tapeats Sandstone (Huntoon 1968).

Near the mouth of Deer Creek, below the falls, vegetation consists primarily of seep willow, salt cedar, coyote willow and scratch-grass (*Muhlenbergia asperifolia*). At the base of the falls, there is a large, shallow pool surrounded by high walls of Tapeats Sandstone. Above the falls, the Creek cuts through the Tapeats Sandstone, forming a narrow canyon with very little vegetation. Further upstream, the Creek flows through the Muav and Bright Angel Formations which form a wide canyon. At this point, Fremont cottonwood, coyote willow and seep willow form a dense overstory along the creek margin.

During the spring, summer and fall, much human activity occurs in the neighborhood of Deer and Tapeats Creek. Many people on river trips use the falls and pool at Deer Creek to swim and bathe. Others hike from Tapeats Creek to Deer Creek via Thunder River and Surprise Valley.

Deer Creek is another dilute, dolomitic tributary. Seasonal variability in temperature was greater at the confluence of the Creek (12 to 19^{o}C) than above Deer Creek Falls (12.5 to 18 C)(Table 3-4). Specific conductance ranged from 350 to 442 micromhos/cm at the mouth and 280 to 440 micromhos/cm above the falls. The pH maintained a constant value of 8.3 at the confluence during the August and October samplings.

The upstream station displayed a constant pH of 8.2 during the same sampling periods.

Kanab Creek

Kanab Creek originates on the Pausagunt Plateau in Kane County, Utah, and flows southward approximately 105 km into Arizona where it enters the Colorado River at R. M. 546.1. Its average gradient is approximately 16 m/km, with the majority of the elvational change occurring in the first 24 km of its course (U. S. G. S. 1954a, 1957a). Kanab Creek drains about 5698 km^2 in southern Utah, but the greater part of the run-off stems from the 673 km^2 watershed north of the town of Kanab (LaRue 1916). The average discharge is 0.14 cms based on 14 years of records taken at Fredonia, Arizona, which is located 50.2 km upstream from the mouth of the Creek. Extremes for this period range from zero to 131 cms in 1970. For the year 1977, the mean flow was .03 cms with a maximum of 2 cms during July, and a minimum of zero flow for many days throughout the year (U. S. G. S. 1977).

Near its mouth, Kanab Creek is bordered by Muav and Redwall Limestone. The Redwall Limestone forms high, steep walls which border the Creek for some distance upstream. Near the mouth the canyon widens somewhat to form a large debris fan consisting of silt and sand derived from the creek upstream. Marginal vegetation at the confluence consists of a few salt cedars and seep willows. Upstream areas are bordered by salt cedar, bullrush, Arizona grape (Vitis arizonica) and cattails (Typha spp.).

Kanab Creek is an example of a sulfate stream within the Grand Canyon system. The tributary is also low in nitrogen and phosphorous and relatively high in silica (Cole and Kubly 1976).

Kanab Creek displayed an identical seasonal variation of water temperatures (9° to 24° C) at the mouth and the upstream sampling station (Table 3-4). The range in specific conductance was quite similar at both stations: 1100 to 1900 micromhos/cm at the confluence and 1120 to 1900 micromhos/cm upstream. The ranges in pH at the mouth (7.9 to 8.0) and upstream (7.7 to 8.0) were similar.

Kanab Creek is typical of many tributary streams in that it is characterized by a high degree of variability in the summer months. During times of flooding, it is a very heavy sediment carrier. Most of this sediment is topsoil, received from a once luxurious grassland (NACOG 1978b). According to Slawson and Everett (1973)

> "An effect of the summer rains and resultant floods in such tributary canyons as Kanab Creek is the washing or leaching effects of rain on the watersheds of the tributary basins. The result is to increase the concentrations of certain ions by increasing the salt load carried by streams. Such increases are most notable in the concentration of nitrate and orthophosphate ions. These concentrations can be related to an increase in bacteriological activity which have been noted during periods of flooding in the side streams. Flooding in the tributary basins would increase the organic matter content of the stream waters. The bacteriological decomposition of this organic matter leads to an increase in microbial populations".

Havasu Creek

Havasu Creek enters the Colorado River from the south side of the Canyon at R. M. 539.5. The Creek derives the majority of its water flow from Havasu Springs (on the Havasupai Indian Reservation) where it issues from the Redwall Limestone Formation at an elevation of about 993 m. Above the Springs, the Creek is intermittent, with flows regulated by seasonal precipitation. The Creek flows northwest from the Springs for approximately 16 km before reaching the Colorado River. The average gradient of the Creek in this area is about 25.7 m/km (U. S. G. S. 1962a). Discharge measurements made at several points downstream from Havasu Springs indicate a base flow of about 2 cms with a range of 1.7 to 2.1 cms (Johnson and Sanderson 1968).

Near the Confluence of Havasu Creek with the Colorado River, vertical walls of Muav Limestone border the stream, and no shoreline vegetation is present. Upstream, the canyon remains narrow and steep. Deposits of travertine in the stream channel and along the margins of the Creek form a series of dams and pools. Shoreline vegetation consists of salt cedar, scratchgrass, some scattered velvet ash <u>(Fraxinus velutina),</u> seep willow and scouring rush.

Havasu Creek is another popular stop for commercial river trips, and during the spring, summer and fall, tourists commonly hike up the Creek to Mooney Falls, 8 km from the confluence.

Havasu Creek is the only major tributary classified as an impure dolomitic stream (Cole and Kuble 1976). The Creek carries carbonate water dominated by calcium and magnesium and has a silica concentration second only to Diamond Creek. Both N and P values are low in Havaus (Cole and Kubly 1976, 1977).

The range of water temperatures at its confluence (14 to 23.5 C), and upstream (14 to 23 C), were similar. The seasonal variation in specific conductance (Table 3-4) was 660 to 740 micromhos/cm at the confluence and 660 to 795 micromhos/cm upstream. The pH ranged from 8.3 to 9.0 at the mouth of the Creek and from 8.0 to 8.8 upstream.

Clear Creek

Clear Creek enters the Colorado River from the north at R. M. 604.9. The Creek drains the southern part of the Walhalla Plateau where it originates at an elevation of 2562 m. It then travels approximately 14 km in a southwesterly direction before reaching the Colorado River. The average gradient is about 123 m/km (Douglas et al. 1947).

Five discharge measurements were made for Clear Creek during the months of June and August. The values obtained ranged from zero flow to 0.1 cms (Johnson and Sanderson 1968). During this study, the stream was flowing on the five dates it was sampled.

At the mouth of the Creek, high walls of Precambrian metamorphic schist and granite form a narrow canyon, whose floor is paved with cobble-sized stones. Vegetation is absent in this part of the canyon. Upstream, the canyon remains narrow, but there is some vegetation consisting primarily of scattered seep willow, coyote willow and some salt cedar along the stream margins.

Clear Creek is accessible to hikers from both the North and South Rims via the Bright Angel and Kaibab Trails. However, the degree of human activity near the mouth of the Creek is probably substantially less than at the confluence of Bright Angel Creek.

Clear Creek was sampled during every trip. The ranges in water temperature at the mouth (8° to 22.5° C), were similar to those 200 m upstream (8 to 23° C). The specific conductance at the mouth of the Creek (350 to 1700 micromhos/cm) varied widely compared with that measured at the 200 m upstream station (100 to 480 micromhos/cm). The ranges in pH were similar at the confluence and upstream station (8.1 to 8.6)

(Table 3-4). Cole and Kubly (1976, 1977) designated Clear Creek as a dilute dolomitic tributary.

Pipe Creek

Pipe Creek enters the Colorado River from the south at R. M. 600.2. Its source is a spring located near Indian Gardens at an elevation of 1182 m. The spring issues from the Muav Limestone at a rate of 23 liters/s (Metzger 1961).

The Creek flows northward from the spring for 5 km, along the Bright Angel Fault before reaching the Colorado River. The average gradient is 91 m/km (Douglas et al. 1947).

The canyon through which the stream flows widens near the mouth of the Creek where there is a small gravel bar. The sparse vegetation consists of seep willow, bermuda grass (Cynodon dactylon) and scratch grass. The upstream area is bordered by high walls of Precambrian metamorphic rock, and an overstory that consists primarily of dense stands of coyote willow and seep willow.

Pipe Creek is located close to the Bright Angel Trail which is one of the more heavily used canyon trails. Hikers often use the Creek as a rest stop and, at times, dam the Creek to form pools for bathing and swimming.

Pipe Creek displayed an identical seasonal variability in temperature (10.0° to 20.5°) at the confluence and upstream station. The specific conductance ranged from 430 to 590 micromhos/cm at the confluence and from 480 to 600 micromhos/cm at the upstream site. The pH values were also similar, varying 0.7 units (8.0 to 8.7) at the mouth and 0.6 units (8.0 to 8.6) upstream (Table 3-4).

Hermit Creek

Hermit Creek enters the Colorado River from the south at R. M. 594.4. Its sources are a number of springs along the South Rim, including Dripping Springs located south of Mesa Eremita and Santa Maria Springs near the head of Hermit Trail. Both Dipping and Santa Maria Springs discharge less than 0.1 liters/s from the Coconino Sandstone and the Supai Formation, respectively. A number of other small springs also issue water from the Redwall and Muav Formations with the combined flow for all these springs being 16 liters/s (Metzger 1961). Hermit Creek is approximately 5 km in length and flows northward from its sources to the Colorado River with an average gradient of 123 m/km (Douglas et al. 1947).

River and creek deposits of sand, mud and boulders are found near the mouth of the Creek which is bordered by dense stands of saw grass and cattail. The wide canyon at the mouth narrows to form a canyon between high walls of Precambrian schist and granite upstream. Seep willow, saw grass, and an understory of scratch-grass grow along the upstream margins.

Hermit Creek is highly susceptible to summer flash flooding. In August, flash flooding moved the course of the Creek near its confluence approximately 6 m. Human activity in the Hermit Creek area is limited to hikers using the Hermit or Tonto Trails.

Similar seasonal variation in water temperatures were recorded from the mouth (12 to 28 C) and upstream station (12 to 28.5 ^{o}C) (Table 3-4). The range of specific conductance values was greater at the confluence (690 to 970 micromhos/cm) than at the upstream station (710 to 940 micromhos/cm). A pH of 8 was recorded twice at the confluence, while upstream, it varied from 8.0 to 8.2 (Table 3-4).

Crystal Creek

Crystal Creek enters the Colorado River from the North Rim at R. M. 594.35. The Creek is about 13 km long and flows south to the Colorado River with an average gradient of 60 m/km. The majority of the stream flow for the Creek comes from Crystal and Dragon Springs. Crystal Springs is located 10 km upstream from the mouth at an elevation of approximately 1342 m and discharges about 0.1 cms from the Muav Limestone (Huntoon 1970). Dragon Springs is located approximately 8 km from the confluence, and enters Crystal Creek about 6 km upstream. The spring is at an elevation of about 1159 m and issues approximately 0.04 cms from the Muav Limestone (Huntoon 1970). Pools occur in the canyon floors above both springs, suggesting drainage from Big Springs, Mile and Dragon Faults near the Kaibab Plateau (Huntoon 1970).

Three discharge measurements taken near the mouth of the Creek in June and August ranged from 0.03 to 0.05 cms (Johnson and Sanderson 1968).

River deposits of gravel, cobbles and boulders are found near the mouth of the Creek. No vegetation grows near the confluence. Upstream, the canyon is wide with an open overstory of salt cedar and seep willow. The stream channel shifted near the mouth of the Creek in May, suggesting that Crystal Creek is highly susceptible to spring and summer flooding.

Crystal Creek displayed similar variation at the mouth and upstream station for the three physico-chemical parameters measured. The water temperature at the confluence ranged from 9 to 25 C while upstream this range was 9° to 26° C. Specific conductance at the mouth was 140 to 474 micromhos/cm, while upstream this value ranged from 240 to 420 micromhos/cm

(Table 3-4). The pH was similar at both stations; values of 8.0 and 8.1 were recorded at the confluence and a value of 7.9 was twice recorded at the upstream station.

Stone Creek

Stone Creek enters the Colorado River from the North Rim at R. M. 557.7. The Creek is intermittent and has a small drainage area (Johnson and Sanderson 1968). It originates near the south side of Steamboat Mountain at an elevation of about 1556 m and flows southwestward for about 5 km before reaching the Colorado River. The average gradient is approximately 190 m/km (U. S. G. S. 1962b).

Discharge measurements made near the mouth of the Creek in June and September ranged from zero flow to 0.03 cms (Johnson and Sanderson 1968).

At the mouth of the Creek, the canyon is wide with river deposits consisting of boulders and cobbles. The only vegetation is a few scattered salt cedars. Upstream, the canyon narrows somewhat, but is still relatively open with diabase sills and dikes forming short vertical walls. The vegetation along the stream consists of salt cedar, arrowweed and some sawgrass.

The seasonal variation in water temperature was similar at the creek mouth (9 to 25° C) and the upstream station (9 to 26° C) (Table 3-4). Specific conductance at the mouth of the Creek ranged from 140 to 475 micromhos/cm, while upstream this value ranged from 240 to 420 micromhos/cm. The pH, measured in August 1978, was similar at both sampling sites (7.7 mouth; 7.8 upstream).

Diamond Creek

Diamond Creek enters the Colorado River from the south at R. M. 464. Diamond Springs, which is located approximately 16 km upstream from the confluence at an elevation of 1098 m, is the main water source for Diamond Creek. Above the Springs, Diamond Creek is intermittent. Although no discharge measurements are available from the Springs, three measurements at the mouth of the Creek in June and October, yielded a range of 0.04 to 0.1 cms. The average gradient for the Creek is approximately 49 m/km (U. S. G. S. 1967a, c, f).

At the mouth of Diamond Creek, the canyon is wide with little vegetation near the Creek itself, although occasional stands of salt cedar and seep willow may occur some distance from the Creek. Upstream, the canyon narrows and the stream meanders between high walls of granite and schist. Seep willow, cattail and rabbitfoot grass (*Polypogon monspeliensis*) occur at or near the margins of the stream.

Diamond Creek is the traditional pull-out point for most commercial river trips, and the road leading to Diamond Creek is heavily used during the spring, summer and fall. Maintenance of the road, which follows the stream channel for two kilometers near the confluence, has on occasion shifted the Creek channel near its confluence. Diamond Creek flash floods regularly during the summer.

The water temperature of Diamond Creek at its confluence with the mainstream ranged from 12 to 27°, while the temperature at the upstream station displayed a similar variation (12° to 27.5°). Specific conductance at the confluence ranged from 470 to 800 micromhos/cm, while at the upstream station, it varied from 410 to 850 micromhos/cm. The pH, measured only during the August trip, was 8.4 at both stations (Table 3-4).

Elves Chasm

Elves Chasm is located at R. M. 572.8 where Royal Arch Creek enters the Colorado River. The creek originates from the Aztec Amphitheater at an elevation of approximately 1525 m and drains a small portion of the Coconino Plateau. The creek is about 5 km long and has an average gradient of approximately 164 m/km. This small, intermittent stream (U. S. G. S. 1962b) has a discharge of from 0.003 to 0.01 cms (Johnson and Sanderson 1968).

The canyon is wide at the mouth of the creek with very little vegetation. The substrate is primarily composed of river deposits of sand, gravel and cobbles. A short distance upstream, just above the high water mark of the Colorado River, several small pools are formed in the Precambrian rock. Vegetation along the margins of these pools consists of seep willow, salt cedar and red bud. Further upstream, there are a number of pools and falls bordered by maidenhair ferns and monkey flower. High walls of Tapeats Sandstone, Redwall Limestone and Travertine form a narrow canyon further upstream.

Elves Chasm displayed a relatively wide seasonal range in temperature and specific conductance at both stations. At the mouth, temperature varied from 8.5 to 17.5 C while the upstream ranged from 8.5 to 21 C. The specific conductance varied from 429 to 1200 micromhos/cm at the mouth and from 525 to 940 micromhos/cm upstream. A pH value of 8.1 was recorded at the mouth of the creek (August 1978). Upstream readings taken during summer and fall trips were 8.2 (Table 3-4). Elves Chasm is classified as a sulfate stream (Cole and Kubly 1976, 1977).

Travertine Falls

Travertine Falls, located at R. M. 459.7 on the south side of the Canyon, is a small waterfall approximately 24 in in height and about 200 m from the Colorado River. The intermittent stream that feeds the waterfall originates near a peak north of Peach Springs Canyon at an elevation of 952 m. The creek flows north approximately 2 km to the Colorado River with an average gradient of 341 m/km (U. S. G. S. 1967e, f, g).

No discharge data are available for the creek. During February and May the creek had an estimated flow of 0.01 cms.

Travertine is deposited along the falls, at the base of the falls, and within the stream channel between the falls and the Colorado River. Seep willow and salt cedar form an open overstory along the stream near the mouth of the creek. Below the falls, alkali goldenbush and rock daisy (*Perityle emoryi*) grow along the stream margins.

Some tributaries were sampled less frequently and consequently yielded less data. These tributaries include Buckfarm, Nankoweap and Unkar Creeks, 155 Mile and National Canyons, Lava Falls Springs, Three Springs and 2.9 Mile Canyon. The physico-chemical data collected for these tributaries are in Table 3-4.

Buckfarm Creek

Buckfarm Creek is an intermittent stream that enters the north side of the Colorado River at R. M. 649.7. The Creek drains a small portion of the eastern section of the Kaibab Plateau and is approximately 16 km long. The average gradient for the Creek is about 83 m/km (U. S. G. S. 1954b).

During this study, the Creek was never observed to flow all the way to its confluence with the Colorado River. Only small pools were found 1.2 km upstream from the mouth in August and December. In addition, there is a large pool near the confluence which is isolated at low mainstream water levels, but becomes inundated in periods of high flow. The discharge is estimated to be low except when summer flash floods occur.

Near the mouth of the Creek, the canyon is open and river deposits of sand and gravel provide a substrate for a dense streamside overstory of arrowweed and coyote willow. Upstream, the canyon narrows between steep, vertical walls of Redwall Limestone. A few small seeps along the canyon walls support a number of maidenhair ferns and helleborine orchids (*Epipactis gigantea*), birchleaf buckthorn (*Rhamnus betulaefolia*) and stands of cattails.

Nankoweap Creek

Nankoweap Creek is a small, intermittent stream that enters the Colorado River at R. M. 636.4. The Creek drains portions of the east Walhalla Plateau and flows northwestward for about 14 km before reaching the Colorado River. Its average gradient is approximately 61 m/km (U. S. G. S. 1954b). Discharge measurements near the mouth of the Creek during June and August ranged from zero flow to 1.09 cms (Johnson and Sanderson 1968).

A large, open alluvial deposit of boulders, cobbles and gravel occurs near the confluence of the Creek. This deposit extends for some distance upstream and is probably a result of deposition from both the Creek and the Colorado River. The sparse marginal vegetation consists of scattered arrowweed and salt cedar.

Unkar Creek

Unkar Creek, which is a small and intermittent stream that drains southern portions of the Walhalla Plateau enters the Colorado River at R.M. 616.5. It flows southeastward for about 8 km before reaching the Colorado River and has an average gradient of about 155 m/km (U. S. G. S. 1962c).

No discharge measurements are available for Unkar Creek. During this study, the Creek was never observed flowing at its confluence. A small amount of water flow was encountered approximately 3 km upstream from the confluence in January.

Near the mouth of the Creek, there are river deposits of gravel, cobbles and boulders. Vegetation is scarce within the floodplain of the Creek and only appears approximately 3 km upstream in the form of marginal vegetation consisting of canebeard grass (*Bothriochloa barbinodis*), saw grass (*Cladium californicum*) and common reeds. The canyon through which the Creek flows is relatively open and is bordered by gentle slopes formed by the Precambrian Dox Formation.

One Fifty-Five Mile Canyon

The small stream that flows into the Canyon at R. M. 539.7 is less than 2 km in length and drains a small portion of the southern Kaibab Plateau (U. S. G. S. 1962a). Near the mouth of the creek, small pools are formed in the Muav Limestone. These pools are surrounded by seep willow, sawgrass, bulrush, ash (*Fraxinus* sp.) and scratchgrass. Below these pools, the creek drops off a shelf into the Colorado River, forming a falls approximately 31 m in height. Bulrush, scratchgrass, blue-eyed grass (*Sisyrinchium demissum*) and maidenhair fern line the canyon wall above the falls.

National Canyon

National Canyon enters the Colorado River from the southeast near R. M. 523.3. The small intermittent stream that flows through this canyon is about 10 km in length and drains portions of the Coconino Plateau (U. S. G. S. 1962a).

The creek was never observed flowing into the Colorado River during the study. In January and August, pools were observed approximately 1.3 km upstream from the confluence. The canyon through which the creek flows is narrow with steep walls of Muav and Redwall Limestone. The floor of the canyon is paved with gravel, sand and cobbles and very little vegetation.

Two Nineteen Mile Canyon

The creek that flows through the canyon at R. M. 470.8 is small and intermittent. The stream flow originates in part from Stanley Spring located 6 km upstream from the confluence. The average gradient is about 78 m/km (U. S. G. S. 1967d, e).

Discharge measurements for the creek are not available. During this study the creek was never observed flowing into the Colorado River. In December and January, small pools were encountered a distance of about 0.8 km up the canyon.

Vertical cliffs of granite and schist form steep walls and a narrow canyon. The floor of the canyon is paved with gravel, cobbles and boulders, and vegetation is limited to a few seep willow and alkali goldenbush.

Vasey's Paradise was the only spring that was consistently sampled. Lava Falls Spring was sampled by Cole and Kubly (1976, 1977), but not during this study. Three Springs and Bridge Canyon were qualitatively sampled for invertebrates and plants, with water chemistry analysis being sporadic.

Vasey's Paradise

Vasey's Paradise is a spring in Marble Canyon located at R. M. 668.1. The spring issues from the Redwall Limestone 38 m above the Colorado River and drains the eastern part of the Kaibab Plateau (Huntoon 1970). Its discharge is estimated to range between 0.1 and 0.3 cms depending on ground water activity (Johnson and Sanderson 1968). The water cascades down the Redwall Cliffs to terraced slopes at the base of the falls. The abundant vegetation near the spring consists of dense stands of monkey flower and poison ivy (*Rhus radicans*).

Vasey's Paradise is a popular stop for commercial river trips during the spring, summer and fall though their effect on the spring is probably minimal.

Vasey's Paradise was sampled for water quality parameters near its confluence. The water temperatures fluctuated from [illegible] to 18.5 C (Table 3-4). The specific conductance ranged from 248 to 420 micromhos/cm and a pH of 8.4 was recorded during the summer and fall trips. Vasey's Paradise was classified by Cole and Kubly as a dilute, dolomitic water.

Lava Falls Spring

Lava Falls Spring is located at R. M. 510.6 on the south side of Lava Falls Rapids. Several springs issue water from the base of the canyon walls forming open pools scattered throughout a dense marsh of sawgrass.

Three Springs Canyon

Three Springs Canyon enters the Colorado River at R. M. 474. The intermittent creek that flows through this canyon is less than 6.0 km in length, with an average gradient of about 190 m/km (U. S. G. S. 1967b).

The estimated flow of this creek ranged from .01 to 0.1 cms during January and May.

At the confluence, steep walls of Tapeats Sandstone form a small, narrow canyon while the stream flows over solid sandstone. Vegetation is scarce at the confluence. The vegetation is more abundant upstream, where the canyon widens as the creek flows along the Bright Angel Shale. Seep willow, salt cedar, monkey flower, cattail and common reed constitute most of the upstream marginal vegetation.

Bridge Canyon

Bridge Canyon is located at R. M. 455.1. This small intermittent creek originates at the head of Bridge Canyon where the elevation is about 1342 m. The creek flows north to the Colorado River and is about 6 km in length with an average gradient of 152 m/km (U. S. G. S. 1967h).

At no time was the creek found flowing at its confluence with the Colorado River. In May and August small pools were encounted approximately 0.8 km upstream. No vegetation was observed growing around the edges of these pools.

BACTERIAL WATER QUALITY

Little research has been done on the bacterial water quality of the Colorado mainstream and its tributaries (but see Slawson and Everett 1972a, b, 1973, Sommerfeld et al. 1976, U. S. G. S. 1976, 1977) due primarily to inaccessability and problems involved in controlling conditions for bacterial analysis in the field. Due to infrequent sampling and the extreme variability and rapid changes associated with summer rains and flooding, specific conclusions are difficult to draw concerning the bacterial water quality. Slawson and Everett (1972a, b, 1973) found that the bacterial water quality of the Colorado River channel was relatively stable with only slight increases in bacterial load occurring during the summer between Lee Ferry and Diamond Creek. The tributaries showed extreme variability in bacterial contamination as a result of summer rains and flood patterns (Slawson and Everett 1973, Sommerfeld et al. 1976).

Coliform bacteria are a diverse group that include species associated with fecal wastes of humans and other warm-blooded animals, as well as those found in the soil and vegetation. These bacteria are used as indicators of contamination and suggest the possible presence of pathogenic organisms such as those causing typhoid fever, cholera and various types of dysentary. For every pathogen, there are millions of coliforms, but they all exist in similar environments (Slawson and Everett 1973).

Contamination of water sources can be evaluated by three tests using this group of bacteria: the total coliform test, the fecal coliform test, and the fecal coliform/fecal streptococcus test. The coliform bacteria of fecal origin are isolated by the fecal coliform test which includes bacteria of both humans and animals. The possible source of the pollution can be traced to humans or other warm-blooded animals by the fecal coliform/fecal streptococcus ratio. A ratio of one and below is indicative of animal origin, whereas four and above is indicative of human origin. Ratios between one and four are a gray area that is ill-defined. The fecal coliform analysis provides a better indication of the possible presence of enteric pathogens than does the total coliform test due to the elimination of non-fecal bacteria (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee 1970).

Total viable bacteria are not specific indicators of pollution as are the coliform bacteria, however elevated microbial populations have been associated with the presence of Pseudomonas aerarginesa, a bacterium that is often the cause of persistent ear and urinary infections (Hoadly 1968).

The desired quality criteria, issued by the Federal Safe Drinking H_2O Standard, are that there should be less than four total coliforms (TC) per 100 ml (milliliter) in surface waters used for drinking. The Arizona water quality standard for primary contact (recreation) is a mean fecal coliform count of less than 200 per 100 ml with 10% of the samples having less than 400 per 100 ml sample (NACOG 1978b).

Grazing and recreational use are both possible sources of contamination. Sommerfeld et al. (1976) found fecal conforms in water from a grazed watershed at a level 16 times greater than in water from a ungrazed control watershed. This may account for the high coliform counts found in the Paria River, Kanab and Diamond creeks, since these watersheds are all subject to heavy grazing.

Aquatic studies for determining the effect of recreational use on bacterial water quality are inconclusive. Carswell et al. (1969), Lee et al. (1970), and Stuart et al. (1971) showed little or no deterioration in bacterial water quality due to recreational use while Sommerfeld et al. (1976) indicated that coliform levels may be influenced by recreational use, especially during the summer months at particularly popular streams and pools. They also found undesirably high coliform levels during periods of low usage and felt that the precise source could only be determined through utilization of fecal conform/fecal streptococcus ratios. Slawson and Everett (1973) showed that with the possible exception of Deer Creek, the popular recreation sites were in excess of the levels recommended for primary contact. However, because of their failure to obtain countable plates, quantitative evaluation could not be made. NACOG (1978b) also fould a positive correlation between coliform counts and site popularity.

Waste or wastewater effluent is flowing into the Colorado mainstream and a number of tributaries at several points. The Wahweap Marina on Lake Powell is a site of effluent contamination. The sewage treatment plant for this area is located in Utah and is in need of improvement according to the recent Arizona Dept. Health Services Basic Plan (1978). NACOG (1978b) reports that the impact of the waste at this facility is local, and available data indicate no major problem. Some of the fecal contamination around the marina is a result of wasteholding tanks and the washing of these tanks.

A second site of effluent discharge is the Bureau of Reclamation sewage treatment plant. The discharge from this plant enters the Colorado mainstream below Glen Canyon Dam. Its impact is apparently minimal because of no dilution of the small flow of effluent (Table 3-6).

In the past, Bright Angel Creek has received excess septic tank effluent from the North Rim facility via Transept Canyon. A tertiary treatment plant was installed in 1977 but most of that year was spent "debugging" the system which operates only during the summer months.

Two non-point sources of effluent are Phantom Ranch where it flows into Bright Angel Creek and Indian Gardens where it enters Pipe Creek. These facilities dispose of effluent by evaporation, leach field or irrigation rinse. Both sites have been operating with marginal septic tank systems (NACOG 1978a).

There are two obvious sources for the fecal contamination in Kanab Creek, and these are located in Fredonia, Arizona and Kanab, Utah. Kanab

Table 3-6. Wastewater treatment facilities summary for Grand Canyon National Park area (from NACOG 1978a).

Facility	Year Constr.	Actual Flow (mgd)	Actual Flow (mgd)	Plant Grade	Type of Ownership	Type of Treatment	Type of Digeting	NPDES Permit No.	Type of Monitoring	Plant Op. Meets Reqs.	Quali of Operat
W.P.R.S. - Glen Canyon Dam	1954	0.0154		2	Federal	Ext. Aer.	Colo. R. Mainstream	AZ0110 019[a]	NPDES	Yes	Good
Grand Canyon National Park - North Rim	1977	0.16	0.08	2 + 5	Federal	Act. Sludge /Chem.	Colo. R. Main-stream ID	AZ0110 426a	None	Yes	
Grand Canyon National Park - South Rim	1928 1971	0.04	0.50	3	Federal	Act. Sludge	Havasu Creek ID		Process	Yes	Fair
U.S.F.S. Jacob Lake Centr. Disp.		0.02	0.014	2	Federal	Aer. Lagoon	Kanab Creek ID	AZ0110 272[b]	NPDES	Yes	Poor
Kanab, Utah		0.3			City	Trickling filter	Kanab Creek D	Utah Permit			

KEY:

ID - Indirect discharge to dry wash tributary to main tributary segment

D - Direct discharge to main tributary segment has a trickling filter wastewater treatment plant that discharges the effluent into Kanab Creek. Indicators of fecal pollution in Kanab Creek increase below the Kanab wastewater treatment plant. The plant is not the only source of fecal pollution in Kanab Creek as evidenced by the high fecal coliform counts upstream from the plant (Slawson and Everett 1974).

> "Contamination of fecal coliform in Kanab Creek greater than 200 per 100 ml were sporadically encountered as far north as Alton, though this level of contamination was detected more frequently at the monitoring stations above and below the town of Kanab" (NACOG 1978b).

Septic tanks are the method of waste disposal in Fredonia, Arizona. There are very few data on bacteriological water quality for the Arizona portion of Kanab Creek. This makes it difficult to assess the impact of the Fredonia waste disposal system on Kanab Creek. Sampling of Kanab Creek at the Arizona-Utah state line in 1972 showed very high counts of fecal coliform. The confluence of Kanab Creek with the Colorado River has also had high counts. Fecal coliform/fecal streptococcus ratios were indicative of recent human fecal input (NACOG 1978a). Slawson and Everett (1974) have shown that during dry periods, the chlorination at the Kanab treatment plant is adequate to kill all coliform, whereas fecal streptococci are more tolerant to chlorination (Slawson and Everett 1974).

> "Relatively low levels of contamination have been associated with low discharges in Kanab Creek. During periods of flooding in Kanab Creek, the situation is expected to be very different. Precipitation greatly increases the volume of wastes to be treated and hence, treatment efficiency is usually greatly diminished by rainfall. Also, low charges associated with dry periods may also contribute to the contamination problem by allowing build-up of organic matter and bacteria in the creek area. Rains would produce overflow problems in sewage treatment facilities and act to flush this accumulated material into the Grand Canyon area." (Slawson and Everett 1974).

The U. S. F. S. Jacob Lake central disposal system discharges into Warm Springs Wash approximately 25 miles from Kanab Creek. No data are available on this area, but it is doubtful that the impact of the plant would be significant due to its distance from a flowing stream (NACOG 1978b).

Havasu Creek at R. M. 533 has been shown by the fecal coliform/fecal streptococcus ratio to have high human fecal contamination. Within the Park boundary, the creek is perennial. The fecal coliform level increases significantly as the creek passes through the Supai Village (Slawson and Everett 1974). The most obvious source for this contamination is the untreated human waste from the Village, though the extensive livestock in the area probably also contribute to the contamination. Irrigation ditches around Supai collect the wastes of human and animal populations. Precipitation in the Canyon then flushes this material into Havasu Creek (Slawson and Everett 1974). In addition to the contamination from the human and animal populations at Supai, NACOG (1978b) reports that the effluent from the National Park Service South Rim sewage lagoon may also occasionally reach Havasu Creek.

CHAPTER 4

AQUATIC PLANTS

Introduction

The objectives of this portion of the study were to 1) inventory plants with aquatic affinities in the study area 2) determine the general distribution and abundance of these plants and 3) determine the extent of aquatic plant utilization.

Early vegetational studies in Grand Canyon National Park dealt primarily with collections of riparian plants from various localities on the mainstream and some of the tributaries. In any survey of aquatic macrophytes, it is difficult to differentiate between absolutely aquatic habitats and terrestrial ones due to seasonal and diurnal water level fluctuations that result in a gradation from dry through waterlogged to submersed soils. Aquatic macrophytes have successfully colonized all of these transitional habitats as well as the water itself (Noirfalise and Sougnez 1961). Consequently, earlier plant lists, as well as our own, include plants ranging from taxa commonly thought of as terrestrial to totally aquatic plants (Appendix 4-1). Many of the early plant lists were compiled from collections made along tributaries (Bryant 1942, Deaver 1948, Deaver and Haskell 1955, Howell 1950) and therefore included some emergent macrophytes. The aquatic flora from early plant lists compiled for the entire Grand Canyon (Clover and Jotter 1944, Patraw 1936) were found to be incomplete and have only recently been made relatively complete (Carothers and Aitchison 1976, Bennett 1978). Other studies of riparian vegetation within the Grand Canyon have documented changes in river bank vegetation due to the influence of Glen Canyon Dam (Carothers and Aitchison 1976, Turner and Karpiscak 1980).

Only three algal surveys were completed in the Grand Canyon prior to the opening of Glen Canyon Dam. Flowers (1959) listed approximately 52 taxa of algae, 20 of which were datoms, from Glen Canyon. Woodbury et al. (1959) was the first to note that the alga, C. glomerata, which is now the dominant alga species within the Grand Canyon, only occurred on the downstream sides of large boulders. Other pre-Dam studies (Weber 1971, Williams and Scott 1962) listed the dominant diatom species from a water quality surveillance station located on the Colorado River near Page, Arizona, about 24 km upstream of Lee Ferry.

The first intensive investigations of the phytoplankton (Crayton and Sommerfeld 1978, Sommerfeld et al. 1976) and periphyton (Czarnecki et al. 1976) have only recently been completed. Crayton and Sommerfeld (1978) reported a total of 127 taxa of phytoplankton (73 diatoms (Bacillariophyta, mostly tychoplankton), 27 greens (Chlorophyta), 22 blue-greens (Cyanophyta), 3 golden-browns (Chrysophyta), and 2 dinoflagellates (Pyrrhophyta)) from the Colorado River based on a year of seasonal samples.

The greatest phytoplankton diversity occurred in May 1975 when 58 taxa were collected, while the highest abundance peaked at about 3000/1 in August 1975. Crayton and Sommerfeld (1978) felt that the limited development of euplanktonic communities within the Grand Canyon was the result of low temperature, high turbidity and the rapid flow rate of water through the Canyon. The dominance of phytoplankton in the system was attributed to fluctuating river levels, high current velocity and turbulence. Czarnecki et al. (1976) reported 345 taxa of periphytic algae (224 diatoms, 83 blue-greens, 34 greens, 3 yellow-greens (Xanthophyta), and 1 red alga (Rhodophyta)) from the Grand Canyon system. As they proceeded downstream, there was a gradual decline in importance values for the three most typical Grand Canyon diatoms (Diatoma vulgare, Cocconeis pediculus and Rhoicosphenia curvata), which was thought to be due to an increase in suspended sediment that caused abrasion or light attenuation.

Results

A total of 131 species (41 families) of aquatic macrophytes were collected from the mainstream and the tributaries during the present study (Appendices 4-2, 4-3), ten of which were additions to the Grand Canyon flora. The most notable of the new species were common poolmat (Zanichellia palustris) and water weed (Elodea canadensis) from the mainstream, and jointed rush (Juncus articulatus) from most tributaries and the mainstream. Sixty-one taxa of diatoms from eight families were collected at the upstream stations of the primary tributaries (Appendix 4-4).

Mainstream

Aquatic macrophytes collected from the mainstream (Appendix 4-2) were emergent or bank plants except for two submerged species (water weed and common poolmat) and one filamentous alga (Cladophora glomerata). The existence of rooted water weed in the Grand Canyon has not yet been confirmed due to our only finding floating fragments at Lee Ferry and Shinumo Creek. Free-floating fragments of common poolmat were collected in

Marble Canyon and were found in large, rooted stands at Lee Ferry and in several tributaries. The filamentous green alga, Cladophora glomerata, was found throughout the study area, especially in the portion inundated by mainstream water and in Marble Canyon.

Emergent macrophytes and bank plants were established in four main habitats along the Colorado River: the littoral zone among protective boulders, on sand beaches slightly above the high water mark, in marshes usually associated with tributary mouths, and in "hanging" travertine springs and seeps. Plants regularly found within the littoral zone included water bentgrass (Agrostis semiverticillata), barnyard grass (Echinochloa crusgalli), cocklebur (Xanthium strumarium) and jointed rush. The latter formed dense, low growing mats in the sand between boulders. Emergents common on sand beaches just above high water levels were three-square bulrush (Scirpus americanus) and horsetail (Equisetum spp.). Several large emergents including cat-tail (Typha spp.), common reed (Phragmites australis) and sawgrass (Cladium californicum) were common in marshy areas. In addition to these marsh plants, maidenhair fern (Adiantum capillus-veneris), cardinal monkey flower (Mimulus cardinalis) and water bentgrass were conspicuous inhabitants of travertine seeps.

The most widespread aquatic macrophytes of the mainstream were the woody bank plants, salt cedar (Tamarix chinensis), coyote willow (Salix exigua), arrowweed (Tessaria sericea) and seep willow (Baccharis salicifolia) (Appenidx 4-2). Other widespread mainstream plants were the large emergents three-square bulrush, horsetail and common reed. Plants rarely found along the mainstream included common poolmat (rooted), Lepidium (aff. L. medium), desert crowfoot (Ranunculus _cymbalaria_ var. _saximontanus),_ and Buckley's centaury _(Centarium calycosum)._

Many of the perennial aquatic plants from the Grand Canyon differ from those elsewhere in northern Arizona in that they remain green all year. Cat-tail, sawgrass, bulrush, water speedwell _(Veronica anagallis-aquatica),_ cardinal monkey flower and water cress _(Rorippa nasturtium-aquaticum)_ were green during both winter trips. A few individuals of cardinal monkey flower and water speedwell were observed blooming during all five sampling trips. With the above exceptions, the flowering times of most of the aquatic macrophytes in the Grand Canyon (Appendix 4-2, 4-3) are similar to those in the literature.

Tributaries

Most tributaries had at least one submerged macrophyte, usually stonewort, and a variable number of emergent and bank plants. The number of species collected in the tributaries ranged from 43 at the Paria River to 11 at Shinumo Creek (Appendix 4-3). Of the other tributaries, Vasey's Paradise had the greatest number of species (30) and National Canyon had the least (2).

The location having the greatest number of submerged species per unit area was the sandy-bottomed pool just above river level at Elves Chasm, where stonewort, common poolmat, curled pondweed, and several large mats of filamentous algae were observed during the fall trip.

During the winter trips, Bright Angel Creek had a well developed band of emergent dicots that included water cress, willowweed _(Epilobium hornemanni)_ and water speedwell. These plants were evidently swept away during spring runoff (April - May 1978) as they were gone before the spring trip.

Plants common to most tributaries were the woody bank species salt cedar and common coyote and seep willow. Emergent species throughout most of the tributaries were southern cat-tail (Typha domingensis), water bentgrass, (Bothriochloa bardinoidis), common reed, rabbitfoot grass (Polypogon monspeliensis) and three-square bulrush. Water speedwell and water cress were the common low dicots (Appendix 4-3).

Several introduced tall emergents such as ravenna grass (Erianthus ravennae), giant dropseed (Sporobolus giganteus) and salt-marsh bulrush (Scirpus paludosus) were only found at a few tributaries. Woody vines that covered significant areas in the various tributaries that they occurred included poison ivy (Rhus radicans), Arizona grape (Vitis arizonica) and Virginia creeper (Parthenocissus inserta). Low monocots with a restricted tributary distribution included galleata (Hilaria jamesii) and blue-eyed grass (Sisyrinchium demissum). Low dicots with restricted distributions included columbine (Aquilegia micrantha), desert crowfoot, field mint (Mentha arvensis), cardinal flower (Lobelia cardinalis), and chicory (Cichorium intybus), the latter two being introduced species.

Phenologically, several species deviated from literature descriptions. Common poolmat was collected in fruit from the Little Colorado River during all trips though it reportedly dies back to the roots during winter months (Haslam 1978). Stonewort and curled pondweed were never collected in bloom or fruit during the study. Generally, the same emergent species stayed green through the winter along both the mainstream and tributaries. The greatest amount of new growth (via vegetative spread and seed germination) occurred during the spring and summer. In May, many Fremont cottonwood (Populus fremontii) seedlings were observed on the sand bars along the

Paria River where they remained through the fall trip. Between the spring and fall sampling trips, the cat-tail and bulrush stands along the Paria River increased considerably in size and cat-tail seedlings became established in shallow areas of the Little Colorado River.

The emergent transect run at the mouth of the Paria River had the highest species diversity (5 - 6 species) of the three emergent transects with horsetail predominating during all three sampling periods (Table 4-1). The lowest importance value recorded for horsetail (118.3) occurred in spring and the highest (196.7) in summer. Buckhorn plantain (*Plantago lanceolata*) was second in importance during all three sampling periods. This species reaches its highest importance value during spring (76.3) and declined through the summer (49.6) and fall (41.8) (Table 4-1).

The transect along the Little Colorado River, located on the inside of a sweeping bend in the river, traversed a long stand of three-square bulrush. The numerous submerged roots of three-square bulrush provided substrate for a filamentous green alga (Order Zygnematales) and small fish, presumably humpback chub fry, during the summer and fall months. Common poolmat became established near the upstream portions of the transect during summer and fall. Three-square bulrush predominated this transect during all three sampling periods (Table 4-1), with species diversity increasing from spring through summer. The predominance of three-square bulrush was due to its high density, which decreased only slightly after spring. Common reed only became apparent in the summer and fall though small shoots were noted just outside the transect during spring.

Table 4-1. Seasonal importance values for plants occurring in transects along Bright Angel Creek, the Little Colorado and Paria Rivers.

Location	Trip	Species	Relative Density (%)	Relative Frequency (%)	Relative Cover (%)	Importance Value
Bright Angel Creek	Winter 1977	Equisetum hiemale	100	100	100	300
	Winter 1978	Equisetum hiemale	100	100	100	300
L. Colorado River	Winter 1978	Scirpus americanus	100	100	100	300
	Spring 1978	Scirpus americanus	100	100	100	300
	Summer 1978	Phragmites australis	0.8	4.1	10.3	15.2
		Scirpus americanus	99.2	95.9	89.7	284.8
	Fall 1978	Phragmites australis	1.2	7.7	1.1	10.0
		Scirpus americanus	98.5	88.5	98.4	285.4
		Tamarix pentandra	0.2	3.8	0.5	4.5
Paria River (near the mouth)	Spring 1978	Equisetum hiemale	48.9	40.0	29.4	118.3
		Muhlenbergia asperifolia	45.6	13.3	10.3	69.2

(continued)

Table 4-1 (cont.). Seasonal importance values for plants occurring in transects along Bright Angel Creek, the Little Colorado and Paria Rivers.

Location	Trip	Species	Relative Density (%)	Relative Frequency (%)	Relative Cover (%)	Importance Value
Paria River (near the mouth)	Spring 1978	Phragmites australis	0.5	6.6	1.5	8.6
		Plantago lanceolata	1.9	20.0	54.4	76.3
		Scirpus americanus	2.9	13.3	2.9	19.1
		Taraxacum off icinale	0.1	6.6	1.5	8.2
	Summer 1978	Equisetum hiemale	87.0	36.4	73.3	196.7
		Melilotus sp.	2.9	18.2	4.4	25.5
		Muhlenbergia asperi-folia	5.0	9.1	2.2	16.3
		Plantago lanceolata	4.6	27.3	17.7	49.6
		Taraxacum officinale	0.4	9.1	2.2	11.7
	Fall 1978	Equisetum hiemale	94.0	50.0	51.0	195.0
		Juncus articulatus	1.2	10.0	2.0	13.2
		Melilotus alba	0.6	10.0	2.0	12.6
		Muhlenbergia asperi-folia	1.8	10.0	2.0	13.8

(continued)

Table 4-1 (cont.). Seasonal importance values for plants occurring in transects along Bright Angel Creek, the Little Colorado and Paria Rivers.

Location	Trip	Species	Relative Density (%)	Relative Frequency (%)	Relative Cover (%)	Importance Value
Paria River (near the mouth)	Fall 1978	Plantago lanceolata	1.2	10.0	30.6	41.8
		Taraxacum officinale	1.2	10.0	12.2	23.4

The Bright Angel Creek transect was in a very dense, single species stand of horsetail (Table 4-1) growing in slow moving water on the outside of a curve. The stand remained green throughout the year.

Quantification of the epilithic diatoms from the upstream stations of the primary tributaries (Table 4-2, Appendix 4-5) suggests that the greatest density occurs in the fall. The greatest number of species (28) was recorded in the fall Tapeats Creek sample. The three dominant taxa from this sample, Navicula tripunctata var. schizonemoides (14.2%), Cymbella affinis (12.1%) and Navicula minima (9.4%) comprised 35.7% of the individuals (Appendix [illegible] The fall Paria River sample was dominated by Achnanthes linearis (45.8%), A. sublaevis var. crassa (7.3%) and Cymbella microcephala var. crassa (22.1%). The lowest total number of cells/cm^2 were found in Shinumo Creek during the summer when only two taxa of diatoms, Epithemia sorex and Cocconeis placentula var. euglypta, were recorded.

Discussion

The occurrence of a particular aquatic plant species along and within a body of water is determined by the interaction of physical, chemical and biological factors (Hutchinson 1975). Water chemistry, seed dispersal and flow rates are some of the major factors determining the overall occurrence of aquatic macrophytes within the Grand Canyon system. Most plants collected during the study are typical of water with a high conductivity and alkalinity. Common mainstream plants (e. g., bulrush, cat-tail, salt cedar) are dispersed via water and wind currents and aquatic animals. The uncommon plants may not produce enough seeds to be dispersed effectively to other suitable areas.

Table 4-2. Total number of diatoms/cm^2 for the 500 m stations. Little Colorado River was sampled from the mouth during Winter 1978 and from the Blue Springs area during the Summer 1978.

Tributary	Winter 1977	Winter 1978	Summer 1978	Fall 1978
Paria River			2594.3	154,693.5
Little Colorado River		288.1		
Bright Angel Creek	2083.5	7501.4		
Shinumo Creek		2520.6	28.8	
Tapeats Creek	172.8			10,325.2
Deer Creek	590.5		172.8	
Kanab Creek		244.9		
Havasu Creek	6394.9	6319.3		

From the data collected during this study, it is evident that the physical effects of flow, especially rapid flow, restrict the distribution of submerged aquatic macrophytes. This can be seen by comparing Elves Chasm (Appendix 4-3) and the mainstream (Appendix 4-2). Though the two are quite similar in water chemistry (Cole and Kubly 1976), Elves Chasm has a stable flow of low velocity, whereas the mainstream has wide diurnal fluctuations in discharge and velocity and much greater turbulence. Three species of submerged macrophytes (common poolmat, stonewort, curled pondweed) and several filamentous algae occurred in a pool sampled at Elves Chasm, while only one submerged macrophyte (common poolmat) and one filamentous alga occurred in the mainstream. Common poolmat seems to be more tolerant of fast flow (Haslam 1978) than other macrophytes probably due to its flexible stems and narrow leaves which offer little hydraulic resistance, and dense, curly roots capable of varying their level as sediment accumulates or erodes.

Cladophora glomerata, the most obvious aquatic mainstream plant, is largely influenced by the same physical factors as submerged aquatic macrophytes. This alga overcomes these factors via a rapid growth rate and the ability of its fragments to continue growth in an unattached state. C. glomerata's wide tolerance range is probably a result of its genetic variability and behavioral flexibility since it is usually polyploid (Whitton 1970).

Emergent aquatic macrophytes and bank plants along the mainstream are seldom subjected to the rigorous effects of flow and sediment endured by the submerged aquatic plants. Only two of the four mainstream habitats in which emergents occur have the potential for being directly affected by the River's flow. Both the sandy beaches that are colonized by horsetail and three-square bulrush and the sparse stands of plants within the protected littoral zone are subjected to erosion during high flows. In pre-Dam days, seasonal high flows prevented the establishment of large stands of emergents and woody bank plants adjacent to the River. Today, these stands are common due to the limited fluctuation in the water level.

Changes in the macrophytic vegetation along Bright Angel Creek during this study seem to have resulted from flooding. During the winter trips, numerous emergent and sumberged aquatic macrophytes were noted along the Creek. Many of the emergents were low dicots having high hydraulic resistance and relatively low anchoring strength (Haslam 1978). Stonewort, which has relatively low anchoring strength, was the most abundant submerged macrophyte. Both plant groups were gone by the spring trip when the Creek was high and swift due to spring run-off. The growth of low dicots never recovered to what it had been in November 1977 during the remaining sampling periods. Tall monocot emergents were flattened but not swept away by the high flows. This indicates that along many of the tributaries, the frequency and duration of high flows resulting from spring run-off or flash flooding play an important role in governing the development of an aquatic flora. This is also suggested by the high species numbers in tributaries not normally subjected to high flows (i. e., Elves Chasm: 20 species; Three Springs: 17 species).

Emergents are important to the mainstream and tributaries in several ways. Their rhizomes stabilize banks of fine sediment, while their submerged, exposed rhizomes and stems serve as a rich substrate for epiphytic periphyton and provide food and shelter for small aquatic organisms. The detrital input of large stands of emergent macrophytes are an important food source for detritivores and provide necessary organic nutrients for algal growth. For example, large numbers of the detritivorous carp are regularly captured in the Colorado River near its junction with Lava Springs, an area rich in organics as a result of flowing through a marsh.

Factors allowing the large emergents to remain green throughout the winter include the mildness of the climate and the buffering effects of the River on winter air temperatures. The climate was quite mild and moist during our winter sampling, though during colder, drier winters, these emergents may die back. The constant temperatures and the transparency of the mainstream at Lee Ferry allow the common poolmat to stay green throughout the year.

The distribution of some plants in the Grand Canyon appear to be limited by substrate type and light penetration. For instance, the cobble bars near the mouth of Clear Creek had very little vegetation, while upstream, where sand covered the cobbles, vegetation was more plentiful. High canyon walls may block light and restrict photosynthesis at certain times of the year, thereby allowing only shade-tolerant species to occupy certain areas. The greater species diversity at the Paria River transect was probably due to the sandy soil and the light penetration allowed by the relatively low horsetail density.

Factors contributing to the density and species numbers of diatom communities in the Grand Canyon system seem to be conductivity and the availability of current regulated habitats (Czarnecki et al. 1976, Czarnecki and Blinn 1978). A factor that may affect intraseasonal fluctuations of periphytic diatom communities is selective feeding by aquatic organisms such as invertebrates and fish (Patrick 1977).

The greatest number of cells/cm^2 occurred in the Paria River and Tapeats Creek and coincided with the highest mean invertebrate species density and number, suggesting a possible correlation between the two. Spring run-off and flash flooding throughout the summer may be responsible for limiting diatom numbers by reducing conductivity and increasing turbidity and scour. After the summer flood season, conductivity and transparency increase and scour decreases, thus allowing diatom numbers to build back up.

Czarnecki et al. (1976) recorded the highest periphytic diatom densities in the summer (June - July). They felt that the summer densities were the result of an increase in the conductivity of macrophytic substrates caused by the end of spring run-off, evaporation due to high ambient temperatures and from recreation related organics. The decrease in fall densities was attributed to a decrease in macrophytes and to lower conductivities resulting from greater run-off. The discrepancies between this report and those of Czarnecki et al. (1976) cannot be resolved since we sampled one month earlier in the fall and did not sample during June - July.

Man has had, and will continue to have, an impact upon the distribution of aquatic and riparian plants by his use of trails and the introduction of exotic species. Trails may cause trampling damage, initiate erosion or channel necessary water away from portions of large emergent stands. This latter impact is evident in the seeps downstream from Deer Creek and along the upstream portion of Lava Springs. Most introduced plant species, such as date palm (Phoenix dactylifera) and alfalfa (Medicago sativa), occur in very low numbers. One introduced species, ravenna grass, collected for the first time during this project, could possible outcompete emergents that are valuable wildlife forage.

Summary

A total of 131 species of aquatic macrophytes were collected from the Colorado River system. Two submerged macrophtes, water weed and common poolmat, were collected from the mainstream, though only common poolmat is known to be established there. The low diversity of submerged macrophytes in the River is due primarily to the effects of high velocity flows during spring run-off and summer flash flooding as suggested by comparing the mainstream with a slow flowing tributary such as Elves Chasm. Water flow levels also influence the occurrence of macrophytes in and along most of the tributaries.

Emergent transects along the Paria and Little Colorado River and Bright Angel Creek displayed varying degrees of species diversity. Five to six species were consistently present in the Paria River transect, with horsetail and buckhorn plantain predominating. Seasonal diversity increased from spring through summer and fall on the Little Colorado River transect with three-square bulrush having the highest importance value. The only plant present along the Bright Angel Creek transect was horsetail.

Periphytic diatoms from the upstream station of selected tributaries displayed the highest density and species numbers during the fall sampling, coincident with peaks in mean invertebrate density and species numbers in the same tributaries.

Chapter 5

AQUATIC INVERTEBRATES

Introduction

The aquatic invertebrates of the Colorado River and its tributaries in the Grand Canyon have only recently been extensively studied. This reflects the difficulties in reaching the side canyons and streams, many of which are accessible only from the River, and in sampling the Colorado River itself because its high flow rate and rocky substrate preclude the use of a conventional benthic sampler.

Early studies of the aquatic invertebrates focused on specific groups from certain locations within the Canyon. Pilsbury and Ferris (1911) collected two species of snails, *Physa gyrina* (Mollusca: Pelecypoda) from Kanab Creek and P. *humerosa* from Indian Gardens near the Bright Angel trail off South Rim, though it has suggested that the specimens identified as P. *humerosa* may have belonged to a subspecies of P. *virgata* (Bequart and Miller 1973). Searls (1931) made collections of aquatic Coleoptera (beetles) from Bright Angel Creek. Moore and Hungerford (1922) and Gregory and Moore (1931) reported seven genera of aquatic and semi-aquatic Hemiptera (true bugs) from the pools and springs in the upper reaches of the Paria River. Recently, 14 species of aquatic Hemiptera were collected from 12 localities along the Colorado River in Marble and Grand Canyon (Polhemus and Polhemus 1976, Zalom 1977).

Only in recent years have any systematic studies of the benthic invertebrates in the Grand Canyon been conducted. Carothers et al. (1976)

collected approximately 247 families of terrestrial and aquatic insects, including adult emergent forms (the immatures and aquatic) of the orders Plecoptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera and Diptera, from Lee Ferry to Pierce Ferry along the Colorado River. The first comprehensive list of aquatic invertebrates from selected tributaries in the Grand Canyon (Cole and Kubly 1976) included seven classes of aquatic invertebrates from 11 major tributaries and the Colorado River mainstream. Representatives from 34 familes were identified in the class Insecta alone. The most common tributary invertebrates were aquatic earthworms (Oligochaeta), mayflies (Ephemeroptera), caddisflies (Trichoptera) and flies (Diptera). Tributaries with a heavy sediment load and thus, an unstable substrate (i. e., Paria River, Little Colorado River and Kanab Creek) were impoverished in terms of species number and density. They speculated that calcium carbonate precipitates may also restrict the invertebrate fauna in the Little Colorado River and Havasu Creek. A seasonal study of the invertebrates of 'Pipe, Bright Angel and Phantom Creeks in Grand Canyon National Park (Minckley 1978) revealed the occurrence of four dominant families; Simuliidae (black flies), Baetidae (mayflies), Chironomidae (midges), and Hydropsychidae (caddisflies). Overall, the Grand Canyon invertebrate populations, like others in the Southwest, are depauperate compared to eastern systems.

Additional aquatic invertebrates have been introduced into the Grand Canyon as part of the trout fisheries management program. In 1932, 50,000 fresh-water shrimp (Crustacea: Amphipoda) were planted in moss at Bright Angel Creek. It has been assumed that these shrimp, recently identified as *Gammarus lacustris* (Gammaridae) (Kubly 1975), were swept out into the mainstream Colorado River where they are now quite abundant. In 1965, fresh-water shrimp (probably G. *lacustris*), snails (possibly Physidae and

Lymnaeidae), leeches (Hirudinea), caddisflies, damselflies (Odonata) and mayflies were planted at Lee Ferry on the Colorado River. The introduced invertebrates originated from the Upper Colorado River Basin, except for the mayflies which were obtained from a commercial source. (D. Bancroft, Arizona Game and Fish Dept., 1978 pers. comm.).

Quantitative, seasonal data on the Grand Canyon aquatic invertebrate fauna are lacking for many canyon tributaries. In order to understand these interrelationships more thoroughly, Museum of Northern Arizona biologists quantitatively sampled 27 tributaries on a seasonal basis from November 1977 to October 1978. The objectives of this study were to determine

1) aquatic invertebrate productivity and diversity within the Canyon,
2) intertributary similarity of the aquatic invertebrate fauna, and
3) the relationship of these findings to the Canyon fisheries.

Results

Six classes of aquatic invertebrates were collected from the Colorado River and its tributaries during this study (Table 5-1), including 51 families from the class Insecta. The fresh-water shrimp (G. *lacustris*) was collected only from the mainstream and near the confluence of various tributaries. Other mainstream families included the water boatmen (Corixidae), broad-shouldered water striders (Veliidae), midges, black flies, pouch snails (Physidae) and aquatic earthworms. Though the mainstream aquatic invertebrates also occurred in many of the tributaries, the majority of groups collected from the tributaries were not taken from the mainstream (Table 5-2). The invertebrates common to most tributaries were the small mayflies, midges, black flies, and aquatic earthworms.

Table 5-1 . Scientific and common names of aquatic invertebrates collected from the Colorado River and its tributaries.

Phylum: Platyhelminthes
- Class: Turbellaria
  - Order: Tricladida
    - Family: Planariidae (flatworms)

Phylum: Mollusca
- Class: Gastropoda
  - Order: Basommatophora
    - Family: Physidae (pouch snails)
      - Lymnaeidae (pond snails)

Phylum: Annelida
- Class: Oligochaeta (aquatic earthworms)

Phylum: Arthropoda
- Class: Arachnida
  - Order: Acarina
    - Family: Sperchonidae (water mites)
- Class: Crustacea
  - Subclass: Ostracoda
    - Order: Podocopa
      - Family: Cypridae (seed shrimp)
  - Subclass: Malacastraca
    - Order: Amphipoda
      - Family: Gammaridae (scuds)
- Class: Insecta
  - Order: Collembola
    - Family: Isotomidae (springtails)
  - Order: Ephemeroptera
    - Family: Heptageniidae (stream mayflies)
      - Baetidae (small mayflies)
      - Caenidae (small mayflies)
  - Order: Odonata
    - Family: Aeshnidae (common darners)
      - Gomphidae (club-tailed dragonflies)
      - Libellulidae (skimmers)
      - Agrionidae (broad-wing damselflies)
      - Lestidae (lestid damselflies)
      - Coenagrionidae (narrow-winged damselflies)
  - Order: Plecoptera
    - Family: Nemouridae (spring stoneflies)
      - Perlidae (common stoneflies)
      - Perlodidae (perlodid stoneflies)
  - Order: Hemiptera
    - Family: Corixidae (water boatmen)
      - Notonectidae (back-swimmers)
      - Belostomatidae (giant water bugs)
      - Naucoridae (creeping water bugs)
      - Gerridae (water striders)
      - Veliidae (broad-shouldered water striders)
      - Mesoveliidae (water treaders)
  - Order: Megaloptera
    - Family: Corydalidae (Dobson flies)
  - Order: Trichoptera
    - Family: Rhyacophilidae (primitive caddis-flies)
      - Glossosomatidae (primitive caddis-flies)
      - Philopotamidae (finger-net caddisflies)
      - Polycentropodidae (trumpet-net caddisflies)
      - Psychomyiidae (trumpet-net caddisflies)

(continued)

Table 5-1 (cont.). Scientific and common names of aquatic invertebrates collected from the Colorado River and its tributaries.

Order: Trichoptera (cont.).
- Family: Hydropsychidae (net-spinning caddisflies)
  - Hydroptilidae (micro-caddisflies)
  - Limnephilidae (northern caddisflies)
  - Brachycentridae (brachycentrid caddisflies)
  - Helicopsychidae (snail-cased caddisflies)

Order: Lepidoptera
- Family: Pyralidae (pyralid moths)

Order: Coleoptera
- Family: Haliplidae (crawling water beetles)
  - Dytiscidae (predaceous diving beetles)
  - Hydrophilidae (water scavenger beetles)
  - Dryopidae (long-toed water beetles)
  - Elmidae (riffle beetles)
  - Curculionidae (snout beetles)

Order: Diptera
- Family: Tipulidae (crane flies)
  - Psychodidae (moth flies)
  - Dixidae (dixid midges)
  - Culicidae (mosquitoes)
  - Ceratopogonidae (biting midges)
  - Chironomidae (midges)
  - Simuliidae (black flies)
  - Stratiomyidae (soldier flies)
  - Tabanidae (horse flies)
  - Empididae (dance flies)
  - Dolichopodidae (long-legged flies)
  - Ephydridae (shore flies)
  - Anthomyiidae (anthomyiid flies)

Table 5-2. List of aquatic invertebrates collected from the Colorado River and the Canyon tributaries.

Families:	a q:: am	r t. ies:	M a	as y' Paradise	uc F m	an ow p	. O ol do R.	nk r	lear	right gwl	ipe	ermit	ys al 4-)	.. um O	H ves U sE	4) on W	apeats	eer	anab	55 E H W	M vasu	ation 1 Oan.	va S /4 gs	O 1/ ile Can	re (2) p . gm	9 N i e	amo	a V e i e Ca.	a e i e Falls	i ge n.	i g W ty	e ce an.
Ephemeroptera																																
Baetidae			X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X		
Caenidae																											X					
Heptageniidae											X	X				X	X					X										
Plecoptera																																
Nemouridae			X						X	X									X			X										
Perlodidae																	X	X														
Perlidae																	X	X														
Odonata																																
Gomphidae			X																													
Libellulidae									X	X	X	X	X	X	X						X	X					X		X			
Coenagrionidae				X	X		X	X	X	X	X	X	X	X	X				X	X	X	X		X			X		X	X		
Agrionidae										X		X																				
Lestidae																															X	
Aeshnidae																		X														
Hemiptera																																
Veliidae	X		X		X				X				X	X		X			X	X		X				X	X		X			
Gerridae			X		X		X					X		X							X											
Gerris sp.																																
Mesoveliidae																																
Belostomatidae			X																				X				X		X			
Naucoridae																																
Corixidae	X																			X											X	
Graptocorixa sp.																																
Notonectidae																				X		X				X					X	
Notonecta sp.																																
Megaloptera																																
Corydalidae									X	X	X	X		X	X	X		X		X							X		X		X	
Corydalus sp.																																
Trichoptera																																
Rhyacophilidae										X							X									X					X	
Polycentropodidae									X	X	X	X		X	X		X	X											X			
Philopotamidae									X	X	X	X			X	X		X									X		X			
Psychomyiidae															X																	
Hydropsychidae			X				X		X	X	X	X	X	X	X	X	X	X	X	X					X		X		X			
Hydroptilidae				X		X		X	X	X	X	X	X		X	X	X	X	X	X	X						X		X			
Glossosomatidae										X							X										X					
Brachycentridae														X			X	X	X													
Limnephilidae					X			X		X		X	X	X	X		X	X	X							X	X					
Helicopsychidae										X	X			X													X					
Lepidoptera																																
Pyralidae			X	X					X	X	X	X	X	X	X		X	X		X									X			

Table 5-2 (cont.). List of aquatic invertebrates collected from the Colorado River and the Canyon tributaries.

	Tributaries:	Paria R.	Vasey's Paradise	Buck Farm	Nankoweap	L. Colorado R.	Unkar	Clear	Bright Angel	Pipe	Hermit	Crystal	Shinumo	Elves Chasm	Stone	Tapeats	Deer	Kanab	155 Mile	Havasu	National Canyon	Lava Springs	190 Mile	Three Springs	219 Mile	Diamond	Travertine Canyon	Travertine Falls	Bridge C.	Bridge	Spring Can.
Coleoptera																															
Curculionidae														X																	
Haliplidae											X			X						X						X					
Dytiscidae				X			X		X		X	X	X						X	X	X				X	X				X	
Hydrophilidae			X	X							X	X		X	X				X	X				X		X					
Dryopidae											X										X					X		X			
Elmidae								X	X	X	X	X	X	X		X	X	X	X									X			
Diptera																															
Tipulidae			X					X			X	X		X	X	X	X	X			X	X				X		X			
Culicidae																							X		X						
Ceratopogonidae											X	X		X		X	X				X					X					
Chironomidae	X	X		X		X	X	X	X	X	X	X	X	X	X	X				X	X			X	X	X	X	X			
Simuliidae		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X						X	X	X		X	X		
Dixidae											X						X														
Stratiomyidae			X		X		X	X	X	X	X			X	X	X	X	X	X	X				X	X	X	X	X			
Tabanidae				X				X	X	X	X	X		X		X										X		X			
Psychodidae									X	X																X	X	X			
Dolichopodidae		X			X									X												X					
Ephydridae						X									X																
Anthomyiidae								X	X	X				X		X	X	X							X	X					
Empididae								X	X	X	X	X	X			X	X	X								X					
Gastropoda																															
Physidae									x		X			X			X		X		X			X					X		
Lymnaeidae			X											X																	
Ostracoda																															
Cypridae									X	X	X			X				X													
Annelida																															
Oligochaeta		X				X		X	X	X	X	X	X	X	X	X	X	X		X	X				X	X		X	X		
Amphipoda																															
Gammaridae			X		X		X	X	X	X				X		X	X														
Hydracarina																															
Sperchonidae								X	X	X	X	X					X	X		X						X					
Collembola																															
Isotomidae				X										X																	
Tricladida																															
Planariidae														X																	

Seasonal invertebrate productivity in the tributaries (Table 5-3) was highly variable and, in general, lower than eastern and other southwestern systems. Productivity, measured as biomass (mg dry weight/m^2) and density (individuals/m^2), ranged from 0 to 1214 mg/m^2 and 0 to 138,666 ind./m^2, respectively. Mean seasonal biomass and density of benthic invertebrates were generally lower in the low gradient sediment-carrying tributaries (i. e., Paria, Little Colorado, Kanab) (Table 5-3) than in the high gradient spring-fed streams (i. e., Bright Angel, Tapeats, Deer). Tributary productivity, measured as biomass, was greater at the upstream location than at the confluence (45 of 60). Seasonal trends in variation of productivity were evident among the tributary confluences using Kendall's coefficient of concordance (Siegel 1956). Biomass ($w_c = 0.328$, $x^2 = 10.80$, $p < .02$) and density ($w_c = 0.612$, $x^2 = 20.18$, $p < .001$) varied in a similar fashion over four seasons with the lowest productivity being in spring and summer. Winter 1978 was not included in the analysis because only a few tributaries were measured at that time. There was also a significant seasonal change in productivity, measured as density ($w_c = 0.342$, $x^2 = 11.27$, $p < .02$) in the upstream transects at the same 11 tributaries. Again, spring and summer samples ranked lowest in terms of productivity (both biomass and density).

The mainstream benthic invertebrates were sampled qualitatively due to logistic difficulties encountered during the study. In general, productivity (biomass and density/m^2) was low, except possibly in the river section between Glen Canyon Dam and the confluence of the Little Colorado River, where sediment input is minimal. Some of the ponar grab samples taken in the side eddies yielded large numbers of aquatic earthworms, midges and fresh-water shrimp. Estimated densities of these samples were

Table 5-3. Seasonal biomass and density values for aquatic invertebrates at the confluence and 200 m upstream (8 km at Paria R.) of the confluence on selected tributaries of the Colorado River. Confluence values are in parentheses. Biomass is expressed as mg dry weight/m² and density as individuals/m².

Tributary	Winter 1977 Biomass	Winter 1977 Density	Winter 1978 Biomass	Winter 1978 Density	Spring 1978 Biomass	Spring 1978 Density	Summer 1978 Biomass	Summer 1978 Density	Fall 1978 Biomass	Fall 1978 Density
Paria R.	(.08) 2.2	(3) 31			(.30) 3.5	(43) 30	(.20) .50	(ˆ) 7	(7.5) 2.8	(118) 32
Nankoweap Cr.	(.10) .17	(10) 22	-	-						
L. Colorado R.	(.2) -	(43) -	(.8) -	(1.6) -	(.6) -	(38)	(.3) -	(11)	.05) .5	(5) 39
Clear Cr.	(1.6) .10	(67) 16	(.6) 8.8	(2.4) 9.9	(.5) .6	(4.3) 40	(.6) 3	(35) 19	(2.7) 18.6	(135) 128
Bright Angel Cr.	(13.8) 68	(457) 1141	(6.1) 46	(51.9) 122.	(19.8) 58.1	(778) 910	11.5) 10.9	(310) 307	35.4) 39.5	(931) 2076
Pipe Cr.	(24.2) 33.5	(1378) 638	12.1) 12.1	(21) 24	(3.5) 36.7	(164) 199	(.8) 62.5	(83) 81	104.7) 66.5	(566) 405
Hermit Cr.	(2.1) 70.5	(54) 517		-	(2.9) 9.9	(9.7) 253	.06) 27.6	(5) 151	14.5) 26 9	(191) 253
Crystal Cr.	(3.8) 30.6	(452) 1308	(.6) 2.9	(2.4) 7.3	(12) 3.5	(118) 141	(1.6) 2.7	(32) 70	5.4) 5.5	(108) 86
Shinumo Cr.	(28.9) 3.4	(495) 27	(4.9) 4	(23.7) 14	(1.9) 3.6	(75) 99	.05) 27.6	(2) 16	2.9) 1.2	(207) 58
Elves Chasm	(571) 309.2	0606) 850	- -	-	(.2) 1.7	(13) 38	(0) 46.7	(0) 205	(3) 1214	(20) 138,666
Stone Cr.	(.9) .9	(54) 11	-	-	(0) 38.3	(0) 43	(.4) .2	(16) 11	-	-
Tapeats Cr.	(60.7) 37.4	(958) 431	-	-	(33.8) 37.3	(510) 99.7	22.1) 34.9	(529) 644	(25.9) 17.1	(756) 1229
Deer Cr.	(23) -	(1015) -	(9.9) 9.2	(39.6) 10.2	(4.1) 43.3	(43) 1066	(.8) 16.8	(19) 624	(2.7) 96.4	(122) 724
Kanab Cr.	(43.6) 10.6	(124) 147	(1.9) 22.3	(1.1) 3.0	(.2) 13	(.5) 57	(0) 19.4	(0) 52	(.1) 2.5	(14) 298
Havasu Cr.	(4.3) 9.4	(16) 105	- -	-	(.2) 16.4	(13) 242	(.2) 13	(5) 194	(.08) 32.4	(5) 1262
Diamond Cr.	(.8) 34.7	(22) 697	21.1) 44.3	(82.3) 152.	(5.5) 19.7	(248) 805	(4.9) 0	(8.1) 0	(3.1) 8.9	(382) 229
*Travertine Falls	-	-	15.5) 32.9	(58.1) 33.9		-	- -	-	-	-

* Based on collections taken 2-22-78

several thousand individuals/m^2. In contrast, grab samples taken below the confluence of the Little Colorado River usually yielded only 5 to 20 individuals/m^2 and consisted of black flies, midges and aquatic earthworms that were collected at exposed gravel bars in the stream channel and along the margins of the River.

Seasonal diversity and evenness values (Table 5-4) based on the relative distribution of aquatic invertebrate families (Appendices 5-1-1 - 5-1-15) revealed that intertributary diversity was lower at the confluence than at the 200 m upstream transect (45 out of 63). All cases of zero diversity were in spring and summer, except for the winter 1977 samples at Nankoweap Creek and the Paria River and the fall 1978 sample from the Little Colorado River. Seasonal intratributary comparisons revealed that diversity, as well as productivity, tended to be lowest in spring and summer.

The Paria River, Elves Chasm and Kanab Creek had the smallest degree of similarity between the upstream and confluent sampling stations, as determined by summing the rank ordered intratributary similarity indices for each season(Appendix 5-2) across the entire year. There was also a significant difference in substrate type between the confluence and the upstream (200 m transect) sampling station (Table 5-5) at these three tributaries. Moreover, there was a seasonal trend in the degree of similarity between the upstream and confluent sampling stations with the stations being most similar in the spring (Kendall's coefficient of concordance, $x^2 = 8.05$, $p < .05$).

Similarity indices for intertributary comparisons were highly variable and generally low (Appendix 5-3A - 5-3E). The Paria River and Hermit Creek

Table 5-4. Seasonal diversity and evenness values for the benthic invertebrate fauna at the confluence and 200 m upstream (8 km at Paria R.) of the confluence on selected tributaries of the Colorado River. Confluence values are in parentheses.

Tributaries	Winter 1977 11/20 - 12/8 H'		J'		Winter 1978 1/20 - 2/6 H'		J'		Spring 1978 5/13 - 5/28 H'		J'		Summer 1978 7/29 - 8/14 H'		J'		Fall 1978 10/1 - 10/18 H'		J'	
Paria R.	(0)	1.3	(0)	.73	–	–	–		(0)	1.1	(0)	.77	(0)	0	(0)	0	(7.6)	.51	(.69)	.37
Nankoweap Creek	(0)	0	(0)	0	–	–	–	–	–	–	–	–	–	–		–		–	–	–
L. Colorado R.	(.69)	–	(1.0)	–	(1.6)	–	(.88)	–	(.68)	–	(.99)	–	(0)	–	(0)	–	(0)	.45	(0)	.32
Clear Creek	(1,5)	1.7	(.79)	.93	(1.2)	2.1	(.88)	.87	(.23)	.72	(.34)	.52	(1.1)	1.5	(.79)	.92	(1.7)	2.1	(.74)	.88
Bright Angel Creek	(1.8)	2.2	(.67)	.81	(1.5)	1.8	(.54)	.64	(.69)	1.5	(.31)	.57	(.59)	2.0	(.33)	.73	(1.5)	.98	(.57)	.33
P[illegible] Creek	(1.2)	1.5	(.51)	.70	(2.1)	1.8	(.78)	.74	(.79)	1.5	(.49)	.73	(.42)	1.4	(.31)	.89	(1.3)	1.7	(.56)	.64
Hermit Creek	(1.0)	1.7	(.94)	.59	–	–	–	–	(1.6)	.90	(.89)	.50	(0)	1.7	(0)	.76	(2.0)	1.6	(.81)	.61
Crystal Creek	(.74)	1.2	(.36)	.62	(1.6)	1.7	(.94)	.80	(1.0)	1.2	(.95)	.77	(1.4)	.84	(.88)	.61	(1.9)	.95	(.84)	.59
Shinumo Creek	(.60)	1.3	(.31)	.95	(.91)	.94	(.47)	.59	(1.1)	1.5	(.98)	.86	(0)	1.0	(0)	.92	(.92)	1.0	(.52)	.64
Elves Chasm	(2.1)	2.2	(.66)	.79	–	–	–	–	(.67)	.95	(.97)	.87	(0)	2.1	(0)	.86	(.97)	.74	(.88)	.24
Stone Creek	(1.3)	.69	(.95)	1.0	–	–	–	–	(0)	1.9	(0)	.98	(2.4)	.69	(.90)	1.0	–	–	–	–
Tapeats Creek	(2.1)	1.6	(.77)	.65	–	–	–	–	(1.4)	1.5	(.56)	.61	(1.2)	1.5	(.52)	.59	(.67)	1.2	(.28)	.53
Deer Creek	(1.6)	–	(.59)	–	(.81)	1.3	(.34)	.71	(1.3)	.76	(.81)	.39	(1.2)	1.1	(.83)	.57	(1.2)	1.4	(.65)	.55
Kanab Creek	(1.6)	1.7	(.65)	.77	(1.4)	2.0	(1.0)	.97	(0)	.80	(.92)	.58	(0)	1.2	(0)	.57	(.57)	1.2	(.81)	.60
Havasu Creek	(.64)	1.1	(.92)	.58	–	–	–	–	(.50)	1.2	(.72)	.53	(.69)	.59	(1.0)	.37	(.69)	1.3	(1.0)	.61
Diamond Creek	(.22)	2.0	(.31)	.72	(1.6)	1.3	(.62)	.52	(1.9)	1.6	(.71)	.56	(.64)	0	(.92)	0	(1.2)	1.6	(.75)	.69
Travertine Falls	–	–	–	–	(1.4)	1.1	(.56)	.60	–	–	–	–	–	–	–	–	–	–	–	–

* Based on collections taken 2/22/78

Table 5-5. Substrate type at the confluent and 200 m transects of the Canyon tributaries. Particle size based on scale established by Cummins (1962).

Tributary	Substrate Type Confluent	 Upstream
Paria R.	silt, sand	gravel, rubble
L. Colorado R.	silt, sand	silt, sand, travertine
Clear	rubble	gravel, rubble
Bright Angel	rubble	rubble
Pipe	sand, gravel	gravel, rubble
Hermit	sand, gravel	gravel, rubble
Crystal	gravel, rubble	gravel, rubble
Shinumo	gravel, rubble	gravel, rubble, boulder
Elves Chasm	sand	gravel, rubble
Stone	gravel, rubble	gravel, rubble
Tapeats	rubble, boulder	rubble
Deer	sand, gravel	rubble
Kanab	silt, sand	gravel, rubble
Havasu	sand, travertine	rubble, travertine
Diamond	sand, gravel	gravel, rubble

displayed the lowest degree of similarity with the other tributaries, with their values rarely exceeding .50. The degree of similarity between each tributary was also significant seasonally with tributaries being most similar to each other in the spring (Kendall's coefficient of concordance, $x^2 = 13.66$, $p < .01$). Only Hermit Creek, which was least similar to the other tributaries in the spring (Appendix 5-3B), deviated from this pattern.

<u>Discussion</u>

Only a qualitative description of the benthic invertebrates of the Colorado River is possible due to an inability to use a conventional benthic sampler. Nevertheless, we found, as did Cole and Kubly (1976), that benthic invertebrate productivity was low, with areas of greater density being found in the eddies and backwaters along the River's margin, where the current is significantly reduced and detritus can accumulate.

The reduced productivity of the mainstream compared to its tributaries and other riverine systems is attributed to its cooler annual water temperature, as well as to its greater depth, current velocity and sediment input. The colder annual water temperatures reduce growth rates and consequently the number of generations produced per year (Hynes 1970a). The release of hypolimnion water from Glen Canyon Dam causes the riverine environment to be temperature-stressed for many miles downstream and effects the invertebrate communities through changes in productivity and diversity (Pearson et al. 1968, Ward 1974).

Many of the tributaries, in particular the Little Colorado River, deliver large amounts of sediment to the Colorado River. This accumulation of sediment reduces light penetration and, consequently, decreases primary and secondary productivity. The stretch of river between Glen Canyon Dam and the confluence of the Little Colorado River (particularly near Lee Ferry) has less input of sediment than the section below the Little Colorado River and is more productive. The reduced sediment input causes the finer sediments to erode downstream and exposes the larger-sized gravels and cobbles upstream (armoring). This increases the heterogeneity of the substrate as well as the invertebrate productivity and diversity (Hynes 1970b).

The greater depth and current velocity in the mainstream further inhibits invertebrate productivity by reducing the number of successful ovipositions and emergences.

The most common mainstream invertebrates are the fresh-water shrimp and the aquatic earthworms. Fresh-water shrimp are cold stenotherms and most aquatic earthworms are not readily affected by temperature (Pennak 1953). Thus, these two groups are able to survive and successfully reproduce in a habitat unfavorable to most invertebrate species.

Invertebrate biomass and density values (i. e., productivity) in the Colorado River tributaries were substantially lower than other southwestern streams (Bruns 1977, Bane and Lind 1978, Lewis and Harrel 1978). Several factors contribute to the low productivity of the Canyon tributaries, which are essentially zoogeographically isolated habitats. The high canyon walls to the north and south and the topographic variability combine to create a formidable dispersal barrier for many aquatic species. For instance, the Canyon topography has effectively blocked the northward dispersal of some species which occur 128 km south in Oak Creek Canyon. Consequently the aquatic hemipteran fauna, like other invertebrate orders in the Canyon, is typical of the Southwest, though it is depauperate when compared to collections made in other areas of Arizona similar to the Canyon in habitat diversity and topography (Polhemus and Polhemus 1976). Additionally, the emergent forms of many aquatic insects are short-lived and wingless or poor fliers (e. g., mayflies, stone flies (Plecoptera), dragonflies, damselflies, water striders (Hemiptera)), which further reduces their dispersal ability (Usinger 1956). Zoogeographic isolation probably contributes to the low intertributary similarity values as well as to the low productivity.

Both productivity and diversity were lowest during spring and summer. Spring runoff and summer flash flooding of the tributaries probably disrupts the benthic invertebrate communities by washing out many species. Consequently, it is not surprising that the tributaries are most similar during these seasons, since only those organisms resistent to increased flows are able to survive. In addition, flooding considerably reduces the algal populations upon which many invertebrates are dependent (Hynes 1970b). The more stable conditions created by little flooding in fall and winter favor increased algal and invertebrate productivity. This pattern of decreased invertebrate productivity during the spring and summer, and a productivity increase during the fall and winter was clearly evident at Diamond Creek (Table 5-3). Prior to the summer sampling, the stream had flooded and altered the substrate from gravel and cobble to a coarse sand. Algal populations noted in the spring were no longer present, and invertebrates, except for a few found near the confluence, were absent. Both the algae and invertebrates had recovered by winter. The invertebrates increased from 4.9 mg/m^2 and

8.1 ind./m^2 in summer to 21.1 mg/m^2 and 82.3 ind./m^2 in winter. Similar trends have been noted in other southwestern systems (Bane and Lind 1978, Bruns 1977).

A second factor which may reduce the summer invertebrate populations within the tributaries is the increased human activity in the Canyon. Tributaries receive much of the impact since most of them are popular stops for commercial river trips, or are readily accessible by hiking. For example, many passengers from commercial river trips walk upstream at Shinumo Creek and alter the stream bed by bathing in the pool at the base of the falls. Substrate instability caused by these constant stream bed alterations may lead to extensive drifting of invertebrates and produce effects similar to flooding. In short, the successional stage of the invertebrate community, as measured by productivity and diversity, will be related to its history (i. e., flooding, run-off, human impact).

Intratributary comparisons of the benthic invertebrate communities at the confluence and upstream sampling stations indicated that productivity and diversity were generally lower at the confluences. Physical and chemical changes associated with the mainstream's diurnal water fluctuations appear to substantially effect the invertebrate fauna at the confluences. At higher mainstream water levels, the confluence of each tributary is more similar to the mainstream with respect to temperature, chemistry, suspended sediments and discharge; at lower mainstream flows, the confluence more closely resembles its particular tributary with regard to each of these parameters.

The mainstream Colorado River can differ quite significantly from its tributaries in several ways. Water temperatures are more variable in the side tributaries (especially in summer), ranging 15° C to 33.5° C with most exceeding 20° C, while the mainstream only varies between 10° C and 15° C. Turbidity and suspended sediments were higher in the mainstream than in the tributaries (986 mg/l and 170 JTU, respectively, in mainstream; 100 mg/l and 30 JTU in tributaries) (Cole and Kubly 1976). The specific conductance of the mainstream ranged from 830 to 1600 micromhos/cm, with a mean of 1050 micromhos/cm, whereas the tributary values ranged from 100 to 5400 micromhos/cm. Overall, the decreased productivity and diversity of the confluence compared to upstream samples, appears due to the instability produced at the confluence by diurnal variations in physical and chemical parameters.

Differences in the nature and stability of the substrate may also contribute to the differences in productivity and diversity between the confluence and upstream areas. The benthic invertebrate communities were most different in tributaries where the substrates of the confluence and upstream station were significantly different (e. g., Paria River, Elves Chasm, Kanab Creek). The confluence substrate of these three tributaries was sand which provides a relatively poor, shifting habitat, with few niches for colonization.

Summary

The benthic invertebrate productivity of the Colorado River was low compared to its tributaries and other southwestern systems. This was due largely to the River's cooler annual temperatures and greater depth, current velocity, and sediment input. Areas of richness were found in the shallower backwaters, eddies, along margins of the River, and in the river section between Glen Canyon Dam and the Little Colorado

River. Most of the invertebrate groups found in the mainstream were also present in the more diverse invertebrate communities of the tributaries.

The invertebrate fauna of the tributaries was depauperate compared to other systems, due to such factors as zoogeographic isolation, spring run-off, summer flash flooding and human impact. The tributaries were least productive and diverse, and at the same time most similar to each other, during the spring and summer.

Intratributary comparisons of the benthic invertebrate communities revealed that productivity and diversity were generally lower at the confluence. The physical and chemical effects produced by the diurnal water fluctuations of the Colorado River on the invertebrate fauna at the confluence appeared to be substantial. Substrate instability also contributed to reducing invertebrate productivity and diversity.

CHAPTER 6

FISHES

INTRODUCTION

Historical Perspective

Extensive investigations of the ichthyofauna in Grand Canyon were not performed until long after the ecology of the mainstream Colorado River had been substantially modified by dams and impoundments. Major habitat changes along with accidental and deliberate introduction of exotic fish and invertebrate species have confounded a precise interpretation of the native fishery of the area.

The earliest chronological documentation of fish species native to this area has been recovered from the 4000 year old flood deposits in Stanton's Cave (Euler 1978, Miller 1971). The fish remains included skeletal material from bonytail and humpback chubs, Colorado squawfish, and flannelmouth and bluehead suckers.

In recent times, the original complement of native fish species from the 389 km study area between Lee Ferry and Separation Rapids has been largely determined through interpretation of early literature pertaining, for the most part, to other areas of the Colorado River Basin (e. g., Everman and Rutter 1895, Jordan 1891). Additional information has been gleaned from the few existing historical technical reports, military journals, and popular accounts dealing with the Grand Canyon area. The John Wesley Powell expeditions of 1869 and 1872 did not record or apparently utilize the area's fish although they were aware of squawfish and humpbacks in the Upper Basin (Dellenbaugh 1904). Another early river explorer, Rober Brewster Stanton, wrote when camped at Lee Ferry..."and now that we do not need them, we could catch a dozen fish every night." (Stanton 1892). Unfortunately, we have no record as to what fish species he was writing about. However, "Colorado River salmon" (squawfish) were included in the Christmas menu of Staton's 1898 Colorado River railroad survey crew (Smith 1965). Also, the turn of the century photographers, explorers and Canyon residents, Emery and Ellsworth Kolb, reported eating squawfish (Kolb 1914) and bonytail chub (Kolb and Kolb 1914) during their expeditions. From the above accounts, we can identify eight native fish species as having inhabited the study area prior to the major habitat changes. These species include the bonytail, humpback and Colorado River (roundtail) chubs, the Colorado squawfish, speckled dace and the razorback, flannelmouth and bluehead suckers.

Once National Park status was granted for portions of the Grand Canyon, the early naturalists and administrative outdoorsmen "improved" the region's fishery by the introduction of sport-fish. Through the years, other exotic species of fish, mostly minnows, have invaded Grand Canyon habitats by means of accidental "bait bucket" introductions. Many of the accidental releases have probably come from the Lake Mead area. Nineteen fish species are known to have been introduced to date (Table 6-1). The reports of Brookes (1931, 1932), Markley (1931), McKee (1930) and Patraw (1931) document introductions of various trout species into clear water Canyon tributaries and only contain passing reference to native species, such as the "suckers" observed by Williamson and Tyler (1932) in Bright Angel and Shinumo Creeks.

Table 6-1. The status, history, distribution and relative abundance of Grand Canyon fishes (Lee Ferry to Separation Rapids)

Species	Status	History[2]	Distribution
NATIVE SPECIES:			
Bonytail chub (Gila elegans)	Ext	Arch 1942 1963	
Humpback chub (*Gila* cypha)[1]	LC	Arch 1914 1979	Adults and young concentrate in the vicinity of Little Colorado River
Colorado River (roundtail) chub (*Gila robusta*)[1]	Ext	1961 1966	
Colorado squawfish (*Ptychocheilus lucius*)[1]	Ext	Arch 1914 1972	
Speckled dace (*Rhinichthys osculus*)		1932? 1979	Ubiquitous, mostly in tributaries, some adults in mainstream
Razorback sucker (*Xyrauchen texanus*)		1944 1979	Only recent (1978) record from mouth of Paria River
Flannelmouth sucker (*Catostomus latipinnis*)		Arch 1979	Ubiquitous, young in tributaries
Bluehead sucker (*Pantosteus (Catostomus) discobolus*)		Arch 1937, 1979	Ubiquitous, young in tributaries
INTRODUCED SPECIES:			
Coho salmon (*Oncorhynchus kisutch*)	Acc, Ext	1971 1976	
Rainbow trout (*Salmo gairdneri*)	Abun	1922 1979	Ubiquitous, adult spawning runs in tributaries
Cutthroat trout (S. *clarki*)	Abun		Ubiquitous
Brown trout (S. *trutta*)	FC	1934 1979	Ubiquitous
Brook trout (*Salvelinus fontinalis*)	FC	1920 1979	Ubiquitous
Carp (*Cyprinus carpio*)	Abun	late 1800's 1979	Ubiquitous
Golden Shiner (Notemigonus crysoleucus)	Acc	1976 1979	
Virgin River spinedace (*Lepidomeda mollispinis*)	Acc, Ext	1972	

(continued)

Table 6-1 (cont.). The status, history, distribution and relative abundance of Grand Canyon fishes (Lee Ferry to Separation Rapids)

Species	Status	History	Distribution
INTRODUCED SPECIES (cont.):			
Woundfin (Plagopterus argentissimus)	Acc, Ext	1972	
Red Shiner (Notropis lutrensis)	Acc, Ext	1968 1976	
Fathead minnow (Pimephales promelas)	LC	1952 1979	Highest densities in tributaries
Channel catfish (Ictalurus punctatus)	LC	1909 1979	Throughout mainstream in low densities, locally common in Little Colorado River and Kanab Creek
Black bullhead (Ictalurus melas)	Acc	1968 1976	
Rio Grande killifish (Fundulus zebrinus)	LC	1938 1979	Unkar, Royal Arch and Kanab creeks
Striped bass (Morone saxatilis)	LC	1970 1979	only near Separation Rapids on Lake Mead
Largemouth bass (Micropterus salmoides)	Acc	1979	
Green sunfish (Chaenobryttus cyanellus)	Acc	1968 1979	
Bluegill sunfish (Lipomis macrochirus)	Acc	1979	
Walleye (Stizostedion vitreum)	Acc	1972	Only record from Lee Ferry area, 1971 - 1972, may be extinct in system

KEY:

Ext - extinct - native species previously represented by viable populations, now no longer in area.
Abun - abundant - easily captured, always present in large numbers
C - common - easily captured, although not present in large numbers
FC - fairly common - occasionally captured, but not unexpected

(continued)

Table 6-1 (cont.). The status, history, distribution and relative abundance of Grand Canyon fishes (Lee Ferry to Separation Rapids)

KEY (cont.):

- LC - locally common - captured easily in specific areas, often present in numbers
- R - rare - always unexpected; may be going extinct
- Acc - accidental - one or two specimen records, isolated incidences of bait bucket releases, relatively unsuccessful transplants or individuals dispersing from Lake Mead; probably not part of breeding ichthyofauna
- 1 - listed in the Federal Register as an endangered species
- Arch - Archaeological remains, 4000 B.P.
- 2 - dates represent first and last published collection records. The 1979 collection records represent species taken in this study.

A preliminary checklist of the area's fish species was first published by Miller (1944). Two years later, Miller (1946) described and named the humpback chub from collections in Bright Angel Creek. The vertebrate collections begun in the early 1930's at Grand Canyon National Park include specimens of humpback and bonytail chubs, razorback and bluehead suckers and speckled dace, all species assumed to be native to the area.

The first systematic fish collecting survey through Grand Canyon was undertaken in 1968 (Miller and Smith 1968) and was followed by several others (Carothers and Aitchison 1972, Holden and Stalnaker 1975a, b, Minckley and Blinn 1976, Suttkus et al. 1976) including those on endangered species (Carothers 1976, 1977, 1978, Minckley 1977, Minckley and Carothers 1980, Suttkus and Clemmer 1977). All of these studies are concerned with fish distribution and neglect, to a large extent, the ecology of these species (but see Minckley 1978).

The present study was undertaken to examine the ecology of Grand Canyon fish species, including, distribution, relative abundance, movement, age and growth, food habits, reproductive cycles, and for gamefish only, condition factors and length-weight relationships. Also discussed are angler use of the area, fish introductions, ectoparasites, status of endangered species within the study area and possible reasons for the decline in native fish.

Overall, 27 fish species, 70% of which are exotics, are thus far known from the study area. Sixty-three percent of these species (17) were collected during this investigation (Table 6-1).

Summary of Fish Species from the Study Area

Native Species

Of the eight original native species (Table 6-1), the bonytail chub, Colorado (roundtail) chub and Colorado squawfish are apparently extinct in Grand Canyon. The disappearance of these species is not restricted to the Grand Canyon area alone, since all three have been officially designated as "endangered" species (CFR 1980) and are therefore protected by Federal Law in those portions of their former rangeswherepopulations persist. Another endangered species native to the Colorado River system is the humpback chub. Although still extant in Grand Canyon waters, its population has evidentally become markedly reduced since the major habitat changes. The humpback chub was previously thought to breed throughout the river system. Recent data indicate that it now only reproduces near the confluence of the Little Colorado and Colorado Rivers in the Canyon. Preliminary indications from ongoing FWS studies on the humpback chub in the Little Colorado River are that the species appears to be maintaining a stable population in this area. The razorback sucker is thought to be going extinct throughout its former range within the Colorado River Basin (Minckley 1979), and was considered extinct in Grand Canyon until our capture of three adults near the confluence of the Paria and Colorado Rivers.

At present, three native species, the bluehead and flannelmouth suckers and the speckled dace, are still represented by what appear to be healthy, reproducing populations through most of their former range. The juvenile suckers remain in the perennial tributaries for two to three years after hatching before moving into the mainstream. Speckled dace are regularly found in the tributaries while their densities in the mainstream are highly variable.

Thus, in Grand Canyon three of the eight native fish species continue to thrive; one is restricted to a tiny portion of its former range, three are extinct, and one is almost assuredly doomed to become extinct.

Introduced Species

Ten of the nineteen exotic species thus far recorded within the study area have been collected or observed so infrequently that they should be considered insignificant components of the Grand Canyon ichthyofauna. The one or two collection records for each species in the past decade probably represent isolated captures of non-breeding, accidental bait-bucket releases (golden shiner, green sunfish, bluegill sunfish), unusual upstream penetration of Lake Mead species (coho salmon, black bullhead, largemouth bass) or unsuccessful transplants by fishery management agencies (Virgin River spinedace, woundf in, walleye). The red shiner, collected at several Canyon localities by Miller and Smith (1968) and twice by Suttkus et al. (1976), was not represented in our extensive sampling and may be extinct. Our collections of largemouth bass and bluegill sunfish constitute the first records of these species from the upper Canyon area although both had been taken from Spencer Creek, 9.5 km below the downstream boundary of our study area (Suttkus et al. 1976).

Another exotic species, the striped bass, seems to be very localized in occurrence. Striped bass have moved upstream into the river system since fingerlings were first introduced into Lake Mead in 1969 (Roden 1978). The vast majority of our striped bass were captured in the lower five km of the study area, from 237 mile rapids (R. M. 453) to Separation Canyon, where it was surprisingly the most common species encountered. Recently, there have been several verbal accounts of this species from River Miles 448.6-469 with the number of sitings increasing as one approaches Lake Mead. There are also undocumented accounts of striped bass occurring sporadically as far upstream as Havasu (R. M. 533). Why this anadramous predator has not penetrated further upstream in Grand Canyon may be related to the rapids near River Mile 453 or to the cold hypolimnetic waters of the Colorado River, either or which may act as an effective barrier to dispersal. If the rapids are the major factor restricting dispersal, then we should expect further upstream movement of the striped bass during periods of maximum water storage in Lake Mead since several of the rapids, including those at R. M. 453, come and go with fluctuating lake levels.

The fathead minnow and Rio Grande killifish are two minnow-sized exotic species that appear well established throughout the Grand Canyon. Both species have been taken in the mainstream, expecially near the confluence of several perennial tributaries, and seem to reach their highest densities in the Little Colorado River, Unkar, Royal Arch and Kanab Creeks.

Four of the six remaining exotic species are trout (rainbow, brown, brook and cutthroat). All have been introduced in the ongoing sportfishery stocking programs that were initiated in the 1920's (see Fish Introductions below). The rainbow trout, which is by far the most common of the salmonids, is ubiquitous in distribution throughout the river system, with the adults being well known by local anglers for their winter/spring spawning runs into several of the larger tributaries (Bright Angel Creek, Clear Creek, Tapeats Creek, etc.). The brown and brook trout are far less numerous with the former being only slightly more frequent in our samples. Cutthroat trout were introduced at Lee Ferry while this study was in progress (1978). Our first capture of this species was in November 1979, when 25 cm specimens were the most common fish taken by anglers at Badger Rapids, 13 km downstream from Lee Ferry (S.W. Carothers, pers. obs.).

Channel catfish were generally very difficult to capture in the mainstream with anything other than hook and line. They are probably ubiquitous in distribution throughout the study area. Mainstream densities are low above Lava Falls and considerably higher from Lava Falls (R. M. 510.6) downstream, with a definite concentration occurring in the area between Separation Rapids and the rapids five km upstream (River Mile 453). Anglers consistently fill their creels in this area with 25-50 cm specimens. Channel catfish attain their greatest size in two of the upper canyon "warm water" tributaries, the Little Colorado River and Kanab Creek, where they are fairly common. Small and large (4.54-6.80 kg.) catfish were captured during virtually every sample at or near the confluence of the Little Colorado River.

The last exotic species, and by far the most common fish in our Grand Canyon collections is the carp. Carp are largely restricted to the mainstream, however, they seemed to congregate in schools of at least 500 individuals near spring or tributary discharges, especially where there are large slow flowing eddies. The smallest carp was a two year old fish (110 mm) taken near Lava Falls. All of these carp are most likely individuals dispersing upstream from Lake Mead since reproduction in the study area has not been verified.

At least one hybrid has also been taken within the study area. During their work in Grand Canyon, Suttkus et al. (1976) captured three specimens of the cross, Catostomus latipinnis x Xyrauchen texanus (flannelmouth x razorback suckers). Hybrids of the Salmo group that occur within Grand Canyon (Suttkus et al. 1976; pers. obs.) have yet to be identified and named.

A total of 27 species of fish are known to be present or to have occurred in the Colorado River and/or its tributaries in Grand Canyon. However, the abundance of each species is anything but even. As indicated by our pooled capture data for the entire study, six species constitute 99.4% of the total collections. The species and their total relative frequencies are: carp (41.6%), speckled dace (15.6%), flannelmouth sucker (13.8%), rainbow trout (13.3%), bluehead sucker (9.3%), and humpback chub (5.8%). The only other species that appear to maintain stable but low density populations throughout the area are brown and brook trout, the fathead minnow, channel catfish and the Rio Grande killifish.

SPECIES ACCOUNTS

NATIVE SPECIES

Family CYPRINIDAE, minnows

BONYTAIL CHUB, *Gila elegans* (Baird and Girard) (EXTINCT in Grand Canyon) (ENDANGERED)

History and Distribution. The earliest record of bonytail chubs in the Grand Canyon area is based on nonfossilized remains from the 4,000 year old flood deposits in Stanton's Cave, 48 kilometers downstream from Lee Ferry (R. M. 658.6) (Euler 1978) (Table 6-1). Subsequent records of this species are limited to single specimens taken by anglers in 1942 and 1944 from Phantom and Bright Angel Creeks, respectively (National Park Service files). More recently, individuals of this species were taken from the base of Grand Falls in the Little Colorado River drainage (Miller 1963) and from Spencer Creek, six miles outside the study area.

Small populations of bonytail chubs still persist in the Upper Colorado River Basin (McAda 1977), the Green and Yampa Rivers (Utah), as well as below the study area in Lake Mohave. Bonytail chubs, previously occurred in the upper portion of the study area and possibly throughout the region, although it now appears to have been extirpated from the Grand Canyon area.

Age and Growth. Age and growth studies indicate that bonytail chubs reach seven years of age in the Green River (Vanicek and Kramer 1969).

Food Habits. Adult bonytails collected from the Green River had primarily consumed terrestrial insects, plant debris and filamentous algae

(Vanicek and Kramer 1969). These data substantiate the observation that they are surface feeders in lotic systems (Minckley 1973). The situation seems to be different in lentic systems, however. Specimens recently taken from Lake Mohave had fed primarily on zooplankton (Minckley 1973). Minckley (1979), in a further discussion of Vanicek's (1967) data, presents the following summary.

> ...Vanicek's (1967) data.. .demonstrate a marked proclivity of bonytail chub for drifting, terrestrial invertebrates and adults of aquatic groups...Adults of aquatic groups, ephemeropterans, plecopterans and presumably some of the undetermined dipterans were most likely taken from the surface. In addition, occurrences of aquatic larvae were typically found in a single fish (2.9%), while many terrestrial items occurred in five (14.3%) or more fish.

Limited data on juvenile bonytail food habits suggest utilization of aquatic invertebrates (Vanicek 1967, Vanicek and Kramer 1969).

Reproduction. Known reproductive behavior of bonytail chubs resembles that of cyprinids in general, with each female being attended by several males. Spawning of about 500 bonytails was observed in Lake Mohave (Jonez and Sumner 1954). The eggs were released near the lake bottom over gravelly shelves up to 9.0 m deep. Recent observations of gravid females extruding eggs indicate that sqawning occurs in the Lake from February through May (W. L. Minckley, pers. comm. 1979). Reproductive success has not been confirmed since no young-of-the-year specimens have been taken.

HUMPBACK CHUB, <u>Gila cypha</u> (Miller) (ENDANGERED)

History and Distribution. The earliest remains of the humpback chub within the study area are from an archaeological site in the now inundated Catclaw Cave near Lake Mead and in the 4,000 year old riverine deposits in Staton's Cave (Euler 1978, Miller 1971). There are no other records of this species within the study area until 1914, when early river explorers (Kolb 1914, Kolb and Kolb 1914) caught and ate it. Until recently, records of this species were rare. One specimen was taken from Bright Angel Creek (R. M. 601.5) in 1942 (Miller 1946) and another in 1968.

Collection records and reliable observations document the occurrence of this species from Lee Ferry to River Mile 492 (Miller and Smith 1968, Minckley and Blinn 1976, Suttkus et al. 1976). Limited numbers of humpback chubs probably occur in the upper reaches of Lake Mead, making it ubiquitous in the Canyon area (Minckley et al., 1981). Sporadic occurrences are also documented in the Little Colorado Basin including the Green (Holden 1977, Holden and Stalnaker 1975a, b, Miller 1964), Yampa (Holden and Stalnaker 1975a, Miller 1964, Seethaler 1978), and the mainstream upper Colorado River near Grand Junction (Kidd 1977).

During this study, humpbacks were regularly encountered in the Little Colorado River upstream from the confluence (Table 6-2), but only rarely in the mainstream below the confluence (Table 6-3). Individuals were taken at rates of 2 - 6 fish/net night in localized areas of the Colorado River mainstream, particularly in the vicinity of Tiger Wash (R. M. 663) and near River Mile 626.5 (see Appendix 6-1 for tagging data).

Within the mainstream habitat, adult humpback chubs were taken primarily from eddies adjacent to fast currents. This distribution pattern

Table 6-2. Seasonal distribution of fishes collected from the Colorado River tributaries between Lees Ferry (River Mile 688.6) and Separation Rapid (River Mile 450.6) from November 1977 - October 1978.

NTER 1977 - 1978	Paria R.	Buck Farm Creek	Colorado R.	UnkarCreek	Clear Creek	Angel Creek	Phantom Creek	Pipe Creek		Crystal Creek	ShinumoCreek	Elves Chasm Creek	Stone Creek	TapeatsCreek	Deer Creek	KanabCreek		Diamond Creek	Travertine Creek
									Tributaries										
mily: Salmonidae																			
Rainbow Trout					X	X		X			X	X		X	X	X	X		
Brown Trout							X				X								
Brook Trout	X																		
mily: Cyprinidae																			
Fathead Minnow										X						X			
Humpback Chub			X																
Speckled Dace	X															X	X	X	
mily: Catostomidae																			
Flannelmouth Sucker			X																
Bluehead sucker			X																
mily: Cyprinodontidae																			
Rio Grande Killifish				X								X							
RING 1978																			
mily: Salmonidae																			
Rainbow Trout					X			X	X										
mily: Cyprinidae																			
Humpback Chub			X																
Speckled Dace	X								X							X	X	X	
ily: Catostomidae																			
Flannelmouth Sucker	X		X																
Bluehead sucker	X		X					X									X		
mily: Ictaluridae																			
Channel Catfish			X																
MMER 1978																			
mily: Salmonidae																			
Rainbow Trout						X					X	X		X	X	X			

Table 6-2 (cont.). Seasonal distribution of fishes collected from the Colorado River tributaries between Lees Ferry (River Mile 688.6) and Separation Rapid (River Mile 450.6) from November 1977 - October 1978.

SUMMER 1978 (cont.) — Tributaries

	Paria R.	Buck Farm Creek	Colorado R.	Unkar Creek	Clear Creek	Bright Angel Creek	Phantom Creek	Pipe Creek	Hermi	Crystal Creek	um e	Elves Chasm Creek	Stone Creek	Tapeats Creek	Deer Creek	Kanab Creek	Havasu Creek	o	Travertine Creek
Family: Cyprinidae																			
Carp			X																
Fathead Minnow																			
Humpback Chub			X	X															
Speckled Dace	X				X	X		X	X	X	X	X	X	X	X	X		X	
Family: Catostomidae																			
Flannelmouth Sucker	X	X	X	X								X			X	X			
Bluehead	X	X	X	X		X				X		X				X	X		
Razorback Sucker	X																		
Family: Ictaluridae																			
Channel Catfish			X	X												X			
Family: Cyprinidontidae																			
Rio Grande Killifish				X															

FALL 1978

	Paria R.	Buck Farm Creek	Colorado R.	Unkar Creek	Clear Creek	Bright Angel Creek	Phantom Creek	Pipe Creek	Hermi	Crystal Creek	um e	Elves Chasm Creek	Stone Creek	Tapeats Creek	Deer Creek	Kanab Creek	Havasu Creek	o	Travertine Creek
Family: Salmonidae																			
Rainbow Trout						X		X				X			X	X			
Brook Trout	X																		
Family: Cyprinidae																			
Fathead Minnow			X																
Humpback Chub			X																
Speckled Dace	X	X	X		X			X	X	X		X			X	X	X	X	
Family: Catostomidae																			
Flannelmouth Sucker	X	X										X			X	X	X		
B[illegible]	X											X			X	X	X		
Family: Ictaluridae																			
Channel Catfish			X													X			

able 6-3. Seasonal distribution of fishes collected from the Colorado River between Lee Ferry and Separation Rapid from November 1977-October 1978.

.NTER 1977 - 1978	River Sections											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mily: Salmonidae												
Rainbow Trout	X	X	X	X	X	X		X	X	X	X	
Brown Trout						X	X					
Brook Trout												
mily: Cyprinidae												
Carp			X	X	X			X	X	X	X	X
Golden Shiner				X								
Humpback Chub		X			X	X						
Speckled Dace				X								
Fathead Minnow												
mily: Catostomidae												
Razorback Sucker												
Flannelmouth	X		X	X	X	X	X	X	X	X	X	X
Bluehead Sucker	X		X	X	X	X	X	X	X	X		
mily: Ictaluridae												
Channelmouth Catfish									X	X	X	
RING 1978												
[illegible]: Salmonidae												
Rainbow Trout					X		X	[illegible]	X	[illegible]	X	X
Brown Trout							X					
Brook Trout			X									
mily: Cyprinidae												
Carp	X	X		[illegible]	X	X	[illegible]	[illegible]	[illegible]	X	X	[illegible]
[illegible]: Catostomidae												
Flannelmouth Sucker	X	X		X			X	X	X	X	X	
Bluehead Sucker	X			X		X						
[illegible]: Ictaluridae												
Channelmouth Catfish			X							X		X
rdly: Percichthyidae												
Striped Bass												X
[illegible]: Centrarchidae												
Largemouth Bass									X			
MMER 1978												
mily: Salmonidae												
Rainbow Trout				X	X	X	X	X	X	X		
Brown Trout						X						

Table 6-3 (cont.). Seasonal distribution of fishes collected from the Colorado River between Lee Ferry and Separation Rapid from November 1977-October 1978.

SUMMER 1978 (cont.)	River Sections											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Family: Cyprinidae												
Carp	X	X		X	X	X	X	X	X	X	X	• X
Humpback Chub	X	X				X	X	X				
Speckled Dace								X	X	X		
Fathead Minnow										X		
Family: Catostomidae												
Raxorback Sucker	X											
Flannelmouth Sucker					X	X	X		X	X		
Bluehead Sucker						X	X	X	X			
Family: Ictaluridae												
Channelmouth Catfish									X		X	
Family: Centrarchidae												
Largemouth Bass												
Green Sunfish												
Bluegill												
FALL 1978												
Family: Salmon idae												
Rainbow Trout	X		X		X	X	X	X	X			
Brown Trout				X		X	X					
Brook Trout	X	X										
Family: Cyprinidae												
Carp	X			X	X	X	X	X	X	X		X
Humpback Chub		X										
Speckled Dace				X					X			
Family: Catostomidae												
Flannelmouth Sucker		X	X	X	X			X	X	X	X	X
Bluehead Sucker		X	X	X	X	X	X	X	X	X	X	
Family: Ictaluridae												
Channelmouth Catfish										X		
Family: Centrarchidae												
Largemouth Bass									X			

has also been found in other river systems (Seethaler 1978). Humpback chubs have also been taken frequently between Glen Canyon Dam and river section IV, with the highest densities occurring in sections II and III where most of the breeding probably takes place (Table 6-4, Figure 3-2) (Holden and Stalnaker 1970, Miller and Smith 1968, Arizona Game and Fish files).

Density and Abundance. Estimated relative densities of humpback chubs in the Little Colorado River varied considerably, depending on the collection technique (electrofishing, angling, seining, gill nets (drifting and set) and trammel nets). Due to the endangered status of the species, all collections were made during the daytime with the exception of electrofishing which was conducted during both day and night.

This species was less abundant in the mainstream than in the Little Colorado River, the only tributary where humpback chubs were found (Table 6-2). Electrofishing was generally unsuccessful, although relative densities of 5 f/h were recorded twice. Individual drifts were quite successful with over 20 individuals occasionally being taken. The species was also susceptible to angling, with 4.3 f/h being recorded. Gill and trammel net sets were the most productive collection techniques. Gill nets yielded up to 35.2 f/h and standard trammel net collections provided up to 70 f/h (Table 6-4).

Based on seining data, the estimated densities of young-of-the-year and juvenile humpback chubs were high, ranging from 71 f/ha, .1 kilometer upstream from the confluence in spring, to a high of 6,364 f/ha in Big Canyon Creek, a tributary of the Little Colorado River, during the summer (Table 6-5).

Table 6-4. Estimated relative densities of carp, brown trout, brook trout, largemouth bass, green sunfish, bluegill sunfish, channel catfish and striped bass collected by electrofishing (f/h) and trammel netting (f/n) from the mainstream Colorado River in river sections I - XII, and also L.C.R. for humpback chubs, during 1977 - 1978.

Species	Season	River Section	Electrofishing	Trammel netting
Carp	Winter	IV		2
		V		14
	Summer	IX		25
		X		0.5
Brown trout	Winter	VI		1
	Spring	VI	1.0	
		VII	1.1	
	Summer	V	5.0	
		VI	1.0	
	Fall	IV	0.2	
		V	0.3	
		VI	0.3	
Brook trout	Spring	III	0.2	
	Fall		0.8	2
		II	1.4	
Largemouth bass	Spring	IX	0.9	
	Summer	IX	1.0	0.25
	Fall	IX	1.2	
Green sunfish	Fall	IX	0.5	
Bluegill sunfish	Summer	IX	0.5	
Channel catfish	Winter	IX	0.8	
		X	0.9	
	Spring	III	0.5	
		IX	1.2	
		XII	2.5	
	Summer	IX	0.5	0.7
	Fall	XI	0.5	
Striped bass	Spring	XII	75	
Humpback chub	Winter	II		1.5
		III		1.0
		IV		0.5
		VI		1.0
		L.C.R.		0.4
	Spring	L.C.R.		70.0
	Summer (June)			0.5
		II		0.5
		III		0.5
		L.C.R.		12.8
	(July)	Big Canyon area		2.0
	(August)	VIII		2
		L.C.R.		12.8
	F[illegible]	II		0.5
		L.C.R.		6.0

Table 6-5. Estimated numbers of fish per hectare seined seasonally from selected tributaries and mainstream areas of the Colorado River, Grand Canyon National Park, Arizona, 1978. Note seasonal differences between mainstream and tributary collections.

Tributaries	Rainbow Trout	Brook Trout	Speckled Dace	Humpback Chubs	Fathead Minnows
Paria River					
Confluence		-,-,50	89,7180,950		
2.2 km station			71,-,1579		
4.8 km station			264,-,2850		
8.0 km station			327,140,4580		
Little Colorado River					
Confluence			-,44,-	-,222,-	
.1 km station			8,2872,110	71,2473,990	-,-,10
8.0 km station				-,2300,-	
20.8 km station			-,9829,-		
Big Canyon Creek				-,6364,-	
Buck Farm Creek					
Clear Creek	*67,[illegible]		67,-,-		
Bright Angel Creek	-,100,1503		-,2800,104		
Phantom Creek					
Pipe Creek	486,-,-		1170,416,-		
Hermit Creek	-,-,416		-,146,229		
Crystal Creek			3,7300,5530		
Shinumo Creek			-,364,1981		
Elves Chasm Creek	-,250,750		-,436,-		
Stone Creek			-,2700,0		
Tapeats Creek	-,448,-		-,22,-		
Deer Creek	-,667,-		-,4800,800		
Kanab Creek			-,4600,-		-,150,450
Havasu Creek			1400,261,-		
Diamond Creek			270,4900,2200		
Traventine Falls Creek			-,4285,-		
IX	[illegible]		633, 20		17,[illegible]
	238,-,		23138,66,		268,-,
XI	[illegible]		540,[illegible]		20,[illegible]

Table 6-5 (cont.). Estimated numbers of fish per hectare seined seasonally from selected tributaries and mainstream areas of the Colorado River, Grand Canyon National Park, Arizona, 1976. Note seasonal differences between mainstream and tributary collections.

Tributaries	Flannelmouth Suckers	Bluehead Suckers	Channel Catfish	Carp
Paria River				
Confluence	78,-,750	11,-,-		
2.2 km station	-,-,211			
4.8 km station	7,-,650	-,-,450		
8.0 km station	-,-,2620			
Little Colorado River				
Confluence	-,1023,-			
.1 km station	4,109,-		-,-,1	
8.0 km station				
20.8 km station				
Big Canyon Creek				
Buck Farm Creek				
Clear Creek				
Bright Angel Creek	-,200,-	-,500,-		
Phantom Creek				
Pipe Creek		56,-,-		
Hermit Creek				
Crystal Creek	-,300,-			
Shinumo Creek		-,1167,6		
Elves Chasm Creek				
Stone Creek				
Tapeats Creek	-,160,-			-,333,-
Deer Creek	-,667,267	-,533,-		
Kanab Creek	-,7650,200	-,6850,4200	-,300,-	
Havasu Creek	-,1176,1607	33,5880,-		
Diamond Creek				
Traventine Falls Creek				
IX	1683, ,-	17, ,-		17, ,33
X	2098,-,	407,-,	33,-,	-,64,
XI	40, ,	20, ,		-, ,

* denotes spring
\+ denotes summer
o denotes fall
\- denotes winter

Mainstream trammel net densities of adult humpback chubs ranged from 0.5 f/h during winter to 2 f/h in the summer (Table 6-4). Within the tributaries, i.e. the Little Colorado River, the humpback chub varied from being the fifth most common species during winter 1977, to the third most abundant species during spring and winter 1978. When all the seasonal tributary collections are combined, humpbacks were the fifth most common fish taken, comprising up to 15% of the ichthyofauna (Table 6-6).

Relative abundance of humpback chubs in the mainstream (largely adults) was much lower than in the Little Colorado River. In the mainstream, this species ranked sixth or lower in terms of relative abundance, comprising less than one percent of the ichthyofauna, except during the first winter trip when it ranked second (Table 6-6). When combining all mainstream fish collections, humpback chubs ranked tenth in relative abundance, and were the fourth most abundant native species. Combination of all the fish collections from both the mainstream and tributaries showed the humpback chub to be the sixth most common species. Carp and rainbow trout were the only introduced species surpassing it in abundance (Table 6-7).

Age and Growth. The sample (N = 10) consisted of dead humpback chubs collected in 1972 and during this study.

Four age classes (IV, V, VI and IX) were represented in the study with no single class being dominant (Table 6-8). The largest chub analyzed was nine years old and measured 380 mm in total length. Growth rates for humpback chubs were determined from opercle analysis. Growth was most rapid during the first year when individuals attained a total lenth of between 80.5 and 92.2 mm (Table 6-8). These results corroborate the length-frequency data (Figure 6-1), which indicate that by January-

Table 6-6. Seasonal relative abundance (expressed as percent) of fishes collected from the mainstream Colorado River and its tributaries (outside parens), Coconino and Mohave Counties, Arizona, during 1977 - 1978.

Winter 1977	Winter 1978	Spring	Summer	Fall
Carp (47.1), 0.6	Carp (87.5), 2.2	Carp (84.1), 8.9	Carp (56.1), 2.4	Carp (67.6), 2.3
Humpback chub (11,8), 1.8	Rainbow trout (5.1), 54.8	Rainbow trout (6.9), 2.4	Rainbow trout (14.6), 1.2	Flannelmouth sucker (10.9), 27.0
Bluehead sucker (11.8), 2.2	Flannelmouth sucker (4.7), 3.6	Striped bass (4.4), 0.0	Bluehead sucker (12.2), 15.1	Rainbow trout (10.3), 4.4
Flannelmouth sucker (8.8), 5.1	Bluehead sucker (1.8), 3.6	Speckled dace (1.6), 30.4	Speckled dace (9.1), 33.2	Bluehead (7.6), 24.2
Rainbow trout (5.9), 63.1	Channel catfish (0.5)	Channel catfish (1.0), 0.8	Flannelmouth sucker (4.9), 30.8	Brook trout (1.4), 0.0
Brown trout (5.9), 0.8	Humpback chub (0.3), 5.9	Flannelmouth sucker (0.7), 31.8	Channel catfish (1.1), 0.9	Brown trout (0.6), 0.0
Brook trout (2.9), 0.8	Brook trout (0.1), 0.9	Brown trout (0.7), 0.0	Brown trout (0.4), 0.0	Speckled dace (0.6), 25.6
Speckled dace (2.9), 23.0	Brown trout (0.0), 1.8	Bluehead sucker, (0.4), 10.1	Brook trout (0.4), 0.08	Largemouth bass (0.4), 0.0
Golden shiner (2.9), 0.0	Speckled dace (0.0), 27.2	Brook tout (0.1), 0.0	Fathead minnow (0.4), 0.08	Humpback chub (0.2), 14.7
Fathead minnow (0.0), 1.6		Largemouth bass (0.1), 0.0	Humpback chub (0.3), 15.0	Channel catfish (0.2), 1.4
		Humpback chub (0.0), 15.6	Largemouth bass (0.3), 0.0	Green sunfish (0.2), 0.0
			Bluegill sunfish (0.1), 0.0	Fathead minnow (0.0), 0.4
			Green sunfish (0.1), 0.0	
			Rio Grande killifish (0.0), 0.08	
			Razorback sucker (0.0), 0.08	

Table 6-7. Relative abundance (expressed as percent) of fishes collected from the mainstream Colorado River and its tributaries, Coconino and Mohave Counties, Arizona, during 1977 - 1978. Based on total collections of fishes.

Exotic and Native Fish	Exotic Species	Native Species
Carp - 41.6	Carp - 73.3	Speckled dace - 35.0
Speckled dace - 15.6	Rainbow trout - 23.0	Flannelmouth sucker - 30.9
Flannelmouth sucker - 13.8	Channel catfish - 1.4	Bluehead sucker - 20.8
Rainbow trout - 13.3	Striped bass - 0.9	Humpback chub - 13.1
Bluehead sucker - 9.3	Brook trout - 0.7	Razorback sucker - 0.03
Humpback chub - 5.8	Brown trout - 0.6	
Channel catfish - 0.7	Fathead minnow - 0.4	
Striped bass - 0.5	Largemouth bass - 0.2	
Brown trout - 0.3	Rio Grande killifish - 0.2	
Brook trout - 0.3	Green sunfish - 0.06	
Fathead minnow - 0.2	Bluegill sunfish - 0.03	
Rio Grande killifish - 0.09	Golden shiner - 0.03	
Largemouth bass - 0.09		
Green sunfish - 0.03		
Bluegill sunfish - 0.01		
Golden shiner - 0.01		
Razorback sucker - 0.01		

Table 6-8. Mean calculated total length (standard error; mm) and mean calculated annual growth increments of Humpback Chub at succeeding ages from the Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Age	n	Mean Capture Length	Mean calculated total length (S.E.) at each annulus								
				2	3	4	5	6	7	8	9
IV	3	237 (16.6)	80.5 (7.3)	125.2 (7.5)	168.8 (11.1)	209.9 (4.0)					
V	3	264 (5.4)	92.2 (2.8)	135.2 (7.8)	186.9 (6.1)	213.6 (8.0)	239.9 (8.3)				
VI	2	310 (14.1)	85.3 (17.4)	115.9 (7.9)	162.3 (7.4)	216.1 (4.8)	250.0 (10.6)	280.2 (1.0)			
IX	2	358 (31.1)	85.6 (8.5)	121.9 (16.3)	164.7 (4.0)	199.5 (4.0)	232.6 (7.4)	281.7 (1.3)	308.7 (8.2)	328.7 (15.8)	347.2 (19.9)
Average			86.0 (8.9)	125.7 (11.4)	172.1 (12.3)	210.2 (7.6)	240.7 (10.1)	280.9 (1.2)	308.7 (8.2)	328.7 (15.8)	347.2 (19.9)
Increment			86.0 (8.9)	39.7 (10.8)	46.4 (9.5)	38.1 (2.3)	30.4 (7.9)	39.7 (12.8)	27.1 (9.5)	20.0 (7.6)	18.6 (4.2)
Number			10	10	10	10	7	4	2	2	2

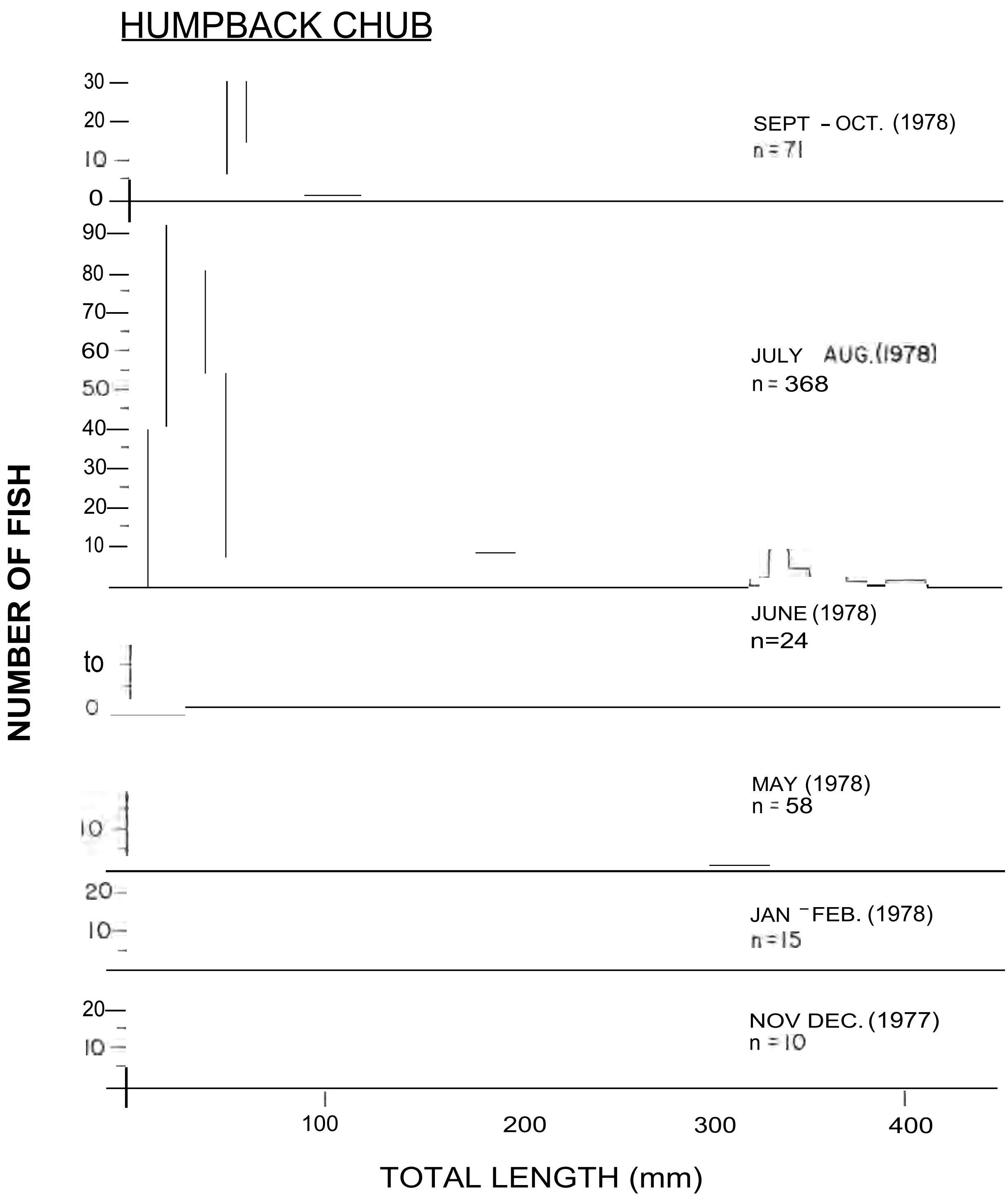

Figure 6-1. Length-frequency distribution of humpback chub from the Colorado and Little Colorado Rivers in Grand Canyon National Park, Arizona.

February, fish spawned in 1977 had reached total lengths up to 75 mm. Year class 0 fish, spawned in 1978, were approaching 80 mm in total length be September-October 1978, again illustrating that the calculated values are representative of actual growth. The mean annual growth increment in the second year was 39.7 mm (Table 6-8). Growth during the next four years fluctuated between 46.6 mm in the third year and 30.4 mm in the fifth year (Table 6-8). Following the sixth year, the mean annual growth increment showed a steady decline to 18.6 mm in the ninth year.

Young-of-the-year fish first appeared during June, having attained a total length of approximately 30 mm (Figure 6-1). Humpback chubs spawned the previous year had reached a total length of approximately 80 - 90 mm by the spring. During summer, two size peaks (170 mm and 330 mm), were observed (Figure 6-1), which correspond to the means for three and eight year old fish, respectively.

Food Habits. Food habits were determined from the stomach contents of three juvenile humpback chubs that died during population investigations in the Little Colorado River. The results of these analyses indicate that juveniles forage on or near the substrate, selecting benthic insect larvae and organic detritus as their primary food items. Food items identified in the stomach of a single winter mortality consisted of several midge larvae (Chironomidae) and a biting midge larva (Ceratopogonidae). The stomachs of two dead humpback chubs collected during the summer contained midge larvae and a long-legged fly larva (Dolichopodidae). The few specimens caught below Glen Canyon Dam were found to have been feeding on planktonic crustaceans which apparently came from Lake Powell (Minckley 1973).

Limited feeding observations during this study indicate that adults actively eat Cladophora as well as organic detritus. They have also been observed feeding at the water's surface in the Green River (Humpback Chub Recovery Program 1978).

Reproduction. Based on the capture of reproductive adults (i. e., tubercles, ripe individuals), the reporductive season of the humpback chub inhabiting the Grand Canyon extends from March through May and may continue into July (Carothers 1976, 1977, 1978). Water temperature range from 16° - 20 C during this period. Very small young-of-the-year fish have been collected in June (Suttkus et al. 1976). Breeding requirements and behavior have never been observed, though they can probably be inferred from two closely related species, the Bonytail and Colorado River chubs, as well as from cyprinids in general. Several males are likely to attend one female during spawning. The eggs are released and externally fertilized as they fall to a variety of substrates.

The numbers of young-of-the-year and one-year-old fish collected from the Little Colorado River vary considerably from year to year and season to season (range 71 to 6,364 fish/ha). All observations in this study reflect the crucial importance of the Little Colorado River as a spawning site the nursery area for this endangered species. Data also indicate that the upper reaches of the Little Colorado River are more heavily utilized for spawning than the confluent zone since larger numbers of small fish were collected there (Minckley et al., 1981). Successful reproduction has also been suggested in Shinumo Creek, based on the collection of one young-of-the-year chub (Suttkus et al. 1976). Thus, reproduction appears to be largely restricted to tributaries in the upper mainstream area though it is suspected to occur sporadically in the mainstream. Young-of-the-year fish were found almost exclusively in the Little Colorado River during this study, while adults were more common in the mainstream. Thus, it seems that reproduction takes place in the upper reaches of tributaries in the upper Colorado River area. The adults live primarily in the mainstream and return to the tributaries to spawn.

A description of sexual dimorphism, breeding coloration and tuberculation patterns are presented in Suttkus and Clemmer (1978).

COLORADO (ROUNDTAIL) CHUB, Gila robusta (Baird and Girard) (EXTINCT in Grand Canyon, ENDANGERED)

History and Distribution. The Colorado chub was recorded near the Glen Canyon damsite between 1961 and 1963 and persisted in that region until 1966 (Arizona Game and Fish Department). No specimen has been taken within the study area since that time.

Populations of Colorado chub are present in the Green, Yampa, Gunnison, White, Duchesne and San Juan Rivers of the Upper Colorado River Basin, as well as in the Upper Colorado River near Grand Junction, Colorado. This species tends to inhabit pools and eddies and often concentrates in the relatively swift, swirling waters below rapids (Minckley 1973).

Density and Abundance. There is no density - abundance information on this species.

Age and Growth. Age and growth studies indicate that individuals of this species complex commonly reach seven years of age (Neve 1976).

Food Habits. This omnivorous species feeds upon aquatic and terrestrial insects, as well as filamentous algae. Larger specimens have been reported to ingest other fishes and iguanid lizards (Minckley 1973, Neve 1974, Vanicek and Kramer 1969). Young-of-the-year Colorado chubs from Fossil Creek, Arizona are known to utilize diatoms and aquatic invertebrates (Neve 1976).

Reproduction. Reproduction occurs from early spring through mid summer (Minckley 1973) on gravel substrates (Neve 1976).

COLORADO SQUAWFISH, *Ptychocheilus lucius* (Girard) (EXTINCT in Grand Canyon, ENDANGERED)

History and Distribution. The earliest records of Colorado squawfish are from the 4000 year old riverine deposits in Stanton's Cave (Euler 1978). This species was an important food source for the native Indian populations living along the lower Colorado and Gila Rivers (Miller 1955). It was also used for food by the first river runners (Kolb 1914, Kolb and Kolb 1914, Smith 1965). Prior to 1911, hundreds of these fish were taken from irrigation canals with pitchforks and used for fertilizer (Miller 1961).

Colorado squawfish were once common in river channels with sufficient depth and current throughout the Colorado River Basin. A few individuals may still occur within Grand Canyon, even though the species is considered virtually extinct in most Arizona waters (Minckley 1973). Limited numbers of Colorado squawfish persist in the Upper Colorado .River system, primarily in the Green, Yampa, San Juan and mainstream Colorado Rivers. Between 1962 and 1968, one squawfish was taken at Lee's Ferry and three others near Glen Canyon Dam (Seethaler 1978, Behnke 1973). One subadult squawfish was taken by an angler in 1972 near the confluence of Havasu Creek (RM 533) in Grand Canyon. One or two fish continue to be caught yearly by anglers in Lake Powell (Seethaler 1978). No Colorado squawfish were taken during this study.

Age and Growth. Historical records document this fish species reaching nearly two meters in length and weighing over 32 kg (Minckley 1973). Population studies on this species (Seethaler 1978) report .7 m long fish to be in their eleventh year. In combination, these data indicate this species to be long lived. Colorado squawfish reach maturity at about 400 mm in length and six years of age.

Food Habits. Squawfish up to 50 mm in length primarily consume larvae, pupae and nymphs of aquatic insects as well as cladocerans and copepods (Beckman 1952, Vanicek 1967). Aquatic insects constitute a more important and diverse portion of the diet in fish ranging between 50 mm and 100 mm in length. Redside shiners are the most common prey species (Vanicek 1967, though flannelmouth suckers (Koster 1960) and rainbow trout fingerlings are also taken (Toney 1974). The piscivorous adults were the major carnivore in the system prior to its impoundments and modifications. Vanicek (1967) also observed a positive correlation between larger size fish and an increasing frequency of empty stomachs, indicating that they are sporadic feeders. There is no information on adult squawfish diets prior to the introduction of numerous exotic fish species.

Reproduction. In the Green River, Colorado squawfish spawn from early July through mid-August, once water temperatures exceed 18 C (Vanicek and Kramer 1969). Previously, when the species was more widespread, spawning occurred from spring to late summer (Sigler and Miller 1963, Miller and Lowe 1967) depending on water temperatures. This reduction in spawning period is probably due to changes in the cues that trigger spawning (increasing water temperatures and receding water levels) subsequent to dam construction (Vanicek and Kramer 1969, Olney 1975). Old timers indicate that Colorado squawfish migrated up the big rivers and major tributaries in spring to spawn prior to dam construction. Spawning behavior of Colorado squawfish has not been observed due to the turbid water of the habitat, though it might be assumed to be similar to closely related species (Patten and Rodman 1969, Casey 1962, Jeppson and Platts 1959, MacPhee 1964).

SPECKLED DACE, _Rhinichthys osculus_ (Girard)

History and Distribution. The first reports of speckled dace from the Grand Canyon (McKee 1932) were misidentified as loach minnows, _Tiaroga cobitis._

Mainstream distribution of speckled dace appeared to be sporadic, with individuals being collected from section IV during the first winter trip, and sections VII, X, and XI during the summer (Table 6-3). Earlier records have documented the presence of this species throughout the study area. The data collected during this study probably reflect the difficulty of collecting for small fishes in the mainstream and do not represent the actual distribution of this species. Speckled dace appeared to prefer the higher gradient, swift-moving streams with rock substrates, although it occurred in all of the tributaries examined. Tributary densities were highest in spring and summer.

Density and Abundance. Mainstream density estimates of speckled dace varied from 20 f/ha in section IX to 23,000 f/ha in section X (Table 6-5). Tributary densities were lower and ranged from zero to 9829 f/ha (Table 6-5).

Mainstream relative density of speckled dace were generally low, ranging from fourth most abundant species during the spring and summer to the eighth most common fish during the winter (Table 6-6). It was the most common fish in the tributaries during the summer sampling period, and second most common during other seasons. Overall, it was the most common species in the tributaries (Table 6-6). When combining all fish collections, speckled dace was the most common native fish and the second most common of all fish species taken during this study (Table 6-7).

Age and Growth. The speckled dace is a small short-lived species which appears to reach a maximum age class of II. The calculated mean annual growth increment was 50.1 mm in the first year and 24.1 mm in the second year (Table 6-9).

A good illustration of age and growth in speckled dace is presented in the length-frequency distribution (Figure 6-2). From November through February, only the larger fish from age class I were present. Young-of-the-year fish appeared in May and constituted the largest age class by July-August. The bimodal distribution at this time represented age class 0 (40.0 mm) and age class I (75.0 mm) (Figure 6-2).

Food Habits. Aquatic invertebrates, especially Ephemeroptera, Diptera and Trichoptera, were the principal food items in the stomachs of speckled dace collected in both the mainstream and tributaries. Several other items were utilized heavily on a seasonal basis (Table 6-10).

Mainstream. The diet of mainstream speckled dace consisted largely of benthic invertebrates and organic detritus (Table 6-10). Immature forms of midges and black flies constituted the largest portion of the diet during all seasons (range 33.47-100%). Scuds (Gammaridae) and mayfly nymphs (Baetidae) were the major food items in the summer

Terrestrial insects were eaten by speckled dace in spring and summer. During spring, a lady beetle (Coccinellidae), black fly adults, and an Ichneumonid wasp were taken, which collectively accounted for 8.91% of the diet. Ants (Formicidae), adult black flies, an adult midge, and a burrower bug (Cydnidae) were consumed during summer, together comprising 7.68% of the diet (Table 6-10).

Table 6-9. Mean calculated total length (standard error; mm) and mean calculated annual growth increments of Speckled Dace at succeeding ages from the Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age		Mean Capture Length	Mean calculated total length (S.E.) at each annulus 1	2
1978	0	7	60.3 (7.8)		
1977	I	16	72.9 (11.2)	51.2 (10.4)	
1976	II	11	97.4 (8.3)	48.4 (8.3)	72.6 (9.9)
Average				50.1 (9.4)	72.6 (9.9)
Increment				50.1 (9.4)	24.1 (6.0)
Number				27	11

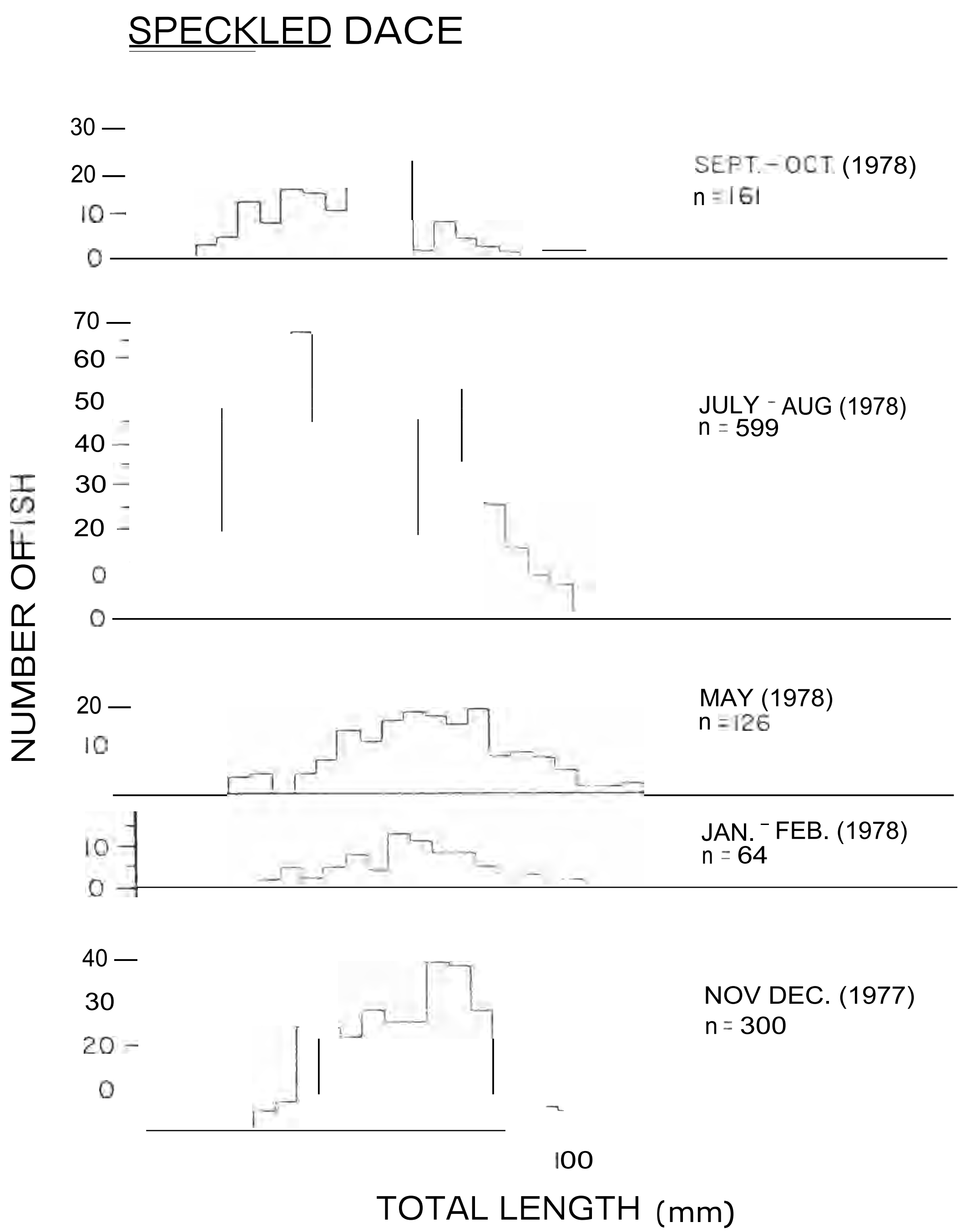

Figure 6-2. Length-frequency distribution of speckled dace from the Colorado and Little Colorado Rivers in Grand Canyon National Park, Arizona.

Table 6-10. Dietary composition of speckled dace (Rhinichthys osculus) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Aquatic Invertebrates												
Ephemoroptera (mayflies)												
Baetidae nymphs		0.13	13.71		2.66	4.53	5.27	7.6[1]	0.57		0.65	7.68
undetermined nymphs		0.13	2.74			1.03		0.21				0.82
Odonata (dragonflies and damselflies)												
Coenagrionidae nymphs			1.21						2.45		1.53	1.46
Plegoptera (stonelfies)												
undetermined nymphs						1.44						
Hemiptera (bugs)												
Corixidae adults		0.89										
Veliidae adults							1.14		0.45			
Coleoptera (beetles)												
Dytiscidae		0.82										
Elmidae larvae								0.05	0.04		0.21	0.06
Elmidae adults				2.97								
undetermined larvae						0.43						
Megeloptera (helgramites)												
Corydalidae larvae						13.40		4.17				4.31
Trichoptera (caddisflies)												
Philopotamidae larvae								1.00				0.88
Hydropsychidae larvae		13.38	2.13		28.03	1.23		3.06	5.75		26.10	9.46
Hydroptilidae larvae			0.30			0.20		0.58				0.38
Limnephilidae larvae		0.06										
undetermined larvae		0.96						0.16				
Lepidoptera (moths)												
Pyralidae larvae		1.17	1.82					9.19	0.12		0.54	0.57
undetermined larvae												1.20
Diptera (flies and midges)												
Tipulidae larvae		0.76						0.16				
Chironomidae larvae		5.20	19.58	7.92	13.39	4.53	3.56	3.70	6.61	28.57	16.77	7.50
Chironomidae pupae	4.55	1.80		22.77			4.13	0.47	1.22	28.57	3.50	1.46
Simuliidae larvae	86.36	7.77	11.58	9.90	34.86	42.06	17.95	12.04	16.43	28.57	5.70	31.49
Simuliidae pupae						2.26	7.83	1.32	1.71		0.21	

(continued)

Table 6-10 (cont.). Dietary composition of speckled dace (Rhinichthys osculus) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main	N	S
Ceratopogonidae larvae									0.16			
Stratiomyiidae larvae			0.30			4.74		0.58	1.10			
Tabenidae larvae		3.88			0.06	1.85		0.11			0.43	
Psychodidae larvae								0.05				
undetermined larvae		0.06						0.05	0.08			
undetermined pupae											0.54	
Gastropoda (snails)												
Physidae adults									3.63			
Ostracoda (seed shrimp)												
Cypridae adults		0.06	4.87					2.53	16.03		1.20	1.90
Annelida (earthworms)												
Oligochaeta adults		1.87					0.43					1.01
Amphipoda (scuds)												
Gammaridae adults			0.91				17.81	0.32				
Hydracarina (watermites)												
Spherconidae adults		0.20			0.24			0.04				
Terrestrial Invertebrates												
Orthoptera (grasshoppes & crickets)												
Acrididae adults					0.12							
Hemiptera (bugs)												
Cydnidae adults							0.28					
undetermined adults					0.06				0.28			
Homoptera (cicadas &hoppers)												
Cicadellidae adults		0.34							Tr			0.06
Fuloridae adults					0.18							
undetermined adults		1.03						0.05				
Coleoptera (beetles)												
Chrysomelidae adults												0.38
Coccinellidae adults				3.96								
Staphylinidae adults											0.43	
undetermined adults								0.11				

(continued)

Table 6-10 (cont.). Dietary composition of speckled dace (*Rhinichthys osculus*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Lepidoptera (moths)												
Pyralidae adults												0.82
Ctenuchidae adults											0.76	2.34
undetermined larvae		2.43										
Diptera (flies and midges)												
Chironomidae adults		4.58			2.32		1.57	0.32	0.65		0.98	+
Simuliidae adults				2.97			0.28	0.26	0.16		0.12	
undetermined adults		2.98			0.55	0.61	0.71	0.05	0.90		0.10	
Hymenoptera (wasps and ants)												
Ichneumonidae adults				1.98	0.12				0.08			
Formicidae adults		2.45			1.79		5.55	0.58	1.06			
undetermined adults		0.20		1.98	1.92						0.54	
Araneida (spiders)												
undetermined adults									0.12			
Invertebrate Remains:		22.83	5.18	23.76	3.34	3.09	8.12	2.90	4.57		2.19	1.46
Algae												
Nostocaceae Nostoc spp.			17.68			Tr			3.26			2.34
Seeds												
Gramineae			0.60				0.14	0.67			2.08	
Plant iginaceae											0.10	
undetermined		0.18										
Detritus and Sand		23.53	17.19	21.78	9.86	18.96	24.79	47.70	32.46	14.28	35.42	22.29
Totals												
No. of Fish	1	58	30	9	34	26	53	85	73	5	74	78
Total mass (%)	100.0	99.67	99.80	99.99	99.50	99.93	99.99	100.0	99.93	99.99	99.98	99.99
Total no. of food organisms	18	473	230	42	1158	404	250	540	1193	7	357	876

Northern Tributaries. Speckled dace in the northern tributaries fed primarily on benthic insects and amorphous organic detritus. Larval forms of net-spinning caddisflies (Hydropsychidae), black flies, and midges were the main prey items throughout most of the year (range 18.80 - 76.28%). Midge and caddisfly larvae were least important during summer. This seasonal drop coincided with a greater intake of mayfly nymphs and larvae of moths (Pyralidae) and Corydalids (Table 6-10).

Adult midges and ants were utilized in small to moderate quantities throughout the year (range 0.90 - 7.01%). Other terrestrial insects eaten by speckled dace included leafhoppers (Cicadellidae) during the winter, a planthopper (Fulgoridae) and an Ichneumonid wasp in the spring, and a Ctenuchid moth in the fall.

Southern Tributaries. The stomach contents of speckled dace from southern tributaries were similar to those in the northern tributaries. Benthic invertebrates predominated in the diet with black fly and midge larvae being the most heavily exploited taxa. Other major food items included mayfly nymphs in winter, seed shrimp (Cypridae) in summer, and net-spinning caddisfly larvae in summer and fall. Larvae of dobson (Corydalidae) and soldier flies (Stratiomyiidae) were of secondary importance during the spring (Table 6-10).

Terrestrial insects were a minor component of the seasonal diets, with Pyralid and Ctenuchid moths, adult midges, and ants being the only taxa comprising greater than 0.50% of any season's diet.

Non-animal dietary items included the alga, *Nostoc*, and organic detritus. *Nostoc* was utilized primarily during winter and was mostly limited to speckled dace collected from Hermit Creek.

Reproduction. Reproduction is apparently limited to the tributaries when water temperatures are between 17 and 23° C. Successful reproduction was first documented in May by the collection of young-of-the-year fish. These data and gonadal somatic indices, suggest that spawning occurs in spring. The number of eggs per female was low, ranging from 932 in the winter to 1440 in the fall.

Family CATOSTOMIDAE

RAZORBACK SUCKER, _Xyrauchen texanus_ (Abbott)

History and Distribution. The first record of the razorback sucker in the Grand Canyon is based on one specimen taken by an angler in Bright Angel Creek in 1944 (National Park Service files) (Table 6-1). This species was present in large numbers in the Gila and Colorado Rivers and was apparently used as food by Indians (Ellis 1914, Miller 1955, La Rivers 1962).

The only other Canyon record of this species prior to this study is a single specimen caught in 1963 near the Lee Ferry - Paria River area (Arizona Game and Fish files). One adult was collected 100 m upstream from the confluence of the Paria and Colorado Rivers in summer 1978. Three individuals have since been seen in the same locality, though none of them were captured (Minckley pers. obs., May 1979, Minckley and Carothers 1980). The razorback sucker is currently suggested for listing as an endangered species.

Hybrids between the flannelmouth and razorback sucker have also been collected by Arizona Game and Fish and Suttkus et al. (1976) at this locality.

Density and Abundance. Based on electrofishing data from this study the razorback sucker was exceedingly rare. It was taken only once in the Paria River and never in the mainstream. Consequently, it was ranked as the least common species both in the tributary collections (Table 6-6) and in all collections combined (Table 6-7).

Age and Growth. The little available data on age and growth indicate that this fish is a slow-growing, long-lived species. Fish that have been examined ranged from 17-22 years of age and measured up to one meter in length (W. L. Minckley pers. comm.).

Food Habits. A partial excerpt from Minckley (1973) details the food habits of this omnivorous species.

> Foods eaten by razorback suckers in the lower Colorado River include algae and dipteran larvae (Jonez and Sumner 1954). Specimens that I have examined from Lake Mohave had their intestinal tracts entirely filled with planktonic crustaceans in May. Feeding activities were observed in about six meters of water...Hubbs & Miller (1953) also noted plankton as food for Xyrauchen in riverine environments of the northern part of its range, and commented on the length and "fuzziness" of the gill rakers in the species, which approach those of the presumably plankton-eating suckers comprising the genus Chasmistes...

Reproduction. Early Arizona settlers reported seeing large numbers of razorback suckers using tributary streams for spawning (Chamberlan 1904). Reproduction occurs from late winter to early summer in Colorado River impoundments (Minckley 1973). Collection of gravid females from other river systems indicate that spawning occurs in the Yampa, Upper Colorado (McAda 1977) and Paria Rivers (Minckley and Carothers 1980) and the mouth of the Virgin River (T.C. McCall pers. comm.).

Typically, spawning occurs along shorelines or in bays (Douglas 1952, Jonez and Sumner 1954) over gravel bars (McAda 1977). Reproduction in the razorback sucker is polyandrous with up to 12 males attending each female. A partial excerpt from Minckley (1973) describes spawning activities in further detail.

> The group (males and female) moves in circles less that two meters in diameter, randomly spiraling over the bottom. The males appear to "herd" a female by nudging with their heads and predorsal keels against her genital region. When

a site is selected the female simply settles to the bottom, with a male closely pressed to each side. Vibrations then commence that culminate in a convulsive finale, at which time gametes are presumably emitted. The three fish then move forward and upward, leaving a cloud of silt and sand marking the spot of activity. Females spawn repeatedly with numerous males. The eggs are transparent and adhesive, attaching to the substrate upon which they are deposited...

FLANNELMOUTH SUCKER, *Catostomus latipinnis* (Baird and Girard)

History and Distribution. Flannelmouth sucker remains have been excavated from the 4,000 year old riverine deposits in Stanton's Cave (R. M. 658.6) (Euler 1978, Miller and Smith 1973). In historical times, this species was used for food by the Indian populations inhabiting the Grand Canyon area (LaRivers 1962, Sigler and Miller 1963).

Flannelmouth suckers are commonly found in the larger, strongly flowing streams of the Colorado River Basin, as well as in the Green, Yampa and San Juan Rivers. During this study, the distribution of flannelmouth suckers was continuous throughout the Colorado River mainstream during all seasons (Table 6-3). Flannelmouth suckers were also captured in the tributaries, especially in low gradient, slow moving streams with mud substrates, such as the Paria and Little Colorado Rivers and Kanab Creek.

Movement data on flannelmouth suckers are inconclusive due to the small number of recaptures (3 out of 387 tagged individuals). One individual marked during May in the Little Colorado River was recaptured in October at River Mile 619, 18.4 km downstream. The other two were recaptured in the same locale that they were marked.

Density and Abundance. Tributaries appear to support higher flannelmouth sucker densities than mainstream areas based on electrofishing, trammel net and seining data. Electrofishing data indicate that relative densities of this species are higher in the confluent areas of the Paria and Little Colorado Rivers and Kanab Creek than in the mainstream. The mean relative density in confluent collections was about double that in mainstream areas, although the ranges were quite similar (2.8-27.5 f/h in confluent areas (Table 6-11) and .4-28 f/h in the mainstream (Table 6-12). Trammel nets yielded density values ranging from .5-5 f/net in the mainstream and from 23-372 f/net in confluent areas. Seining data indicate that during the summer, relative densities of flannelmouth suckers ranged from 4-7650 f/ha in the tributaries and from 40-2098 f/ha in the mainstream (Table 6-5). Relative density in the tributaries varied from 4 to 78 f/ha during spring and from 50 to 2620 f/ha during fall.

Age and Growth. Flannelmouth suckers taken during this study ranged from zero to ten years in age. The oldest fish was a ten-year old female (515 mm). Several larger fish were taken including a female from age class VIII (570 mm) and four other fish of unknown age and sex (580-610 mm). As a result of this variability in length, there is considerable overlap in fish length among adjacent size classes. Two modes, which represent young-of-the-year fish and adults, are apparent in the length-frequency distribution (Figure 6-3). The adult population appears to be normally distributed around 450 mm in length, which corresponds to age classes VI (mean length at capture, 442.1 mm) through VIII (466.0 mm). Twenty to 50 mm young-of-the-year fish first appeared in July-August (Figure 6-3).

Female flannelmouth suckers from age class IV were significantly larger than males from the same age class, except during age class II, when males were larger (t-test, $p < .10$). The difference in size among the sexes increases with age (t-test, $p < .05$ during the first year, $p < .01$ during the third year). During the fourth year, after sexual maturity is reached, the females grow even faster relative to the males ($p < .0005$) (McAda 1977).

Table 6-11. Mean number of fish taken by electrofishing and trammel net sets in the confluences of the Paria and Little Colorado Rivers, and Kanab Creek, Coconino and Mohave counties, Arizona, during 1977 - 1978. Numbers in ( ) refer to trammel net densities, others refer to electrofishing.

	Winter 1977	Winter 1978	Spring	Summer	Fall
CARP:					
Paria R.			21	176	21.2
L. Colorado R.	(--)	.4(--)	8.6(24)	16.6(--)	1.9(3)
Kanab Creek		1		23	
FLANNELMOUTH SUCKER:					
Paria R.			3	27.5	4.8
L. Colorado R.	(23)	10.8(25)	21.3(372)	4.0(128)	2.8(138)
Kanab Creek	(--)	--(--)	--(--)	7(--)	--(10)
BLUEHEAD SUCKER:					
Paria R.			1		.4
L. Colorado R.	(4)	5(3)	6(24)	--(4)	--(--)
Kanab Creek	(--)	--(--)	--(--)	--(6)	--(3)
CHANNEL CATFISH:					
L. Colorado R.	(--)	--(--)	2(--)	--(12)	4(6)

Table 6-12. Estimated relative densities of rainbow trout, carp, flannelmouth and bluehead suckers, collected by electrofishing and trammel netting the mainstream Colorado River, Coconino and Mohave counties, Arizona, in river sections I - XII during 1977 - 1978. Data presented as the calculated number of fish taken per hour (f/hr) and fish taken per net (f/n), respecitvely.

	River Section											
Sampling Period	I	II	III	IV	V	VI	VII	VIII	IX		XI	XII
RAINBOW TROUT:												
Winter 1977	* (1)	(.5)		(.6)	(1)							
Winter 1978	(.3)		.4(.5)		6.3(7)	(6)		3.6(1)	1.7(8)	1.7	.3	
Spring					8.2(1)		10.8		.8		.4	2.5
Summer				33	26.2	74(6)	11.5(18)	40(1)	.5(1.3)	.5		
Fall	4.8(1)		3.8(.5)	(1)	2.6(1.3)	5.5(3)	2.9(2)	2.3	.9			
CARP:												
Winter 1978								21.5	31.7	48.3	.7	110
Spring		30			8.8	35	32.6		68.8	70.5	8.4	15
Summer		18.8			68.3	101.2	9.5	62		68	1030	62
Fall					11.3	9.7	7.9					
FLANNELMOUTH SUCKER:												
Winter 1977												
Winter 1978			(.5)	.4	1.3(1)	(1)			.4(1)	.6	.7	
Spring		1		8.6			.9	.4	2.4	8.4	6	
Summer				16.6	1.3	23	.5	28	.5	2.5		
Fall	21.2	3.3	.6	1.9	1.3		(5)	3.8	.5(1)	.3(1)		(1)
BLUEHEAD SUCKER:												
Winter 1977				(1)	(1)				(1)			
Winter 1978			(1)			(3)	(2)	(4)	(4)			
Spring	(2)					.3						
Summer						.2(2)	(6)	.2				
Fall	.4	(2)	(2.5)	(6.5)	(1)	(.3)		(.5)	(4)	(1)	(1)	(1)

* numbers in parentheses are trammel netting densities
\+ numbers outside parentheses are electrofishing densities

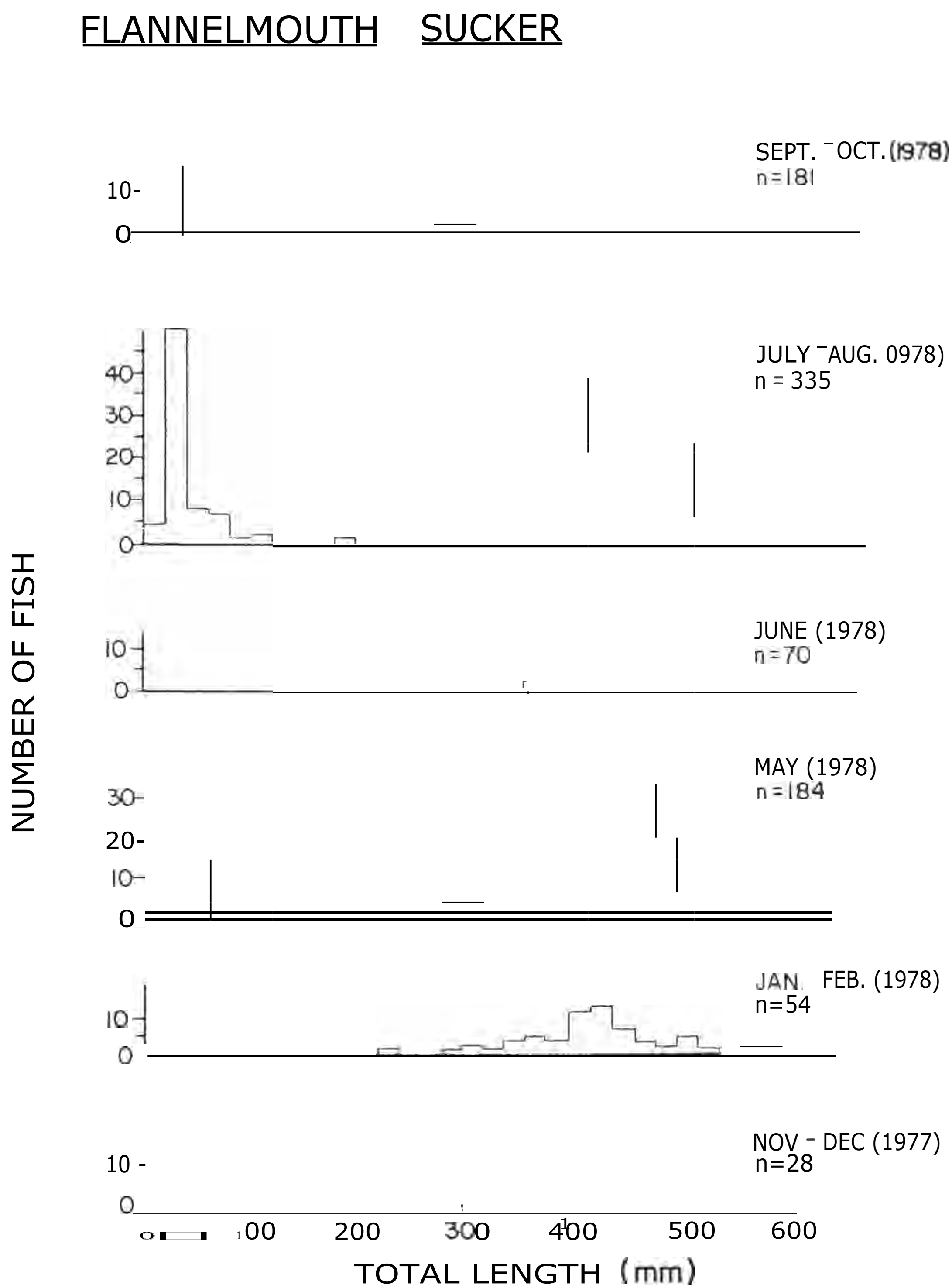

Figure 6-3. Length-frequency distribution of flannelmouth suckers from the Colorado River and selected tributaries in Grand Canyon National Park, Arizona.

Flannelmouth suckers show the most rapid growth during their first year. The average annual growth increment of 121.6 mm in the first year (Table 6-13) is followed by a sharp decrease to 63.5 mm. The third year shows a slight increase in the annual growth increment, though the following years exhibit a steady decline.

Food Habits. Flannelmouth suckers are omnivores that feed heavily on midges, black flies, scuds, organic detritus and *Cladophora*.

Mainstream. Animal matter consumed by mainstream flannelmouth suckers consisted primarily of scuds and immature Dipterans (black flies and midges), which collectively comprised from 17.27 to 73.44% of the seasonal diet (Table 6-14). Micro-caddisfly larvae (Hydroptilidae), a pyralid larva, riffle beetle larvae (Elmidae), crane fly larvae (Tipulidae), water mites (Spherchonidae) and a net-winged midge larva (Blephariceridae) were the only other aquatic invertebrates consumed in more than trace amounts. Terrestrial insects, including ants, adult black flies and midges, leafhoppers and a phanthopper (Table 6-14) were also ingested. Ingestion of winged insects is thought to be incidental and confined to insects eventually settling on the river bottom and to emergent forms preyed upon while in transition between their aquatic pupal stage and adult winged form. Non-animal gut contents included *Cladophora*, seeds (Gramineae and Compositae), detrital materials (Table 6-14), and diatoms (Table 6-15).

Variations in the seasonal diet were primarily due to fluctuating consumption of scuds and black flies. Together, these accounted for 25.18% and 72.89% of the winter and fall diets, respectively. Their consumption decreased markedly during spring (12.34%) and summer (15.06%). Midge larvae and *Cladophora*, which were the most important food items in winter and spring, respectively (Table 6-14), fluctuated to a lesser extent.

Table 6-13 . Mean calculated total lengths (standard deviation; mm) and mean calculated annual growth increments of Flannelmouth Suckers at succeeding ages from Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age		Mean Capture Length	1	2	3	4	5	6	7	8	9	10
				Mean calculated total length (S.D.) at each annulus									
1970	O	13	81.5 (9.7)										
1977	I	13	105.6 (11.9)	77.2 (0.7)									
1976	II	8	224.8 (60.8)	119.2 (36.5)	188.9 (54.3)								
1975	III	40	307.9 (44.3)	118.6 (22.1)	187.3 (43.6)	267.4 (53.0)							
1974	IV	33	381.5 (40.8)	125.2 (27.0)	185.5 (40.2)	269.9 (33.3)	346.3 (33.9)						
1973	V	15	401.6 (34.5)	129.2 (37.6)	187.3 (40.7)	248.1 (41.4)	306.1 (38.3)	365.1 (41.4)					
1972	VI	24	442.1 (26.9)	133.7 (29.9)	199.8 (35.8)	258.5 (40.7)	317.4 (32.3)	364.9 (32.3)	406.8 (28.9)				
1971	VII	6	451.8 (41.9)	130.2 (33.6)	193.7 (39.4)	257.4 (31.1	301.1 (26.9)	339.0 (29.9)	382.5 (29.1)	425.4 (43.6)			
1970	VIII	5	466.0 (63.5)	134.6 (31.1)	182.0 (39.1)	233.1 (69.5)	282.3 (82.5)	335.3 (74.0)	368.4 (75.8)	407.3 (72.7)	440.6 (71.3)		
1969	IX	7	501.9 (19.0)	131.8 (33.1)	190.8 (28.6)	255.0 (28.8)	305.8 (75.4)	353.8 (15.1)	389.2 (13.2)	425.4 (12.7)	457.7 (7.9)	482.6 (17.2)	
1968	X	1	515.0 (-)	133.7 (-)	175.3 (-)	207.8 (-)	292.7 (-)	337.9 (-)	381.3 (-)	410.2 (-)	428.3 (-)	446.3 (-)	466.2 (-)
Average				121.6 (14.9)	189.3 (5.3)	261.3 (10.4)	321.9 (20.3)	357.9 (11.5)	395.5 (14.0)	419.8 (8.4)	448.9 (10.2)	478.1 (12.8)	466.2 (-)
Increment				121.6 (14.9)	63.5 (5.5)	72.0 (11.9)	63.2 (11.3)	50.0 (6.4)	40.1 (3.6)	38.6 (3.7)	31.6 (4.1)	24.0 (2.4)	19.9 (-)
Number				152	139	131	91	58	43	19	13	8	1

Table 6-14. Dietary composition of flannelmouth suckers (*Catastomus latipinnis*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Aquatic Invertebrates												
Ephemeroptera (mayflies)												
Baetidae nymphs								0.07				
Trichoptera (caddisflies)												
Hydropsychidae larvae			0.01		4.58			0.32			4.93	
Hydroptilidae larvae				0.25				0.01		0.01		0.08
Brachycentridae larvae								0.02				
Lepidoptera (moths)												
Pyralidae larvae				0.02								
undetermined larvae												
Coleoptera (beetles)												
Elmidae larvae				0.02			0.04	0.19				
Diptera (flies and midges)												
Tipulidae larvae			0.01	0.03			0.04					
Blephariceridae larvae										0.15		
Ceratopogonidae larvae				Tr			Tr	0.02			Tr	
Chironomidae larvae	9.03		2.94	3.13			1.38	11.41	48.25	0.09	8.72	1.02
Chironomidae pupae	2.74		0.74	1.80	5.50		1.95	2.21		0.46	0.66	
Simuliidae larvae	5.73		7.84	2.65			2.47	1.41		17.90	0.15	0.06
Simuliidae pupae	0.90		2.01	1.94			3.00	1.93		8.45	0.08	0.17
Stratiomyiidae larvae								0.03				
undetermined pupae							0.03					
Ostracoda (seed shrimp)												
Cypriae adult								0.02			0.01	0.15
Amphipoda (scuds)												
Gammarida adults	18.55		36.48	7.95			12.03	0.87		46.54	8.42	
Hydracarina (watermites)												
Sperchonidae adults	0.01			0.10			0.24	0.28			0.01	
Terrestrial Invertebrates												
Hemiptera (bugs)												
Cydnidae adult												
undetermined adult							0.02			0.02		

(continued)

Table 6-14 ,cont.). Dietary composition of flannelmouth suckers (Catastomus latipinnis) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Homoptera (cicada & hoppers)												
Cicadellidae adults	0.03			0.01				0.04				
Fulgoridae adults										0.03		
Diptera (flies and midges)												
Chironomidae adults			0.01	Tr			0.04	0.03		0.01		
Simuliidae adults				0.02								
undetermined adults	0.03			0.01	5.50		0.06	0.04		0.02		
Hymenoptera (wasps and ants)												
Formicidae adults				0.05	3.66		0.06	0.03			0.02	
undetermined adults					1.83							
Invertebrate Remains				0.03			0.73	0.05			0.01	
Algae												
Cladophorales	2.83			11.22			0.02			0.02		
Cladophora spp.			Tr					7.73			1.01	Tr
Seeds												
Compositae	0.25			0.03			0.17					
Graminae	0.09				0.91		4.33	0.18		0.33	0.41	
undetermined	0.16			1.59			0.83	0.04		0.16	0.05	
Detritus and Sand	59.61		49.90	69.30	77.98		72.55	73.05	51.75	25.81	75.45	98.48
Totals												
No. of fish	13	-	10	26	1	-	41	22	10	14	45	14
Total mass (%)	99.96	-	99.94	99.95	99.96	-	99.99	99.98	100.0	100.0	99.93	99.96
Total no. of food organisms	1151	-	541	1458	18	-	901	2255	77	1182	2012	71

Table 6-15. Diatoms identified in the seasonal diets of catostomids collected from the Colorado River, Grand Canyon National Park, Arizona, 1977 - 1978.

	Bluehead Mt. Sucker		Flannelmouth Sucker	
Season	Marble Canyon	Grand Canyon	Marble Canyon	Grand Canyon
Winter	N=0	Diatoma * Cymbella ** Gomphonema ** Cocconeis Melosira Navicula Synedra N=11	Cocconeis Diatoma Cymbella Rhoicosphenia Navicula Gomphonema Achnanthes Biddulphia N=2	Cymbella * Diatoma ** Cocconeis Rhoicosphenia N=8
Spring	Diatoma Rhoicosphenia ** Cocconeis *** Synedra Cymbella Achnanthes Siurella N=2	Navicula Gomphonema Diatoma ** Cocconeis Rhoicosphenia Siurella Synedra Achnanthes Cymbella N=4	Diatoma * Cocconeis ** Achnanthes Rhoicosphenia Cymbella N=5	Diatoma * Melosira Cocconeis ** Gomphonema Rhoicosphenia Synedra Navicula Achnanthes Witzschia N=17
Summer	Diatoma Gyrosigma ** Cocconeis Cymbella Rhoicosphenia Navicula N=4	Cocconeis Diatoma Cymbella Siurella Epithemia N=32	Chlorococcales * Rhoicosphenia Cocconeis Diatoma N=2	Cocconeis * Diatoma ** Navicula Rhoicosphenia Cymbella N=15
Fall	Diatoma Cocconeis Cymbella Synedra Achnanthes N=5	Diatoma Cocconeis Cymbella Synedra Gomphonema Rhoicosphenia Navicula N=8	Cocconeis Diatoma Rhoicosphenia Navicula Cymbella N=2	Cocconeis Diatoma Rhoicosphenia Navicula Chlorococcales N=4

* first dominant
** second dominant
*** t"rd dominant

The diatom component of riverine flannelmouth diets consisted primarily of *Diatoma, Cymbella,* and *Rhoicosphenia* during winter and *Diatoma* and *Cocconeis* during spring and summer. Common diatoms in the fall diet included *Diatoma, Navicula,* and *Cocconeis* (Table 6-15).

Northern Tributaries. Organic detritus comprised the bulk of the gut contents from flannelmouth suckers captured in the northern tributaries (Table 6-14). Immature midges, scuds, black flies and net-spinning caddisflies, which collectively comprised 18.15% and 22.96% of the summer and fall diets, respectively, were the major organisms consumed. Other food items ingested during this period included water mites and seed shrimp. *Cladophora* was an important food item during summer (7.73%), while seeds (Gramineae) constituted a minor component of the summer and fall diets. The diet of a single specimen collected during spring consisted of midge pupae, a net-spinning caddisfly larva, an ant, a seed and organic detritus (Table 6-14). No individuals were collected for stomach content analysis during winter.

Southern Tributaries. The stomach contents of flannelmouth suckers caught in the southern tributaries indicated that scuds and larval black flies and midges were the major winter food items (Table 6-14). Midge larvae constituted 48.25% and 1.02% of the summer and fall diet, respectively. Non-animal gut contents consisted of organic detritus and *Cladophora.* No specimens were obtained for stomach analysis during spring.

Reproduction. Spawning in flannelmouth suckers appears to occur in spring (as inferred from gonadal indices) and/or early summer (Minckley 1973). Within the study area, reproduction takes place in low gradient, mud-bottomed streams at water temperatures of 17 - 23 C. Numerous young-of-the-year fish were collected during summer.

BLUEHEAD SUCKER, Catostomus discobolus (Cope)

History and Distribution. Archaeological remains of bluehead suckers were found at Stanton's Cave (Euler 1978, Miller and Smith 1973). Bluehead suckers were first recorded from the study area in 1937 (National Park Service files).

Bluehead suckers are found in the Green, Yampa, San Juan and Upper Colorado Rivers as well as in the mainstream Colorado River. Within the study area, bluehead suckers were especially common between river sections I and X, although individuals were taken throughout the area (Table 6-2, 6-3). Bluehead suckers were also common, especially during summer, in the high gradient, swiftly moving tributaries with rocky substrates.

Density and Abundance. In the mainstream, bluehead sucker densities were highest between river sections IV and IX (Table 6-12). The seining data (Table 6-5) indicate that the densities tend to be higher in confluent areas although this is not borne out by the electrofishing and trammel net data (Table 6-11, 6-12). Mainstream densities based on electrofishing and trammel netting data ranged from .2 - 4.5 f/h and .3 - 6.5 f/n, respectively, while similar data from confluent areas showed densities of .4 - 6 f/h and 3 - 24 f/n. Tributary seining during summer yielded relative densities ranging from 500 - 6,850 f/ha while mainstream collections during the same period ranged from 17 - 407 f/ha. During spring, tributary seining yielded relative densities ranging from 11 - 56 f/ha, and in the fall from 6 - 4,200 f/ha. The relative abundance of bluehead suckers ranked between third and fifth (except for eighth in in spring mainstream collections) during all seasons in both the mainstream and tributary areas (Table 6-6). Based on all collections, bluehead suckers were the third most common native fish and the fifth most common of all fish species (Table 6-7).

Age and Growth. Bluehead suckers captured within the study area ranged from hatchlings to eight years of age (Table 6-16). Two females (318 mm and 360 mm) from age class VIII were the oldest specimens observed, although they were surpassed in length by a six year old female (361 mm) and several other individuals of unknown age and sex (368-397 mm). Consequently, there is considerable overlap in fish size among adjacent age classes.

Growth is most rapid during the first year, with an average increment of 93.7 mm. The growth increment decreased in subsequent years until it reached a constant increase of about 25 mm per year at age six (Table 6-16).

The majority of young-of-the-year fish appeared during May, although one fish in the 20 - 29 mm size class was collected during January-February. Based on our sample, the adult population seems to be evenly distributed among all size classes (Figure 6-4). Fish from age class V showed no significant difference between the sizes of male and female bluehead suckers, although data suggests that females grow larger than males and live somewhat longer. In our sample, 19 females grew to larger than 300 mm, while only one male (333 mm) exceeded 300 mm. In addition, no male was observed to be older than six years, whereas six females were aged at seven and eight years.

Food Habits. This omnivorous species feeds extensively on aquatic invertebrates within the study area. Their diet consists primarily of dipterans and scuds in the mainstream and dipterans in the tributaries.

Table 6-16 . Mean calculated total lengths (standard deviation, mm) and mean calculated growth increments of Bluehead Suckers at succeeding ages from the Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age	n	Mean Capture Length	Mean calculated total length (S.D.) at each annulus							
				1	2	3	4	5	6	7	8
1978	O	6	61.3 (2.8)								
1977		18	86.8 (18.4)	69.3 (12.3)							
1976	II	14	137.5 (36.3)	84.3 (23.6)	119.9 (33.7)						
1975	III	22	200.4 (44.8)	98.3 (27.7)	136.8 (28.6)	174.3 (38.9)					
1974	IV	14	238.5 (28.5)	106.0 (23.9)	138.2 (26.9)	174.0 (27.6)	211.8 (25.1)				
1973	V	27	243.6 (25.5)	97.3 (16.6)	126.3 (19.7)	155.6 (22.3)	185.9 (24.4)	220.1 (25.5)			
1972	VI	13	247.5 (22.9)	94.2 (11.9)	127.5 (12.6)	156.0 (19.5)	179.6 (19.5)	202.8 (20.9)	227.4 (20.2)		
1971	VII	4	333.3 (25.7)	119.3 (17.0)	158.4 (79.4)	193.8 (23.2)	224.8 (18.8)	247.1 (17.8)	277.5 (12.8)	310.5 (26.8)	
1970	VIII	2	339.0 (29.7)	141.5 (38.6)	188.6 (38.7)	218.9 (53.2)	252.6 (50.1)	268.3 (47.0)	284.0 (40.6)	298.6 (35.9)	323.3 (32.8)
Average				93.7 (14.0)	132.3 (11.9)	167.2 (13.7)	195.4 (18.2)	219.7 (15.9)	243.9 (25.0)	306.5 (6.1)	323.2 (-)
Increment				93.7 (14.0)	34.0 (4.2)	32.8 (3.9)	30.8 (4.8)	29.3 (6.1)	24.9 (4.0)	26.9 (9.5)	24.7 (-)
Number				114 10.68	96 9.8	82 9.06	60 7.75	46 6.78	19 4.36	6 2.45	2 1.41

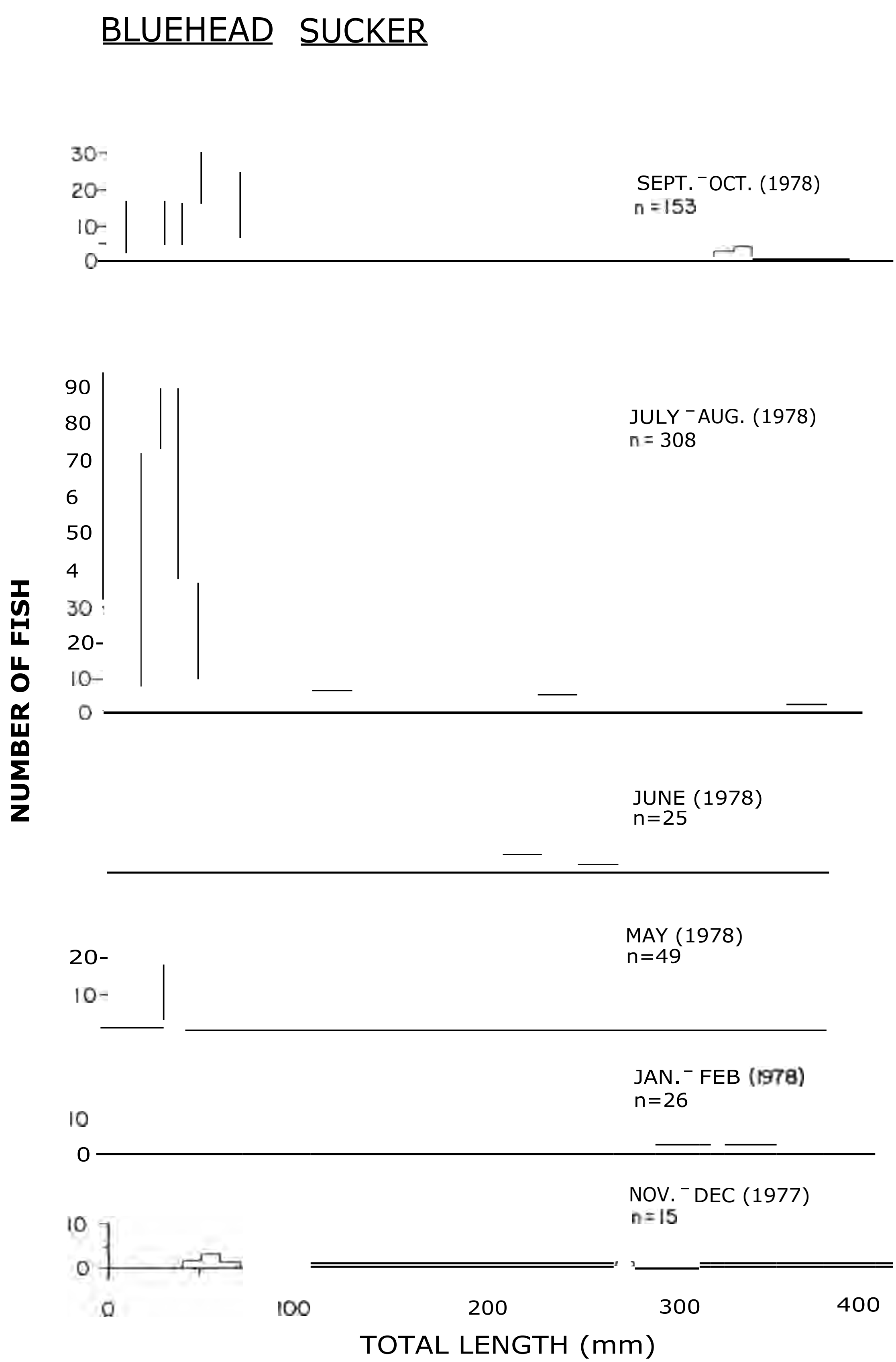

Figure 6-4. Length-frequency distribution of bluehead suckers from the Colorado River and selected tributaries in Grand Canyon National Park, Arizona.

Mainstream. Black fly and midge larvae, the most heavily exploited prey resources, collectively comprised from 6.28 to 57.31% of the seasonal diet (Table 6-17). Black fly pupae, scuds and midge pupae comprised an additional 5.00 to 6.65% of the diet. Other aquatic invertebrates consumed included crane fly larvae in winter and net-winged midge larvae in summer. Adult black flies and midges were present in small quantities, especially during the summer. As in the case of flannelmouth suckers, the presence of winged insects in the stomach contents appeared incidental. Non-invertebrate gut contents included organic detritus, which was the principal dietary component during most of the year, and *Cladophora* (1.89%).

The digestive tracts of the bluehead suckers contained an abundance of diatoms during all seasons. Winter samples were dominated by Diatoma, *Cymbella,* and *Gomphonema,* while *Diatoma, Navicula, Rhoicosphenia* and *Cocconeis* predominated during summer and fall consisted largely of *Diatoma* and *Cocconeis* (Table 6-15).

Northern Tributaries. Major invertebrate food items of bluehead suckers collected in the northern tributaries included black fly, midge and pyralid moth larvae, mayfly nymphs and midge pupae. Black fly larvae were the principal invertebrate prey item consumed during summer (34.99%), while midge larvae predominated in winter (1.29%) and fall (17.77%) (Table 6-17). The gut of a single specimen collected during spring did not contain identifiable dietary items. Other invertebrates items included black fly pupae, micro-caddisfly larvae, seed shrimp and net-winged midge larvae. There were no identifiable terrestrial insects in bluehead suckers from northern tributaries. Non-animal gut contents consisted of organic detritus and *Cladophora.*

Table 6-17. Dietary composition of bluehead suckers (*Catostomus discobolus*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Aquatic Invertebrates												
Ephemeroptera (mayflies)												
Baetidae nymphs						5.97		1.22			0.40	
Trichoptera (caddisflies)												
Hydroptilidae larvae								0.28				
Helicopsychidae larvae								0.06				
undetermined larvae								0.06				
Coleoptera (beetles)												
undetermined larvae							0.01					
Lepidoptera (moths)												
Pyralidae larvae								0.56				
Diptera (flies and midges)												
Tipulidae larvae	0.17											
Blephariceridae larvae							0.02	0.03				
Chironomidae larvae	3.73	1.29	11.54	4.36		7.78	8.81	4.98	3.76	2.59	17.77	12.67
Chironomidae pupae	15.8		1.52	0.64		1.99	1.63	0.25	0.01	0.35	0.22	
Simuliidae larvae	53.58	0.32	39.43	1.92		50.90	39.70	34.99	22.89	14.48	0.67	
Simuliidae pupae	2.98		0.65	4.36		1.81	3.39	0.20	0.22	3.83		
Ceratapogonidae larvae								0.03				
undetermined larvae	0.01						0.01					
Ostracoda (seed shrimp)												
Cypridae adult								0.19			0.07	
undetermined adult			8.93			0.18						4.22
Amphipoda (scuds)												
Gammaridae adults	1.93						0.64			2.47		
Hydracarina (watermites)								0.03				
Sperchonidae adult												
Terrestrial Invertebrates								Tr				
Diptera (flies and midges)												
Simuliidae adults							0.01					
Chironomidae adults							0.10					
undetermined adults							0.03	0.22		0.01		

(continued)

Table 6-17 (cont.). Dietary composition of bluehead suckers (*Catostomus discobolus*) in the Colorado River and and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

		Winter			Spring			Summer			Fall	
	Main		S	Main			Main			Main		
Hymenoptera (wasps and ants)												
undetermined adults							Tr					
Invertebrate Remains							0.11	Tr				
Algae												
Cladophorales												
Cladophora spp.							0.03	0.06		1.89	0.27	
Seed												
Compositae												
undetermined							0.01					
Detritus and Sand	35.99	98.37	37.90	99.72	100.0	31.34	45.49	56.72	73.06	74.38	80.56	83.09
Totals												
No. of fish	19	6	7	5	1	16	76	38	17	19	41	11
Total mass (%)	99.97	99.98	99.97	100.0	100.0	99.97	99.99	99.88	99.94	100.0	99.96	99.98
Total no. of food organisms	3134	6	280	119	-	235	5681	833	454	910	1143	25

Southern Tributaries. Food habits of southern tributary bluehead suckers are similar to those in northern tributaries (Table 6-17). Black fly and midge larvae, the most extensively utilized invertebrate prey items, collectively comprised from 12.67 to 58.88% of the seasonal diet. Both were consumed most heavily in spring, with their relative mass in the diet decreasing steadily through summer and into fall. Other prey items included seed shrimp in fall and winter, and mayfly nymphs during spring. Non-animal dietary components included organic detritus in all seasons and trace amounts of plant seeds during summer.

Reproduction. Bluehead suckers spawn from early spring through early summer at water temperatures of 19.5° C (Minckley 1978). Spawning was observed in Shinumo Creek during June 1978.

Introduced Species

Nineteen species of introduced fishes have been reported from the Grand Canyon. Twelve introduced species are currently present, with nine being relatively common, and the remaining three occurring sporadically within the study area.

Family SALMONIDAE, Trouts and salmon

COHO SALMON, Oncorhynchus kisutch (Walbaum)

History and Distribution. Coho salmon have been twice introduced into Grand Canyon waters; in Lake Mead by the Nevada Fish and Game Department in 1970 and into the Colordo River at Lee Ferry by the Arizona Game and Fish Department in 1971 (Table 6-18). One specimen was collected subsequently at R. M. 494.5, near Whitmore Wash, by Suttkus et al. (1976). Regardless of the source this fish had travelled at least one hundred miles.

Age and Growth. There is no available age and growth information on coho salmon freshwater populations, although from other studies, the species is known to be long-lived.

Food Habits. Coho salmon feed heavily on fish, aquatic invertebrates, zooplankton and terrestrial insects in lotic systems (Engel 1976, Harney and Nordes 1972, McKnight and Serns 1974). This species feeds almost exclusively on threadfin shad in Lakes Mead and Mohave (Minckley 1973).

Reproduction. Natural reproduction of coho salmon seems unlikely in the Colorado River due to seasonal turbidity and a lack of suitable bottom types (Minckley 1973).

Table 6-18. Summary of fish stocking records between Lee Ferry (P.M 688.6) and Separation Rapid (RM 450.6), Coconino and Mohave Counties, Arizona.

Species	Date	Locality	# Stocked	Size	Source
Coho salmon	12/1971	Lee Ferry	20,000	Fingerlings	AZ Game and Fish
Rainbow trout	9/1923	Bright Angel	20,000	Fingerlings	National Park Service
	5/1923	Tapeats Crk.	5,000	Eyed Eggs	
	9/1924	Bright Angel	6,000	Fingerlings	
	2/1931	Havasu Crk.	18,000	Eyed eggs	
	1/1932	Bright Angel	21,000	Eyed eggs	"
	12/1934		31,000	Eyed eggs	
	9/1935	"	21,000	Eyed eggs	
	5/1939		13,800	Fingerlings	
	6/1940	"	18,000	Fingerlings	"
	6/1940	Tapeats Crk.	2,000	Fingerlings	
	7/1940	Clear Crk.	18,000	Fry	
	11/1941	Bright Angel	32,000	Fingerlings	
	7/1942	"	28,000	Fingerlings	
	7/1942	Phantom Crk.	14,000	Fingerlings	
	4/1944	Havasu Crk.	4,500	Fry	
	6/1947	Bright Angel	10,394	Fingerlings	
	4/1948	Havasu Crk.	13,000	Fingerlings	
	3/1950	Bright Angel	45,240	Fingerlings	
	4/1954	Havasu Crk.	20,000	Fingerlings	"
	7/1958	Bright Angel	45,000	Fingerlings	"
	6/1964		23,900	Fingerlings	"
	1964	Lee Ferry	10,200	Adv. Finger-lings	AZ Game and Fish
	1964		5,000	Catchable	
	1965		10,000	Fingerlings	"
	1965		8,830	Catchable	
	1966		10,000	Fingerlings	"
	1966		4,500	Catchable	
	1967		3,100	Catchable	
	1968	"	5,500	Catchable	
	1969		20,000	Adv. Fingerlings	
	1969		6,545	Catchable	
	1970		20,000	Adv. Fingerlings	
	1970	Diamond Crk.	6,173	Fingerlings	U.S. Fish and Wildlife
	1971	Lee Ferry	5,110	Catchable	AZ Game and Fish
	1971	Diamond Crk.	11,000	Fingerlings	U.S. Fish and Wildlife
	1972	Lee Ferry	4,585	Catchable	AZ Game and Fish
	1973		5,075	Catchable	
	1974		3,990	Fingerlings	"
	1975		30,000	Fingerlings	
	1975	"	4,500	Catchable	

(continued)

Table 6-18 (cont.). Summary of fish stocking records between Lee Ferry (RM 688.6) and Separation Rapid (RM 450,6), Coconino and Mohave Counties, Arizona.

Species	Date	Locality	# Stocked	Size	Source
Rainbow trout (cont.)	1976	Lee Ferry	100,000	Fingerlings	AZ Game and Fish
	1977	"	100,000	Fingerlings	
	1978		50,000		
Brown trout	7/1926	Shinumo Crk.	50,000	Eyed eggs	National Park Service
	8/1930		50,000	Eyed eggs	
	12/1930	Garden Crk.	4,000	Eyed eggs	
	1/1930	Bright Angel	100,000	Eyed eggs	
	12/1930		45,000	Eyed eggs	"
	12/1934	"	50,000	Eyed eggs	"
Brook trout	8/1920	Bright Angel	5,000	Fingerlings	
	6/1927	Havasu Crk.	10,000	Fingerlings	
	12/1928	Clear Crk.	50,000	Eyed eggs	
	1/1931	"	25,000	Eyed eggs	
	12/1934	"	18,000	Eyed eggs	"
	1977	Lee Ferry	47,880	Fingerlings	AZ Game and Fish
	1978		100,000	Fingerlings	"
	12/1978	Lee Ferry		Fingerlings	
Cutthroat trout	1979	Lee Ferry	50,000	Catchable	
Woundfin dace	7/1972	Lee Ferry	650	Fingerlings	"

RAINBOW TROUT, *Salmo gairdneri,* (Richardson)

History and Distribution. Rainbow trout have been stocked in Grand Canyon waters many times since the first introduction at Tapeats Creek in 1923 (Table 6-18). The original range of this species extended from near latitude 24° North, in Mexico, to the Kuskokwin River in Alaska (Needham and Gard 1959) as well as in the Great Basin area up into British Columbia (Lindsey 1956).

Rainbow trout were reported to have a widespread distribution throughout the mainstream Colorado River and perennial tributaries, especially after construction of the Glen Canyon Dam. Pre-dam reports document their presence in Bright Angel and Havasu Creeks (Brooks 1932, McKee 1930). Mainstream occurrences were probably limited to fall, winter and spring when colder water temperatures and lower sediment concentrations prevailed. Since completion of the Glen Canyon Dam, this trend may be more pronounced as indicated by the highly patchy and contracted summer densities found in this study. During the fall and winter, the distribution of rainbow trout was essentially continuous from river sections I through IX (Table 6-3). Their distribution became increasingly limited as the water became warmer. During the spring they were recovered only from sections V through XII and in the summer from sections IV through X. The tributary distributional patterns were similar, with the trout being fairly widespread in winter, whereas their spring, summer and fall distribution was more limited (Table 6-2). Rainbow trout usually preferred the higher gradient streams and occurred at least 1.6 km upstream in Clear, Kanab and Havasu creeks.

Two of the 141 rainbow trout tagged during this study were recaptured by anglers. One fish, marked at Bright Angel Creek in January, was recaptured three weeks later in the same locality. The other, marked at Shinumo Creek during the winter, was caught .2 km from the original site five months later.

Density and Abundance. Mainstream densities of rainbow trout ranged from .3 - 40 f/h and from .2 - 18 f/n, for electrofishing and trammel netting, respectively (Table 6-4). Tributary densities of rainbow trout varied from 67-243 in the spring, 100-500 during summer and from 50-750 f/ha in the fall (Table 6-5).

Rainbow trout generally ranked second in relative abundance in the seasonal mainstream collections. Their relative abundance in the tributaries was highest during winter and lowest in spring and summer (Table 6-6). This species was the second most abundant fish and the second most common exotic species taken from the mainstream. Rainbow trout were the third most abundant fish and the most common exotic species in the tributaries. Overall, rainbow trout were the fourth most common species and the second most common exotic species taken during this study (Table 6-7).

Age and Growth. Rainbow trout is one of the fastest growing species in the Colorado River. Individuals that could be aged ranged from young-of-the-year to four years. The mean annual growth increment was 157.4 mm during the first year and 65.7 mm in the second. Growth in the two following years declined steadily to 25 mm (Table 6-19). Fish older than four could not be aged accurately because their scales were unreadable. Assuming the growth increment to be about 25 mm per year after age IV, we estimate that many individuals are in age classes IV to IX (400-525 mm) (Figure 6-5), with the largest specimen captured (805 mm) being 20 years old.

Table 6-19 . Mean calculated total length (standard deviation; mm) and mean calculated annual growth increments of Rainbow Trout at succeeding ages.from the Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age	n	Mean Capture Length	Mean calculated total length (S.D.) at each annulus				
				1	2	3	4	5
1978	O	13	78.8 (1.4)					
1977	I	70	160.5 (60.2)	139.8 (25.9)				
1976	II	80	226.8 (54.6)	162.0 (17.0)	217.8 (24.1)			
1975	III	25	336.7 (52.0)	190.9 (3.0)	283.8 (12.5)	332.8 (15.5)		
1974	IV	2	381.5 (58.7)	173.2 (5.9)	293.5 (20.9)	356.0 (44.8)	381.0 (58.8)	
Average				157.4 (17.3)	234.6 (29.0)	334.5 (6.2)	381.0 (-)	
Increment				157.4 (17.3)	65.7 (17.6)	50.0 (3.6)	25.0 (-)	
Number				177	107	27	2	

RAINBOW TROUT

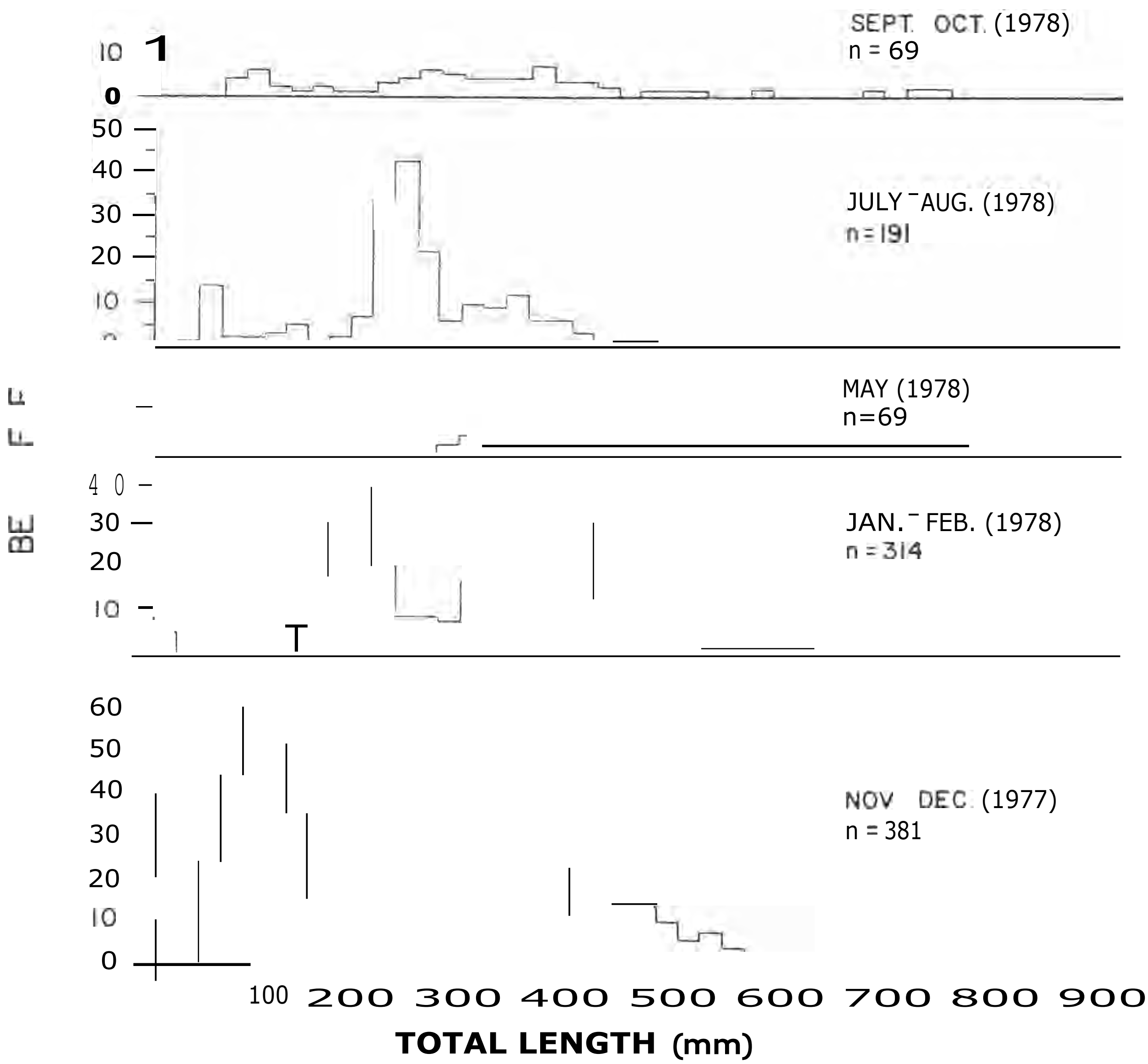

Figure 6-5. Lenyth-frequency distribution for rainbow trout from the Colorado River and selected tributaries in Grand Canyon National Park, Arizona.

Yearling fish, collected during November-December 1977, were approximately 110 mm in length, and grew to a length of about 260 mm by the next September-October. Young-of-the-year rainbow trout were first caught in January-February when they were approximately 20 mm in length. By September-October, three individuals had grown to about 110 mm (Figure 6-5).

Condition Factors. The condition factor (range 0.8 in winter to 1.1 in fall) and length-weight relationship (Table 6-20) were similar to other southwestern rainbow trout populations (Carlander 1969).

Food Habits. Major food items taken by rainbow trout in the mainstream Colorado River were aquatic invertebrates (primarily scuds and black fly larvae) during winter and fall, and terrestrial insects in spring and summer. *Cladophora* was an important dietary item throughout the year. Rainbow trout in tributaries utilized benthic invertebrates, *Cladophora*, and to a lesser extent than in the mainstream, terrestrial insects (Table 6-21).

Mainstream. Mainstream rainbow trout consumed 65 different food items throughout the year; the greatest number recorded for any Colorado River fish species. The riverine diet of this species reflects its visual orientation, large body size and ability to actively exploit food resources throughout the habitat. *Cladophora* constituted from one-quarter to one-half of the dietary intake throughout the year (Table 6-21). Based on invertebrate taxa identified from algal masses in the stomachs, *Cladophora* was taken both from the substrate and drift.

Invertebrates constituted an important element in the annual diet of mainstream rainbow trout. Aquatic taxa predominated in fall and winter,

Table 6-20. Condition factors and length-weight relationships for gamefish collected from the Colorado River and its tributaries, Coconino and Mohave Counties, Arizona, during 1977 - 1978.

	Length-Weight Relationship (Log W = Log c + N(Log L))	Condition Factor ($K = W \cdot 10^5/L^3$)
RAINBOW TROUT:		
Winter	Log W = - 4.9725 + 2.9222	.8
Spring	Log W = - 3.8205 + 2.4895	.9
Summer	Log W = - 4.6801 + 2.8531	.9
Fall	Log W = - 4.7988 + 2.9090	1.1
Total Sample	Log W = - 4.6539 + 2.8265	.9
BROWN TROUT:		
Winter	Log W = - 6.0403 + 3.3951	.8
Spring	Log W = - 4.5568 + 2.7749	.8
Summer	Log W = - 3.0415 + 2.1706	.8
Fall	Log W = - 4.2932 + 2.7058	.9
Total Sample	Log W = - 4.7771 + 2.8265	.8
BROOK TROUT:		
Winter	Log W = - 2.9351 + 1.9945	1.1
Spring		1.3
Fall	Log W = - 6.6201 + 3.7108	1.2
Total Sample	Log W = - 5.1867 + 3.1056	1.2
CHANNEL CATFISH:		
Winter		1.2
Spring	Log W = - 6.1911 + 3.4467	.9
Summer	Log W = - 4.4710 + 2.7571	1.0
Fall	Log W = - 5.3064 + 3.1621	1.3
Total Sample	Log W = - 4.4710 + 2.7571	1.0
STRIPED BASS:		
Winter	Log W = - 5.4361 + 3.1550	.9
LARGEMOUTH BASS:		
Winter	Log W = - 3.2795 + 2.3263	1.3
Spring		.8
Summer	Log W = - 3.2276 + 2.3054	1.5
Fall	Log W = - 5.1514 + 3.1428	1.3
Total Sample	Log W = - 2.0429 + 1.8143	1.2

(continued)

Table 6-20 (cont.). Condition factors and length-weight relationships for gamefish collected from the Colorado River and its tributaries, Coconino and Mohave Counties, Arizona, during 1977 - 1978.

	Length-Weight Relationship (Log W = Log c + N(Log))	Condition Factor ($K = W \cdot 10^5/L^3$)
BLUEGILL SUNFISH:		
Summer		2.2
GREEN SUNFISH:		
Summer		1.8
Fall		2.1
Total Sample		1.9

Table 6-21. Dietary composition of rainbow trout (<u>Salmo gairdneri</u>) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main	[N]	[S]
Aquatic Invertebrates												
Ephemeroptera (mayflies)												
Baetidae nymphs	0.01	0.65	6.81	Tr	2.28	24.63	Tr	1.47	1.90		0.86	3.28
Heptageniidae nymphs		Tr						0.08				
undetermined nymphs		Tr										
Odonata (dragonflies and damselflies)												
Libellulidae nymphs		0.14										
Coenagrionidae nymphs		0.01			0.43							
Agrionidae nymphs		0.02										
undetermined nymphs		0.02			0.45							
Plecoptera (stoneflies)												
Periodidae nymphs		0.01						0.43				
Hemiptera (bugs)												
Notonectidae adults			0.20									
Corixidae adults							Tr					
Veliidae adults		0.01	0.11									
undetermined larvae								0.01				
Coleoptera (beetles)												
Dytiscidae larvae		0.02	0.05	0.06			0.06		8.46			
Dytiscidae adults		0.09	3.13									0.14
Hydrophilidae adults		Tr										
Elmidae larvae		0.01	0.02									0.05
Elmidae adults		Tr										
undetermined adults			0.06									
undetermined larvae		Tr		0.04								
Megaloptera (helgramites)												
Corydalidae larvae		1.88						5.41				15.89
Trichoptera (caddisflies)												
Rhyacophilidae larvae								0.85				
Philopotamidae larvae		0.01									0.12	
Psychomiidae larvae		Tr										

(continued)

Table 6-21 (cont.). Dietary composition of rainbow trout (*Salmo gairdneri*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Hydropsychidae larvae		1.38	1.82		0.31	0.91	Tr	3.34		0.01		0.05
Hydroptilidae larvae		0.03				0.91					0.19	0.34
Limnephilidae larvae	0.01	0.01			2.00							
Brachycentridae larvae		Tr						0.41				
Helicopsychidae larvae		0.18			4.71							
Polycentropodidae larvae		0.04										
undetermined larvae	Tr	0.01	0.05							Tr		
Lepidoptera (moths)												
Pyralidae larvae	Tr	0.12	0.03		0.36			0.38	0.42		0.34	0.19
undetermined larvae	0.04			0.94			0.02			0.01		
Diptera (flies and midges)												
Tipulidae larvae	Tr	0.48		0.01								
Blephariceridae larvae				Tr			Tr			0.04		
Psychodidae larvae		Tr							0.63			
Chironomidae larvae	0.13	0.06	0.09	0.04	0.33	3.47	0.02	1.60	5.07	0.02		0.19
Chironomidae pupae	Tr	0.02	0.03	0.03	0.02	1.82	0.02	0.54	1.48	0.08		0.24
Simuliidae larvae	3.59	0.22	7.02	5.23	0.74	6.71	2.78	24.19	5.07	1.26	1.44	2.66
Simuliidae pupae	0.02	Tr	0.03	0.54			0.16	0.35		5.36	0.05	0.63
Ceratapogonidae larvae												
Stratiomyiidae larvae		0.02			0.17			0.35	15.43			0.39
Tabanidae larvae		Tr	0.25			1.82	0.04					
Anthyomiidae larvae		Tr										
Empididae larvae		Tr										
undetermined larvae						0.55	Tr					
undetermined pupae	0.02					1.09	Tr					
Gastropoda (snails)												
Physidae adults		0.15			8.63		0.39		18.18	0.12		36.52
Ostracoda (seed shrimp)												
Cypridae adults		Tr							0.42			2.17
Annelida (earthworms)												
Oligochaeta adults		Tr					Tr			0.61		
Amphipoda (scuds)												
Gammaridae adults	38.78	2.06	1.33	3.82	4.44		2.16	0.66		39.50		
Hydracarina (watermites)												
Sperchonidae adults		0.04	0.44	Tr				0.10		Tr		0.10

(continued)

Table 6-21 (cont.). Dietary composition of rainbow trout (*Salmo gairdneri*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Terrestrial Invertebrates												
Ephemeroptera (mayflies)												
Baetidae adults		0.04				0.56						
Orthoptera (grasshoppers & crickets)												
Acrididae adults		0.09	1.33	5.94			5.47	0.38		0.15		4.06
Gryllidae adults			0.14	Tr			1.03					
Hemiptera (bugs)												
Cydnidae adults				0.01				0.07		Tr		
Pentatomidae adults				20.40			0.58	0.62		1.37		
undetermined adults		Tr		0.23			0.10		0.63	0.01		0.87
Homoptera (cicadas & hoppers)												
Cicadellidae adults	0.03	0.01	0.32	0.21			0.02	0.23		Tr		
Fulgoridea adults				Tr			Tr			0.01		
Aphididae adults				0.03						Tr		
undetermined adults		Tr		Tr								
Planipennia (lace wings)												
Hemeroboidea adults				0.25			0.02					
Coleoptera (beetles)												
Coccinellidae adults				0.34			0.08			0.06		
Scarabaeidae adults				0.39			0.83					
Chrysomelidae adults										0.02		0.05
Curculionidae adults	0.01	Tr		Tr				1.80		Tr		
Cantharidae adults				Tr			Tr			0.02		
Elmidae adults	0.03									Tr		
undetermined adults			1.94					0.24	1.27			0.24
Trichoptera (caddisflies)												
Hydroptilidae adults				Tr								
undetermined adults	Tr	Tr		0.14			1.23			0.02	0.43	0.10
Lepidoptera (moths)												
Noctuidae adults				0.13			0.02			0.01		
Pyralidae adults										0.08		
Ctenuchidae adults				0.60						0.40		
undetermined adults			0.17									1.11
undetermined larvae		Tr		0.52			0.01					

(continued)

Table 6-21 (cont.). Dietary composition of rainbow trout (Salmo gairdneri) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Diptera (flies and midges)												
Chironomidae adults	Tr	Tr	0.03	Tr		0.18	0.01	0.07		Tr		
Simuliidae adults	0.01		0.65	0.10	0.45		0.14	0.30	3.80	0.10		0.97
Asilidae adults										0.10		
undetermined adults	0.02	0.09	0.27	0.31	0.62	0.18	0.04	0.88	1.06	Tr	0.34	4.73
Hymenoptera (wasps and ants)												
Ichneumonidae adults				0.22						0.02		
Formicidae adults		Tr		0.31	0.24		1.95	0.47		0.01		0.19
Vespoidea adults				0.45			0.07					
Apoidea adults				0.42			Tr		4.23	0.09		
undetermined adults	0.02	0.01		0.31		1.28	0.04	0.03		Tr		
Araneida (spiders)												
undetermined adults							Tr					0.19
Isoptera (termites)												
undetermined adults		Tr										
Invertebrate Remains	Tr	0.11	0.03	0.04		10.58	0.22	0.64	0.42	0.24	1.39	0.53
Aquatic Vertebrates												
Salmo spp. eggs	13.06	32.02										
Rhynichthys osculus	1.61						11.29					
Terrestrial Vertebrates												
Squamata (lizards & snakes)												
Iguanidae							5.13					
Algae												
Cladophorales												
Cladophora spp.	25.92	30.40	1.44	39.71	50.72		51.20	8.32		45.12	41.25	2.61
Seeds												
Amaranthaceae							Tr					
Compositae		Tr	0.02	0.09			Tr				5.95	
Cupressaceae		0.42									0.05	
Graminae										0.01		
Rosaceae										Tr		
undetermined seed		Tr		0.01			0.01			Tr		

(continued)

Table 6-21 (cont.). Dietary composition of rainbow trout (Salmo gairdneri) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main	N	S
Detritus and Sand	16.59	29.09	72.17	18.01	23.10	45.30	14.71	45.71	31.29	5.12	47.53	21.50
Totals												
No. of fish	37	176	20	47	5	11	60	14	10	36	5	11
Total mass (%)	99.90	99.97	99.98	99.88	100.0	99.99	99.85	99.93	99.76	99.97	99.94	99.99
Total no. of food organisms	1883	1608	525	4553	151	117	4275	512	80	4086	29	217

while terrestrial insects were more heavily utilized in spring and summer (Table 6-21). Scuds, the major invertebrate prey of rainbow trout, comprised from 2.16 to 39.50% of a season's diet, with the peak being in fall and winter. Pupal, and especially larval black flies made up a relatively consistent percentage of each season's diet, ranging from 2.94 to 6.62%. Small amounts of midge larvae and pupae were consumed throughout the year.

The most heavily exploited terrestrial insects were stink bugs (Pentatomidae), grasshoppers (Acrididae), ants (Formicidae) and scarabaeid beetles (Scarabaeidae), which collectively, comprised 27.04 and 8.83% of the spring and summer diets, respectively. This pattern of utilization coincides with the insects' massive spring and summer emergences along the mainstream. Trout eggs were common winter food items of mainstream rainbow trout. Vertebrate taxa consumed by rainbow trout included a lizard (Iquanidae) during summer and speckled dace in the summer and winter (Table 6-21).

Northern Tributaries. Rainbow trout in northern tributaries ingested 63 types of food and had diets similar to mainstream individuals (Table 6-21). Cladophora constituted the major component of the diet in all seasons except summer when it represented 8.32% of the stomach contents. Its presence indicates that trout foraging activities extended into the mainstream, since Cladophora is absent from northern tributaries. Mayfly nymphs were taken most extensively during the spring (2.28%) and summer (1.47%), and to a lesser extent at other times. Dobson fly larvae were utilized only during winter (1.88%) and summer (5.41%). Individual families of caddisfly larvae were ingested in large quantities whenever present. Net-spinning caddisflies were taken during the winter and summer, snail-cased caddislfies (Heliopsychidae) and northern caddisflies (Limnephilidae) in the spring and finger-net (Philopotamidae) and micro-caddisflies in the fall. Collectively, these three families made up from 0.31 to 7.02% of each season's diet. Dipteran pupae were utilized only slightly throughout the year (range 0.02 to 0.89%), while the larvae, especially of black flies and midges, were utilized extensively during the summer (25.79%). Scuds were identified in the stomach contents from three of the four s4pling periods. This again demonstrates rainbow trout movement between northern tributaries and the mainstream, since scuds were generally absent from the tributaries.

Surface feeding was of minor importance in northern tributaries as terrestrial insects made up only 1.28 and 5.09% of the spring and summer diets, respectively. Taxa utilized included snout beetles (Curculionidae), stink bugs, ants, grasshoppers and adult black flies and midges. Trout eggs were a principal food item only during the winter.

Southern Tributaries. Forty-six types of food were identified in the stomachs of rainbow trout taken from southern tributaries. Rainbow trout food habits in these tributaries were strikingly different from those in the mainstream and northern tributaries (Table 6-21). Cladophora was present in small quantities during fall and winter and absent from the diet in spring and summer. Mayfly nymphs were the major prey item throughout much of the year, ranging from 1.90 to 24.63% of the total diet. Pouch snails (Physidae) were the most common aquatic invertebrate present in the stomach contents curing summer (18.18%) and fall (36.52%). Common dipterans in the diet included black fly, soldier fly (Stratiomyiidae), midge, horse fly (Tabanidae) and moth fly (Psychodidae) larvae, as well as midge and black fly pupae. Together, these taxa made up from 3.48 to 28.29% of the seasonal diet. Dobson fly larvae were heavily preyed upon only in the fall (15.89%). Other aquatic invertebrates consumed in more than trace amounts were predaceous diving beetles (Dytiscidae), seed shrimp, net-spinning caddislfies and scuds. Terrestrial insects, especially grasshoppers, black flies and bees were common prey items in the summer (10.99%) and fall (12.51%) (Table 6-21).

Reproduction. Reproduction takes place primarily in high gradient and, to a lesser extent, secondary tributaries. Spawning occurs from late fall through early spring and peaks in winter when water temperatures are between 7 and 12 C. The number of eggs per female ranged from 936 to 2994.

CUTTHROAT TROUT, _Salmo clarki_ (Richardson)

History and Distribution. Cutthroat trout were first introduced at Lee Ferry in December 1978. This stocking consisted of an unknown number of fingerlings planted by the Arizona Game and Fish Department. Another 50,000 catchable cutthroat trout were introduced in December 1979. Both of these introductions occurred after completion of this study. Consequently, nothing is known about cutthroat trout in Grand Canyon.

BROWN TROUT, Salmo trutta (Mitchell)

History and Distribution. Brown trout were first introduced into Shinumo Creek in 1934 (Table 6-18). Since the 1950's, anglers have taken brown trout from Bright Angel and Phantom Creeks, where the species was collected recently by Minckley (1978).

Mainstream collections of brown trout were limited to river sections IV through VII, which infers that this species has a limited mainstream distribution (Table 6-3). Their tributary distribution was restricted to Bright Angel, Phantom and Shinumo Creeks, all of which join the mainstream between river sections IV and VII. Overall, brown trout were taken sporadically during this study, generally between river miles 580 and 601.

Density and Abundance. Brown trout densities ranged from .2 to 5.0 f/hr based on electrofishing data (Table 6-4). Trammel net densities were also low, with this species only being taken during the fall (Table 6-4).

Brown trout ranked sixth or seventh in terms of abundance during the seasons it was collected in the mainstream. This species was the ninth most common fish, and the sixth most common exotic in mainstream waters. Brown trout were the eighth most common fish taken from tributaries and the sixth most common exotic. The species was the ninth most common fish when combining all samples, and was the sixth most common exotic collected during this study (Table 6-7).

Age and Growth. The three brown trout taken in this study were in their second or third year of life.

Food Habits. Scuds and immature dipterans were the major food items throughout the year (no specimens collected in winter). Several other groups such as Pentatomids, Ctenuchids and *Cladophora* were important seasonally (Table 6-22).

Mainstream. Aquatic organisms in the stomachs of mainstream brown trout consisted primarily of scuds, black fly larvae and pupae and *Cladophora*. Dominant terrestrial insects, in order of importance, were stink bugs, Ctenucha moths, ants, adult black flies and grasshoppers. Seasonal variations in brown trout diets were similar to those of rainbow trout. Specimens take in the spring contained large amounts of *Cladophora*, terrestrial insects and scuds, which collectively, formed 82.30% of the diet. Black fly larvae and pupae were the primary summer food items and accounted for 64.15% of the total dietary mass. Fall diets consisted primarily of scuds (52.12%), immature black flies (16.68%) and terrestrial insects (22.24%). No brown trout were taken during winter.

Northern Tributaries. Food items from two brown trout collected during winter consisted of broad-shouldered water striders (Veliidae; 54.44%), snail-cased caddisfly larvae (14.79%), leafhoppers (4.73%), mayfly nymphs (2.37%), black fly larvae (2.37%), invertebrate remains (9.47%) and detritus and sand (11.83%). One specimen, collected in spring, contained remains of speckled dace (88.46%), horsefly larvae (2.55%), coenagrioned damselfly nymphs (1.99%), snail-cased caddisfly larvae (0.27%), black fly pupae (0.21%), mayfly nymphs (0.13%) and detritus and sand (6.38%).

Southern Tributaries. No brown trout were taken from southern tributaries.

Table 6-22. Dietary composition of brown trout (Salmo trutta) in the Colorado River, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter Main	N	Spring Main	N	Summer Main	N	Fall Main	N
Aquatic Invertebrates								
Hemiptera (bugs)								
undetermined adults					3.46			
Diptera (flies and midges)								
Chironomidae larvae			0.04		0.33			
Chironomidae pupae			0.09		0.42		0.07	
Simuliidae larvae			4.31		26.79		3.81	
Simuliidae pupae			0.08		37.36		12.87	
Amphipoda (scuds)								
Gammaridae adults			13.88				51.12	
Terrestrial Invertebrates								
Orthoptera (grasshoppers & crickets)								
Acrididae adults			2.02					
Hemiptera (bugs)								
Pentatomidae adults			23.36					
Homoptera (cicadas and hoppers)								
Fulgoridae adults			0.02					
Aphididae adults			0.08					
Cicadoideae adults			0.19		0.50			
Planipennis (lace wings)								
Hemeroboidea					0.92			
Coleoptera (beetles)								
undetermined adults			0.09					
Lepidoptera (moths)								
Ctenuchidae			0.70				20.73	
Diptera (flies and midges)								
Chironomidae adults			0.02					
Simuliidae adults			0.06		2.95			
undetermined adults			0.24					
Hymenoptera (wasps and ants)								
Ichneumonidae adults			0.19					
Formicidae adults			1.02		1.43		1.51	
Vespoidea adults			0.02					
undetermined adults			2.53					
Algae								
Cladophorales								
Cladophora spp.			37.88		0.50			
Detritus and Sand			13.16		25.27		9.84	
Totals								
No. of fish	-		4		5		3	
Total mass (%)	-		99.98		99.93		99.95	
Total no. of food organisms	-		248		218		114	

Reproduction. The presence of brown trout indicates that successful reproduction occurs in Grand Canyon waters as this species has not been stocked since 1934 (Table 6-18). Reproduction was not verified during this study.

Condition Factors. Condition factors and length-weight relationships (Table 6-20) were similar to other western populations of brown trout.

BROOK TROUT, *Salvelinus fontinalis* (Linnaeus)

History and Distribution. The native range of brook trout extends from southeastern Canada down through the Carolinas and into Georgia, and westward to the Great Lakes region and the headwaters of the Upper Mississippi River system (Hubbs and Lagler 1970).

Brook trout were the first introduced into Grand Canyon waters at Bright Angel Creek in 1920. This species was reintroduced at Lee Ferry in 1977 by the Arizona Game and Fish Department. At present, it is most commonly found sixty miles downstream from Lee Ferry. During this study, brook trout were taken from section III during the spring and from sections I and II during the fall (Table 6-3). During winter they were collected 2.4 km upstream in the Paria River (Table 6-2).

Density and Abundance. Electrofishing and trammel netting yielded brook trout densities ranging from 0.3 to 3.3 f/h and 2 f/h, respectively (Table 6-4). Density estimates were 50 f/ha during the first winter trip in the Paria River.

Brook trout ranked from fifth to ninth most common fish in the mainstream depending on the season. Brook trout were the eighth most common fish and the fifth most common exotic in all mainstream collections. The species ranked from eighth to tenth in seasonal relative abundance in the tributaries, where, for all seasons, it was the ninth most common species and fifth most common exotic (Table 6-6). This species was the tenth most common fish and the fifth most common exotic taken during this study (Table 6-7).

Age and Growth. None of the brook trout exceeded two years of age. This coincides with stocking efforts which were initiated in 1977 (Table 6-18). Collection of brook trout from Clear Creek in 1944 (NPS files) indicate that this species can reach ten years of age in the study area (Table 6-18).

Food Habits. Brook trout fed primarily on the larger aquatic invertebrates (i. e., scuds, earthworms and snails) in Grand Canyon waters.

Mainstream. Riverine aquatic invertebrates predominated in mainstream brook trout diets and comprised 73.04, 90.98 and 94.13% of the spring, summer and fall diets, respectively. Food items, in order of importance, were scuds, aquatic earthworms (Oligochaeta), pouch snails, Cladophora, midge pupae, black fly larvae and pupae, midge larvae and ants (Table 6-23). Adult midges, grass seeds (Graminae), aphids and leafhoppers were present in small amounts.

Northern Tributaries. The summer diet of juvenile brook trout ($<$ 150 mm) consisted of midge pupae (41.24%) and detritus (58.76%). Juveniles collected in winter contained 100% detritus.

Southern Tributaries. No brook trout were collected from southern tributaries.

Reproduction. It is not known if brook trout reproduce successfully in Grand Canyon.

Condition Factors. Condition factors and length-weight relationships weresimilarto other southwestern populations (Table 6-20).

Table 6-23. Dietary composition of brook trout (Salvelinus frontinalis) in the Colorado River and northern tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter Main N	Spring Main N	Summer Main N	Fall Main N
Aquatic Invertebrates				
Hemiptera (bugs)				
undetermined adults				0.05
Diptera (flies and midges)				
Chironomidae larvae			0.28	0.23
Chironomidae pupae			1.65	0.77
Simuliidae larvae			0.06	1.78
Simuliidae pupae				1.60
Gastropods (snails)				
Physidae adult			6.37	
Annelida (earthworms)				
Oligochaeta adult			52.17	0.44
Amphipoda (scuds)				
Gammaridae		73.04	30.45	89.26
Terrestrial Invertebrates				
Homoptera (cicadas and hoppers)				
Aphididae adult				Tr
Cicadoidea adult				Tr
Coleoptera (beetles)				
undetermined adult			0.37	
Diptera (flies and midges)				
Chironomidae adult			0.06	0.23
Simuliidae adult				
undetermined adult			0.12	0.02
Hymenoptera				
Formicidae adult				0.09
undetermined adult				0.01
Invertebrates Remains				0.05
Algae				
Cladophorales				
Cladophora spp.			3.48	
Seeds				
Graminae				0.09
Euphorbiaceae				Tr
Detritus and Sand		26.95	4.95	5.31
Totals				
No. of fish	-	1	5	6
Total mass (%)	-	99.99	99.96	99.93
Total no. of food organisms	-	5	131	772

Family CYPRINIDAE, minnows

CARP, *Cyprinus carpio* (Linnaeus)

History and Distribution. The European carp was introduced into Arizona in the late 1800's though it was only first reported from Grand Canyon waters in 1968. Carp have undoubtedly been present in the study area for many years as the species previously occurred in Lake Mead and above Lee Ferry (Jonez and Sumner 1954, McDonald and Dotson 1960).

The mainstream distribution of carp is continuous from Lee Ferry to Separation Rapids, and changes little seasonally (Table 6-2). In the tributaries, carp were generally limited to low gradient, slow-flowing streams with mud substrates such as the Paria River and Little Colorado River (as far as 8 km upstream) and Kanab Creek (as far as .8 km upstream). Carp were once taken from Tapeats Creek and they were observed near the confluence of Deer Creek.

Six of the 2156 carp tagged during this investigation were recaptured. Two of these fish remained at their capture locale for three and six months. One was recaptured 4.3 km downstream three month after it was tagged, while another had moved 11.2 km upstream after four months. The greatest amount of movement was exhibited by one fish that moved from Lava Falls Rapids (F.M. 509) downstream to Lake Mead Marina, a distance of 264 km in four months.

Density and Abundance. Mainstream densities of carp ranged from 17 - 64 f/ha and from .5 - 25 f/n, for seining (Table 6-5) and trammel netting (Table 6-4), respectively. Confluence densities were generally higher, ranging from 3 -24 f/h and .4 - 176 f/n, for electrofishing and trammel netting, respectively (Table 6-11). Carp were present in low densities in all but the larger tributaries (i. e., Paria and Little Colorado Rivers and Kanab Creek).

Carp were the most frequently taken species in the mainstream (Table 6-6). They were the sixth most abundant fish and the second most common exotic taken from the tributaries (Table 6-6). Overall, carp were the most common species taken in this study (Table 6-7).

Age and Growth. Carp collected in the study area ranged from two to 12 years in age, with the majority being from age classes IV through VIII. Very few young carp were collected during this study (Figure 6-6). The two oldest females were 10 and 12 years old and measured 615 and 853 mm in length, respectively. The oldest male was 11 years old and measured 402 mm. Based on specimens belonging to age class VI, the growth rates for each sex were similar.

Rapid growth during the first year (206.5 mm) is followed by a sharp decline to 56.4 mm in the second year. Subsequently, the annual growth increment drops to a constant annual increase of approximately 30 mm (Table 6-24).

The length-frequency distribution (Figure 6-6) shows the adult population to be distributed between 400 and 475 mm in length, which corresponds to age classes IV through VIII (Table 6-24). A few smaller carp (130-190 mm) were collected during winter, spring and summer. None of these were young-of-the-year fish.

Food Habits. Dietary studies indicate that carp in the mainstream forage primarily on *Cladophora* during all seasons. Scuds and midge larvae

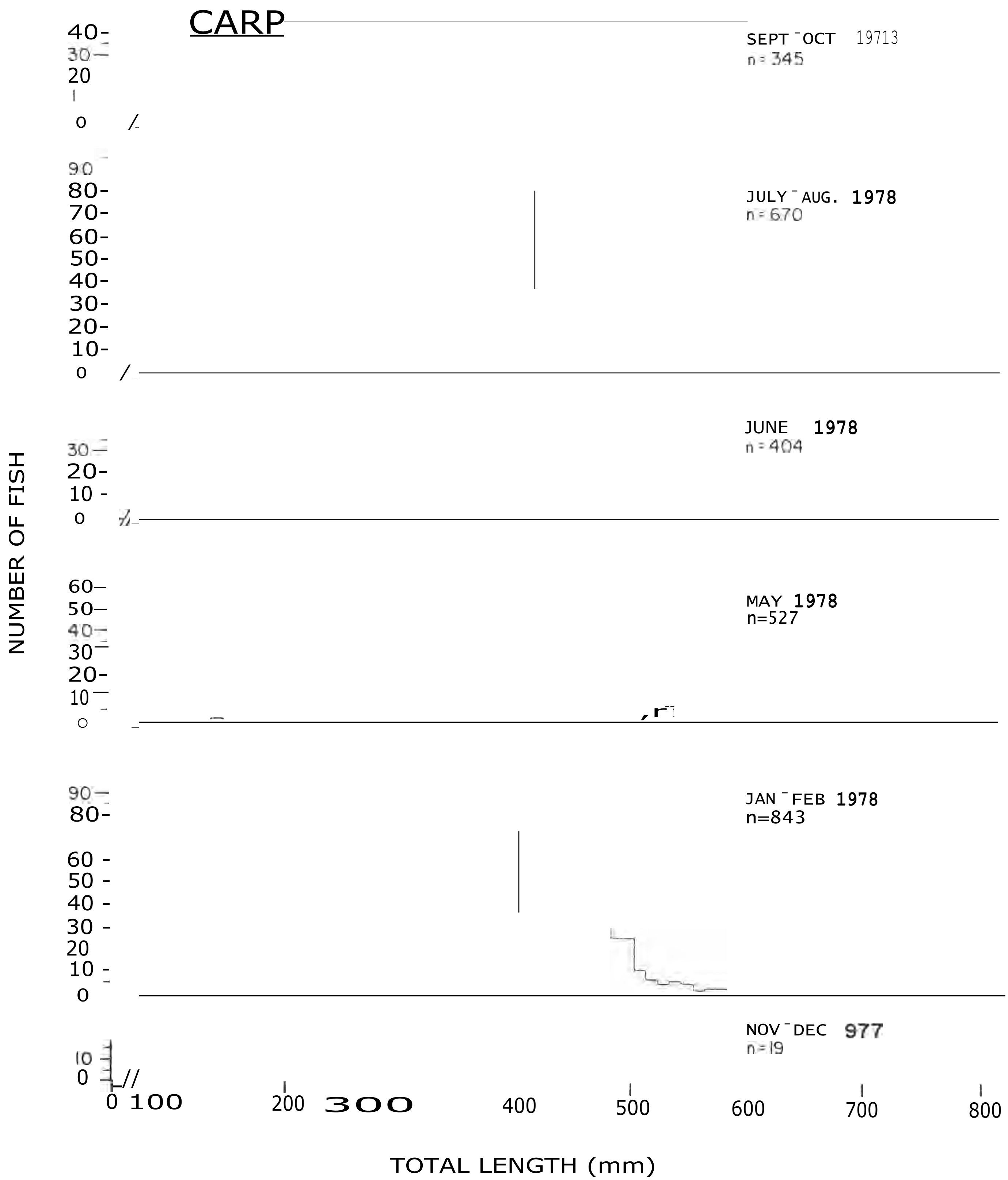

Figure 6-6. Length-frequency distribution for carp from the Colorado River and selected tributaries in Grand Canyon National Park, Arizona.

Table 6-24 . Mean calculated total lengths (standard error; mm) and mean calculated annual growth increments of Carp at succeeding ages from the Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age	n	Mean Capture Length	Mean calculated total length (S.E.) at each annulus							
				1	2	3	4	5	6	7	8
1974	IV	25	389.5 (50.2)	205.4 (46.5)	268.5 (45.0)	323.9 (49.0)	368.9 (51.5)				
1973	V	34	429.0 (34.9)	211.6 (40.8)	266.6 (44.3)	314.1 (45.5)	359.9 (42.0)	400.6 (39.1)			
1972	VI	37	449.0 (30.8)	209.5 (31.6)	269.1 (35.3)	316.6 (30.4)	357.8 (27.4)	393.0 (26.8)	425.4 (28.0)		
1971	VII	20	452.8 (33.4)	202.0 (26.4)	249.5 (32.6)	297.9 (24.6)	334.8 (25.9)	370.1 (26.8)	405.0 (30.0)	430.7 (50.9)	
1970	VIII	12	487.9 (60.3)	199.6 (27.7)	253.2 (78.8)	294.6 (32.6)	330.4 (40.2)	368.1 (44.0)	406.8 (52.0)	434.5 (53.3)	465.7 (55.8)
Average				207.2 (4.1)	263.8 (7.6)	312.4 (9.7)	354.4 (13.0)	388.2 (13.1)	416.3 (9.9)	432.1 (4.3)	465.7 (-)
Increment				207.2 (4.1)	56.6 (5.1)	48.6 (3.8)	42.0 (3.7)	37.3 (2.5)	34.2 (2.3)	26.5 (4.0)	31.2 (-)
Number				128	128	128	128	103	69	32	12

were the most commonly ingested aquatic invertebrates (Table 6-25). Together, these two invertebrates, which were most important in winter and spring, comprised 0.09 to 11.12% of the seasonal diet. Additional invertebrate prey items included aquatic earthworms, black fly larvae and midge and black fly pupae. Few terrestrial insects were ingested. A speckled dace was the only vertebrate found in carp stomachs. *Cladophora*, which consistently made up the greatest portion of the seasonal diet (from 55.11 to 86.61%), was most heavily utilized in summer and fall. Organic detritus and plant seeds were also major dietary items.

Reproduction. Data collected during this study indicate that spawning occurs in Grand Canyon waters from late winter through August, peaking in the spring. Carp seem to prefer low gradient streams and water temperatures between 19 and 22 C. The number of eggs per female ranged from 61,624 to 69,303.

The absence of young-of-the-year fish (Figure 6-6) indicates that breeding is unsuccessful. Presumably, most of these fish have migrated upstream from Lake Mead.

Table 6-25. Dietary composition of carp (*Cypinus carpio*) in the Colorado River, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter Main	Spring Main	Summer Main	Fall Main
Aquatic Invertebrates				
Trichoptera (caddisflies)				
undetermined adults		1.09		
Diptera (flies and midges)				
Chironomidae larvae	0.73	1.47	Tr	0.38
Chironomidae pupae	Tr	2.21	0.01	0.01
Simuliidae larvae	2.30	0.02		0.01
Simuliidae pupae	0.65	0.01	0.80	0.14
Annelida (earthworms)				
Oligochaeta	3.29			
Amphipoda (scuds)				
Gammaridae larvae	8.82	7.74	0.08	1.41
Terrestrial Invertebrates				
Homoptera (cicadas and hoppers)				
undetermined adults		0.16		
Coleoptera (beetles)				
undetermined adults				Tr
Diptera (flies and midges)				
Chironomidae adults	Tr			
Simuliidae adults	0.02	Tr		
undetermined adults	0.16			Tr
Hymenoptera (wasps and ants)				
Formicidae adults	Tr	0.02		Tr
undetermined adults			0.07	
Invertebrate Remains	9.09	6.90	Tr	3.99
Aquatic Vertebrates				
Rhinichthys osculus				0.05
Algae				
Cladophorales				
Cladophora spp.	55.11	69/87	86.61	79.31
Seeds				
Compositae	0.09			
undetermined	5.50	2.07	0.22	Tr
Detritus and Sand	14.23	8.38	12.20	14.67
Totals				
No. of fish	51	32	24	93
Total mass(%)	99.99	99.94	99.99	99.97
Total no. of food organisms	1226	448	143	2227

GOLDEN SHINER, *Notemigonus crysoleusus* (Mitchell)

History and Distribution. This species was first introduced into Mormon Lake, near Flagstaff, Arizona in 1934 (Miller and Lowe 1967). Prior to this study, the only golden shiner ever reported in the Grand Canyon area was at Kanab Creek (Suttkus et al. 1976). During this study, one specimen was taken in the mainstream just above the confluence of the Little Colorado River. This individual was probably introduced by a bait bucket transfer since the species is a popular bait minnow.

Density and Abundance. Occurrence of golden shiners in the study area is extremely rare, and consequently the species has a very low relative density (Table 6-6, 6-7).

Age and Growth. The collected specimen was a two-year old male.

Food Habits. Black fly larvae were the only prey items found in a specimen taken from the mainstream during winter.

VIRGIN RIVER SPINEDACE, Lepidomeda millispinous (Miller and Hubbs)

History and Distribution. One specimen of this fish was collected at the mouth of the Paria River in July 1972 (Suttkus et al. 1976). It is unlikely that this species occurs naturally as the species is restricted to the Virgin River system of Utah-Arizona-Nevada. This specimen was probably introduced inadvertently during the woundfin transplant in 1972. No Virgin River spinedace were taken in this study.

Food Habits. Virgin River Spinedace primarily eat aquatic insect larvae, though algae are also taken when aquatic invertebrates are not present. This species is on opportunistic forager in that it feeds throughout the water column.

WOUNDFIN, Plagopterus argentissimus (Cope) (ENDANGERED)

History and Distribution. In 1972, the woundfin was introduced into the Paria River both at the bridge north of Page on Route 89 and at the bridge near Lee Ferry (Table 6-18), in an attempt to establish another population of this endangered cyprinid. This introduction seems to have been unsuccessful since extensive collections during the present study along the Paria River near Lee Ferry, as well as earlier efforts (Minckley and Blinn 1976, Suttkus et al. 1976), have not produced any specimens. The woundfin in thought to be restricted to the Virgin River system of Utah-Arizona-Nevada. It was federally listed as endangered in 1970 (35 FR 16947).

Age and Growth. This species seldom exceeds 100 mm in length and lives, in most cases, less than two years (Lockard 1980).

Food Habits. Animal matter is the primary food source of woundf ins, although debris, plant material and algae are also ingested (Lockard 1980).

RED SHINER, Notropis lutrensis (Baird and Girard)

History and Distribution. No red shiners were collected during this study, though the species is known from the Grand Canyon (Minckley 1973). Collection records (Suttkus et al. 1976) indicate that this species occurs primarily in the lower reaches of the Grand Canyon, downstream from the study area. The species is probably absent from the Grand Canyon's upper reaches due to its limited tolerance to cold water (Suttkus et al. 1976).

Age and Growth. Red shiners, like most cyprinids, seldom live more than three years or exceed 100 mm in length.

Food Habits. In other river systems, red shiner diets consist of plankton, benthic invertebrates, juvenile fish, terrestrial insects and fish eggs (Minckley 1973). The piscivorous nature of this species is believed to be detrimental to fish populations of the Lower Colorado River (Miller 1952).

Reproduction. Reproduction occurs in calm water or occasionally in riffles over a boulder or gravel substrate (Minckley 1972). Populations in Arizona reservoirs spawn along open sand-gravel beaches from March through June (Minckley 1973).

FATHEAD MINNOW, *Pimephales promelas* (Rafinseque)

History and Distribution. Fathead minnows are widespread throughout the eastern United States, Texas and New Mexico. Probably introduped by anglers, they were first recorded from Arizona and the study area in 1952 (Miller and Lowe 1967). Numerous collections of this species in the mainstream and especially tributaries, reflect its sporadic occurrence throughout the study area. Fathead minnows were taken in small numbers from river section X and from Crystal and Kanab Creeks in the winter and summer. They were collected in the Little Colorado River and Kanab Creek in the fall.

Age and Growth. No age and growth information was collected on this species. As with most cyprinids, it is likely that fathead minnows seldom exceed two years of age.

Food Habits. Fathead minnows within the study area eat dipterans, organic detritus and small amounts of filamentous algae.

Mainstream. Immature black flies were the major invertebrate food item of five fathead minnows collected during summer. Immature midges were of secondary importance. Organic detritus and sand were the most abundant stomachs contents and accounted for 62% of the food by mass.

Northern Tributaries. Balck fly larvae were the main food item of eight fathead minnows taken from northern tributaries during winter. Supplemental items included a midge larva and organic detritus. The stomach of one individual collected during summer contained seed shrimp, midge larvae and organic detritus.

Southern Tributaries. The stomach contents of one individual, taken in fall from the Little Colorado River, consisted primarily of organic detritus.

Reproduction. Spawning was not documented during this study, though it appears to occur in summer based on one female exhibiting a relatively high gonadal somatic index and containing an estimated 4306 eggs.

Family ICTALURIDAE, catfishes

CHANNEL CATFISH, *Ictalurus punctatus* (Rafinesque)

History and Distribution. Channel catfish, a common species of the eastern United States, were first recorded from the Inner Canyon in 1909. The species was in the Lower Colorado River by the early 1900's (Miller and Lowe 1967), though there is no information as to when they were introduced into the study area. A productive channel catfish fishery existed in the Lower Colorado River and continued to exist for several years after the construction of Glen Canyon Dam (Bancroft and Sylvester 1978).

This species is distributed sporadically throughout the mainstream, and is most common between sections IX and XI. This species appeared to prefer low gradient tributaries, as it was common in the Little Colorado River and Kanab Creek (Johnson and Sanderson 1968, Minckley and Blinn 1976).

Density and Abundance. The density of channel catfish in the mainstream varied from .1 to 4.2 f/h and from zero to 0.7 f/n, for electrofishing and trammel netting, respectively (Table 6-4).

Channel catfish were the seventh most common fish and the third most common exotic species taken in both the mainstream and tributaries (Table 6-4), as well as over the entire study (Table 6-7).

Age and Growth. Channel catfish caught during this study ranged from three to eight years in age (Table 6-26). Two catfish measuring 522 mm and 566 mm in length were estimated to be 12 to 14 years of age, respectively. Growth of channel catfish was relatively rapid and reached a peak annual increment of 90.7 mm in the second year. Thereafter, the annual growth increment declined to a constant increase of about 25 mm (Table 6-26).

Table 6-26 . Mean calculated total lengths (standard error; mm) and mean calculated annual growth increments of Channel Catfish at succeeding ages from Colorado River and selected tributaries, Coconino and Mohave counties, Arizona.

Year	Age	n	Mean Capture Length	Mean calculated total length (S.E.) at each annulus							
				1	2	3	4	5	6	7	8
1975	III	2	274.5 (24.8)	96.4 (11.6)	184.0 (2.3)	246.8 (14.0)					
1974	IV	3	280.3 (0.6)	81.1 (12.5)	170.6 (22.9)	213.3 (4.2)	242.5 (18.7)				
1973	V	3	307.0 (8.2)	80.4 (15.6)	165.3 (13.0)	230.0 (7.4)	261.7 (0.3)	294.3 (9.9)			
1972	VI	8	337.6 (26.7)	76.7 (16.4)	167.4 (21.8)	214.8 (16.1)	242.5 (16.4)	271.1 (16.7)	299.7 (13.6)		
1971	VII	2	343.0 (39.6)	88.1 (9.8)	160.9 (29.8)	213.2 (15.4)	247.4 (12.4)	288.6 (12.3)	314.0 (22.5)	333.0 (25.6)	
1970	VIII	2	414.5 (0.7)	57.8 (2.4)	175.4 (4.2)	206.2 (0.1)	244.7 (10.0)	282.6 (21.1)	311.0 (31.2)	346.6 (32.2)	373.0 (40.0)
Average				79.1 (9.4)	164.4 (6.3)	219.0 (11.6)	246.5 (7.2)	279.6 (10.1)	304.0 (6.2)	339.8 (8.0)	373.0 (-)
Increment				79.1 (9.4)	90.7 (10.7)	49.2 (9.4)	30.5 (3.8)	32.3 (5.0)	28.0 (1.0)	27.3 (9.6)	26.4 (-)
Number				20	20	20	18	15	12	4	2

Food Habits. Major dietary items of channel catfish included fish, scuds, immature dipterans and Cladophora (Table 6-27).

Mainstream. Stomachs of specimens collected during winter contained large quantities of aquatic invertebrates, fish and amorphous detrital material. The principal food items, in order of relative mass, were scuds, a flannelmouth sucker, black fly larvae and speckled dace, collectively comprising 92.62% of the seasonal diet. Midge and black fly larvae and pupae were utilized to a limited extent. Cladophora was the dominant food item in spring, followed by black fly pupae, scuds and black fly larvae. Together, these items made up 84.46% of the spring diet. Other food items included midge larvae and pupae, ants, leafhoppers, a predaceous diving beetle and a centipede (Chilopoda). Terrestrial resources, especially cicadas (Cicadidae), ants, beetles and grass seeds (Graminae), were utilized most heavily in summer when they comprised 15.82% of the diet. Cladophora, scuds and black fly larvae constitued another 29.38% of the summer diet.

Northern Tributaries. Aquatic invertebrates and organic detritus were the primary food items in the stomachs of seven juvenile ($\leq$ 150 mm) channel catfish collected in Kanab Creek during summer (Table 6-27). Major food items were midge and black fly larvae and pupae, mayfly nymphs and micro-caddisfly larvae, which collectively made up 59.04% of the diet. Other items included net-spinning caddisfly larvae, pyralid moth larvae, black fly adults and biting midge larvae, together making up 8.59% of the diet. Stomack contents of one juvenile collected in Kanab Creek during fall consisted of midge larvae and organic detritus.

Table 6-27. Dietary composition of channel catfish (Ictalurus punctatus) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main	N	S
Aquatic Invertebrates												
Ephemeroptera (mayflies)												
Baetidae nymph								4.88				
Odonata (dragonflies and damselflies)												
undetermined nymphs							Tr					
Hemiptera (bugs)												
Corixidae adults								0.69				
undetermined adults				0.07					0.03			
Megaloptera (helgramites)												
Corydalidae larvae									11.27			
Coleoptera (beetles)												
Dytiscidae				0.03								
Tricoptera (caddisflies)												
Hydropsychidae larvae								3.95				
Hydroptilidae larvae							Tr	4.18				
undetermined larvae									0.01			
Lepidoptera (moths)												
Pyralidae larvae								1.86				
undetermined larvae				0.06								
Diptera (flies and midges)												
Tipulidae larvae				Tr				0.69				
Chironomidae larvae	0.42			0.41		50.0	0.08	17.20	0.07		80.0	0.01
Chironomidae pupae	0.02			0.35			0.04	13.02	0.01			
Simuliidae larvae	5.90			1.79		50.0	1.45	13.02	0.22			
Simuliidae pupae	0.01			4.54			0.41	6.74	0.65			
Ceratapogonidae larvae								1.16				
Stratiomyiidae larvae							Tr					
undetermined pupae							Tr					
Amphipoda (scuds)												
Gammaridae adults	75.93			3.59			8.68					
Hydracarina (watermites)												
Sperchonidae adults								0.23				

(continued)

Table 0-27 (cont.). Dietary composition of channel catt.-n (Ictalurus punctatus) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Terrestrial Invertebrates												
Hemiptera (bugs)												
Cydnidae adults							Tr		0.10			
Pentatomidae adults									0.01			
Homoptera (cicadas & hoppers)												
Cicadidae adults							6.64					
Cicadellidae adults				0.47								
Coleoptera (beetles)												
undetermined adults							2.04					
Diptera (flies and midges)												
Chironomidae adults									0.01	Tr		
Simuliidae adults				0.02			0.06	1.62				
undetermined adults				0.13			Tr					
Hymenoptera (wasps and ants)												
Formicidae adults				0.07			1.20		0.22			
undetermined adults				0.03			Tr					
Araneida (spiders)									0.01			
undetermined adults												
Isoptera (termites)												
Termitidae adults							0.01					
Invertebrate Remains				0.02			Tr	0.93	0.28			
Aquatic Vertebrates												
<u>Rhyichthys osculus</u>	4.41											
<u>Catastomus latipinnis</u>	6.38											
<u>Pantosteus discobolus</u>												87.23
Aquatic Monocotyledons												
<u>Zannichellis</u> spp.									1.83			
Algae												
Cladophorales												
<u>Cladophora</u> spp.				74.54			19.52		15.34			12.73

(continued)

Table 6-2/ (cont.). Dietary composition of channel catfish (*Ictalurus punctatus*) in the Colorado River and tributaries, Grand Canyon National Park, Arizona, 1977 - 1978.

	Winter			Spring			Summer			Fall		
	Main	N	S	Main	N	S	Main	N	S	Main		
Seeds												
Graminae							5.34		0.07			
Compositae				0.01			0.48		0.78			
undetermined				0.01			0.05					
Detritus and Sand	6.89			13.75			53.93	29.76	69.02		20.0	0.01
Totals												
No. of fish	5	-	-	8	-	1	10	7	11	-	1	5
Total mass (%)	99.96	-		99.89	-	100.0	99.93	99.93	99.93	-	100.0	99.98
Total no. of food organisms	763	-	-	273	-	2	539	260	113	-	9	60

Southein Tributaries. The Little Colorado River was the only southern tributary from which channel catfish were taken. These specimens consumed a variety of resources, including fish, aquatic vegetation, aquatic and terrestrial insects, plant seeds and organic detritus (Table 6-27). Major food items during summer were Cladophora, a dobson fly larva, and pond weed (Zannichellia), together constituting 28.44% of the diet. Food items consumed in smaller quantities were black fly larvae and pupae, ants, grass seeds, burrower bugs (Cydnidae) and stink bugs. Bluehead suckers and Cladophora made up 99.96% of the fall diet. Items ingested in trace quantities included larvae of black flies, midges, biting midges and a crane fly, along with midge pupae and a water boatman (Corixidae). One specimen collected during spring contained only black fly and midge larvae.

Reproduction. Reproduction was verified by summer collections of young-of-the-year channel catfish from the Little Colorado River and Kanab Creek. These collections, as well as gonadal somatic indices, indicate that spawning occurs in the spring and summer.

BLACK BULLHEAD, *Ictalurus melas* (Rafinesque)

History and Distribution. Black bullheads were first reported within the study area in 1968, 103 km below Lee Ferry (Miller and Smith 1968). They have also been collected from the Colorado River mainstream in the vicinity of Carbon Creek (Minckley and Blinn 1976).

Density and Abundance. Black bullheads are probably still extant within the study area in very low numbers, even though none were taken during this study.

Age and Growth. Black bullheads reach six years of age in other river systems (Carlander 1969).

Food Habits. This species is generally omnivorous, though it becomes very carnivorous when animal prey items are abundant.

Reproduction. Spawning occurs in spring and early summer. The nests are built in cavities or depressions excavated out of the substrate (Minckley 1973).

Family CYRPINODONTIDAE, killifishes

RIO GRANDE KILLIFISH, *Fundulus zebrinus* (Jordan and Gilbert)

History and Distribution. The Rio Grande killifish, a native of Texas and New Mexico, probably gained access to the study area via the Little Colorado River system, where it was locally abundant as early as 1938 (Miller and Lowe 1967). This species occurs sporadically within the study area, typically in low gradient tributaries such as Crystal, Kanab and Elves Chasm Creeks, as well as upstream in the Little Colorado River. This species has been reported only once in the mainstream Colorado River (Suttkus et al. 1976).

Age and Growth. This species probably lives about two years, though the specimens collected in this study were all one year of age.

Food Habits. Midge larvae, mayflies, leafhoppers and organic detritus were the major food items consumed by Rio Grande killifish.

Mainstream. No Rio Grande killifish were collected for stomach analysis from the mainstream Colorado River.

Northern Tributaries. The major food item in winter specimens taken from northern tributaries was midge larvae. A leafhopper and organic detritus were also present.

Southern Tributaries. One Rio Grande killifish, taken from Elves Chasm Creek in winter, contained mayfly nymphs, a seed shrimp and organic detritus. A specimen taken in summer from the Little Colorado River contained a midge larvae and organic detritus.

Reproduction. The taking of very small individuals during this study indicates that reproduction occurs in Grand Canyon waters.

Family PERCICHTHYIDAE, Sea Basses

STRIPED BASS, *Morone saxatilis* (Walbaum)

History and Distribution. Striped bass have developed into Lake Mead's major fishery since their introduction in 1969 (Roden 1978). Striped bass were collected only at River Mile 650.6, during this study.

Density and Abundance. The density of striped bass in river section VII of the mainstream (the only capture site of this species) was 75 f/h and zero f/n, for electrofishing and trammel netting, respectively (Table 6-4).

Striped bass ranked third in relative abundance during spring, which was the only season this species was collected (Table 6-6).

Age and Growth. The striped bass caught during this study were all in their second year of life except for a 28.2 kg female. This female's scales could not be aged, nor could an age estimate be made due to the lack of younger age class data. Her minimum average weight gain per year would be about 2.8 kg.

Food Habits. The only item retrieved from striped bass stomachs was a single carp scale. This tends to confirm accounts that adult striped bass are primarily piscivorous (Minckley 1973). No specimens were taken in northern or southern tributaries.

Reproduction. Reproduction of striped bass was not verified during this study. The taking of several ripe males and a ripe female (28.2 kg) after completion of this study (spring 1979) near the Bridge Canyon campsite (R.M. 452.6), suggest an upstream spawning run. Other observations, made during April - May 1979, strongly indicate that reproduction takes place in the upper end of Lake Mead.

Conditions Factor. Condition factors and length-weight relationships were similar to striped bass populations in other areas.

Family CENTRARCHIDAE, sunfishes

LARGEMOUTH BASS, *Micropterus salmoides* (Lacepede)

History and Distribution. The first collections of largemouth bass in Grand Canyon waters were made between River Miles 509 and 516 during this study. This eastern United States native appeared to be confined to the mainstream. Individuals of this species have probably moved upstream from Lake Mead where it has been present for many years.

Age and Growth. Individuals collected during this study ranged from two to four years in age. The length-weight relationships were slightly higher than other southwestern populations. This may result from lower fish densities in Grand Canyon waters, and hence reduced competition.

Food Habits.

Mainstream. Indications are that this species is primarily piscivorous as speckled dace were the only food item recovered in stomach contents.

Reproduction. Spawning in Grand Canyon waters, as indicated by gonadal somatic indices and the taking of gravid females, occurs in summer. Reproduction was not confirmed, though two females taken during summer averaged 8336 eggs.

BLUEGILL SUNFISH, *Lepomis macrochirus* (Rafinesque)

History and Distribution. The one bluegill sunfish taken during this investigation at River Mile 508.6, constituted the first record of this species from the study area.

Age and Growth. The collected specimen was in its third year of life.

Food Habits. Smaller invertebrates, especially zooplankton and aquatic insects constitute the major food items of both juvenile and adult fish (Minckley 1973).

Reproduction. No reproductive data were obtained.

GREEN SUNFISH, Lepomis cyanellus (Rafinesque)

History and Distribution. The distribution of green sunfish in Grand Canyon waters appears to be localized. Two specimens were collected at River Mile 508.6 during this study. Only one report of green sunfish at River Mile 656 had been made previous to this study (Miller and Smith 1968).

Density and Abundance. The relative abundance and density of green sunfish was very low within the study area (Table 6-42) as only two specimens were taken.

Age and Growth. Green sunfish taken during this study were in their third year of life.

Food Habits. Stomach contents of one green sunfish, taken from the mainstream during fall, indicate that this species feeds primarily on black flies and midges. Unidentifiable invertebrate remains also comprised a significant portion of the diet.

Reproduction. It is not known if green sunfish reproduce in Grand Canyon areas.

Family PERCIDAE, perches

WALLEYES, Stizostedion vitreum (Mitchill)

History and Distribution. Walleyes have previously been taken in the vicinity of Lee Ferry (Stone 1971, 1972), although none were collected during this study.

Food Habits. The food of young walleyes consists of small crustaceans, insects and fishes, while the adults are mainly piscivorous (Cross 1967).

Reproduction. Walleyes reproduce when water temperatures rise to 7 to 10 C. Males congregate on shallow shoals of lakes and rivers over silt-free, rocky bottoms, where they are joined by single females ready to spawn. The eggs are scattered and become anchored to stones via adhesive membrances. Embryo development takes approximately two weeks (Cross 1967).

PARASITISM

The copepod (Crustacea) Lernaea cyprinaceae Linnaeus, is a fish parasite known to cause considerable mortality in pond and hatchery habitats, especially when conditions of high temperature and high population densities exist simultaneously (Uzman and Rayner 1958). L. cyprinaceae was first described from, and is endemic to, European fishes (Wilson 1918). It is thought to have been introduced from Asia in shipments of ornamental and tropical fish. Parasitism by L. cyprinaceae is less common in natural streams than in lakes and ponds (Bulow et al. 1979), though James (1968) found near epizootic infestations in some Arizona desert streams where summer and fall discharges were typically low, resulting in high water temperatures, ponding and relatively crowded fish populations.

During this study, we found heavy L. cyrpinaceae parasitism on native fishes in the Grand Canyon. This is the first report of this parasite in Grand Canyon and the only documentation of heavy infestations in the largest remaining breeding population of the endangered Gila cypha.

Heavy infestations of L. cyprinaceae were only found on fishes taken from two low-gradient tributaries, Kanab Creek and the Little Colorado River. Only juveniles of the native species Catostomus latipinnis, C. discobolus, Rhinichthys osculus and Gila cypha were infested, while adult natives and sympatric exotic species were found to be parasite free.

L. cyprinaceae infestation was first observed during August 1978, when we found infested juveniles of R. osculus (6.5%) and P. discobolus (20.7%) in Kanab Creek (Table 6-28).

Table 6-28. Incidence of *Lernaea cyprinaceae* on native fishes of the Little Colorado River (LCR) and Kanab Creek (KC) in Grand Canyon, Arizona, 1978.

	Gila cypha	*Rhinichthys osculus*		*Catostomus latipinnis*		*Pantosteus discobolus*	
	LCR	KC		LCR	KC	KC	
	October	August	October	October	October	August	October
Number of fish examined	65	46	30	8	3	29	49
Length of fish (mm):							
Mean	73	33	35	98	87	39	68
Range	58-189	17-87	21-44	64-130	56-126	31-45	44-87
Percentage of fish parasitized	53.8	6.5	10.0	50.0	33.3	20.7	55.1
Number of *Lernaea* per fish	1-5	1-4	1-2	1-2	1	1-2	1-10

By October 1978, parasitism had become more pronounced, both in terms of the number of species parasitized and the relative frequency with which infested fish were encountered. During October, juvenile R. osculus (10.0%), P. discobolus (55.1%) and C. latipinnis (33.3%) in Kanab Creek carried one or more copepods, and for the first time, the parasite was found on G. cypha (53.8%) and C. latipinnis (50.0%) in the Little Colorado River. Although adults of all four of these native species were taken during both sampling periods, none showed any evidence of copepod parasitism. Most of the parasitized fish contained from one to two parasites per individual, although one juvenile P. discobolus, taken from Kanab Creek in October, had ten parasites.

The attachment site was most frequently near the base of the pectoral, pelvic or dorsal fin, as has been found in previous studies (Bulow et al. 1979, Haley and Winn 1959). Other attachment sites were the caudal fin, body wall, mouthparts (external) and opercle.

No individuals of exotic species (Cyprinus carpio, Ictalurus punctatus, Pimephales promelas, Fundulus zebrinus and Salmo gairdneri) taken from either tributary carried parasites. These species have no apparent resistance to L. cyprinaceae parasitism since each has been previously reported as hosting this copepod in other aquatic systems (Hoffman 1967, James 1968, Wilson et al. 1966).

The only other "parasites" found on or in fishes were occasional fungal growths on what appeared to be old Lernaea scars.

The occurrence of L. cyprinaceae on juvenile native fish species inhabiting the Little Colorado River and Kanab Creek is apparently a recent outbreak as previous reports on the ichthyofauna of Grand Canyon have failed to reveal any significant ectoparasite infestations from either the mainstream Colorado River or it tributaries (R. R. Miller, unpublished, Minckley and Blinn 1976, Suttkus et al. 1976). Suttkus et al. (1976) reported collecting near the confluence of the Little Colorado River on nine separate occasions from 1972 to 1976; they also reported collecting in Kanab Creek four times between 1975 and 1976. Although many of their sampling periods were during late summer and fall, Suttkus (in Johnson 1976) reported observing L. cyprinaceae only once each on G. cypha and C. carpio in the Little Colorado River. Our collecting records (Minckley and Blinn 1976, and unpubl. data) from spring 1975 to present indicate that L. cyprinaceae was virtually absent from the system until August 1978.

The origin of L. cyprinaceae in these two Grand Canyon tributaries is unknown. It is most probable that parasitized exotic species from the Lake Mead area, or hatchery Salmonids planted below Lake Powell, are the original source.

The presence of copepod parasitism on the native species in Kanab Creek and the Little Colorado River, its absence in the mainstream Colorado River and the relative absence of L. cyprinaceae on the exotic species throughout the system can be readily explained on the basis of the thermophilic nature of the parasite and habitat selection by both native and exotic fish species. The optimum temperature range for the development of L. cyprinaceae is from 23° to 30 C; below 14° C the parasite fails to complete its life cycle (Figure 6-7) (Bauer 1959, Putz and Bown 1964). The temperature of the hypolimnetic river water ranges from 7 to 10° C throughout the year (Cole and Kubly 1976), since the discharge now comes

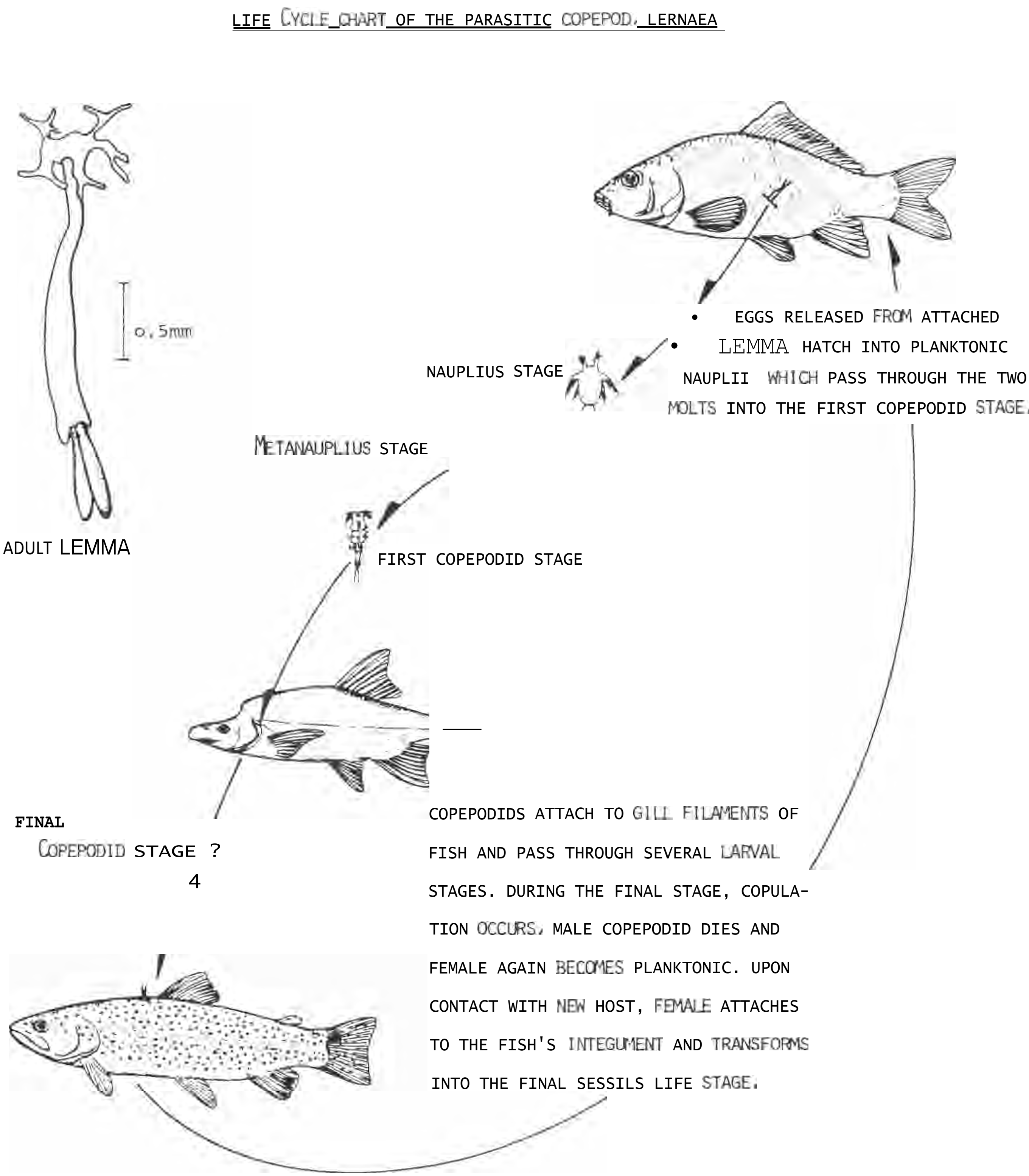

Figure 6-7. **Life cycle chart of the parasitic copepod, Lernaea.**

through penstock gates in Glen Canyon Dam approximately 60 m below the surface of Lake Powell. The exotic species presently inhabiting the Colorado River in Grand Canyon show a wide range of temperature tolerance and often move freely between the warm and cold habitats of the tributaries and mainstream, although they demonstrate a preference for the mainstream habitat. The adults of the native species tolerate and are frequently captured in the mainstream river, though they seem to require the warmer tributary areas for spawning and rearing (Minckley and Blinn 1976, Suttkus et al. 1976). During August and October of 1978, the temperatures of Kanab Creek and the Little Colorado River were both well within the optimal range for L. *cyprinaceae* maturation. Also, during low discharges of late summer and fall, both tributaries tend to have sluggish currents and standing pools, further characteristics of optimum copepod habitat (Bulow et al. 1979). The only fish restricted to the optimum copepod habitat for any period of time are the immature native species. We therefore suggest that the juvenile native fish, after reaching some unknown critical size, move into the colder Colorado River habitats where any L. *cyprinaceae* they host will most likely perish. At this time the survival rates of parasitized immatures of native species in this system are unknown.

Note:

G. *cypha*, though once common throughout the Colorado River Basin (Minckley 1973), is now extremely rare. It is very likely that invasion of the Little Colorado River by L. *cyprinaceae* will further threaten this already endangered species, since this is the only known locality of successful reproduction for G. cypha. James (1968) found that another member of the genus, G. robusta, was particularly susceptible to parasitism by L. cyprinaceae. It is well known that this particular copepod can cause substantial injury to its host (James 1968, McNeil 1961, Tidd 1934).

INTERRELATIONSHIPS

DISTRIBUTION AND MOVEMENT

Distribution of Grand Canyon fishes was determined by various sampling techniques as well as through direct observation. Movement was determined from recaptures of marked fish. Using these data, trends in distribution could be identified in the more common species, while observations on movement were tentative due to the small number of recaptures.

Distribution of fish within the Colorado River and its tributaries reflects the population size of each species. Those fish with large populations (i. e., the flannelmouth and bluehead suckers, speckled dace, rainbow trout and carp) are widespread throughout the study area. Conversely, other species such as the humpback chub, razorback sucker and largemouth and striped bass have a limited distribution and a small population size. Other factors affecting fish distribution include tributary influences, fluctuating water levels and reproductive cycles.

Tributaries affect fish distribution in several ways. The most obvious effect on distribution occurs during the various spawning seasons when large concentrations of fish occur in those systems. Tributaries later provide important nursery grounds for the juveniles. Large concentrations of food organisms also result in increased fish densities. During times of high mainstream flow, the tributaries act as refugia for smaller fish and for adults of the more warmwater fishes such as the humpback chub and flannelmouth suckers. Tributaries may also increase the productivity of the mainstream a short distance below their confluent zones through the input of allochonthous detritus which causes an increase in benthic productivity. This allows the number of fish occurring in those areas to increase.

The effect of the reproductive cycle on fish distribution is apparent in the increased stream use during the respective spawning period of each species. This is most obvious in the case of rainbow trout which spawn in the higher gradient tributaries from fall to late spring. Less apparent is the increased stream use by the native bluehead suckers and speckled dace which also use the higher gradient streams for spawning. Lower gradient streams are utilized by flannelmouth suckers and possibly by carp although successful reproduction has not been verified in the latter species.

Distribution of fishes restricted to the mainstream is also affected by the reproductive cycle. Spawning is suspected to cause a change in the mainstream distribution of the larger salmonids in that they move to and from spawning areas during their reproductive period. Striped bass move upstream from Lake Mead to spawn.

Fluctuating water levels, caused by the production of hydroelectric power, affects fish distribution by denying access to tributaries and essential backwater habitats. This is readily apparent at the confluent zones of most low gradient tributaries which essentially go dry during low water. The confluent zones of most of the larger high gradient tributaries become shallow, turbulent, riffle areas, which affects both fish distribution and invertebrate productivity.

Movement of fishes is affected by the same factors influencing distribution. However, because of the small number of recaptures obtained, it is not possible to determine what factor(s) affect movement the most. Most species for which recaptures were obtained (i. e., rainbow trout, carp and flannelmouth suckers) tended to be relatively sedentary. The one exception to this was a carp that traveled downstream an estimated 264 km.

In summary, distribution and movement of fishes are thought to be influenced by population size, reproductive cycles, tributaries and fluctuating water levels. The native flannelmouth and bluehead suckers, speckled dace, and the exotic carp and rainbow trout were found to be ubiquitous within this region, while the humpback chub, channel catfish and brown and brook trouts were less widespread. Other species (i. e., the largemouth and striped bass, green and bluegill sunfish, fathead minnow and Rio Grande killifish) occurred sporadically. The razorback sucker and golden shiner were represented by only one individual. Speckled dace, bluehead suckers and rainbow trout generally preferred high gradient streams, while flannelmouth suckers and carp preferred low gradient streams.

Movement data, based on tagging operations, were inconclusive due to the small number of recaptures, though it appeared that rainbow trout, carp and flannelmouth suckers tend to be sedentary.

RELATIVE DENSITY AND RELATIVE ABUNDANCE

Density and relative abundance of fishes within the study area was determined by catch per unit effort and by ranking the various collections.

The fact that exotic fish species were more abundant than native species in the mainstream reflects collecting susceptibility and the habitat preferences of the species. Flannelmouth and bluehead suckers tend to be bottom dwellers, while carp and rainbow trout are generally present within the water column. Conversely, native fish species outnumbered the exotics in the tributaries. Fish in the mainstream, were for the most part, larger adults, while fishes collected in the various tributaries were more often juvenile and young-of-the-year native fish species.

AGE AND GROWTH

Various bony structures such as scales, opercula, vertebrae and dorsal and pectoral spines have long been used and accepted as a means of aging fish (Creaser 1926, DeBont 1966, Hoffbauer 1898, Menon 1950, Reibisch 1899, Van Oosten 1929). Most of these bony structures show seasonal changes in growth rate, especially in temperate waters, where there is a distinct seasonal, and hence, environmental change (e.g. temperature, photoperiod, turbidity, etc.) (DeBont 1966, Lagler 1956, Sheri and Power 1969, Tesch 1968). This change in growth rate is identified on the structure as a "growth ring" or "annulus". The annuli are used for determining age, length at the end of each year and the growth rate (Van Oosten 1929).

Scales are probably the most widely accepted of all currently used aging techniques (for reviews see Creaser 1926, Van Oosten 1929), though several studies utilizing both scales and opercula found the opercular bone more accurate and easier to use (Blake and Blake 1978, English 1951, Frost and Kipling 1959, LeCren 1947, McConnel 1951, Nilsson 1921).

In many studies, aging techniques are accepted without critical study, even though age and the number of "annuli" do not correspond (DeBont 1966). It should not be a forgone conclusion that even the clearest growth marks are annuli. For the sake of reliability, two methods should be utilized (Tesch 1968) and the validity of each should be substantiated for each fish species.

Determining the age and growth rate of fish species is important for better understanding its life history and ecology. Comparison of the age structure and growth rate of a species with conspecific populations or with its regional average may partly identify varying environmental conditions (Lagler 1956). For example, changes in the mainstream thermal regimes, since construction of the Glen Canyon Dam, have probably altered the growth pattern of several native species (Usher et al. unpub. ms). The warmer temperatures and higher productivity of the side canyon streams favor a more rapid growth rate in the younger age class fishes. Once the individuals approach sexual maturity and/or maximum body size for the smaller streams, they move into the colder and less productive mainstream where growth rates are slower. Between study comparisons such as this measure environmental suitability and point the way for future management.

The goals of this study are to provide 1) age and growth information for the common native and exotic fishes of the Colorado River in Grand Canyon, 2) regional comparisons, when possible, to help identify the suitability of conditions in the Colorado River for each species and 3) verification (DeBont 1966, Hile 1941, LeCren 1947, Van Oosten 1929) of the various aging techniques (DeBont 1966, Hile 1941, LeCren 1947, Van Oosten 1929) for fishes in Grand Canyon.

FOOD HABITS

Native fishes of the Grand Canyon have evolved to exploit specific habitats within a once highly variable environment, as indicated by the variety of morphological and behavioral adaptations. Some of these adaptations became "obsolete" with the construction of Glen Canyon Dam, which resulted in significant alterations of the Colorado River system in Grand Canyon (Pemberton 1976) (Chapter 2). Consequently, there were profound, though unquantified, alterations in native fish reproductive physiology and in the variety and abundance of prey resources. At present, only three native species (speckled dace, flannelmouth suckers and bluehead suckers) inhabit Grand Canyon in moderate to high densities. Small numbers of humpback chubs occur, though they are generally confined to a relict segment of their natural range. Ecological interrelationships with the continually growing number of introduced species are also major factors influencing native fish populations.

Seasonal foraging strategies of the common Grand Canyon fish were examined to determine their food habits and feedling interrelationships. Fishes studied were the speckled dace, flannelmouth and bluehead suckers, rainbow, brown and brook trouts, carp and channel catfish. Other species were present in low numbers or collected too infrequently to allow comprehensive coverage of seasonal food habits. Some were not collected due to their endangerd status. Previous research on the diets of Grand Canyon fishes consists of two studies (Minckley 1978, Bancroft and Sylvester 1978), both of which were restricted to specific segments of the aquatic system.

The diet of each fish species is discussed in terms of relative mass (dry weight) (see Chapter 2), using 0.1 mg dry weight as an absolute unit. This procedure was chosen because a numerical value cannot a accurately quantify filamentous algae or amorphous detrital materials.

Intraspecific variations in fish diets from several localities were compared by dividing the study area into three areas: the Colorado River from Lee Ferry (R. M. 688.6) to Separation Rapids (R. M. 450.6) (Mainstream), tributaries draining into the Colorado River from the north (Northern Tributaries) and tributaries draining into the Colorado River from the south (Southern Tributaries).

Documentating interspecific competition in natural situations is difficult, if not impossible because of the great complexity of most populations and communities. Competition requires that niches of two or more organisms overlap in the use of some limited resource (McNaughton and Wolf 1973). Interspecific overlap of food resources thus indicates potential competition between sympatric fish species.

General conclusions from dietary analysis of Grand Canyon fishes are that each species uses a variety of items and that many important food items are utilized by several species, even though the diets of each species had characteristic seasonal and locale features. The similarity indices (Figures 6-8 - 6-10), suggest that food habits of the fish species are broadly similar during various seasons. All of the species ingested benthic invertebrates, and to varying degrees, terrestrial insects, Cladophora and plant seeds. Fluctuations in overlap were indicative of periodic shifts in foraging strategies by more opportunistic species (e. g., rainbow trout, channel catfish, brown trout).

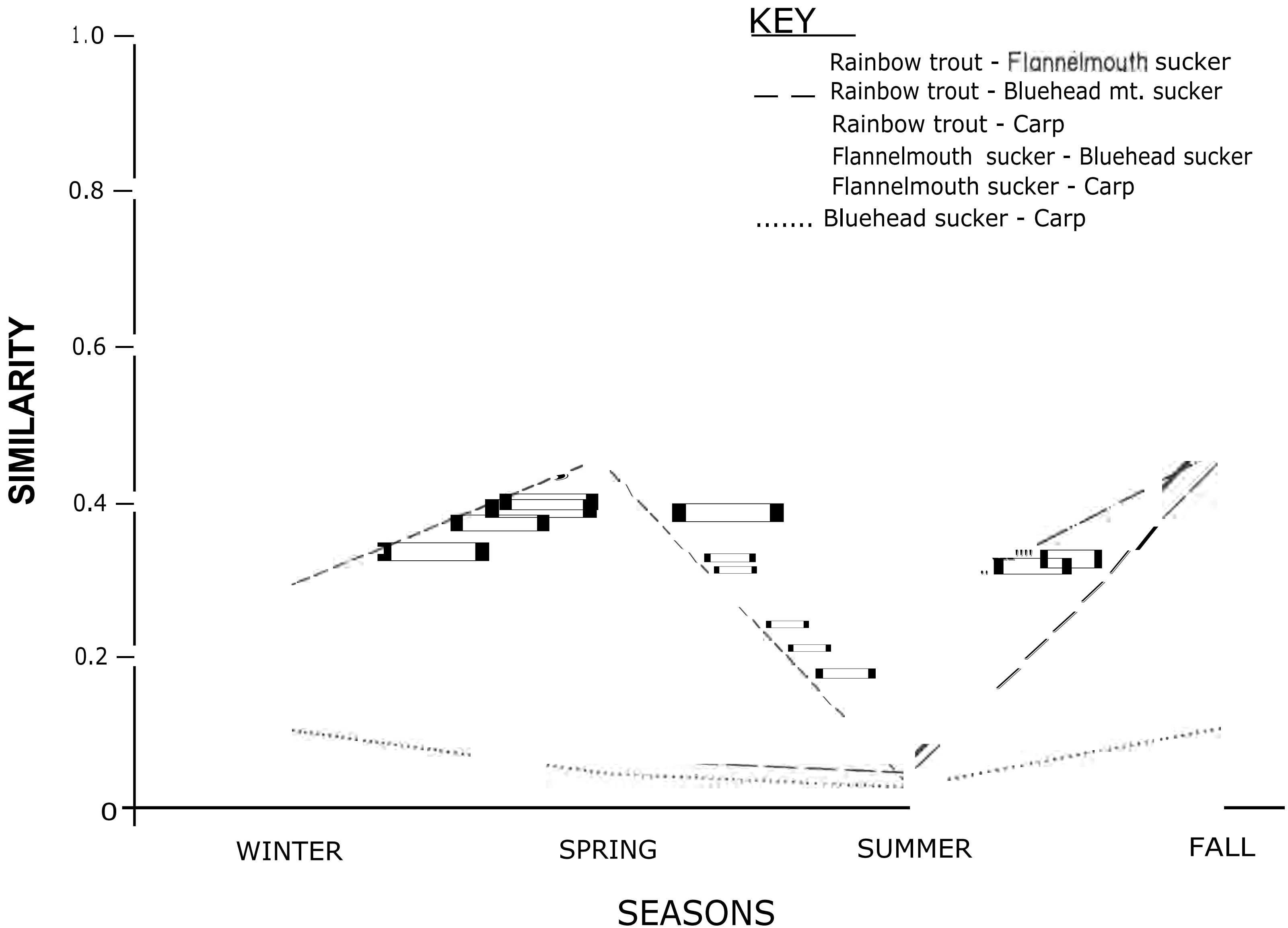

Figure 6–8. Similarity indices between the food of common ot the Colorado River, Grand Canyon National Park, Arizona, 1977 - 1978.

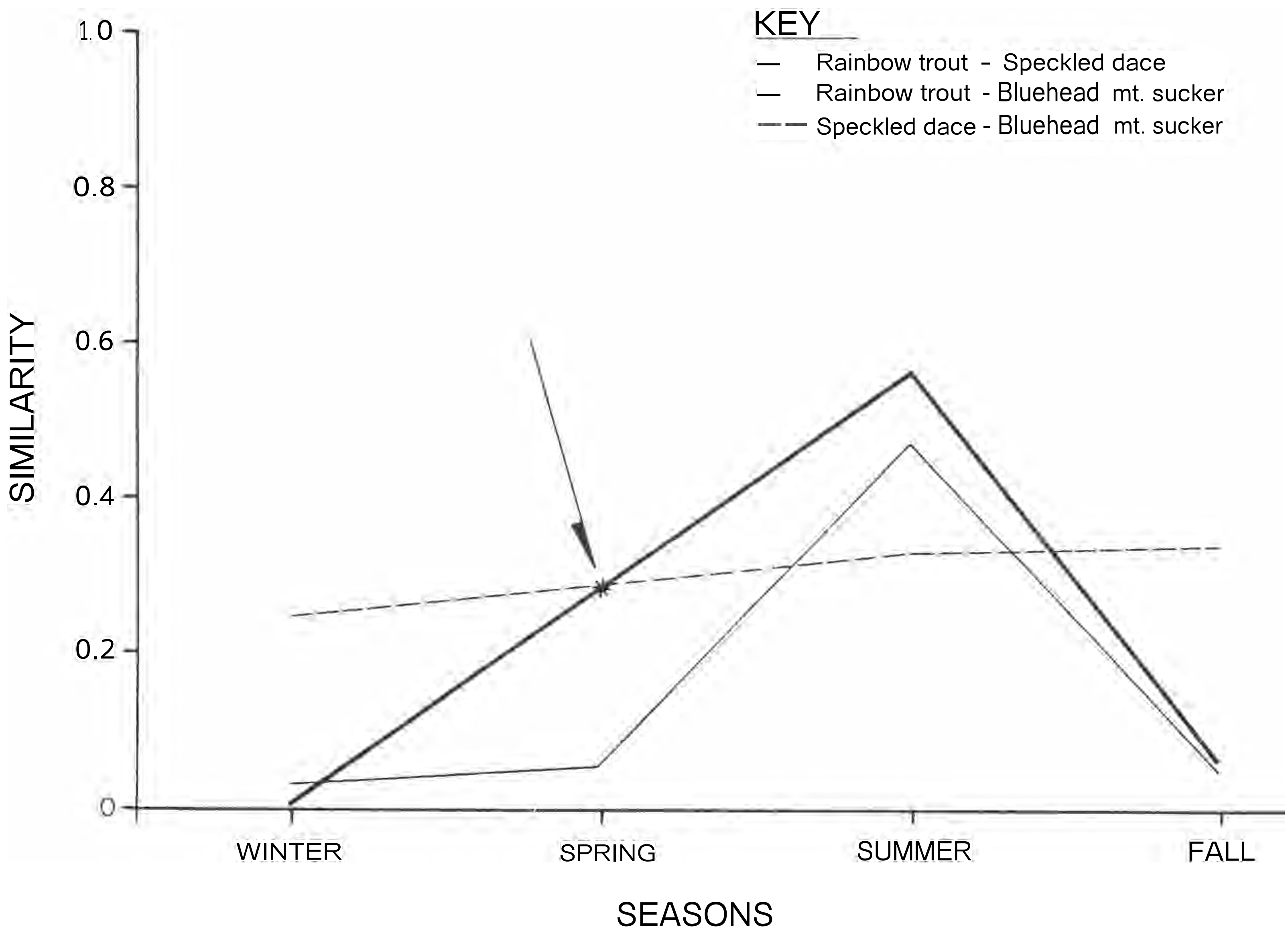

Figure 6-9. Similarity indices between the food habit of common fish species of tributary systems north of the Colorado River, Grand Canyon National Park, Arizona 1977 - 1978.

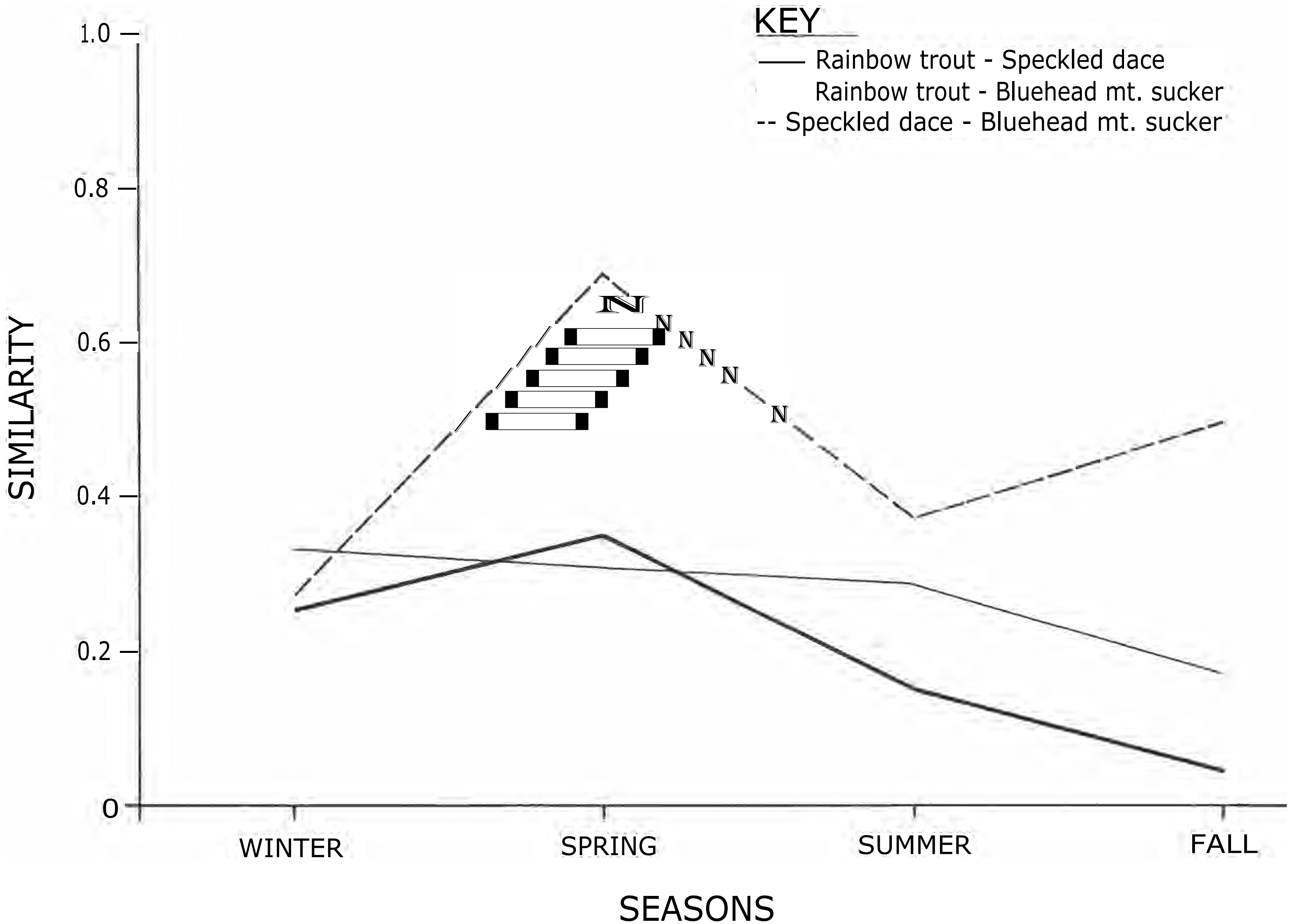

Figure 6-10. Similarity indices between the food habits of common fish species of tributary systems south of the Colorado River, Grand Canyon National Park, Arizona, 1977 - 1978.

Flannelmouth suckers, bluehead suckers and speckled dace were dietary specialists and generally foraged on or near the substrate. Principal foods consisted of benthic invertebrates, though detritus formed substantial portions of catostomid diets. Data indicated that flannelmouth suckers preferred mainstream backwaters and confluent zones of the larger, slower-flowing tributaries (i. e., Paria River, Kanab Creek, Little Colorado River). These areas accumulated nutrient-rich silt deposits and were relatively warm due to low gradients and slow water exchange. Bluehead suckers showed strong preferences for swifter water and rockier substrates. In previous studies, bluehead suckers have been observed scraping food items off stones with their cartilage-sheathed jaws (Minckley 1973). Speckled dace also preferred foraging in swifter waters as indicated by their main food items, which are most often found attached to rocks or associated with gravel and cobble stream beds. Seasonal overlap in the diets of these three species was generally low since the quantities of the food items common in their diets varied substantially. One exception occurred with speckled dace and bluehead suckers taken from southern tributaries in spring. In both these species, high dietary overlap was due to opportunistic predation on black fly larvae, which comprised approximately 50% of the dietary mass of both species (Table 6-10, 6-17).

Common exotic species, particularly rainbow trout, brown trout and channel catfish, had generalized diets and often shifted foraging activities in response to ephemeral food resources. The river system as a whole, appeared to provide salmonids with optimum habitat conditions. Cold, swift tributaries (i. e., Bright Angel and Tapeats Creeks) served as excellent spawning grounds, winter feeding areas and protective habitat for juveniles. The mainstream, in turn, provided trout with amphipods and immature dipterans throughout the year and winged insects during warmer seasons.

Carp were taken in eddies near fast currents in the mainstream, while channel catfish generally preferred backwaters, eddies and the confluent zone of the Little Colorado River. The feeding behavior of these fish is characterized by detailed inspections and upturning of the substrate, which generally yields Cladophora, benthic invertebrates and, in the case of channel catfish, small native fishes. Channel catfish also exploited substantial quantities of terrestrial insects, such as mayflies, which may be taken by feeding on the water's surface (see Holden and Stalnaker 1975b).

Overlap between the food habits of exotic and native species was variable (Figures 6-1 - 6-3). Diets of rainbow trout and flannelmouth suckers in the mainstream were similar during the winter and transition seasons, but changed dramatically in summer, due to riverine salmonids foraging on floating terrestrial insects. In contrast, the summer diets of rainbow trout in northern tributaries overlapped substantially with those of sympatric bluehead suckers and speckled dace, which was attributable to mutual exploitation of local black fly larvae. Overlap between carp and native species was generally low, due to the large quantities of Cladophora consumed by carp. Similarity indices between channel catfish and native species were also low due to catfish predation on natives rather than contrasting habitat requirements.

Food habits of less common exotic fishes (e. g., largemouth bass, Rio Grande killifish, fathead minnows, etc.) were not discussed because of small sample sizes. The apparent scarcity of these species suggests that their interactions with native fishes are not extensive at present. Possible exceptions include brook trout and striped bass, whose ranges and densities may be increasing in Grand Canyon. An established population of the piscivorous striped bass in the study area could have serious implications, and it is recommended that a program be implemented to monitor this species' range and influence on native fishes and salmonids.

Cladophora was heavily exploited by carp, rainbow trout, brown trout, channel catfish and, to a lesser extent, flannelmouth and bluehead suckers. Consumption of this material is considered to be a function of innate feeding responses by visually oriented species (i. e., rainbow and brown trout), or indiscriminate searches for invertebrate food items by bottom-dwelling fishes (Eder and Carlson 1977, Minckley 1979, Summerfelt el al. 1970, Tippets and Moyle 1978). Epiphytes of Cladophora may serve as a supplemental food item since this alga serves as a feeding substrate for invertebrate fauna. Gut contents of flannelmouth and bluehead suckers contained great amounts of diatoms, the most abundant of which are common epiphytes of Cladophora (Whitton 1975). Diets of additional fish species were not examined microscopically, though it is probable that the number of diatoms ingested increased relative to Cladophora consumption. Arnold (1971) suggested that oil droplets contained within diatoms provide a major energy source for pupfish in northern Mexico. This may also be the case for many Grand Canyon fishes.

Detritus was the major dietary component of flannelmouth and bluehead suckers, and was common in the diets of carp, channel catfish, rainbow trout, brown trout and speckled dace. The bulk of detritus in catostomid diets consisted of silt and organic sediment, the latter of which contained an abundance of diatoms. Other detritual materials in the stomachs of salmonids and speckled dace consisted of small stones, fragments of higher plants and amorphous faunal debris. Detritus from carp and channel catfish was a conglomerate of organic sediment, macrophytes and debris. Organic sediment, substantial amounts of which are derived from tributaries and riparian zones adjacent to the Colorado River, appeared to be essential to bottom-dwelling fishes by providing a substrate for the production of benthic microorganisms and invertebrates.

Scuds, introduced into the Colorado River by the National Park Service in 1937, were most often encountered near the substrate in shallow backwaters, and were heavily exploited by both native and exotic species. Ingestion of scuds resulted in substantial interspecific overlap during winter and fall, when feeding activities of most fishes were concentrated on benthic invertebrates. It is possible that scuds become relatively scarce in some shoreline and backwater habitats during periods of heavy interspecific exploitation.

Immature midges and black flies constituted two of the most important aquatic insect groups in the lotic ecology of Grand Canyon as they were represented in the diets of virtually all fishes analyzed. Qualitative field observations indicated that black flies were generally attached to current-exposed rocks in local tributaries and to inundated gravel bars of the mainstream, while midges were more common in the silt-laden substrate of shallow aquatic habitats throughout the study area. Midge larvae were a dominant food of most juvenile fishes in Grand Canyon and appeared to be fundamental in the transition from micro-organisms to large invertebrate food resources. This was particularly evident in the diets of speckled dace, bluehead suckers, and to a lesser extent, rainbow trout, which shifted from heavy utilization of midge larvae to black flies and other large invertebrates as the fishes increased in size (Table 6-29). Flannelmouth suckers fed on a more diverse array of food items as size increased, although midges formed a major portion of flannelmouth diets through all life stages. Dietary overlap between fish taxa in tributaries was generally attributable to heavy predation on black fly larvae. The potential for competition between rainbow trout and sympatric native fishes was most evident during summer in the northern tributaries due to maximum black fly exploitation and minimum availability.

Mayfly nymphs and caddisfly larvae (particularly Hydropsychidae) were eaten by rainbow trout, speckled dace and, occasionally, catostomids. Both organisms were common in tributary substrates and were present in the fishes diets throughout the year. Predatory interrelationships were generally subtle, as the degree of mayfly and/or caddisfly utilization by sympatric fish species was variable. The highest degree of overlap occurred between the winter diets of rainbow trout and speckled dace from tributaries south of the Colorado River, when mayflies and caddisflies formed 8.71 and 18.88% of the rainbow trout and speckled dace diets, respectively.

Trout eggs were the dominant food item of rainbow trout taken from northern tributaries during winter. This interspecific predation substantially reduced the degree of winter overlap between the diets of rainbow trout and native fishes that were not driven from northern

Table 6-29. The percentage composition by mass (% M) of foods eaten by various size classes of dominant fish species collected in tributaries north of the Colorado River during summer 1978, in Grand Canyon National Park, Arizona.

Food items	Rainbow Trout			Speckled Dace			Flannelmouth Suckers				Bluehead Suckers			
	<1	1	2	<1	1	2	<1	1	2	3+	<1	1	2	3+
Baetidae nymphs	2.0	0.9			12.5	4.1		4.2	-	Tr.		1.7		1.2
Corydalidae larvae	9.1							-	-					
Rhyacophilidae larvae	1.4							-	-					
Philopotamidae larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsychidae larvae	2.1	0.3	-	-	6.7	-	-	68.1	-	-	-	-		
Hydroptilidae larvae	-	-	-	-	1.0	-	-	-	-	Tr.	0.5	-	-	0.3
Brachycentridae larvae	0.6	0.1	-	-	-	-	-	-	-	Tr.	-	-		
Helocopsychidae larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Pyralidae larvae	-	0.3	-	2.6	1.9	-	-	-	-	-	-	-	-	0.6
Elmidae larvae	-	-	-	-	1.0	-	-	-	-	0.2	-	-	-	-
Psychodidae larvae	-	-	-	2.6	-	-	-	-	-	-	-	-	-	-
Blephariceridae larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
Simuliidae larvae	31.8	13.8	35.3	7.9	30.8	10.9	-	-	-	1.3	10.0	-	50.0	43.7
Simuliidae pupae	0.2	0.5	4.0	-	1.9	-	-	-	-	1.8	-	-	-	0.3
Chironomidae larvae	2.5	0.4	-	26.3	15.4	1.5	25.0	10.6	-	10.2	11.0	4.2	-	4.5
Chironomidae pupae	0.2	1.2	-	-	-	1.0	-	-	-	2.6	1.0	0.8	25.0	0.2
Ceratopogonidae larvae	-	-	-	-	-	-	-	-	-	Tr.	0.5	-		
Stratiomyiidae larvae	0.2	0.7	-	-	-	1.5	-	-	-	Tr.				

(continued)

Table 6-29 (cont.). The percentage composition by mass (% M) of foods eaten by various size classes of dominant fish species collected in tributaries north of the Colorado River during the summer of 1978, Grand Canyon National Park, Arizona.

Food items	Rainbow Trout			Speckled Dace			Flannelmouth Suckers				Bluehead Suckers			
	1	1	2	<1	1	2	<1	1	2	3+	1	1	2	3+
Cypridae adults	-	-	-	18.4	-	15.5	-	-	-	Tr.	3.8			
Gammaridae adults	-	-	-	-	-	-	-	-	-	0.8	-	-	-	-
Sperchonidae adults	0.1	-	-	-	-	-	-	-	-	0.2	0.5			-
Acrididae adults	-	1.1	-	-	-	-	-	-	-	-	-	-	-	-
Pentatomidae adults	-	1.8	-	-	-	-	-	-	-	-	-	-	-	-
Curculionidae adults	-	5.2	-	-	-	-	-	-	-	-				
Formicidae adults	-	0.2	15.6	-	3.8	1.5	-	-	-	0.2				
Investebrate remains	-	1.8	-	7.9	-	2.1	-	-	-	Tr.	-	-	-	-
Cladophora sp.	-	29.5	9.8	-	-	-	-	-	-	7.0	-	-	-	0.1
Seeds	-	-	-	-	-	1.5	-	-	-	0.2	-	-	-	-
Detritus and Sand	47.5	40.0	1.2	26.3	25.0	57.5	75.0	17.0	-	75.4	67.0	93.3	25.0	48.9
Others	2.3	2.2	34.1	8.0	-	2.9	-	0.1	-	0.1	5.7	-	-	-
No. of fish	9	3	2	4	17	23	1	1	0	20	23	3	3	9
Length (mm)	0-160	161-222	223-350	0-70	71-115	45-62	0-70	71-115	116-174	175+	0-70	71-132	133-181	182+

* The numbers, 1, 1, 2, and 3+ refer to the size classes into which the food items were divided. The length in mm of th various size classes areas follows. Rainbow trout: <1 = 0-160, 1 = 161-122, 2 = 223-350; speckled dace: <1 = 0-37, 1 = 38-44, 2 = 45-62; flannelmouth suckers: <1 = 0-70, 1 = 71-115, 2 = 116-174, 3 = 175+; bluehead sucker: <1 = 0-70 1 = 71-132, 2 = 133-181, 3 = 182+.

tributaries by spawning trout. The intraspecific disturbance of spawning beds by rainbow trout also indicates that trout populations are subject to some natural population control. Large numbers of terrestrial insects (i. e., stink bugs, grasshoppers, ants, leafhoppers, etc.) along the riparian zone during the warmer seasons (Stevens 1976) provided riverine trout and catfish populations with an additional food source. Availability of these drifting terrestrial insects greatly reduced the overlap between rainbow trout and native fishes (Figure 6-8).

Disproportionate utilization of some organisms suggests selective foraging on the part of certain fishes. During this study, estimations of resource availability were limited to quantitative observations of benthic invertebrates in selected tributaries, since materials necessary for analyzing drift and benthos of the mainstream were beyond the scope of this project. Dietary preferences of fish in selected tributaries suggest possible trends, but are not directly comparable to previous studies (Schreiber 1978, Tippets and Moyle 1978) which included surface organisms, algae and other aquatic resources.

Selective predation on benthic invertebrate taxa varied with the fish species (Table 6-30 - 6-33). Some organisms showed positive electivities (preference) in the diets of several fish (e. g., black fly larvae, midge larvae and seed shrimp), while others were generally negative (avoidance or disregard) (e. g., soldier fly larvae and net-spinning caddisfly larvae). Selection on the part of fish is influenced by factors such as activity and size of the invertebrate prey (Ware 1973) and the foraging stategy of the fish (visual vs. olfactory). For example, flannelmouth suckers are more likely to consume midge larvae and seed shrimp than are rainbow trout, as salmonids are visually

Table 6-30 . Electivity indices for invertebrates important in the winter diets of rainbow trout (*Salmo gairdneri*) in Bright Angel Creek, Grand Canyon National Park, Arizona.

	Electivity	
Food organism	Mass	Number
Baetidae nymphs	-.94	+.13
Libellulidae nymphs	-.28	+.86
Corydalidae larvae	+.41	+.84
Hydropsychidae larvae	-.64	+.20
Helicopsychidae larvae	-.88	-.73
Pyralidae larvae	-.90	-.24
Simuliidae larvae	-.72	+.72
Chironomidae larvae	-.97	-.38
Physidae adults	.*	.*
Gammaridae adults	+.05	+.98
Sperchonidae adults	-.94	-.08

* Food organism occurred in diet but not in benthic samples; can be considered a positive value.

Table 6- 31. Electivity indices for invertebrates important in the seasonal diets of flannelmouth suckers (Catostomus latipinnis) in the Paria River, Grand Canyon National Park, Arizona.

Food organism	Winter Mass	Winter No.	Spring Mass	Spring No.	Summer Mass	Summer No.	Fall Mass	Fall No.
	Electivity							
Baetidae nymphs	.-	-	-	.-	*			
Hydropsychidae larvae	.-	-	-.64	-.72	-.09	-.08	-.28	-.94
Simuliidae larvae	.-		.-	.-	.-	-	.*	.*
Chironomidae larvae	.-	.-		.-	*	*	+.77	+.75
Chironomidae pupae	.-		.*	*	-	-	.*	.*
Ceratopogonidae larvae	.-			.-	-	.-	*	.*
Cypridae adults	.-			.-	.-	.-	.*	.*
Gammaridae adults	.-		.-	.-	-		-.76	-.87

* Food organism occurred in diet but not in benthic samples; can be considered a positive value.

Table 6- 32. Electivity indices for invertebrates important in seasonal diets of bluehead suckers (*Catostomus discobolus*) in Havasu Creek, Grand Canyon National Park, Arizona.

	Electivity							
	Winter		Spring		Summer		Fall	
Food organism	Mass	No.	Mass	No.	Mass	No.	Mass	No.
Baetidae nymphs	.-	-	+.56	-.08	-	-	-	-
Simuliidae larvae	.-	.-	+.85	+.74	+.99	+.97	-	.-
Simuliidae pupae	.-	-	+.89	+.24	.*	.*	-	.-
Chironomidae larvae	+.92	+.66	+.99	+.91	.*	*	+.99	+.95
Chironomidae pupae	.*	.*	.*	.*	.*	*	-	-
Cypridae adults	•*	*	•*	*	-	-	*	*

* Food organism occurred in diet but not in benthic samples; can be considered a positive value.

Table 6- 33. Electivity indices for invertebrates important in the seasonal diets of speckled dace (<u>Rhinichthys osculus</u>) in Diamond Creek, Grand Canyon National Park, Arizona.

Food organism	Electivity							
	Winter		Spring		Summer		Fall	
	Mass	No.	Mass	No.	Mass	No.	Mass	No.
Baetidae nymphs	-.14	-.45	-.67	-.78	.*	*	-.29	-.65
Hydropsychidae larvae	-.51	-.54	-.13	-.33	+.96	+.30	.-	.-
Hydroptilidae larvae		.-	-.19	-.53		.-		-
Simuliidae larvae	+.14	+.02	+.72	+.63	*	*	+.86	+.73
Simuliidae pupae	.-	.-	-.06	+.06	.-	.-	.-	
Chironomidae larvae	+.92	+.81	+.32	-.06	*	*	.-	
Chironomidae pupae	.-	.-		.-	.-	.-	.*	*
Stratiomyiidae larvae	-.13	-.48	+.01	-.71	.-	-	.-	

* Food organism occurred in diet but not in benthic samples; can be considered a positive value.

oriented and may fail to detect these resources. Catostomids, on the other hand, often ingest such obscure items as sand and organic detritus. The activities of sympatric fish species may also influence prey selection as the more aggressive fishes may force smaller or non-territorial species into less productive feeding areas (Maitland 1965).

Spawning rainbow trout taken in Bright Angel Creek showed positive electivities for dobson fly larvae, skimmer nymphs, pouch snails and, to a lesser degree, black fly and net-spinning caddisfly larvae. All of these groups are large, active or abundant, and consequently very susceptible to being observed on the bottom. Scuds were also actively selected, indicating that rainbow trout frequently move into the Colorado River to feed since the exotic amphipods are generally rare or absent above the confluence of the tributaries.

Flannelmouth suckers, bluehead suckers and speckled dace showed positive electivities for seed shrimp, micro-caddisflies and midge and black fly larvae. The apparent dependence on small, benthic invertebrates is attributable to the bottom-dwelling habit of these fish. It is doubtful that catostomids select individual prey items. Consequently, positive electivities suggest that flannelmouth and bluehead suckers forage in selected areas rather than feeding at random on benthic debris. Scuds also showed positive electivities in the diets of both catostomid species, which indicates that suckers move between a tributary and the mainstream in order to secure food. Speckled dace appeared to be highly selective predators, as demonstrated by their relatively low consumption of sand and detritus.

In general, those organisms most common and/or detectable in tributary substrates were major food items. Variations in food preference were functions of fish morphology, foraging strategy and habitat requirements.

REPRODUCTION

Reproductive activity of Grand Canyon fishes was determined by gonadal somatic indices, collection of ripe individuals, collection of young-of-the-year fish and, occasionally, by direct observation. Using these methods, reproduction was confirmed for most fish species.

The majority of the Grand Canyon fish species spawn in spring, though there is much intra- and interspecific variation. Salmonids initiate reproductive activities in early fall with their upstream spawning migrations into the higher gradient tributaries. These activities continue until early spring when bluehead suckers and later speckled dace enter these same streams to spawn. The lower gradient streams are used for spawning by humpback chubs, flannelmouth suckers, razorback suckers and carp during spring. These species exhibit a limited degree of spatial overlap during their several month reproductive period.

Salmonids generally begin reproductive activities when tributary water temperatures drop below 12 C, while other species initiate spawning only when water temperatures reach 15 C or higher. Most reproduction ceases by summer when water temperatures go above 20 C, however, a number of species exhibit limited reproduction sporadically throughout the year (Minckley 1979).

The number of eggs per female varied considerably between species, ranging from 262 to 69,303 for exotic species, and from 932 to 14,417 in native fish. These values are similar to other conspecific western populations (Carlander 1969, 1977, McAda 1977).

CONDITION FACTORS AND LENGTH-WEIGHT RELATIONSHIPS

Condition factors are a means of determining the well being or plumpness of fish (Hile 1936). In general, this technique measures the shape of fish and then attributes a value ranging from 0 - 3 to that individual. Values close to zero reflect poor condition, whereas a value of 3.0 reflects "ideal condition." In actuality, these extreme values are seldom achieved since most fish populations have values fluctuating around 1.0 (Cooper 1961).

Length-weight relationships describe growth in fish. This technique allows weights to be determined with only the length measurement, and vice versa (Lagler 1956). The values of the slope "N" will equal 3.0 when growth in isometric, however within a normal population of fish, the slope values range from 2.5 - 4.0 (Ricker 1958). Values less than 3.0 demonstrate that linear growth in occurring at a greater rate than increase in weight, while values greater than 3.0 indicate that weight is increasing faster than length.

Condition factors and length-weight relationships were determined for all gamefish collected during this investigation (Table 6-20). The condition factors for each game species are: rainbow trout (range, .8 - 1.1; mean, .9); brown trout (.8 - .9; .8); brook trout (1.1 - 1.3; 1.2); channel catfish (.9 - 1.3; 1.0) striped bass (.9); largemouth bass (.8 - 1.3; 1.2); green sunfish (1.8 - 2.1; 1.9); and bluegill sunfish (2.2).

Length-weight relationships (Table 6-20) are presented in terms of the slope, N. The slope for each game species was: rainbow trout (range, 2.85 - 2.92; mean, 2.83); brown trout (2.17 - 3.40; 2.93); brook trout (1.99 - 3.71; 3.1); channel catfish (2.76 - 3.45; 2.76); striped bass (3.16); and largemouth bass (2.31 - 3.14; 1.81). Length-weight relationships were not completed for bluegill and green sunfish due to the small sample size.

Gamefish taken in this study conformed to the general pattern, varying around a condition factor of 1.0. Other western populations of these game species also have condition factor values around 1.0 (Bancroft and Sylvester 1978, Carlander 1969, 1977, McDonald and Dotson 1960, Minckley 1972). Variability in the condition factors could be the result of feeding conditions (Bennet 1971), size of fish (Kramer and Smith 1960), species differences (Clugston 1964), growth rates (Clugston 1964) or other factors.

Length-weight relationships showed that most species exhibited almost isometric growth, although some seasonal variations were apparent. The growth patterns of the fish species in this study were similar to those in other western populations (Carlander 1969, 1977, Minckley 1972).

FISH INTRODUCTIONS

Exotic fishes were first introduced into the study area in 1919, prior to the creation of Grand Canyon National Park. These introductions were made by the U. S. Forest Service, but neither the species nor the numbers planted were recorded (Williamson and Tyler 1932). The National Park Service began stocking Grand Canyon tributaries in 1920 by planting brook trout into Bright Angel Creek. In later years, they also stocked Clear and Havasu Creeks with brook trout (Table 6-18). Rainbow trout were first introduced at Tapeats Creek in 1922 by the U. S. Forest Service (Brooks 1932). Subsequently, this species was introduced into several tributaries (Table 6-18) and is now the most common fish stocked into the study area. Stocking of brown trout began in 1924 at Bright Angel Creek and later into Bright Angel and Garden Creeks (Table 6-18).

Introduction of exotic species was stopped by the National Park Service in 1964 after a final stocking of rainbow trout into Bright Angel Creek. The U. S. Fish and Wildlife Service ended their introduction of exotic species after a final planting of rainbow trout into Diamond Creek in 1971 (Table 6-18). No federal agency presently maintains an active program of fish introductions within the study area.

The Arizona Game and Fish Department started an ongoing stocking program in 1964. Since that time, 441,310 rainbow trout, 147,880 brook trout and 20,000 coho salmon have been introduced at Lee Ferry. In 1972, 650 woundf in, a native of the Virgin River, were introduced into the Paria River in an attempt to establish that endangered species. An unknown number of cutthroat trout were planted at Lee Ferry in December 1978. In December 1979, 50,000 cutthroat trout were planted at Lee Ferry.

The success of fish introductions prior to 1964 was apparently limited. Rainbow trout have maintained populations in Tapeats, Havasu and Bright Angel Creeks via limited reproduction and stocking (Brooks 1932, Williamson and Tyler 1932). Brown trout have become established after only four plantings. Brook trout were present in Clear Creek until 1944 based on one extant specimen (National Park Service files). In later years, they have presumably been lost to fishing enthusiasts. At present, brook trout are expanding their range within the mainstream Colorado River due to reintroductions at Lee Ferry.

REASONS FOR THE DECLINE OR NATIVE FISHES AND CURRENT RESTORATION EFFORTS

Factors causing the decline in the native fishes of Grand Canyon are largely recent and due to man's influence on the Colorado River. One hundred years ago, the Colorado River was, in many ways, unpredictable. It was truly the "Red River" of the West, carrying over 100,000 acre feet of sediment to the Colorado Delta each year. Although it was occasionally intermittent, the Colorado could become a raging torrent during spring floods with flows up to 5667 cms. Water temperatures fluctuated seasonally, warming in the spring and summer, and cooling in fall and winter. The fishes of this region adapted to the harsh regime by developing bizarre morphological adaptations, as well as, in one instance, a large body size. Prior to the impoundments, eight fish species lived in the Colorado River system of Grand Canyon. This represented one of the highest rates of endemism in North American fish (Miller 1958).

At present, the Colorado River is totally different from historical times. The deterioration of the natural habitat began with the impoundment of Lake Mead at the western end of Grand Canyon in 1936. In 1963, the entire river system was affected by the construction and operation of Glen Canyon Dam near the eastern boundary of Grand Canyon. The present conditions are characteristic of a controlled river in that it undergoes a diurnal as well as seasonal vertical fluctuation in water levels, based on the hydroelectric power demand. Water flow is highest in spring and summer and lowest in fall and winter. Turbidity is greatly reduced and scouring flows no longer occur. Water temperatures are always cold ($< 14^\circ$ C) and vary little seasonally due to the hypolimnetic water releases from the Glen Canyon Dam. Several exotic species now flourish as a result of their being better adapted or more tolerant to cold and fluctuating water conditions. Two of the original native species (Colorado squawfish and humpback chub), are federally endangered, while two others, the bonytail chub and razorback sucker are proposed for federal endangered and threatened status, respectively. Colorado squawfish and humpback chubs are listed in Group II by the Arizona Game and Fish Department, a designation which states that a "species or subspecies (is) in danger of being eliminated from Arizona." The bonytail chub and razorback sucker are in Group III, "species or subspecies whose status in Arizona may be in jeopardy in the foreseeable future." Of the original ichthyofauna, five species persist, with one, the razorback sucker, being exceedingly rare in Grand Canyon waters.

Reasons for the Decline

The decline in the number of native Grand Canyon fish species is primarily due to the effects of Hoover and Glen Canyon Dams and the impact of exotic species. It has been well documented that large mainstream dams on the Colorado River have been detrimental to native fishes (Holden and Stalnaker 1975a, b, Vanicek 1967, Vanicek and Kramer 1969). Dam operation altered the historical flow regime and water temperatures of the River, destroyed backwater areas and eliminated normal water fluctuations, all of which were detrimental on reproduction of native species. Prior to impoundment of the Colorado River seasonal fluctuations in discharge, sediment concentration and water temperatures played an important role in the reproductive biology of the native fishes. During the high spring flows, many new, although ephemeral, aquatic habitats were created within Grand Canyon. Many of the tributary canyons became ponded, with slow-moving, large, shallow backwaters. "Estuary-like" conditions were created at the confluent zones of these tributaries and extended several hundred meters upstream. These areas were warmer because of the inflowing warmer tributary waters and/or solar insolation. These warm backwater areas played a crucial role in the reproductive cycle of the native fishes, most of which require water temperatures of 15 - 18 C to initiate spawning, while the razorback sucker prefers temperatures of 12 - 18 C. Bonytail and humpback chubs prefer water temperatures of from 15 - 18 C (Holden 1973, Vanicek and Kramer 1969). Flannelmouth suckers spawn at water temperatures of 6 - 12 C and bluehead suckers spawn at temperatures between 6 - 12 C (McAda 1977, Minckley 1978).

Access to backwater areas during spring floods was simple and direct and allowed spawning runs into these habitats in Grand Canyon (Miller 1963) as well as in other areas of the Colorado River (McAda 1977, Minckley 1973, 1979, Seethaler 1978). After spawning, these warm backwater areas and permanent tributaries became valuable nursery areas for development of the young fishes. Today, the various tributaries still serve this function (Minckley 1978). The importance of such backwater areas cannot be stressed enough as it is well known that Colorado squawfish, razorback suckers and bonytail and humpback chubs use these areas as juveniles, prior to moving into the harsher riverine environment (Holden 1977, Holden and Stalnaker 1975a, b, Kidd 1977, McAda 1977, Miller 1971, Minckley 1965, Seethaler 1978). The only juvenile humpback chub collected from the mainstream was in a small ephemeral backwater, created by low water releases, near Granite Rapids (Minckley unpubl. data).

At present, the mainstream Colorado River within Grand Canyon never approaches optimum spawning temperatures for most native species, except during times of low water, when solar insolation creates suitable temperatures in the ephemeral shoal and backwater areas. Consequently, spawning by native cyprinids is, at best, very limited in the mainstream. Native catostomids may spawn in the mainstream since they have a greater tolerance for lower temperatures.

Tributary waters reach optimum temperatures and as such are important spawning sites for the remaining aative fish. Colorado squawfish, bonytail chubs (Miller 1963) and humpback chubs (Minckley 1977) occur well upstream in the Little Colorado River. It is likely that these tributaries functioned as the primary spawning and nursery grounds prior to impoundment.

Water fluctuations have a major impact on Grand Canyon fishes. Since the impoundment of Lake Powell, the mainstream has experienced daily water fluctuations as part of the normal hydroelectric operations. In general, water releases are highest in summer due to peak power demand. These diurnal water fluctuations undoubtedly have a considerable impact on the tributary fauna. For example, the Paria River, at its confluence, is 35 m wide and 2 m deep (est.) at high water. A few hours later, at low water, it is a mud flat, with a channel one meter wide and 4 cm deep (est.). During spring, this river is the spawning grounds for thousands of flannelmouth suckers and the remaining razorback sucker population. However, low water levels render this reproductive effort almost futile by allowing dessication of the spawn. In the mainstream, these fluctuations expose the shoreline on a daily basis and reduce the amount of cover available for smaller fishes. Consequently, juvenile fish are more susceptible to predation and are exposed to colder mainstream water and more current, perhaps before they can readily handle such conditions.

Daily water fluctuations also hinder movement of both native and exotic spawners into tributaries. Minckley (1978) stated that

> The Colorado River flow, as controlled by Glen Canyon Dam, must determine to a large extent the success of the overall yearly reproductive effort. Although no correlation was attempted between the water releases and the number of spawners entering Bright Angel Creek during a given period, it is thought that these parameters would correlate highly. This is suggested because it seems likely that there is an optimum water level at which more fish could enter Bright Angel and Pipe Creeks, as well as other tributaries, because of easier access. Conversely, there is a given Colorado River flow below which access to the spawning areas is denied. If such low flows occurred during the main spawning run, and for an extended period of time, the impact on the trout population could be dramatic.

Movement into or out of tributaries is also affected seasonally with the ease or difficulty of movement being determined by the water levels. Also, Glen Canyon Dam has put an end to the spawning migrations which once occurred within the study area by preventing native fishes from moving downstream to the Paria River or other tributaries.

Secondly, exotic fish affect native species via predation and competition, and are generally better adapted to the altered habitat.

Native species, none of which were endangered, were found in the stomachs of channel catfish, rainbow trout and largemouth bass. The majority of channel catfish containing native fish were taken from the Little Colorado River, the site of the largest humpback chub population in Grand Canyon. This indicates that predation on humpback chubs does occur. Predation on the eggs and larval stages of fishes also occurs, as illustrated by trout eggs and larval bluehead suckers being found in rainbow trout stomachs (Minckley 1978). The ubiquitous and omnivorous carp very likely preys on eggs and larval fishes in the low gradient streams during times [illegible]. Predation on eggs and larval forms is probably a greater threat than competition to native fishes in the lower Colorado River. As descirbed by Minckley (1979)

> I now consider competition for resources that are in short supply to be a secondary [illegible] of extinction of native species.. .almost all declines in native fish populations are directly attributable to predation by small adults or juveniles of introduced kinds upon early life-history stages of indigenous forms. Shoreline and backwater habitats once exclusively available to non-piscivorous juveniles of suckers and minnows now are inhabited by mosquito-fish and young centrarchids, and cropping by those animals destroys the native fauna.

Such predation is still thought to be an important factor, though its importance was probably previously more extensive during equilibration of the native-exotic fish populations. The major predators of Grand Canyon are all introduced species; carp, channel catfish and largemouth bass.

Competitions, as such, exists in many forms and, as defined by Pianka (1978)

> occurs when two or more organismic units use the same resources and when those resources are in short supply... Competition is not an on-off process; rather its level presumably varies continuously as the ratio of demand over supply changes. Thus, there is little, if any, competition in an ecological vacuum, while competition is keen in a fully saturated environment. All degrees of intermediate (levels of competition) exist.

The aquatic habitat of the Colorado River and its tributaries is neither a vacuum nor is it fully saturated, and consequently, competition most likely occurs at varying "intermediate" levels. Though these interactions were not quantified it is likely that competation is most severe during spring and summer when productivity is lowest.

Competition does seem to be occurring between native and exotic fishes during spawning and is most apparent at times of salmonid reproduction in the tributaries. Minckley (1978) observed that the native fish and smaller salmonids were not present in tributaries such as Pipe, Phantom and Bright Angel Creeks when salmonids were spawning. This was observed to a lesser degree during this investigation due to our smaller number of sampling dates. The competition observed in both studies was not for spawning areas, but for space, and reflected the agrressive actions of the large spawning rainbow trout against smaller fish. This resulted in native and smaller fish leaving the respective tributary or becoming very secretive and difficult to collect. This pattern, which was observed in all of Minckley's (1978) tributaries, varies with the year and tributary. Competition for space may also occur between native and exotic fish throughout the Grand Canyon, since the exotic species are generally more aggressive than native fish, and thus may exclude them from areas where they previously occurred.

Another factor allowing exotic fish to survive better than native species isthat the former are better adapted to the altered environment. Two of the most common exotic fish in the Grand Canyon, the carp and rainbow trout, are examples of this. The carp is a true generalist, occurring worldwide and thriving within almost every conceivable aquatic habitat. Grand Canyon waters are no exception to this [illegible] their high densities. Most carp in the study are though to be upstream migrants from Lake Mead, since reproductive attempts in Grand Canyon are apparently unsuccessful. Salmonids are very well adapted to living in the cold, fluctuating waters of the study area.

Maintained initially by stocking, they now have established spawning runs into several tributaries. This intercanyon reproduction may be supporting the salmonid fisheries of Grand Canyon.

All exotic species within Grand Canyon are assured a continued existence if the current conditions remain unchanged. Lake Powell and Lake Mead constitute perpetual source areas for exotics. Introductions also occasionally occur from the upstream areas of several of the major tributaries, i. e., the Little Colorado River and Kanab Creek. Furthermore, the Arizona Game and Fish Deparment continues to stock salmonids at Lee Ferry, resulting in their continued presence in Grand Canyon. Native fishes have no such quarantees of a continued existence given these conditions.

Restoration Efforts

Recovery Plans

The purpose of a recovery plan is to restore and maintain self-sustaining populations of a given species to a delisted or non-listed state in their native ecosystem. The Colorado squawfish recovery plan was approved in March 1978, while the humpback chub recovery plan was approved during April 1979. At present, no recovery plans are being prepared on the bonytail chub and razorback sucker. In May 1978, the National Park Service closed the Little Colorado River to fishing in order to eliminate that particular threat to the humpback chub population. The area closed included the lower 1.6 km of the tributary and 0.8 km upstream and downstream from its confluence.

Propagation

Currently, the Colorado squawfish and razorback sucker have been successfully spawned at Willow Beach National Fish Hatchery. In March 1978, four adult and 15 juvenile humpback chubs caught during this project were shipped to Willow Beach National Fish Hatchery for initiation of propagation studies. To date, this species has not been induced to spawn. Two female bonytail chubs are being held at Willow Beach until males of this species can be obtained for spawning purposes.

Reintroductions

To date, three transplants of about 100 Colorado squawfish each have been made from the stock held at Willow Beach. These transplants were made at Hotchkiss National Fish Hatchery, Colorado; Chino National Fish Hatchery, California, and Copper Badin Wash in California. The Colorado squawfish recovery team recommended that this species also be placed in the Salt River, Arizona and the San Juan River of New Mexico-Colorado-Utah during fall 1978. Prior to the implementation of this reintroduction, the states of Arizona and New Mexico permission. Consequently, neither of these localities were stocked and plans for the stocking of Colorado squawfish have been temporarily halted.

CHAPTER 7

CREEL CENSUS

Introduction

As a result of fish introductions and major stocking efforts by the National Park Service and the Arizona Game and Fish Department (AGF), substantial populations of rainbow, brook and brown trout (*Salmo trutta*) now exist within Grand Canyon. There are a number of locations within Grand Canyon that provide remarkable trout fishing opportunities. These areas include the Colorado River itself as well as several canyon streams (i. e., Clear, Bright Angel, Shinumo, Tapeats and Havasu Creeks) that are not all equally accessible. At two points between Glen Canyon Dam and Lake Mead (Lee Ferry and Diamond Creek), the Colorado River is accessible by motor vehicle. The only angler use studies conducted in this region have been at Lee Ferry and the Glen Canyon Dam Tailwaters (Bancroft and Sylvester 1978), areas not at all indicative of angler use in the rest of Grand Canyon.

Since 1972, there have been at least 55,000 visitors per year reaching the inner gorge of the Grand Canyon. Of these visitors, 15,000 are river runners (Carothers et al. 1976) and the remaining 40,000 are day hikers and backpackers (Grand Canyon Complex, Proposed Master Plan, 1975). In 1977, 82,952 people visited Lee Ferry and an unknown number of people came to Diamond Creek on the Hualapai Reservation. With the exception of Lee Ferry (Bancroft and Sylvester 1978), none of these records show the extent of angler use. This study was undertaken to provide angler use information for Grand Canyon National Park and to determine the following: 1) The number of angler days expended, 2) angler selectivity of species, 3) total harvest, and 4) species composition of harvest. This report considers only those areas of Grand Canyon with easy to moderate public access. Other Canyon trout streams that are more difficult to access (e. g., Clear, Shinumo, and Tapeats Creeks) are not addressed in this report since they are probably not visited by more than a few people each year.

Results

Bright Angel Creek:

Weekday and weekend statistics (Appendix 7-1) have been compiled for comparison with other studies. However, due to sample size, only monthly statistics will be discussed herein.

Angler Composition. During the census period, a total of 126 anglers were surveyed at Bright Angel Creek in Grand Canyon. The mean number of anglers was highest in December (9.00 anglers per day). However, the greatest number of anglers were censused during the month of January (41 anglers when total angler hours was also greatest (159.9)). The number of anglers decreased through February and March. During the census period, 89% of the interviewed anglers (N = 85) were Arizona residents. However, during the month of November, 16% more nonresidents were censused than residents (N = 26). Nonresident anglers (N = 59) represented 11 states, with the majority being from California (32%) and New Mexico (20%). The remaining nine states represented were Illinois, Maryland, Michigan, Montana, Nevada, New Jersey, New York, Ohio and Texas.

Catch Composition. During the census period, 41% of the 205 fish caught were released. Of the 121 fish kept, 97% were rainbow trout and 3% were brown trout. Mean total lengths of 415 mm and 251 mm were calculated for rainbow trout and brown trout, respectively. The mean length of rainbow trout in the Creek varied from 439 mm in January. to a low of 239 mm in March. The mean weight for rainbow and brown trout was 1.04 and 0.25 kg, respectively.

Angler Success and Catch Rate. The 126 anglers censused fished for an estimated total of 417.15 hours (equation 2, Appendix 2-1) . The length of an average angler day (equation 1; Appendix 2-1) varied from 1.92 hours in March to 3.90 hours in January. During the census, a relatively high percentage of success was achieved, with 56% of the anglers taking at least one fish (range 70% in November to 44% in January). Catch per person hour (CPPH) was also relatively high (0.49 fish per hour), showing peaks in December (0.85 fish per hour) and March (1.56 fish per hour). January and February showed much lower catch rates of 0.17 and 0.33 fish per hour, respectively. Rainbow trout appeared in the creel at an average of 0.28 fish per hour, while brown trout averaged only 0.01 fish per hour. No brown trout appeared in the December and January creels.

Angler Pressure. Although the greatest number of angler hours (991.38) were expended during the month of January, the greatest number of angler days (279.00) occurred in December. Angler days per month and harvest per month showed similar trends peaking in December, declining through January and February with an upward turn in March.

The percent of all visitors fishing peaked at 14% (N total = 1763) in January and decreased to lows in November and March (7%, N = 2653, and 6%, N = 2784, respectively).

A major portion of angler pressure was concentrated at the confluence of Bright Angel Creek, where 41% of the successful angler hours (N = 417.15) were expended by 42% of the successful anglers (N = 70). The Campground, Phantom Ranch, and the Upper End had moderate angler pressure, where 17%, 14%, and 16% of the successful angler hours were spent, respectively. The Lower End and the Bridge experienced far less pressure than the other areas with only 4% and 7% of the successful angler hours, respectively. Forty-nine percent of the total harvest (N = 1826) was taken at the confluence and only 15% from Phantom Ranch, the second highest contributor.

Angler Methods and Techiques. Ninety-four percent of the anglers interviewed preferred casting to any other method of fishing (i. e. trolling or still fishing). The majority of the anglers preferred bait fishing while the remainder used lures or flies. The types of bait used included cheese, corn, worms, helgramites, and salmon eggs, with the latter being preferred by 70% of the anglers.

Lee Ferry and Glen Canyon Dam Tailwaters:

Total angler days (10,395; Table 7-1), as calculated by AGF for the period July 1977 to June 1978, was similar to total anglers (10,346) as determined by the National Park Service for the same period. According to AGF, total angler hours (45,878) and angler days (10,395) as recorded for 1977 - 1978, have increased appreciably from the 1960's and early 1970's (Table 7-1).

Table 7-1. The Colorado River Glen Canyon Tailwater Fishery, Coconino County, Arizona, 1963-1978 (modified from Bancroft and Sylvester, 1978)*.

Year	1963-1964	1964-1965	1965-1966	1966-1967	1967-1968	1968-1969
Angler Hours	9,766	15,732	11,424	18,952	22,829	11,717
Angler Days	2,477	4,161	2,681	4,430	4,161	3,337
Trout Caught*	10,654	13,512	7,757	7,899	6,597	4,082
Other Species**	98	985	138	695	2,638	945
Trout/hour	1.09	0.86	0.68	0.42	0.29	0.35
Total Harvest (all species)	10,752	14,497	7,895	8,594	9,235	5,027
Trout as a % of Total Harvest	99	93	98	92	71	81

(continued)

Table 7-1 (cont.) The Colorado River Glen Canyon Tailwater Fishery, Coconino County, Arizona, 1963-1978 (modified from Bancroft and Sylvester, 1978)*.

Year	1969-1970	1970-1971	1971-1972	1977-1978	Total	Mean
Angler Hours	17,563	15,620	16,595	45,878	186,067	18,606
Angler Days	3,808	3,290	3,518	10,395	42,321	4,353
Trout Caught*	8,016	8,421	4,372	7,854	79,164	7,916
Other Species**	57	24	44	0	5,624	562
Trout/hour	0.46	0.54	0.26	0.17	5.34	0.53
Total Harvest (all species)	8,073	8,445	4,416	7,854	84,788	8,478
Trout as a % of Total Harvest	99	99	99	100	93	93

Rainbow Trout and Eastern Brook Trout Combined.

** Channel Catfish and Others.

Total harvest as reported by AGF for the 1977 - 1978 period came to 7,854 fish. This represents an increase over the 4,416 fish taken in 1971 - 1972, but a decrease from the 10,752 fish taken during 1963 - 1964, the first year of the fishery. Ninety-three percent of the total harvest = 84,788) for the ten years of data presented consisted of trout, with the remaining 7% probably representing channel catfish (*Ictalurus punctatus*). The total number of trout taken was highest in 1964 - 1965 (13,512 trout). This number declined through 1969 and has since remained at about 8000 trout per year except for 1971 - 1972 when only 4372 trout were caught (Table 7-1). Trout taken per hour was highest in 1963 - 1964, with 1.09 trout being taken per angler hour. This catch per angler hour dropped steadily to a low of 0.17 in 1977 - 1978, this primarily due to the increase in angler hours (Table 7¯1).

Diamond Creek; Hualapai Reservation:

According to the office of HWLOR, 16 fishing permits were issued for Diamond Creek at its confluence with the Colorado River during the months of November and December 1977. In the months of January, February and March of 1978, there was little angler activity due to increased river turbidity and poor road conditions. No further information was provided.

Colorado River Expeditions:

An estimated average of only 0.38 anglers per trip (202.54 anglers per year) go down the Colorado River through Grand Canyon on commercial expeditions. Total harvest by these anglers was estimated at 0.82 fish per trip or 437.06 fish per year. The harvest consisted of trout, channel catfish, and carp (*Cyprinus carpio*), with trout being the major component. Tapeats, Deer and Havasu Creeks appear to be the most heavily utilized areas by expedition anglers, whereas the mainstream Colorado through Marble and Grand Canyons receives sporadic use.

Discussion

Bright Angel Creek:

Only in the last several years has the general public become aware of the trout fishery at Bright Angel Creek. Eight years ago, a creel census clerk would have been lucky to find one or two anglers fishing along Bright Angel Creek during the trout spawn (B. Topping, angler, pers. comm.). Prior to 1976, anglers came to the Canyon for its trout fishery, however their visits were seldom synchronized with the spawning runs of the trout. As the fishery's reputation has spread, and the spawning period has become more widely known, as many as 25 anglers may be found during the spawn, competing for the better fishing spots along Bright Angel Creek (B. Topping, pers. comm.).

Personal observation, discussions with Inner Canyon rangers and the literature (Minckley 1978) all indicate that the most intense period of the trout spawn occurs during November, December and early January. During the study period, angler pressure, represented by angler days, closely coincided with the trout spawn. The number of total angler hours and total estimated angler days were also high during the spawn. Early in March, heavy rains resulted in flood conditions at Bright Angel Creek and the closing of trails into the Canyon. These factors, in conjunction with an apparent decrease in spawn intensity, may explain the decrease in angler days in February and March.

Bright Angel Creek provides the general public (i. e., those who are willing to make the hike or take the mule train) with an exceptional Inner Canyon fishery . As indicated by the catch composition (97% rainbow trout, 3% brown trout), anglers come to Bright Angel Creek for its trout. Although Bright Angel Creek is a small fishery, as exemplified by the total estimated harvest (1826 fish during the census period), several of the angler statistics (e. g., mean fish length, percent successful anglers, and CPPH)rank with or exceed larger quality fisheries such as those at Lee Ferry and the Glen Canyon Dam Tailwaters.

The results obtained during the March sampling period appear to deviate substantially (e. g. 1.56 CPPH) from those of the four previous months. This may be attributable to several factors, but is most probably due to sample size (number of interviews). In order to obtain acceptable results from which reasonably reliable conclusions can be drawn, the surveyor should obtain a sample representing 10% of the population (D. Bancroft,pers. comm.). Although the four months prior to March fall within this range, the March sample represents only 6% of the visitation for that month. The results from the March sample are, therefore, of limited value. Sampling only successful anglers may appear to bias the results from all five months, resulting in a slight over-estimate. In comparison with other studies of a similar nature, however, this difference should prove insignificant (D. Bancroft, pers. comm.).

Lee Ferry and Glen Canyon Dam Tailwaters:

The trout fishery of Lee Ferry and the Glen Canyon Dam Tailwaters is utilized by anglers from the entire Southwest. This popular trout fishery has experienced a dramatic increase in angler use since 1972. The number of angler days has increased threefold during the past six years.

Through the efforts of the AGF, the trout fisheries at Lee Ferry and the Glen Canyon Dam Tailwaters have been maintained as one of the quality fisheries of the Southwest. All of the 7,854 fish taken from these waters during the 1977 - 1978 AGF census were trout. Although the catch rate (fish/hour) has dropped since the inception of the fishery (1.09 in 1964 to 0.17 in 1978), the average fish taken has increased substantially in size from 0.31 pounds in 1964 to 1.70 pounds in 1978.

Diamond Creek; Hualapai Reservation:

Due to the lack of available information, any discussion of angler activity at this location would be pure conjecture. Angler activity occurs at the confluence of Diamond Creek and the Colorado River (personal observation) to an unknown extent.

Colorado River Expeditions:

Although fishing does occur during Grand Canyon river expeditions, it is "sporadic at best" (anonymous reply). Two outfitters indicated an average of one to two anglers per trip, while the remaining responses indicated an average of between zero and one angler per trip. Some outfitters actively discourage passengers who show an interest in fishing on river expeditions, while other passengers may be discouraged by the high cost of Arizona fishing licenses for nonresidents. For most people, Colorado River expeditions are adventures rather than fishing trips.

River running is limited almost exclusively to the late spring and summer months when fishing is poor due to turbid river conditions and the absence of spawning trout in the tributaries. The estimated harvest by the river running public was low (437.06 fish during the river season), even in comparison with that of Bright Angel Creek during the spawn. Although most anglers prefer trout or catfish, carp tend to appear occasionally in the catch.

An estimate of angler days has not been provided due to the inaccuracies which would arise by calculating that figure from the available data. Due to the subjective nature of the estimates of angler pressure during commercial raft trips provided in this section, extreme caution should be exercised in their utilization.

Conclusions and Recommendations

The extent of angler activity in Grand Canyon is not fully understood. Bright Angel Creek as well as a number of other locations throughout Grand Canyon National Park provide the general public with quality trout fisheries. Due to differences in accessibility, angler use varies considerably at these locations. Although this study provides the first coverage of an inner canyon fishery, a great deal remains to be learned.

Over the past six years, angler use of Grand Canyon has increased substantially and may continue to grow. Therefore, it is essential to gain a better understanding of this resource in order to avoid degradation of these quality fisheries, provide uses consistent with N.P.S. mandates and manage wisely. Therefore, we recommend the following:

1) Continue creel census investigations of Bright Angel Creek to further document angler activity and to substantiate the findings of this study;

2) Extend the census period to encompass the entire year;

3) Initiate angler use studies of other inner canyon tributaries, including Diamond Creek.

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Our study area was set within one of the most beautiful areas known to man, yet our work tasks left little time for pondering the philosophically rewarding aspects of canyon beauty. Most of our crew had traveled the Colorado River many times during previous National Park Service investigations, but we were always careful to keep our distance from the cold, turbulent waters of this powerful and truly frightening river. This project required a certain intimacy with the river none of us had tempted before. We were after the river's fish, and we were after them with every collecting device known, save explosives. To this end, we could not have completed our mission without taking some calculated risks.

Tomas Olsen, George Ruffner and Philip Shoemaker not only piloted our boats, but joined the rest of the team during winter wet suit swims as we pursued the fish with trammel, trap and gill nets and great lengths of heavy seines. To their credit, these brave lads complained little when the powerful electric field of our boat mounted and backpacking electrofishing devices came frighteningly close to their net stations. Norman G. Sharber, principal counsel to all matters of importance to the project built from the most basic components, an extremely compact electrofishing unit that could withstand the rigers of a Colorado River run and still deliver a pulsed DC current so successfully that we were finally capturing hundreds of fish at a time.

Others who contributed to project field work were Marvin Jensen and Stephen Martin of the National Park Service at Grand Canyon. Drs. W. C. Minckley, Arizona State University, Dean Blinn, Northern Arizona University, J. E. Johnson and William Miller, U.S. Fish and Wildlife Service all contributed to various aspects of the biological questions we were pursuing. Terry McCall and Dave Bancroft, Arizona Game and Fish Department, also gave willingly of their advice throughout the project.

Gene Herzog and Joe Madrigal, Water and Power Resources Services provided photographic coverage of two expeditions and some of their photographs have been included in this document. Gary Bryant and Gordon Mueller, also of Water and Power Resources Services, provided our liaison with their bureau and in addition to extensively reviewing a first draft of the report, they gave freely of their patience waiting for the final. The first draft editorial review by Gordon Mueller and Dr. William Miller allowed substantial improvements in our final product.

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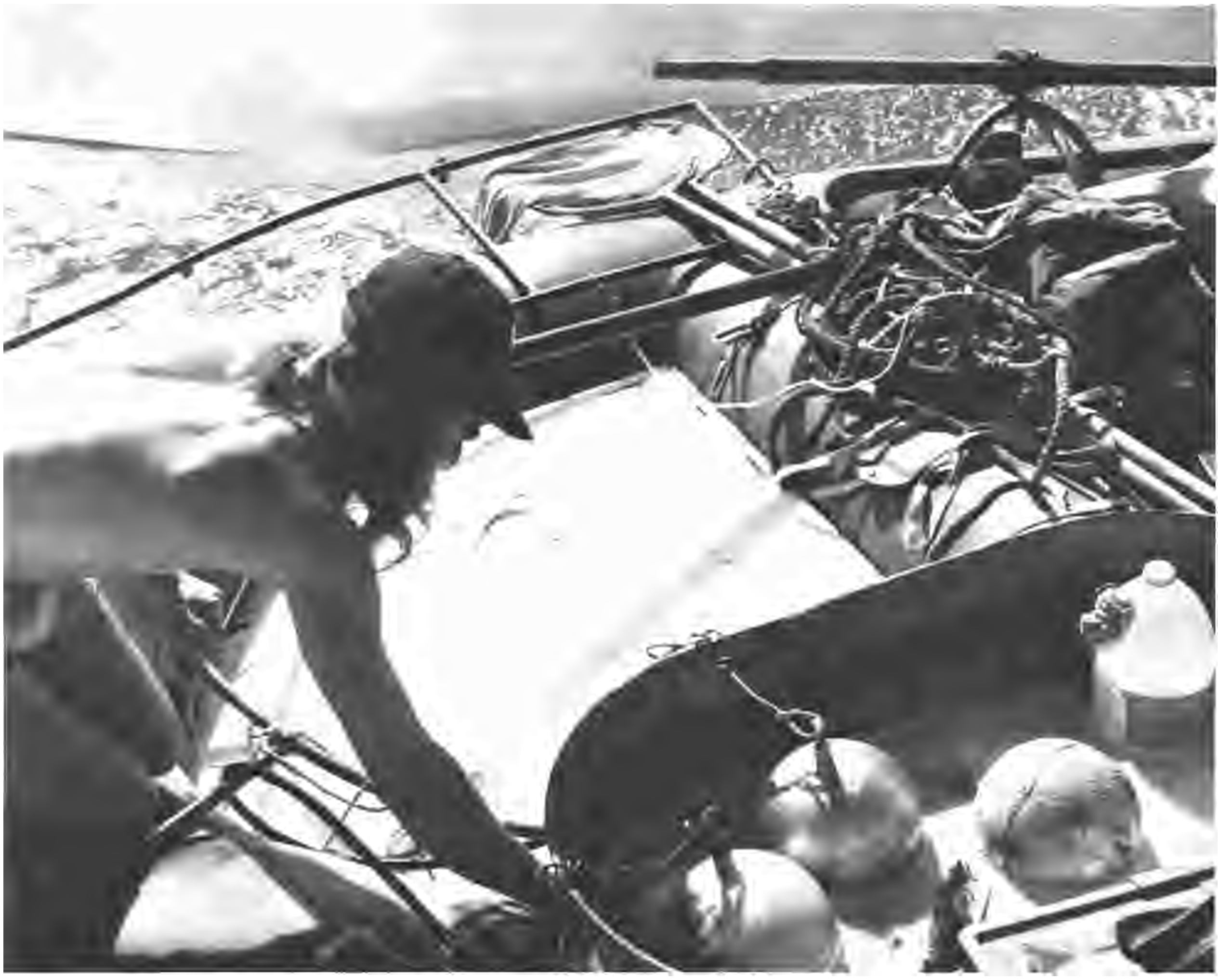
1. Lee Ferry, Colorado River Mile 0, Arizona. Preparations prior to March river expedition. The two boats in foreground are 17 ft. Havasu II inflatable rafts, the two larger boats in center of photograph are 22 ft. snout boat catamarans constructed from inflatable surplus beige pontoons.

2. Colorado River near River Mile 638.6.

3. Electrofishing from Havasu II in lower gorge of Grand Canyon area near River mile 588.6. From left, Marvin Jensen, Chief of River Unit, Grand Canyon National Park; Steven W. Carothers, project co-principal investigator; Thomas Olsen, project boatman/biologist; Phillip Shoemaker, project boatman/biologist.

4. Expedition boats and electrofishing gear on River near River Mile 603.6. From left: C. 0. Minckley, project co-principal investigator; S. W. Carothers; G. A. Ruffner, project biologist/boatman; N. G. Sharber, electrician; Howell Usher, project biologist.



5. Electrofishing boat. Note the three spherical copper electrodes.

6. Electrofishing boat in operation. From left: James Jordan, project biologist (operating electrofishing unit); Thomas Olsen; C. 0. Minckley.

7. The results of 10 minutes electrofishing in "carp eddy" near River Mile 508.6.

8. Quantitative sampling of aquatic invertebrates in side-stream. Greg Hofknecht, project biologist.

9. Removing algae (Cladophora) from trammel nets. For each 24 hours of trammel net fishing, the crew spent as many hours picking algae from the nets before they could be used again. From left: C. 0. Minckley, N. G. Sharber, Phillip Shoemaker; Steven Martin, River ranger, Grand Canyon National Park.

10. Helicopter evacuation of humpback chub (Gila cypha) which are air-lifted alive from the mouth of the Little Colorado River to the South Rim where they were then transported by automobile to the Willow Beach Fish Hatchery near Boulder City, Nevada, for propagation purposes.

11. Adult humpback chub at Willow Beach Fish Hatchery. Individual one of adults air-lifted from the Little Colorado River.

12. January sampling of mouth of Little Colorado River with 60 ft. bag seine. Note the wet suits. From left: C. O. Minckley; G. A. Ruffner; Nicholas Czaplewski, project biologist; Thomas Olsen.

13. Closing 60 ft. bag seine at mouth of Little Colorado River. From left: G. A. Ruffner, S. W. Carothers, Howell Usher, C. O. Minckley and Thomas Olsen.

14. House Rock Rapid, Colorado River, River Mile 670.6.

15. Lava Falls Rapid, Colorado River Mile 509. Moving from one study site to the next. From left: Phillip Shoemaker; Gloria Griffith Hardwick, project biologist; Joe Mulnix.

16. Checking the nets. Swedish gill net at the mouth af the Little Colorado River.

17. Processing the day's specimens on beach near Phantom Ranch, Colorado River Mile 601.6. From left: Nicholas Czaplewski, Steven W. Carothers, Phillip Shoemaker.

18. Havasu Creek, near its confluence with the mainstream river at Colorado River Mile 631.6.

19. Pierce Ferry, Lake Mead, Arizona. De-rigging boats at trip's end on Lake Mead. From left: L. T. Green, project biologist; C. 0. Minckley.

20. South Rim view of Colorado River and central Grand Canyon. From Lee Ferry to the Grand Wash Cliffs, the River cuts through 275 miles of the southern Colorado Plateau.

Appendix 1-1. Metric - English conversions.

Length

1 kilometer = .62 miles

1 meter = 3.28 feet

1 meter per kilometer = 5.28 feet per mile

Area

1 square kilometer = .386 square miles

Volume

1 $meter^3$ per second = 35.29 $feet^3$ per second

1 liter per second = 15.84 gallons per minute

Mass

1 metric ton = 1.10 tons

Temperature

F = 32 + 9/5 ^{o}C

Appendix 2-1. Equations for the calculation of angler use and angler pressure for the Bright Angel Creek Creel Census, November 1977 to March 1978.

Length of Average Angler Day*:

(1); Total hours checked · total anglers checked =

Total Angler Hours**:

(2); Total anglers creeled x length of average angler day =

Catch Per Person Hour** (CPPH):

(3); Total number of fish caught ÷ total angler hours =

Total Angler Pressure (Angler Hours Per Month)**:

(4); [(Total anglers creeled ÷ number of days checked) x length of average angler day] x number of days in the month =

Total Angler Pressure (Angler Days Per Month)**:

(5); Total angler pressure (anglers hours per month) ÷ length of average angler day =

Total Angler Pressure (Harvest Per Month)**:

(6); (Number of fish caught number of days checked) x number of days in the month =

Total Angler Pressure (CPPH Per Month)**:

(7); Total angler pressure (harvest per month) ÷ total angler pressure (Angler hours per month) =

* Figure based on actual interview data, not an estimate.

** Estimates based on interview data.

Appendix 2-2. Equations for the calculation of angler pressure during commercial raft trips; Colorado River, Grand Canyon, Coconino and Mohave Counties, Arizona.*

Total Anglers: Mean Per Trip;

(1) ($\bar{x}$ anglers/trip/company) number of companies =

Number Per Trip;

(2) $\bar{x}$ number of anglers per trip x total number of commercial trips per year** =

Harvest: Mean Per Trip;

(3) [anglers/trip x #fish/angler) x #trips] ÷ total #trips =

Number Per Trip;

(4) $\bar{x}$ harvest/trip x #trips/year =

Angler pressure estimated from commercial river expedition, angler use survey questionnaire.

** National Park Service, Draft Colorado River Management Plan, October 1977.

Appendix 4- 1 . List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Equisetaceae "horsetail family"
- Equisetum arvense L. "bottle brush"
- X E. hiemale L. var. affine (Englem.) A.A. Eaton "scouring-rush"
- X E. laevigatum A. Braun "smooth scouring-rush"

Polypodiaceae "fern family"
- Adiantum capillus-veneris L. "maidenhair fern"

Typhaceae "Cat-tail family"
- X Typha domingensis Pers. "southern cat-tail"
- X Typha latifolia L. "broad-leaved cat-tail"

Sparganiaceae "bur-reed family"
- Sparganium emersum. Rehm. var. multipedunculatum (Morong) Reveal (S. angustifolium Michx.) "bur-reed"

Potamogetonaceae "pondweed family"
- * Potamogeton crispus L. "curled pondweed"
- P. diversifolius Raf.
- P. foliosus Raf. "leafy pondweed"
- Potamogeton natans L. "broad-leaved pondweed"
- * P. pectinatus L. "sago pondweed"

Zannichelliaceae "horned pondweed family"
- * Zannichellia palustris L. "common poolmat"

Alismataceae "water-plantain family"
- Alisma triviale Pursh "water plantain"
- Sagittaria cuneata Sheld. "arrowhead"

Hydrocharitaceae "frogs-bit family"
- * Elodea canadensis Michx. "water weed"

Poaceae "grass family"
- Agropyron repens (L.) Beauv. "quackgrass"
- A. smithii Rydb. "western wheatgrass"
- A. subsecundum (Link) Hitchc. "bearded wheatgrass"
- X A. trachycaulum (Link) Malte "slender wheatgrass"
- Agrostis exarata Trin. "spike bent"
- A. idahoensis Nash. "Idaho red top"
- A. scabra Willd.
- X A. semiverticillata (Forsk.) C. Chr. "water bent"
- A. stolonifera L. (A. alba L.) "red top"
- X A. stolonifera L. var. palustris (Huds.) Farw. (A. palustris Huds.) "creeping bent"
- Alopecurus aequalis Sobol. "short-awn foxtail"
- A. geniculatus L. "water foxtail"
- X Andropogon glomeratus (Walt.) B.S.P. "bushy beardgrass"
- X Arundo donax L. "giant reed"
- Beckmannia syzigachne (Steud.) Fern "American sloughgrass"
- X Bothriochloa barbinodis (Lag.) Hexter (Andropogon barbinodis Lag.)
- X Bromus catharticus Vahl. "rescue brome"
- X B. japonicus Thurb. "Japanese chess"
- B. richardsonii Link. "fringed brome"
- X B. rubens L. "red brome"
- X B. tectorum L. "downy chess"
- Calamogrostis canadensis (Michx.) Beauv. "blue joint"
- C. inexpansa Gray "northern reed grass"
- X Cenchrus insertus M.A. Curtis (C. pauciflorus Benth.) "field sandbur"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Poaceae (cont.)

X Cynodon dactylon (L.) Pers. "Bermuda grass"
X Dactylis glomerata L. "Orchard grass"
Danthonia intermedia Vasey. "Timber oatgrass"
Deschampsia caespitosa (L.) Beauv. "tufted hairgrass"
Digitaria sanguinalis (L.) Scop. "common crabgrass"
X Distichlis spicata (L.) Greene var. stricta (Torr.) beetle [D. stricta (Torr.) beetle] "desert" saltgrass"
X Echinochloa crusgalli (L.) Beauv. "barnyard grass"
X Elymus canadevisis L. "Canada Wild rye"
E. triticoides Buckl. "beardless wild rye"
Eragrostis cilianensis (All) Mosher "stink grass"
E. pectinacea (Michx.) Nees.
* Erianthus ravennae (L.) Beauv. "Ravenna grass"
X Festuca pratensis Huds. (F. elatior L.) "meadow fescue"
Glyceria borealis (Nash) Batchelder "northern Mannagrass"
G. striata (Lam.) Hitchc. "fowl manna-grass"
Hierochloe odorata (L.) Beauv. "sweet grass"
X Hilaria jamesii (Torr.) Benth. "Galleta"
Hordeum brachyantherum Nevski. "meadow barley"
X H. jubatum L. "fox-tail barley"
X Imperata brevifolia Vasey "satintail"
Lolium multiflorum Lam.
L. perenne L.

Poaceae (cont.)

X Muhlenbergia asperifolia (Nees and Mey.) Parodi "scratchgrass"
Muhlenbergia filiformis (Thurb.) Rydb. "Pull-up Muhly"
M. minutissima (Steud.) Swallen "Minute Muhly"
M. racemosa (Michx.) B.S.P.
M. richardsonis (Trin.) Rydb. "Mat Muhly"
M. sylvatica Torr.
X Oryzopsis milacea (L.) Benth and Hook. "smilo grass"
Panicum bulbosum H.B.K. "bulb panicum
X P. capillare L. var. occidentale Rydb. "witchgrass"
P. obtusum H.B.K. "vine mesquite"
P. virgatum L. "switchgrass"
Phalaris arundinacea L. "reed canary grass"
Phleum alpinum L. "Alpine Timothy"
P. pratense L. "Common Timothy"
X Phragmites australis (Cav.) Trin. (P. communnis Trin.) "common reed"
X Poa annua L. "annual bluegrass"
P. compressa L. "Canadian bluegrass"
P. interior Rydb. "inland bluegrass"
P. pratensis L. "Kentucky bluegrass"
P. reflexa Vasey and Scribn. "nodding bluegrass"
X Polypogon interruptus H.B.K. "ditch polypogon"
X Polypogon monspeliensis (L.) Desf. "rabbitfoot grass"
X Schizachyrium scoparium (Michx.) Nash (Andropogon scoparius Michx.) "Little bluestein"
Setaria glauca (L.) Beauv. (S. lutescens (Wiegel) Hubb) "yellow bristlegrass"

(continued)

Appendix 4- 1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Poaceae (cont.)
- S. verticillata (L.) Beauv. "bur bristlegrass"
- Sorghum halapense (L.) Pers. "Johnson grass"
- Sphenopholis Obtusata (Michx.) Scribn. "prairie wedgegrass"
- X Sporobolus cryptandrus (Torr.) Gray "sand dropseed"
- S. flexuosus (Thurb.) Rydb. "Mesa dropseed"
- * S. giganteus Nash. "giant dropseed"
- S. texanus Vasey

Cyperaceae "sedge family"
- X Carex aquatilis Wahl.
- C. athrostachya Olney
- C. curatorium Stacy
- C. douglasii Boott.
- C. festivella Mack.
- C. geophila Mack.
- C. hassei Bailey
- C. haydeniana Olney
- X C. hystricina Muhl. "porcupine caric-sedge"
- C. lanuginosa Michx. "wooly sedge"
- C. microptera Mack.
- X C. nebraskensis Dewey
- C. occidentalis Bailey
- -C. praegracilis W. Boott. "clustered field sedge"
- C. rostrata Stokes "beaked sedge"
- C. scoparia Schk.
- C. senta Boott.
- C. thurberi Dewey
- X Cladium californicum (Wats.) O'Neill. "sawgrass"
- Cyperus aristatus Rottb. "flat sedge"
- C. erythronhizos Muhl.
- C. esculentus L.
- Eleocharis acicularis (L.) R. & S. "spike rush"
- X E. macrostachya Britt.

Cyperaceae (cont.)
- X E. parishii Britt
- E. radicans (Poir.) Kunth
- X E. rostellata (Torr.) Torr.
- Fimbristylis thermalis Wats.
- X Scirpus acutus Muhl. "hardstem bulrush"
- X S. americannus Pers. "three-square bulrush"
- X S. olneyi Gray
- * S. paludosus A. Nels. "salt-marsh bulrush"

Palmae "palm family"
- * Phoenix dactylifera L. "date palm"

Lemnaceae "duckweed family"
- Lemna minimia Phil.

Juncaceae "rush family"
- X Juncus acutus L. var. sphaerocarpus Engelm. "spiny rush"
- * J. articulatus L. "jointed rush"
- J. badius Saksd.
- X J. balticus Willd. var. montanus Engelm "wire rush"
- J. bufonius L. "toad rush"
- J..confusus Coville
- J. interior Wieg.
- J. mertensianus Bong.
- X J. mexicanus Willd.
- X Juncus saximontatus A. Nels. forma brunnescens (Rydb.) Herm.
- J. tenuis Willd. "slender rush"
- X J. torreyi Coville
- J. xiphioides E. Mey.

Liliaceae "lily family"
- Smilacina stellata (L.) Desf. "star-flower
- Veratrum californicum Durand. "corn lily"
- Zigadenus elegans Pursh. "White camas"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Iridaceae "iris family"
- X <u>Sisyrinchium demissum</u> Greene "blue-eyed grass"

Orchidaceae "orchid family"
- X <u>Epipactis gigantea</u> Douglas ex Hook. "giant helleborine"
- <u>Habenaria sparsiflora</u> Wats. "sparsely-flowered bog orchid"
- <u>Spiranthes romanzoffiana</u> Cham. "hooded ladies tresses"

Saururaceae "lizard tail family"
- <u>Anemopsis californica</u> (Nutt.) H. and A. var. <u>subglabra</u> kelso "Yerba Mansa"

Salicaceae "willow family"
- <u>Populus angustifolia</u> James. "narrow-leaf cottonwood"
- X P. fremontii Wats. "Fremont cotton-wood"
- <u>Salix bebbiana</u> sarg. "Bebb willow"
- S. bonplandiana H.B.K. "bonpland willow"
- X S. <u>exigua</u> Nutt. "coyote willow"
- S. <u>geyeriana</u> Andress. "geyer willow"
- X S. <u>gooddingii</u> Ball "Goodding willow"
- X S. <u>laevigata</u> Bebb. "red willow"
- S. <u>lasiandra</u> Benth. "Pacific willow"
- S. <u>lasiolepis</u> Benth. "Arroyo willow"
- S. <u>lutea</u> Nutt. ex Schneider "yellow willow"
- S. <u>scouleriana</u> Barratt ex Hook. "scouler willow"

Juglandaceae "walnut family"
- <u>Carya illinoinensis</u> (Wang.) K. Kock "pecan"
- X <u>Juglans major</u> (Torr.) Heller "Arizona walnut"

Betulaceae "birch family"
- <u>Alnus oblongifolia</u> Torr. "Arizona alder"

Betulaceae (cont.)
- <u>Betula occidentalis</u> Hook. "water birch"

Ulmaceae "elm family"
- X <u>Celtis reticulata</u> Torr. "net leaf hackberry"

Urticaceae "nettle family"
- <u>Urtica serra</u> Blume "nettle"

Polygonaceae "buckwheat family"
- <u>Oxyria digyna</u> (L.) Hill
- <u>Polygonum amphibium</u> L. "water smart-weed"
- P. <u>argyrocoleon</u> Steud. "silverheath knotweed"
- P. <u>aviculare</u> L. "prostrate knotweed"
- P. <u>bistortoides</u> Pursh. "bistort"
- P. <u>coccineum</u> Muhl.
- P. <u>convolvulus</u> L. "black bindweed"
- P. <u>douglasii</u> Greene
- P. <u>kelloggii</u> Greene
- X P. <u>persicaria</u> L.
- X P. <u>punctatum</u> Ell. "water smartweed"
- <u>Rumex acetosella</u> L. "sheep sorrel"
- R. <u>altissimus</u> Wood. "peachleaf dock"
- R. <u>californicus</u> Rechf.
- X R. <u>crispus</u> L. "curly dock"
- R. <u>hymenosepalus</u> Torr. "wild rhubarb"
- R. <u>mexicanus</u> Meisn. (R. <u>triangulivalvis</u> (Danser) Rechf.)

Chenopodiaceae "goose foot family"
- <u>Atriplex argentea</u> Nutt. "silver salt-bush"
- A. <u>lentiformis</u> (Torr.) Wats. "quail brush"
- <u>Bassia hyssopifolia</u> (Pall.) Kuntze. "five hook bassia"
- <u>Chenopodium album</u> L. "common lambs quarters"
- C. <u>fremontii</u> Wats.
- C. <u>rubrum</u> L. (C. <u>chenopoidioides</u> (L.) Aellen)

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Chenopodiaceae (cont.)
- Salsola iberica Sennen and Pau [S. Kali L. var. tenuifolia (Tausch) Aellen]
- Suaeda torreyana Wats. "desert seep-weed"

Amaranthaceae "amaranth family"
- Amaranthus graecizans L. "prostrate pigweed"
- A. palmeri Wats. "Palmer's amaranth"

Aizoaceae "carpet weed family"
- Trianthema portulacastrum L. "horse purslane"

Portulacaceae "Portulaca family"
- Montia perfoliata (Donn.) Howell "miners-lettuce"
- Portulaca oleracea L. "common purslane"

Caryophyllaceae "pink family"
- Arenaria confusa Rydb. "sandwort"
- Cerastium arvense L. "mouse-ear chickweed"
- C. nutans Raf. "powder horn"
- Sagina saginoides (L.) Karst var. hesperia Fern. "pearlwort"
- Silene antirrhina L. "campion"
- Stellaria umbellata Turcz. "chickweed"

Ranunculaceae "crowfoot family"
- Aconitum columbianum Nutt. "monks hood"
- Aquilegia cearulea James ssp. pinetorum (Tidestrom) Payson. "Rocky Mountain columbine"
- A. chrysantha Gray
- * A. micrantha Eastw.
- Caltha leptosepala DC. "elks lip"
- Clematis ligusticifolia Nutt. "clematis"

Ranunculaceae (cont.)
- Myosurus cupulatus Wats. "mousetail"
- M. minimus L.
- Ranunculus aquatilis L. var capillaceus D.C.
- R. cardiophyllus Hook. var. subsagittatus (Gray) L. Benson
- X R. cymbalaria Pursh var. saximontanus Fern. "desert crowfoot"
- R. flammula L. var. ovalis (Bigel) L. Benson
- R. inamoenus Greene
- R. scleratus L.
- Thalictrum fendleri Engelm.

Cruciferae "mustard family"
- Arabis drummondii Gray. "rock cress"
- Capsella bursa-pastoris (L.) Medic "sheperds purse"
- Cardamine cordifolia Gray "bitter cress"
- Descuriana californica (Gray) O.E. Schulz "tansy mustard"
- X Lepidiumaf.L. medium Greene
- Rorippa curvisiliqua (Hook) Bessey "yellow cress"
- R. islandica (Oeder) Borbas "bog marsh cress"
- X R. nasturtium-aquaticum (L.) Schinz and Thell. "water cress"
- R. obtusa (Nutt.) Britt
- R. sphaerocarpa (Gray) Britt
- R. sylvestris (L.) Besser. "yellow cress"
- Sisymbrium altissimum L. "tumble mustard"

Cleomaceae "cleome family"
- Cleome latea Hook. "yellow bee plant"
- C. serrulata Pursh. "Rocky Mountain bee plant"
- Wislizenia refracta Engelm. "jackass clover"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Saxifragaceae "saxifrage family"
- Parnassia parviflora DC. "grass of Parnassia"
- Ribes inerme Rydb. "whitestem gooseberry"
- R. wolfi Rothrock.
- Saxifraga rhomboidea Greene "saxifrage"

Rosaceae "rose family"
- Agrimonia striata Michx. "Argimony"
- Geum strictum Ait. "Avens"
- X Petrophytum caespitosum (Nutt.) Rydb. "rock mat"
- Potentilla biennis Greene "cinque-foil"
- P. diversifolia Lehm.
- P. glandulosa Lindl.
- P. norvegica L. "rough cinquefoil"
- P. pulcherrima Lehm.
- P. rivalis Nutt. "brook cinque-foil"
- Rosa Arizonica Rydb.
- R. fendleri Crepin

Leguminosae "pea family".
- X Acacia gregii Gray var. arizonica Isely "catclaw acacia"
- X Alhagi camelorum Fisch. "camel thorn"
- Amorpha californica Nutt. "stinking willow"
- X Cercis occidentalis Torr. "California redbud"
- Glycerrhiza lepidota (Nutt.) Pursh. "licorice"
- Lupinus kingii Wats. "kings lupine"
- X Medicago sativa L. "alfalfa"
- X Melilotus alba Desr. "white sweet clover"
- X M. officinalis (L.) Lam. "yellow sweet clover"

Leguminosae (cont.)
- Oxytropis lambertii Pursh. "Lambert locoweed"
- X Prosopis juliflora (Swartz) D.C. "honey mesquite"
- Trifolium hybridum L. "Alsike clover"
- Trifolium pinetorum Greene
- T. pratense L. "red clover"
- T. repens L. "white clover"
- X Trifolium sp.

Geraniaceae "geranium family"
- X Erodium cicutarium (L.) L' Her. "filaree"
- Geranium caespitosum James "cranes-bill"
- G. richardsonii Fisch. and Trautr.

Callitrichaceae "water starwort family"
- Callitriche verna L. "water starwort"

Anacardiaceae "cashew family"
- X Rhus radicans L. var. rydbergii (Small) Rehder. "poison ivy"

Aceraceae "maple family"
- Acer negundo L. var. interius (Britt) Sarg. "box elder"

Rhamnaceae
- X Rhamnus betulaefolia Greene "birch-leaf buckthorn"
- X Zizyphus obtusifolia (Hook. ex T. and G.) A. Gray var. canescens (A. Gray) M.C. Johnst. [Condalia lyciodes (Gray) Weberb. var. canescens (Gray) Trel.] "gray-leaved Abrojo"

Vitaceae "grape family"
- X Parthenocissus inserta (Kerner) Fitsch. "Virginia creeper"
- X Vitis arizonica Engelm. "Canyon grape"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Malvaceae
- Iliamna grandiflora (Rydb.) Wiggins "wild hollyhock"
- Sida nederacea (Dougl.) Torr. "alkali sida"
- Sidalcea neomexicana Gray "alkali pink"

Elatinaceae "waterwort family"
- Elatine brachysperma Gray
- E. triandra Schkuhr. "waterwort"

Tamaricaceae "tamarisk family"
- Tamarix aphylla (L.) Karst.
- X T. pentandra Pall. "saltcedar"

Loasaceae "stick leaf family"
- X Eucidne urens Parry "sting bush"

Elaeagnaceae "Oleaster family"
- X Elaeagnus angustifolia L. "Russian olive"

Guttiferae
- Hypericum anagalloides C. and S. "tinker's penny"
- H. formosum H.B.K "St. John's wort"

Onagraceae "evening primrose family"
- Epilobium adenocaulon Hausskn. "willow weed"
- E. halleanum Hausskn.
- X E. hornemanni Reichenb.
- E. saximontanum Hausskn
- Oenothera flava (A. Nels.) Garrett
- X O. hookeri T. and G.
- O. longissima Rydb.

Umbelliferae "parsley family"
- Berula erecta (Huds.) Coville "water parsnip"
- Caucalis microcarpa H. and A.
- Cicuta douglasii (D.C.) Coult. and Rose "water hemlock"

Umbelliferae (cont.)
- Conium maculatum L. "poison hemlock"
- Perideridia parishii (Coult and Rose) Nels. and Macbr.

Cornaceae "dogwood family"
- Cornus stolonifera Michx. "Red Osier dogwoodI'

Primulaceae "primrose family"
- Androsace occidentalis Pursh. "rock jasmine"
- A. septentrionalis L.
- Dodecatheon alpinum (Gray) Greene "shooting star"
- Samolus parviflorus Raf. (S. floribundus H.B.K.) "water pimpernil"

Oleaceae "olive family"
- Fraxinus anomala Torr. "single-leaved ash"
- F. cuspidata Torr. var. macropetala (Eastw.) Rehd. "fragrant ash"
- X F. pennsylvanica Marsh. ssp. velutina (Torr.) G.N. Miller "velvet ash"

Gentianaceae "gentian family"
- X Centarium calycosum (Buckl.) fern "Buckley 's Centaury"
- Gentiana affinis Griseb. "pleat gentian"
- G. parryi Engelm

Apocynaceae "dogbane family"
- X Apocynum cannabinum L. "dogbane"
- A. sibiricum Jacq. var. salignum (Greene) fern "clasping leaf dogbane"
- A. suksdorfii Greene

Asclepiadaceae "milkweed family"
- X Asclepias subverticillata (Gray) Vail. "poison milkweed"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Asclepiadaceae (cont.)
 Sarcostemma cynanchoides Deche. [Funastrum cynanchoides (Desne. Schlechter] "climbing milkweed"

Convolvulaceae
X Convolvulus arvensis L. "field bindweed"
 Cuscuta campestris Yuncker "dodder"
 C. coryli Engelm. "Hazel dodder"
 C. indecora Choisy "pretty dodder"

Polemoniaceae "phlox family"
 Collomia linearis Nutt.

Hydrophyllaceae "water leaf family"
 Phacelia magellanica (Lam.) Cov.

Boraginaceae "borage family"
 Hackelia floribunda (Lehm.) Johnst.
 Heliotropium curassavicum L. "heliotrope"
X Lappula redowskii (Hornem.) Greene "stickseed"
 Mertensia franciscana Heller "bluebells"

Verbenaceae "vervain family"
 Phyla cuneifolia (Torr.) Greene "wedge-leaf frog fruit"
X Verbena bractea Lag and Rodr. "prostrate vervain"
 Verbena macdougalii Heller

Labiatae "mint family"
X Mentha arvenis L. var. villosa (Benth) S.R. Stewart "field mint"
 M. spicata L. "spearmint"
 Nepeta cataria L. "catnip"
 Prunella vulgaris L. "heal all"

Solanaceae "potato family"
X Datura meteloides D.C. "Sacred Datura"

Solanaceae (cont.)
 Nicotiana glauca Graham "tree tobacco"
 N. trigonophylla Dunal. "desert tobacco"
 Solanum douglasii Dunal.
 S. nodiflorum Jacq.

Scrophulariaceae
 Besseya arizonica Pennell
 B. plantaginea (James) Rydb.
 Castilleja confusa Greene "Indian paint brush"
 Limosella acaulis S. and M. "mudwort"
 L. aquatica L.
X Maurandya antirrhiniflora H. and B. "blue snapdragon vine"
X Mimulus cardinalis Dougl. "Cardinal monkey flower"
 M. guttatus D.C.
 M. nasutus Greene
 M. primuloides Benth.
 M. rubellus Gray "red-stemmed Mimulus"
 Penstemon rydbergii A. Nels. "beard tongue"
 P. virgatus Gray
X Penstemon sp.
X Veronica americana (Raf.) Schwein
X "American brooklime"
X V. anagallis-aquatica L. "water speedwell"
 V. serphyllifolia L. var. borealis Laestad.

Plantaginaceae "plantain family"
 Plantago insularis Eastw. "wooly plantain"
X P. lanceolata L. "buckhorn plantain"
X P. major L. "common plantain"
 P. virginica L. "pale-seeded plantain"

Rubiaceae "madder family"
X Galium stellatum Kell. var. eremicum Hilend and Howell "desert bedstraw"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Rubiaceae (cont.)
- Galium tinctorium L. "bedstraw"
- G. triflorum Michx. "fragrant bed-straw"
- Hedyotis pygmaea R. and S. (Houstonia wrightii Gray)

Caprifoliaceae "honeysuckle family"
- Sambucus glauca Nutt. "blueberry elder"
- S. microbotrys Rydb. "red elderberry"

Valerianaceae "Valerian family"
- Valeriana capitata Pall. ex Link. "Valerain"
- V. edulis Nutt.
- V. occidentalis Heller.

Campanulaceae "bellflower family"
- Campanula parryi Gray
- Campanula rotundifolia L. "harebell"
- Lobelia anatina Wimmer.
- X L. cardinalis L. ssp. graminea (Lam.) McVaugh. "cardinal flower"

Compositae "sunflower family"
- Achillea millefolium L. var. lanulosa (Nutt.) Piper (A. lanulosa Nutt.)
- Agoseris aurantiaca Greene
- Agoseris glauca (Pursh.) D. Dietr. "mountain dandelion"
- Ambrosia psilostachya D.C. "western ragweed"
- Arnica chamissonis Less. ssp. foliosa (Nutt.) Maguire (Arnica foliosa Nutt.)
- Artemisia biennis Willd. "sagebrush"
- X A. ludoviciana Nutt.
- A. tridentata Nutt. "big sagebrush"
- Aster adscendens Lindl. "aster"
- A. foliaceus Lindl. var. burkei Gray
- A. intricatus (Gray) Blake. "shrubby alkali aster"
- X A. spinosus Benth. "spiny aster"

Compositae (cont.)
- X Baccharis emoryi Gray. "Emory Baccharis"
- X B. salicifolia (R. and P.) Pers. (B. glutinosa Pers.) "seep willow"
- X B. sarathroides Gray "desert broom"
- B. viminea D.C. "mule fat"
- Bidens tenuisecta Gray "bur marigold"
- X Chrysothamnus nauseosus (Pall.) Britt.
- X Cichorium intybus L. "blue sailors"
- Cirsium nidulum (Jones) Petrak.
- X Cirsium sp. -- (undescribed species)
- X Conyza canadensis (L.) Cronq. (Erigeron canadensis L.) "horse-weed"
- Coreopsis tinctoria Nutt. [C. cardamine-folia (D.C.) T. and G.] "Manza-nilla silvestre"
- Erigeron formosissimus Greene "flea-bane"
- X Flaveria mcdougallii Theroux, Pinkara and Kiel
- X Franseria confertifolia L.
- X Gnaphalium chilense spreng. "small-flowered cudweed"
- G. exilifolium A. Nels. (G. grayi Nels and Macbr.)
- G. palustre Nutt. "lowland cudweed"
- X Haplopappus acradenius (Greene) Blake "alkali goldenbush"
- Helianthus ciliaris D.C. "plains sunflower"
- Lactuca pulchella (Pursh.) Riddell
- X L. serriola L. "prickly lettuce"
- X Perityle emoryii Torr. "Emory rock daisy"
- Solidago altissima L. "tall goldenrod"
- S. decumbens Greene
- S. ana Nutt.
- X S. occidentalis (Nutt.) T. and G. "western goldenrod"
- Sonchus asper (L.) Hill "spiny sow thistle"
- S. oleraceus L. "annual sow thistle"

(continued)

Appendix 4-1 (cont.). List of aquatic macrophytes reported from the Grand Canyon. * indicates plants collected during the present study (Oct. 1977 - Oct. 1978) that are new to the Grand Canyon flora; X indicates other plants collected during the present study.

Compositae (cont.)

X <u>Stephanomeria pauciflora</u> (Torr.) A. Nels. "desert straw"

X <u>Taraxcum officinale</u> Weber. "common dandelion"

X Tessaria sericea (Nutt.) Shinners [<u>Plucea sericea</u> (Nutt.) Coville] "arrow weed"

<u>Verbesina enceloides</u> (cav.) Benth.and Hook. "yellow top"

X <u>Xanthium strumarium</u> L. (X. <u>saccharatum</u> Wallr.) "common cocklebur"

Appendix 4-2. **List of aquatic macrophytes collected from the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978.**

		River Sections												Months in Bloom										
Family	Species	I	II	**III**	**IV**	V	VI	VII	VIII	IX	X	XI	XII	J	F	M	A	M	J	J	A	S	O	N
Palmae	*Phoenix dactylifera					X																		
Juncaceae	Juncus acutus		X																		X	X	X	
	*J. articulatus	X	X				X	X		X								X	X	X	X			
	J. mexicanus				X												X	X	X					
	J. torreyi	X	X																	X	X			
Salicaceae	Populus fremontii																X	X						
	Salix exigua	X	X		X	X	X	X	X	X	X	X	X											
	S. gooddingii						X	X			X	X	X											
	S. laevigata										X													
Ulmaceae	Celtis reticulata				X																			
Polygonaceae	Polygonum persicaria		X																	X	X	X	X	
	Rumex crispus		X													X	X	X		X	X	X	X	
Ranunculaceae	Ranunculus cymbalaria		X															X		X	X	X	X	
Cruciferae	Lepidium af. L. medium		X												X	X	X	X		X	X			
Leguminosae	Acacia gregii					X	X				X	X	X				X	X		X	X	X	X	
	Alhagi camelorum					X												X		X				
	Melilotus officinalis	X																		X	X	X	X	
	Prosopis juliflora						X				X	X	X							X				
Tamaricaceae	Tamarix pentandra	X	X		X	X	X	X	X	X	X	X	X							X	X			
Loasaceae	Eucidne urens																			X	X			
Eleagnaceae	Eleagnus angustifolia	X																						
Onagraceae	Epilobium hornemannii		X																					
Gentianaceae	Centarium calycosum	X															X	X	X					
Apocynaceae	Apocynum cannabinum	X			X																			
Asclepiadaceae	Asclepias subverticillata		X															X	X	X	X	X		
Lab iatae	Mentha arvensis	X	X																	X	X	X	X	X
Scrophulariaceae	Penstemon sp.		X																					
	Veronica americana	X	X						X										X	X	X	X		
	V. anagallis-aquatica	X	X	X		X											X	X	X	X	X	X	X	
Plantoginaceae	Plantago lanceolata	X																X	X	X				
	P. major	X	X	X												X	X	X	X	X	X	X	X	

Appendix 4-2. List of aquatic macrophytes collected from the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978.

		River Sections[1]												Months in Bloom											
Family	Species	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	J	F	M	A	M	J	J	A	S	O	N	D
Equisetaceae	*Equisetum* spp.	X	X	X	X		X											X	X	X					
Polypodiaceae	*Adiantum capillus-veneris*		X	X					X	X															
Typhaceae	*Typha domingensis*	X	X	X	X	X	X		X	X		X	X				X	X	X						
	T. *latifolia*		X	X													X	X	X						
Zannichelliaceae	**Zannichellia palustris*	X															X	X	X	X	X	X			
Hydrocharitaceae	**Elodea canadensis*	X																	X	X	X	X	X		
Poaceae	*Agrostis semiverticillata*	X	X															X	X	X	X	X	X		
	A. stolonifera	X																	X	X	X				
	Andropogon glomeratus	X																		X	X	X			
	Bothriochloa barbinoides	X			X			X									X	X	X	X	X	X	X		
	Bromus catharticus		X															X	X	X	X				
	B. japonicus		X																	X	X	X			
	Echinochloa crusgalli	X	X																	X	X	X	X		
	Elymus canadensis	X	X																	X	X	X	X		
	Imperata brevifolia					X	X	X	X	X	X	X								X	X	X	X		
	Muhlenbergia asperifolia				X	X															X	X	X		
	Panicum capillare		X															X	X	X					
	Phragmites australis	X	X	X	X	X	X	X	X	X	X	X									X	X	X		
	Poa *annua*	X															X	X	X						
	Polypogon monspeliensis	X	X														X	X	X	X					
Cyperaceae	*Carex aquatilis*	X	X	X												X	X								
	C. nebraskensis	X														X	X								
	Cladium californicum								X	X	X									X	X	X			
	Eleocharis macrostachya				X													X	X	X					
	E. *parishii*							X										X	X	X					
	Scirpus acutus	X	X		X					X	X								X	X	X				
	S. *americanus*	X	X	X	X														X	X	X				

Appendix 4-2. List of aquatic macrophytes collected from the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978.

Family	Species	River Sections[1] I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Months in Bloom J	F	M	A	M	J	J	A	S	O	N	D
Compositae	Artemesia ludoviciana					X															X	X	X	X	
	Baccharis emoryi					X																	X	X	
	B. salicifolia	X		X				X			X					X	X	X	X	X	X	X	X	X	X
	B. sarothroides													X	X	X									
	Cirsium sp.		X																		X	X	X		
	Conyza canadensis		X																	X	X	X	X		
	Flaveria mcdougallii									X											X	X	X		
	Gnaphalium chilense	X	X		X													X	X	X	X	X	X		
	Lactuca serriola		X																	X	X	X	X		
	Solidago occidentalis		X																		X	X			
	Tessaria sericea	X	X			X	X	X	X	X	X	X	X			X	X	X	X						
	Total Number of Species	33	38	17	15	13	11	15	10	13	14	9													

* Denotes additions to Grand Canyon flora

1 The key to river section numbers is found in Table 2-1.

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

	Tributaries and Springs																											Months in Bloom											
Species	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Equisetaceae																																							
<u>Equisetum hiemale</u>	X		X		X			X	X				X	X																									
E. <u>laevigatum</u>			X	X					X		X																												
Polypodiaceae																																							
<u>Adiantum capillus veneris</u>																																							
Typhaceae																																							
<u>Typha domingensis</u>	X	X	X	X	X					X		X	X	X	X	X	X							X							X	X	X	X					
T. <u>latifolia</u>	X		X				X	X							X						X	X		X							X	X	X	X					
Potamogetonaceae																																							
*<u>Potamogeton crispus</u>																	X																						
*P. <u>pectinatus</u>		X															X															X	X	X	X	X			
Zannichelliaceae																																							
*<u>Zannichellia palustris</u>																	X														X	X	X	X	X	X			
Poaceae																																							
<u>Agropyron trachycaulum</u>	X																															X	X	X	X	X	X		
<u>Agrostis semiverticillata</u>	X	X	X	X				X		X			X	X				X	X																				

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

	Tributaries and Springs																											Months in Bloom											
Species	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
A. stolonifera																	X															X	X	X					
Andropogon glomeratus			X	X																	X	X											X	X	X				
Arundo donax																												X	X	X	X	X	X	X	X	X			
Bothriochloa barbinodis		X	X					X	X		X	X		X																X	X	X	X	X	X	X			
Bromus japonicus	X																													X	X	X							
B. rubens					X																					X			X	X	X								
B. tectorum														X															X	X	X								
Cenchrus insertus							X																									X	X	X	X	X			
Cynodon dactylon			X											X																		X	X	X					
Dactylis glomerata																														X	X	X							
Distichlis spicata																	X														X	X	X	X	X	X			
Echinochloa crusgalli																																	X	X	X				
Elymus canadensis									X																								X	X	X	X			
*Erianthus ravennae																															X	X	X						
Festuca pratensis	X																													X	X	X							
Hilaria jamesii						X																									X	X	X	X	X				
Hordeum jubatum	X																															X	X	X					
Imperata brevifolia			X	X				X		X			X					X				X											X	X	X	X			

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Muhlenbergia asperifolia	X	X	X					X		X			X		X	X		X		X		X													X	X	X		
Oryzopsis milacea								X																								X	X						
Panicum capillare																																X	X	X					
Phragmites australis	X	X	X			X					X	X					X				X	X													X	X	X		
Poa annua	X										X																				X	X	X						
Polypogon interruptus						X																X										X	X	X	X	X			
P. monspeliensis	X	X			X		X	X						X												X					X	X	X	X					
Schizachyrium scoparium									X	X																								X	X	X			
Sporobolus cryptandrus	X	X																													X	X	X	X	X	X	X		
*S. giganteus		X																																X	X	X	X		
Cyperaceae																																							
Carex aquatilis																														X	X								
C. hystricina			X										X	X	X																X	X	X	X					
Cladium californicum																		X	X															X	X	X			
Eleocharis macrostachya																																X	X	X					
E. rostellata																																X	X	X					
Scirpus acutus	X	X						X											X														X	X	X				
S. americanus	X	X	X					X	X					X				X															X	X	X				
S. olneyi														X							X	X										X	X	X					
*S. paludosus		X																															X	X					

(continued)

Appendix 4-3. List .of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Palmae																																							
*Phoenix dactylif era		X																																					
Juncaceae																																							
Juncus acutus																										X								X	X	X			
*J. articulatus																																X	X	X	X				
J. balticus																															X	X	X						
J. mexicanus																															X	X	X						
J. saximontanus																																	X	X	X				
J. torreyi			X		X		X		X				X			X	X																	X	X				
Iridaceae																																							
Sisyrinchium demis-sum																			X												X	X							
Orchidaceae																																							
Epipactis gigantea									X	X																				X	X	X							
Salicaceae																																							
Populus fremontii	X		X																													X	X						
Salix exigua	X	X		X	X				X	X																					X	X							
S. gooddingii																															X	X							
S. laevigata																															X	X							
Junglandaceae																																							
Junglans major																																							
Ulmaceae																																							
Celtis verticulata																																							

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Polygonaceae																																							
P. punctatum							X	X																											X	X	X		
Rumex crispus																														X	X	X	X	X	X	X	X		
Ranunculaceae																																							
*Aquilegia micrantha																			X												X	X							
Ranunculus cymbalaria							X																									X	X	X	X	X	X		
Cruciferae																																							
Rorippa nasturtium-aquaticum					X	X		X	X																						X	X	X	X					
Rosaceae																																							
Petrophytum caespitosum								X	X																								X	X	X	X	X		
Leguminosae																																							
Acacia gregii																															X	X	X	X	X	X	X		
Cercis occidentalis																	X	X													X	X							
Medicago sativa						X	X																								X	X	X	X	X	X			
Melilotus albus																																	X	X	X	X	X		
M. officinalis																																	X	X	X	X			
Trifolium sp.				X																																			
Geraniaceae																																							
Erodium cicutarium																										X				X	X	X	X	X					

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Anacardiaceae																																							
Rhus radicans									X																					X	X	X	X	X					
Rhamnaceae																																							
Rhamnus betulaefolia										X																						X	X						
Zizyphus obtusifolia								X																								X	X	X	X	X			
Vitaceae																																							
Parthenocissus inserta																																X	X	X	X				
Vitis arizonica							X	X																							X	X	X	X					
Tamaricaceae																																							
Tamarix chinensis	X	X		X		X		X	X		X		X	X	X	X	X	X						X	X					X	X	X	X	X	X	X			
Loasaceae																																							
Eucidne urens					X																										X	X	X	X	X				
Eleagnaceae																																							
Eleagnus angustifolia	X																																X						
Onagraceae																																							
Epilobium hornemanii																																		X	X	X			
Oenothera hookeri	X																																	X	X	X	X		

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Oleaceae																																							
Fraxinus pennsylvanica								X																						X	X	X							
Gentianaceae																																							
Centarium calycosum													X	X																	X	X	X	X	X				
Convolvulaceae																																							
Convolvulus arvensis																																X	X	X	X	X			
Boraginaceae																																							
Lappula redowskii																										X			X	X	X	X	X	X	X				
Verbenaceae																																							
Verbena bractea								X																								X	X	X	X	X			
Kabiatae																																							
Mentha arvensis			X																															X	X	X	X	X	
Solanaceae																																							
Datura meteloides						X																								X	X	X	X	X	X	X	X	X	
Scrophulariaceae																																							
Maurandya antirrhiniflora									X										X												X	X	X	X	X	X			
Mimulus cardinalis						X			X			X					X	X	X		X	X			X					X	X	X	X	X	X	X	X		
Veronica americana						X				X																							X	X	X	X			

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
V. anagallis-aquatica			X		X	X																								X	X	X	X	X	X	X	X		
Plantaginaceae																																							
Plantago lanceolata	X																															X	X	X					
P. major	X																													X	X	X	X	X	X	X	X		
Rubiaceae																																							
Gallium stellatum					X																									X	X	X							
Campanulaceae																																							
Lobelia cardinalis																		X															X	X	X	X	X		
Compositae																																							
Artemesia ludoviciana								X	X									X																	X	X	X	X	
Aster spinosus																																							
Baccharis emoryi			X											X	X	X																					X	X	
B. salicifolia			X			X	X	X					X	X	X	X	X					X	X	X						X	X	X	X	X	X	X	X	X	X
B. sarothroides																												X	X	X									
Chrysothamnus nauseosus	X																																	X	X	X	X		
*Chichorium intybus	X																														X	X	X						
Cirsium sp.																					X	X												X	X	X	X	X	
Conyza canadensis	X								X				X			X																		X	X	X	X		
Franseria confertifolia	X																															X	X	X	X	X	X	X	
Gnaphilium chilense			X		X																											X	X	X	X	X	X		

(continued)

Appendix 4-3. List of aquatic macrophytes collected from tributaries and springs of the Colorado River during October, November - December 1977, January - February 1978, May 1978, July - August 1978, and September - October 1978. The key to the tributary and spring designations is given in Table 2-1.

Species	Tributaries and Springs																											Months in Bloom											
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	J	F	M	A	M	J	J	A	S	O	N	D
Haplopappus acredenius																																X	X	X	X	X			
Perityle emoryi																												X	X	X	X	X	X	X	X	X			
Solidago occidentalis																																		X	X	X			
Sonchus asper					X		X	X																				X	X	X	X	X	X	X					
Stephanomeria pauciflora					X																								X	X	X								
Taraxcum officinale	X																													X	X	X	X	X	X	X	X		
Tessaria sericea	X					X	X											X											X	X	X	X							
Xanthium strumarium	X	X		X			X																							X	X	X	X	X	X	X			
TOTAL No. of Species	43	19	23	11	19	12	16	24	30	11	5	5	13	21	8	7	20	13	8	2	8	17	2	5	7	5	0												

Appendix 4-4 . List of diatoms collected from eight selected tributaries.

Class Centrobacillariophyceae
  Order Eupodiscales
    Family Coscinodiscaceae
      Melosira granulata (Ehr.) Ralfs

Class Pennatilbacillariophyceae
  Order Fragilariales
    Family Fragilariaceae
      Diatoma vulgare Bory
      Fragilaria capucina Desm.
      F. capucina var. mesolepta
      F. leptostauron (Ehr.) Hust.
      Synedra ulna (Nitz.) Ehr.
  Order Achnanthales
    Family Achnanthaceae
      Achnanthes affinis Grun.
      A. deflexa Reim.
      A. lanceolata (Breb.) Grun.
      A. lanceolata var. omissa Reim.
      A. linearis (W. Sm.) Grun.
      A. linearis f. curta H.L. Sm.
      A. minutissima Kutz.
      A. subleavis var. crassa Reim.
      A. wellsiae Reim.
      Cocconeis diminuta Pant.
      C. pediculus (Schum.) Cl.
      C. placentula var. euglypta (Ehr.) Cl.
      Rhoicosphenia curvata (Kutz.) Grun. ex. Rabh.
  Order Naviculales
    Family Gomphonemaceae
      Gomphonema affinie Kutz.
      G. intracatum Kutz.
    Family Cymbellaceae
      Amorpha perpusilla (Grun.) Grun.
      Cymbella affinis Kutz.
      C. microcephala Grun.
      C. microcephala var. crassa Reim.
      C. minuta Hilse
      C. prostrata (Berk.) Cl.
      C. sinuata Greg.
    Family Naviculaceae
      Amphipleura pellucida Kutz.
      Caloneis silicula var. limosa (Kutz.) Vanlan.
    Naviculaceae (cont.)
      Navicula cryptocephala Kutz.
      N. cryptocephala f. minuta Boye-P.
      N. cryptocephala var. veneta (Kutz.) Rabh.
      N. decussis Ostr.
      N. gregaria Donk.
      N. grimmei Krosske.
      N. laterostrata Hust.
      N. minima Grun.
      N. miniscula Grun.
      N. pseudoreinhardtii Patr.
      N. pupula Kutz.
      N. pupula var. capitata Skr. and Meyer.
      N. pupula var. rectangularis (Grey.) Grun.
      N. tridentula Krasske
      N. tripunctata (Mull.) Bory
      N. tripunctata var. schizonemoides (V.H.) Patr.
      Pleurosigma delicatatum W. Smith
      Rhopalodia gibba (Ehr.) O. Mull.
  Order Epithemiales
    Family Epithemiaceae
      Denticula elegans Kutz.
      Epithemia adnata (Kutz.) Breb.
      E. sopex Kutz.
  Order Bacillariales
    Family Nitzschiaceae
      Nitzschia capitellata Hust.
      N. denticula Grun.
      N. fonticola Grun.
      N. frustulum Kutz.
      N. frustulum var. perpusilla (Robh.) Grun.
      N. hungarica Grun.
      N. hybrida Grun.
      N. kutsingiana Hilse
      N. palea (Kutz.) W. Smith
      N. recta Hantzsch.
      N. romona Grun.
  Order Surirellales
    Family Surirellaceae
      Surirella brightwellii W. Smith

Appendix 4-5. Percentage of each diatom species found per cm^2 for the 500 in stations in eight selected tributaries.

Species	Paria R. Summer 1978	Paria R. Fall 1978	L. Colo R. Winter 1978	B. Angel Crk. Winter 1977	B. Angel Crk. Winter 1978	Shinumo Crk. Winter 1978	Shinumo Crk. Summer 1978	Tapeats Crk. Fall 1978	Deer Crk. Winter 1977	Deer Crk. Fall 1978	Kanab Crk. Winter 1978	Havasu Winter 1977	C[illegible]. Winter 1978
scinodiscinaceae												2.3	
Melosira granulata								0.6					
agilariaceae													
Diatoma vulgare								0.2					
Fragilaria capucina													57.3
F. capucina var. mesolepta													0.4
F. leptostauron								0.6					
Synedra ulna													3.8
hnanthaceae													
Achnanthes affinis	1.1	0.8						7.3				9.5	
A. deflexa			10.2			7.4				7.3			
A. lanceolata								2.7					
A. lanceolata var. omissa										2.4			
A. linearis	34.5	45.8	10.2		18.9	3.4		2.1		4.9	5.9	11.3	5.1
A. linearis f. curvata		2.2			59.9					7.3		20.7	
A. minutissima	51.1		10.2			0.6		4.0	25.0			2.7	
A. sublaevis var. crassa		7.3						0.2	16.7				0.8
A. wellsiae													1.3
Cocconeis diminuta				2.7					33.0				
C. pediculus			4.8	3.6	2.3			1.3					
C. placentula				9.1	3.2		50.0	9.0		4.9			0.4
[illegible]phenia curvata				[illegible]									

(continued)

Appendix 4-5. Percentage of each diatom species found per cm^2 for the 500 in stations in eight selected tributaries.

Species	Paria R. Summer 1978	Paria R. Fall 1978	L. Colo.R. Winter 1978	B. Angel Crk. Winter 1977	B. Angel Crk. Winter 1978	Shinumo Crk. Winter 1978	Shinumo Crk. Summer 1978	Tapeats Crk. Fall 1978	Deer Crk. Winter 1977	Deer Crk. Fall 1978	Kanab Crk. Winter 1978	Havasu Crk. Winter 1977	Havasu Crk. Winter 1978
mphonemaceae													
Gomphonema affine								1.5					0.4
G. intracatum		0.3											
mbellaceae										9.8			
Amorpha perpusill			4.8	1.8	0.5			7.3					
Cymbella affinis					1.8	3.4	16.7	12.1		2.4		0.9	3.0
C. microcephala	9.5		15.0	4.5	2.3					12.2		8.6	0.4
C. microcephala var. crassa		22.1											
C. minuta		2.8	4.8										
C. prostrata			10.2										
C. sinuata	0.5	0.6											
viculaceae													
Amphipleura pellucida													0.4
Caloneis silicula											11.8		
Navicula cryptocephala						3.4		4.4					
N. cryptocephala f. minuta	2.8	0.2			0.5			1.5					
N. cryptocephala var. veneta				17.3	8.7	5.1		3.1		14.6	11.8	0.9	
N. decussis		6.7											
N. gregaria						1.7							2.1
N. ~immei		6.6											
N. terostrata								1.0					

(continued).

A endix 4-5. Percentage of each diatom species found per cm^2 for the 500 in stations in eight selected tributaries.

Species	Paria R. Summer 1978	Paria R. Fall 1978	L. Colo. R. Winter 1978	B. Angel Crk. Winter 1977	B. Angel Crk. Winter 1978	Shinumo Crk. Winter 1978	Shinumo Crk. Summer 1978	Tapeats Crk. Fall 1978	Deer Crk. Winter 1977	Deer Crk. Fall 1978	Kanab Crk. Winter 1978	Havasu Crk. Winter 1977	Havasu Crk. Winter 1978
N. minima								9.4		2.4			
N. miniscula				39.6				2.7					10.2
N. pseudorein-hardtii								0.2					0.5
N. pupula												1.8	0.4
N. pupula var. capitata		0.8											
N. pupula var. rectangular is													1.7
N. tridentula		0.3											
N. tripunctata													
N. tripunctata var. schizone-moides				10.9		4.6		14.2		4.9			2.6
Pleurosigma deli-catatum						1.1							
Rhopalodia gibba						3.4							
ithemiaceae													
Denticula elegans			4.8					0.2	8.3	2.4		3.2	3.0
Epithemia aduata						0.6							
E. sorex			4.8	4.5	0.9	37.1	50.0						
tzschiaceae													
Nitzschia capitel lata								0.6					
N. denticula													1.3
N. fonticola		0.3						1.0					
N. frustulum		1.1		0.9									

(continued)

Appendix 4-5. Percentage of each diatom species found per cm^2 for the 500 m stations in eight selected tributaries.

Species	Paria R. Summer 1978	Paria R. Fall 1978	L. Colo. R. Winter 1978	B. Angel Crk. Winter 1977	B. Angel Crk. Winter 1978	Shinumo Crk. Winter 1978	Shinumo Crk. Summer 1978	Tapeats Crk.	Tapeats Crk. Fall 1978	Deer Crk. Winter 1977	Deer Crk. Fall 1978	Kanab Crk. Winter 1978	Havasu Crk. Winter 1977	Havasu Crk. Winter 1978
N. **frustulum** var. **perpusilla**						2.3		83.3	4.8					
N. hungarica		0.3							0.8					
N. **hybrida**														
N. **kutzingiana**		1.4				12.6						5.9		
N. **palea**		0.2			13.1				6.5		4.9	35.3		1.7
N. recta									0.4					
N. romana				0.9										
Nitzschia spp.	0.5		10.2	0.9	1.0					16.7	17.1		0.5	2.1
Surirellaceae														
Surirella brightwellii												29.4		
TOTAL No. of Taxa:	7	20	12	12	12	14	2	2	28	5	4	6	11	21

Appendices 5-1-1 - 5-1-15. Percent total biomass and density (in parens) of aquatic invertebrates in selected tributaries of the Colorado River at the confluence and 200 m upstream on a seasonal basis.

Key to families:

Aeshnidae	Culicidae	Glossosomatidae	Lymnaeidae	Polycentropodidae
Agrionidae	Curculionidae	Gomphidae	Mesoveliidae	Psychodidae
Anthomyiidae	Cypridae	Haliplidae	Naucoridae	Psychomyiidae
Baetidae	Dixidae	Helicopsychidae	Nemouridae	Pyralidae
Belostomatidae	Dolichopodidae	Heptageniidae	Notonectidae	Rhyacophilidae
Brachycentridae	Dryopidae	Hydrophilidae	Oligochaeta	Simuliidae
Caenidae	Dytiscidae	Hydroptilidae	Perlidae	Sperchonidae
Ceratopogonidae	Elmidae	Hydropsychidae	Perlodidae	Stratiomyidae
Chironomidae	Empididae	Isotomidae	Philopotamidae	Tabanidae
Coenagrionidae	Ephydridae	Lest idae	Physidae	Tipulidae
Corixidae	Gammaridae	Libellulidae	Planariidae	Veliidae
Corydalidae	Gerridae	Limnephilidae		

Appendix 5-1-1. Paria Creek.

	Fall 1977		Spring 1978		Summer 1978		Fall 1978	
	Conf.	Ups.	Confl.	Ups.	Conf.	Ups.	Conf.	Ups.
Dolich	83.3(50.0)							
Oligo	16.7(50.0)			-(5.9)	100.0(100.0)		68.2(64.3)	
Chiron		8.0(9.1)	100.0(100.0)	-(11.8)			27.3(12.1)	-(4.2)
Gomp							4.5(23.6)	
Hydropsy		74.0(59.1)		97.9(58.8)		100.0(100.0)		91.3(87.5)
Baetid		8.0(13.6)		2.1(23.5)				-(4.2)
Nemour		6.0(9.1)						
Simul		2.0(4.5)						
Belo		2.0(4.5)						
Pyral								5.3(4.2)
Other								3.3(-)

Appendix 5-1-2. Little Colorado River.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Oligo	33.3(50.0)	not sampled	54.5(42.9)	no invertebrtes ollected		not sampled		3.1(3.4)	13.8(16.7)	
Simul	66.6(50.0)								12.1(8.3)	
Chiron			45.5(57.1)		100.0(100.0)		100.0(100.0)	87.5(89.7)	22.4(41.7)	a
Gamin									34.5(16.7)	
Baetid									10.3(8.3)	1
Ephydrid									6.9(8.3)	
Empi								6.3(3.4)		
Dolich								3.1(3.4)		

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Hydropt	21.3(29.1)						-(7.7)		3.0(3.4)	
Coena	18.0(-)	8.2(11.3)		3.4(2.8)				6.3(-)		17.7(6.3)
Baetid	14.1(10.4)	7.6(14.6)	79.0(84.1)	14.9(55.0)	58.7(85.7)	9.6(25.4)	32.0(53.9)	4.0(4.0)	22.4(8.1)	34.2(33.7)
Chiron	11.9(37.7)	-(24.1)	3.1(7.6)	-(8.9)		3.1(10.1)	-(4.9)	-(2.1)	28.6(64.2)	3.8(19.6)
Pyral	10.9(3.9)	6.4(6.6)	8.2(-)	-(4.0)		22.1(16.7)	3.3(3.3)	6.1(2.9)	3.4(-)	
Gamm	10.0(-)									
Simul	6.0(4.3)		2.5(2.2)	10.3(16.4)	3.5(7.4)		2.0(5.1)		3.3(-)	
Hydropsy		3,7(3.3)	2.4(-)	2.4(2.7)		-(19.7)				
Elmi	-(2.0)	4.5(12.7)	2.3(2.7)		-(2.6)	7.5(17.5)	6.2(21.0)	3.2(5.0)	2.8(4.4)	5.9(10.0)
Coryd		4.4(-)		9.6(-)	31.4(-)	9.6(-)	52.6(-)	39.9(-)		
Philo		10.6(9.9)			4.8(3.5)				2.3(-)	3.4(-)
Oligo		46.2(4.2)		31.4(5.9)			16.8(-)	18.7(-)	16.8(3.9)	15.6(-)
Sperch	-(2.0)								5.8(4.2)	
Helicop	(6.3)					12.5(-)		12.5(79.1)	5.3(5.5)	4.8(19.8)
Empi						-(2.2)			2.1(-)	
Taban		3.0(-)		25.0(-)		15.2(-)				
Agrion										7.8(-)
Rhyac		-(7.5)								
Other	7.8(4.4)	5.5(5.7)	2.4(3.4)	3.0(4.1)	1.5(0.3)	3.5(8.3)	4.0(4.1)	9.3(6.8)	4.3(6.5)	6.7(10.6)

Appendix 5-1-4. Pipe Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Baetid	9.3(3.6)		73.6(75.4)	6.9(51.4)	81.5(90.3)	0.3(26.7)	7.7(40.4)	5.5(23.3)	3.6(7.7)	11.2(11.2)
Nemour	1.6(-)									
Chiron	13.1(65.5)	4.2(48.9)	1.6(4.9)	-(5.4)	3.7(3.2)	0.3(26.7)	-(35.2)	-(18.9)	6.9(28.2)	9.6(23.6)
Simul	17.1(17.1)	0.8(2.5)	16.3(16.4)	-(5.4)				-(3.7)	19.4(24.4)	18.8(20.3)
Stratiom	0.7(-)				3.7(3.2)				7.1(2.6)	
Anthom	31.2(3.2)									
Oligo	16.0(2.0)	37.6(3.8)		79.3(13.5)		27.3(33.3)	9.5(16.2)	37.4(41.5)	0.9(-)	
Gamm	4.2(-)									
Sperch	6.7(6.7)	5.0(16.9)		-(2.7)			2.5(3.3)		2.5(7.7)	-(2.2)
Hydropsy		32.6(12.7)	1.6(-)	11.2(16.2)				0.7(2.7)	37.8(10.3)	28.3(31.5)
Empi			7.0(-)							
Taban					11.1(3.2)					
Coryd						72.0(6.7)	78.8(-)	53.6(-)		
Pyral		18.8(11.8)							16.7(9.0)	13.4(5.6)
Philo									2.2(2.6)	
Cyprid									1.3(-)	5.1(-)
Libellul		1.1(-)						0.8(0.2)		
Flydropt				-(2.7)		0.1(6.7)		0.1(-)		
Coena				-(2.7)				0.2(-)		10.3(-)
Polycent										1.8(-)
Helicop								0.1(3.0)		
Other	-(2.0)	-(3.3)	-(3.2)	2.6(-)			1.5(4.9)	1.6(4.9)	1.5(7.8)	1.5(5.5)

Appendix 5-1-5. Hermit Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Elmi	46.2(30.0)		8.4(38.9)	1.5(2.2)		2.7(28.6)	4.4(19.0)	11.3(59.6)		
Limn	33.3(20.0)									
Chiron	20.5(50.0)	-(43.1)	-(5.6)	47.7(73.9)		-(3.6)	2.4(16.9)	-(5.3)		
Oligo		7.2(-)	78.0(22.2)				14.8(-)			
Coena		59.9(31.7)	10.0(11.1)	6.2(2.2)		5.1(39.3)	56.7(20.4)	-(5.3)		
Baetid			2.4(11.1)		100.0(100.0)	-(3.6)	-(5.6)	-(7.4)	a	a
Philo						-(3.6)	7.3(12.7)	2.6(4.8)		
Physid		21.9(-)					6.7(-)	4.1(-)		
Simul			-(11.1)				3.6(16.9)	-(6.9)	1	1
Cyprid		-(3.5)		7.7(15.2)			-(2.1)			
Polycent		-(3.0)					-(2.8)			
Libellul		3.8(4.5)								
Stratiom		3.4(2.0)		33.8(4.3)		-(3.6)		-(3.2)		
Hydropt		-(3.5)		3.1(2.2)						
Taban						70.8(3.6)				
Coryd						15.2(3.6)		73.2(-)		
Hydroph						-(3.6)				
Hydropsy						2.7(7.1)		-(6.9)		
Pyral								3.7(3.7)		
Halip		-(2.0)								
Other		3.6(6.5)	1.2 (-)			3.5(-)		5.4(3.7)		

Appendix 5-1-6. Stone Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Stratiom	33.3(27.8)	88.2(50.0)	no invertebrates collected	-(12.5)			not sampled	not sampled	not sampled	not sampled
Simul	27.3(27.8)			-(12.5)						
Hydropsy	12.1(33.3)									
Hydropt					12.5(33.3)					
Tipul					62.5(33.3)					
Baetid		11.8(50.0)		-(25.0)	25.0(33.3)	66.7(50.0)				
Coryd				96.5(12.5)						
Chiron				-(12.5)		33.3(50.0)				
Philo				-(12.5)						
Oligo				-(12.5)						
Other				3.4(-)						

Appendix 5-1-7. Clear Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Oligo	43.3(17.4)									
Simul	33.3(47.8)	-(12.5)		4.2(6.7)	34.8(30.8)	8.9(14.3)	-(4.0)	-(7.4)	70.6(44.4)	4.9(18.2)
Anthom	8.3(4.3)									
Pyral	6.7(13.0)	-(12.5)						-(5.2)		3.3(9.0)
Chiron	3.3(8.7)		-(6.2)	4.2(6.7)	34.8(53.8)	10.7(42.6)	18.6(44.4)	-(10.5)	17.6(33.3)	4.9(23.6)
Tipul	3.3(4.3)									
Baetid	1.7(-)	37.5(12.5)	100.0(93.8)	87.5(80.0)	17.4(7.7)	1.8(14.3)	17.9(18.0)	4.0(21.1)		7.0(14.5)
Hydropsy	-(4.3)				13.0(7.7)			3.1(-)		
Coena		50.0(37.5)				30.3(14.3)	26.0(7.0)	2.8(12.6)		10.8(14.5)
Elmi							13.7(12.0)	-(11.6)		2.5(7.3)
Coryd							8.8(-)	62.6(-)		62.8(-)
Hydropt		12.5(12.5)					5.6(6.0)	-(4.2)		
Philo							2.5(6.0)	11.9(18.9)		-(3.6)
Libellul							3.2(-)	6.8(5.3)		
Stratiom		-(12.5)							5.9(11.1)	
Sperch									5.9(11.1)	-(3.6)
Taban						48.2(14.3)				
Empi				4.2(6.7)				3.2(3.2)		
Other							2.8(3.0)	5.5(2.2)		3.8(5.4)

Appendix 5-1-8. Crystal Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Libellul	57.1(-)	8.6(-)								
Coena	17.1(3.6)	42.1(9.0)		9.5(	63.9(25.0)	48.5(23.1)	5.8(5.0)	83.2(68.8)	52.2(22.2)	8.1(3.7)
Tipul	11.4(-)									
Chiron	7.1(83.3)	-(59.4)	14.7(18.2)	9.0(21.5)	1.6(8.3)		5.5(20.0)		8.7(33.3)	18.2(38.5)
Simul	2.9(2.4)	3.2(-)	42.7(43.2)	27.0(30.4)	4.9(16.7)	46.5(69.2)	5.5(3.8)	-(4.7)		14.1(7.7)
Cerato	2.9(6.0)	2.6(15.9)							8.7(11.1)	23.2(26.9)
Baetid			42.7(38.6)	43.6(43.0)	11.5(41.7)	2.0(3.8)	12.5(28.8)	3.6(9.4)		
Stratiom		37.0(12.9)			18.0(8.3)	3.0(3.8)			17.4(11.1)	23.2(26.9)
Gamm							60.8(12.5)			
Elmi							2.8(3.8)	5.6(12.5)		
Hydropt							2.8(17.5)			2.0(3.7)
Limn									8.7(11.1)	
Empi									4.3(11.1)	
Hydroph							-(6.3)			
Dytis		4.9(-)								
Hydropsy				10.9(3.8)						
Taban								5.1 (-)		16.2(3.8)
Pyral										10.1(3.7)
Other	1.5(4.7)	1.6(2.8)		-(1.3)			4.3(2.3)	2.5(4.6)		-(0.5)

Appendix 5-1-9. Shinumo Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Chiron	87.5(85.9)	7.4(33.3)	28.6(39.3)	15.2(			29.4(70.1)	13.3(23.7)	9.4(19.7)	9.0(23.1)
Elmi	7.9(7.6)			1.5(5.6)		-(16.7)	15.4(17.5)	8.0(7.9)	6.9(3.8)	4.1(5.1)
Oligo	2.5(-)			13.6(5.6)			6.1(2.6)			
Baetid	-(2.2)	29.6(0.1)	50.0(25.0)	36.4(27.8)		-(50.0)	8.4(8.4)	70.7(63.2)	63.0(71.2)	77.9(66.6)
Simul		-(33.3)	21.4(35.7)	9.1(22.2)						1.8(1.3)
Polycent					100.0(100.0)					
Coryd				-(33.3)		99.0(33.3)	39.7(-)	4.0(2.6)		
Coena							0.9(-)	4.0(2.6)	9.8(-)	
Hydropsy									5.8(-)	
Pyral		63.0(33.3)							4.7(-)	
Empi									0.4(-)	7.2(3.8)
Brachy				24.2(5.6)						
Other	2.0(4.2)					1.0(	-(1.2)			

Appendix 5-1-10. Elves Chasm.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Physid	65.2(3.5)	62.9(19.0)			no invertebrates collected	59.6(23.7)		83.9(83.8)	not sampled	not sampled
Oligo	14.0(4.5)									
Simul	3.6(28.2)	-(23.4)	62.5(40.0)			-(10.5)	10.3(53.3)			
Limn	3.4(2.3)	-(3.8)								
Gamin	2.5(-)						88.8(33.3)			
Chiron	-(26.4)	-(3.8)	37.5(60.0)	6.4(28.6)		-(2.6)	0.9(13.3)			
Baetid	-(15.4)	-(8.2)		61.3(57.1)		-(23.7)		5.2(7.8)		
Cyprid	-(3.8)									
Cerato	-(2.9)									
Elmi	-(2.4)	-(7.0)				-(5.3)				
Stratiom	-(4.1)					2.1(2.6)				
Coryd		25.3(				24.6(5.3)				
Coena		5.8(19.0)				4.8(2.6)		8.1(2.3)		
Dytis				32.3(14.3)						
Hydroph						4.9(10.5)				
Polycent		-(2.5)								
Pyral		-(2.5)								
Philo						-(2.6)				
Hydropsy		-(5.7)				-(2.6)				
Other	11.0(6.8)	6.0(5.0)				4.0(-)		2.9(6.0)		

Appendix 5-1-11. Tapeats Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Hydropsy	43.5(16.9)	15.0(16.5)	23.5(5.3)	24.8(4.5)	16.0(-)	9.4(2.2)	4.8(-)		not sampled	not sampled
Tipul	31.6(23.3)	20.7(51.9)	2.6(-)				11.9(-)	5.1(8.8)		
Elmi	7.5(2.3)	3.2(12.7)	-(6.9)	3.0(4.7)			7.9(-)	-(7.5)		
Period	6.4(2.6)	14.1(	7.8(-)		12.4(-)		5.8(-)	4.6(57.1)		
Baetid	4.8(10.2)	14.4(4.4)	24.9(16.1)	3.7(34.5)	44.9(51.2)	55.1(37.3)	58.9(39.8)	72.2(		
Anthom	3.3(-)	8.8(3.2)								
Simul			23.5(14.8)	6.4(40.6)	12.4(33.9)	10.5(39.8)				
Stratiom			5.7(5.0)	21.6(-)						
Cerato			6.3(-)							
Heptag	-(18.8)	8.9(			10.2(6.8)	19.7(7.5)	-(3.6)	9.1(		
Chiron	-(15.8)	5.5(5.1)	-(45.9)	3.9(7.7)	-(5.1)	2.4(7.5)	8.3(9.4)	6.1(22.1)		
Empi	-(3.4)	2.1(								
Brachy			-(2.4)							
Gam		4.3(								
Taban				41.0(-)						
Glosso		-(2.5)								
Other	2.9(6.8)	3.0(3.7)	5.6(3.7)	4.6(8.0)	4.1(2.9)	2.9(5.6)	2.9(3.5)	2.9(4.4)		

Appendix 5-1-12. Deer Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.		Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Baetid	34.5(22.2)	not sampled	4.0(16.7)	76.5(57.1)	65.2(57.1)	2.8(40.1)	69.5(51.9)	16.4(57.2)	82.9(82.3)	3.5(50.0)
Hydropsy	22.8(12.7)					34.5(48.3)	-(3.4)	13.0(17.8)	4.1(3.4)	34.3(26.3)
Chiron	20.8(45.5)		3.1(50.0)	-(3.5)	-(14.3)		8.0(19.0)	-(9.7)	-(2.4)	-(2.6)
Anthom	7.1(-)									
Hydropt	4.6(11.1)									
Oligo	2.6(-)		22.5(8.3)		21.7(-)		16.1(25.3)			
Stratiom	2.5(-)				8.7(14.3)					-(2.6)
Polycent	2.3(-)									
Perli			66.1(4.2)	6.8(-)		55.8(4.7)		54.9(3.5)		59.9(15.8)
Simul			4.4(20.8)	14.6(19.4)		-(5.2)				
Empi					4.3(14.3)					
Brachy							3.4(-)	2.1(7.1)	-(5.5)	-(2.6)
Gamm									3.9(-)	
Sperch									2.0(2.0)	
Perlo						6.1(-)				
Physid								4.8(-)		
Aeshn								3.0(-)		
Tipul								2.4(-)		
Other	2.9(8.8)			2.1(2.5)		0.8(1.7)	2.8(3.9)	3.3(4.7)	7.2(4.4)	2.4(-)

Appendix 5-1-13. Kanab Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Coryd	83.5(2.4)			92.1(3.2)	n	94.8(3.4)				
Coena	4.8(2.4)					-(3.4)		2.1(-)	83.3(25.0)	
Nemour	2.7(17.1)	-(5.4)								
Hydropsy	3.1(2.4)				e	-(3.4)				50.0(20.0)
Simul	-(7.3)	4.3(7.2)	100.0(100.0)	4.3(71.0)	t	-(10.3)				
Chiron	-(53.7)	3.0(25.2)		-(3.2)	b	-(3.4)	75.0(75.0)	7.9(8.4)	11.1(25.0)	-(10.0)
Elmi					a		25.0(25.0)			
Empi					e	-(3.4)			5.6(25.0)	14.7(10.0)
Tipul	-(4.9)									
Hydropt	-(2.4)				o 1			45.0(34.3)		
Limn	-(2.4)	14.1(5.4)			1					
Anthom	-(2.4)	35.6(12.6)								
Sperch	-(2.4)				e			2.1(-)		5.9(10.0)
Oligo		39.1(36.9)						22.9(50.0)	-(25.0)	5.9(10.0)
Baetid				3.5(22.6)		2.5(69.0)		19.3(5.4)		8.8(20.0)
Cyprid								0.7(-)		
Brachy										8.8(10.0)
Stratiom						-(3.4)				5.9(10.0)
Other	5.7(-)	3.9(7.2)				2.7(-)		-(1.8)		

Appendix 5-1-14. Havasu Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Baetid	80.8(66.6)	18.8(65.0)	44.4(80.0)	14.9(63.3)	33.3(50.0)	14.7(83.3)		22.3(55.7)	not sampled	not sampled
Chiron	19.2(33.3)						66.6(50.0)			
Elmi			55.6(20.0)	-(4.4)			33.3(50.0)	3.6(8.7)		
Simul		-(2.5)		-(2.2)	66.7(50.0)					
Coena		49.3(20.0)		3.4(3.3)				3.7(-)		
Oligo		27.1(2.5)								
Hydropsy		2.0(5.0)		19.9(-)		20.7(12.5)		63.0(19.4)		
Coryd				54.0(-)		63.6(-)				
Dytis		-(2.5)		4.1(-)						
Pyral								4.0(-)		
Hydropt				-(22.2)				2.8(13.0)		
Spherch		-(2.5)								
Other		2.6(-)		3.3(4.4)		-(4.2)		1.7(3.2)		

Appendix 5-1-15. Diamond Creek.

	Winter 1977		Spring 1978		Summer 1978		Fall 1978		Winter 1978	
	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.	Conf.	Ups.
Chiron	93.3(75.0)	-(33.6)	-(4.3)	-(5.4)		no invertebrates collected	7.0(6.3)	3.3(16.5)	-(5.0)	-(3.9)
Baetid	6.7(25.0)	15.5(16.2)	34.0(41.3)	33.3(49.7)			64.0(49.3)	14.8(47.1)	35.3(35.1)	16.9(22.9)
Stratiom			38.1(13.0)	4.3(3.0)			0.9(0.7)		2.7(2.4)	
Cerato			7.1(18.5)							
Anthom			6.6(							
Tipul			3.6(5.4)							
Hydroph			2.0(					-(2.4)		
Dryop					98.3(66.7)					9.4(-)
Hydropsy		16.4(13.5)		6.0(3.4)	1.7(33.3)				3.3(24.6)	5.1(58.5)
Oligo		22.5(6.2)								9.4(-)
Caeni		18.4(5.4)								37.1(-)
Libellul		8.6(2.7)		22.8(						
Taban										
Coryd								67.9(2.4)		
Hydropt		-(3.9)	-(3.3)	-(3.4)			13.2(28.2)	-(3.5)		
Sperch				-(2.3)						
Empi				-(2.0)						
Limn										6.9(-)
Glosso								-(5.9)		
Simul		8.7(14.3)	-(3.3)	18.2(25.8)			14.9(15.5)	7.6(18.8)	24.7(23.5)	6.2(6.0)
Other		10.0(4.8)	8.5(7.0)	7.8(4.6)				6.3(3.6)	6.9(4.5)	2.3(9.2)

Appendix 5-2. Intratributary similarity indices (C) of mainstream confluence and 200 m transects in selected tributaries. The omission of a particular season indicates that the tributary was not sampled at that time.

	Winter 1977	Spring 1978	Summer 1978	Fall 1978	Winter 1978
Par.	0	.1180	0	.0420	
Cl	.2731	.8616	.6466	.6603	.4549
B. A.	.4769	.6927	.3102	.1961	.4351
Pipe	.6050	.6333	.2990	.6500	.7246
Her.	.4328	.1033	0.359	.8179	
Cry.	.7100	.8720	.4742	.2354	.5926
Shi.	.3442	.8046	0	.4124	.9165
Elv.	.4601	.2860	0	.0040	
St.	.6110	0	.332	.6990	
Tap.	.5727	.5227	.8609		
Kan.	.4557	.3333	0	.0840	.3000
Hav.	.6663	.6776	.5000	.1040	
Dmd	.4975	.5871	0	.7303	.5900
L.C.R.		.5710		.8970	
Deer		.2615		.6397	.5983
Trav					.4212

Key:

Par - Paria River
Cl - Clear Creek
B. A. - Bright Angel Creek
Pipe - Pipe Creek
Her - Hermit
Cry - Crystal Creek
Shi - Shinumo Creek
Deer - Deer Creek
Elv - Elves Chasm
St - Stone Creek
Tap - Tapeats Creek
Kan - Kanab Creek
Hav - Havasu Creek
Dmd - Diamond Creek
Tray - Travertine Falls
LCR - Little Colorado River

Appendix 5-3A -- 5-3E. Intertributary similarity indices (C) of selected tributaries during Winter 1977, Spring 1978, Summer 1978, Fall 1978, and Winter 1978. The omission of a particular season indicates that the tributary was not sampled at that time.

Par - Paria River
Cl - Clear Creek
B. A. - Bright Angel Creek
Pipe - Pipe Creek
Her - Hermit Creek
Cry - Crystal Creek
Shi - Shinumo Creek
Deer - Deer Creek

Elv - Elves Chasm
St - Stone Creek
Tap - Tapeats Creek
Kan - Kanab Creek
Hav - Havasu Creek
Dmd - Diamond Creek
Tray - Traventine Falls
LCR - Little Colorado River

Appendix 5-3A. Intertributary similarity indices (C) for Winter 1977.

	Par.	Cl.	B.A.	Pipe	Hen	Cry.	Shi.	Ely.	St.	Tap.	Kan.	Hay.	Dmd.	Deer	Tray.
Par		.1731	.2939	.2394	.0849	.1152	.311	.2231	0	.2603	.2023	.2072	.3942		
Cl.			.4177	.1510	.3043	.3040	.2869	.4456	.1429	.0440	.1080	.3738	.3015	.1695	
B.A.				.4074	.3664	.3879	.3272	.3964	.0140	.2611	.3343	.3111	.482	.3440	
Pipe					.4347	.5225	.4762	.1470	.0080	.1781	.3233	.1021	.5167	.3675	
Her.						.5238	.3118	.2866	.0479	.517	.3331	.2030	.4194		
Cry.							.3522	.1480	.1280	.0545	.3000	.1101	.4523	.2554	
Shi.								.3019	0	.0520	.3252	.0270	.4765	.5265	
Ely.									0	.2200	.1683	.4587	.3475		
St.										0	.0360	0	.0683		
Tap.											.1039	.0950	.2378		
Kan.												.0440	.3748	.4782	
Hay.													.2468		
Dmd.														.2475	
Deer															.5311

Appendix 5-3B. Intertributary similarity indices (C) for Spring 1978.

	Par.	Cl.	B.A.	Pipe	Her.	Cry.	Shi.	Ely.	St.	Tap.	Kan.	Hay.	Dmd.	L.C.R.	Deer
Par.		.3177	.4246	.5100	.1181	.3910	.4088	.3530	.5370	.3570	.3563	.4795	.3292	.1400	.2860
Cl.			.6873	.5876	.0670	.5637	.4116	.6377	.3838	.4788	.3000	.7404	.6457	.0890	.8516
B.A.				.7357	.1385	.7650	.6053	.6324	.6239	.6346	.4046	.6754	.7631	.1111	.7688
Pipe					.0960	.5890	.4418	.5680	.6071	.4980	.3042	.7477	.7757	.0760	.5304
Her.						.2281	.3540	.4292	.1251	.1111	0	.0531	.1351	.7234	.0350
Cry.							.7146	.6450	.5380	.7640	.5373	.5145	.7784	.2370	.6720
Shi.								.5637	.5557	.6417	.4550	.3662	.5610	.3548	.5097
Ely.									.3750	.4220	.2331	.5936	.5523	.3080	.6115
St.										.4970	.3912	.4304	.4692	.1470	.4260
Tap.											.6395	.4675	.7034	.0990	.6083
Kan.												.2664	.4915	.0220	.4272
Hay.													.5531	.0330	.6903
Dmd.														.0760	.7434
L.C.R.															.0550

Appendix 5-3C. Intertributary similarity indices (C) for Summer 1978.

	Par.	Cl.	B.A.	Pipe	Her.	Cry.	Shi.	Ely.	St.	Tap.	Kan.	Hay.	Deer	Dmd.
Par.		0	0	0	.0709	0	0	.0260	0	.0220	.0341	.1250	.4842	0
Cl.			.2704	.4102	.2510	.3245	.1431	.3004	.5696	.3615	.3148	.1431	.1952	.1431
B.A.				.3310	.2779	.0511	.4302	.3564	.3552	.1041	.3236	.2811	.2761	0
Pipe					.1078	.0380	.3338	.3160	.5337	.3420	.3694	.2949	.2669	0
Her.						.3024	.2384	.2909	.0719	.1164	.2061	.1734	.1199	0
Cry.							.0380	.1952	.0380	.4442	.2094	.0380	.0940	0
Shi.								.3432	.5000	.3806	.5308	.5280	.4100	0
Ely.									.2631	.4209	.4790	.2771	.3282	0
St.										.4482	.5348	.5000	.4010	0
Tap.											,5390	.4062	.4642	0
Kan.												.7561	.4577	0
Hay.													.5350	0
Deer														0

Appendix 5-3D. Intertributary similarity indices (C) for Fall 1978.

	Par.	Cl.	B.A.	Pipe	Her.	Cry.	Shi.	Ely.	Tap.	Kan.	Hay.	Dmd.	Deer	L.C.R.
Par.		.3265	.0520	.1150	.1200	.0580	.0840	.0450	.0940	.0840	.2550	.0839	.2619	.0420
Cl.			.1899	.4236	.5287	.3982	.4316	.1219	.4128	.1760	.3226	.4550	.3345	.1369
B.A.				.1331	.2052	.1944	.1343	.0791	.1252	.0886	.1408	.1289	.0709	.0240
Pipe					.2081	.1098	.4510	.1120	.4412	.6918	.3139	.4695	.3090	.2230
Her.						.3198	.2561	.1251	.2154	.1241	.1931?	.2776	.1471	.0691
Cry.							.2148	.1099	.1879	.0820	.2098	.1687	.1119	.0160
Shi.								.1101	.8774	.1441	.6620	.6593	.6690	.2371
Ely.									.0904	.0771	.1021	.1029	.1001	0
Tap.										.1439	.6653	.6447	.6803	.2272
Kan.											.2071	.1729	.1401	.1181
Hay.												.5265	.7494	.0170
Dmd.													.5694	.1650
Deer														.1011
L.C.R.														

Appendix 5-3E. Intertributary similarity indices (C) for Winter 1978.

	Cl.	B.A.	Pipe	Cry.	Shi.	Deer	Kan.	Dmd.	Tray.
Cl.		.4924	.6607	.4028	.4409	.1695	.2995	.2837	.2564
B.A.			.3992	.2811	.5737	.3440	.3425	.3316	.3703
Pipe				.3696	.3676	.3675	.4454	.2506	.2182
Cry.					.2442	.2554	.2001	.1138	.3652
Shi.						.5265	.4002	.2804	.3302
Deer							.4782	.3001	.5311
Kan.								.3600	.3320
Dmd.									.3352
Tray.									

Appendix 6-1. Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
HUMPBACK CHUBS:			
Summer 1978	R. M. 669.1	00000-00001	blue
	Little Colorado River at confluence	00003-00007, 00009-00010, 00012-00016, 00024, 00026-00047, 00049-00054, 00056-00061, 00063-00076, 00078-00079, 00081-00088, 00090-00091, 00093-00100, 00102-00103, 00106-00107, 00109-00112, 00114, 00146, 00149-00150, 00190, 00198-00199, 00206, 00210-00211, 00214	blue
	Little Colorado River near Big Canyon	00018-00020, 00023, 00025	
	R. M. 556.6	00202	blue
Fall 1978	R. M. 658.6	00105	blue
	Little Colorado River at confluence	00108, 00215, 00237, 00247, 00255, 00350	blue
FLANNELMOUTH SUCKER:			
Winter 1978	R. M. 581.6	00140-00141	red
	Deer Creek	00186	red
	Kanab Creek	00264	red

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
Spring 1978	Paria River	02001-02017	green
	R. M. 627.4	02167-02170, 02050-02065, 02067-02074, 02076-02127, 02145, 02149, 02150, 02066	green
	R. M. 493.6	02663, 02665-02667	green
	R. M. 488.6-484.6	02695-02701	green
	R. M. 485.6	02668-02676	green
Summer 1978	Paria River	01509-01591, 01605-01629, 01631-01656	yellow
	R. M. 647.9		
	R. M. 627.4	00685-00691, 00694-00696	yellow
	R. M. 597.6-595.6	07142	yellow
	Shinumo Creek	01809-01816	yellow
	R. M. 560.6		
	R. M. 556.6-555.6	01893	yellow
	R. M. 553.2		
	Kanab Creek	01920-01923, 01926-01928, 01935-01947	yellow

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
Fall 1978	Paria River	04428-04500	blue
	R. M. 627.4	04502-04551	blue
Winter 1978	R. M. 627.4	00016	red
	R. M. 627.1	00008, 00012 00014, 00016	red
	R. M. 581.6	00136, 00142	red
	Deer Creek	00174, 00187 00191	red
Spring 1978	R. M. 627.4	02058	green
RAINBOW TROUT:			
Winter 1978	Bright Angel Creek	00001, 00003-00007, 00026-00028	red
	Crystal Creek	00038, 00040-00041, 00046	red
	Shinumo Creek	00111-00112, 00114-00115, 00117-00118, 00120-00122, 00124-00132, 00143-00164	red
	R. M. 581.1	00133-00135	red
	Tapeats Creek	00165-00172	red

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
	Deer Creek	00175-00185, 00188-00190, 00192	red
	R. M. 542.6	00258-00259	red
	R. M. 540.6	00269-00284	red
	R. M. 536.6	00285-00296	red
	R. M. 534.6	00315, 00337-00341	red
	R. M. 521.6	00345	red
	R. M. 520.6	00370, 00372, 00374	red
	R. M. 519.6	00383-00391	red
	R. M. 514.35	00406-00414	red
Summer 1978	R. M. 574.6-572.6	01820, 01825-01827	yellow
	R. M. 556.6-555.6	01838-01888	yellow
Fall 1978	R. M. 568.6	04552	blue
	R. M. 550.6	04553-04554	blue
	R. M. 520.6	04751	blue
BROWN TROUT:			
Winter 1978	Shinumo Creek	00002, 00005 00006	red

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
CARP:			
Winter 1978	R. M. 590.6-589.6	00031-00032, 00034-00035, 00051-00052, 00056, 00061-00089, 00096, 00099, 00101-00110	red
	R. M. 581.1	00090-00092, 00094	red
	R. M. 548.6	00194, 00196-00225	red
	R. M. 548.6-546.6	00226-00257	red
	R. M. 546.1	00260-00262	red
	R. M. 545.1	00263, 00265-00267	red
	R. M. 538.1	00268	red
	R. M. 535.6	00297-00300, 00312-00314	red
	R. M. 534.6	00316-00336	red
	R. M. 521.6	00342-00343, 00348-00369	red
	R. M. 521.1	00371, 00373, 00375-00382	red
	R. M. 519.1	00392-00405	red
	R. M. 515.1	00415-00433	red

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
	R. M. 508.6	00434-00575	red
	R. M. 505.8-505.5	00576-00645	red
	R. M. 501.6-499.6	00646-00669	red
	R. M. 497.6	00670-00672	red
	R. M. 496.6	00673-00683	red
	R. M. 492.6-491.1	00684-00698	red
	R. M. 490.1	00699-00712	red
	R. M. 489.6	00713-00731	red
	R. M. 468.6-464.4	00732-00825	red
	R. M. 457.1-456.6	00826-00855	red
	R. M. 453.1	00856-00898	red
	R. M. 450.6	00899-00915	red
Spring 1978	Paria River	02018-02021	green
	R. M. 655.6	02022-02045	green
	R. M. 627.1	00028-00048, 02151-02166	green
	R. M. 592.6	02174-02188	green
	R. M. 582.6	02189-02240	green
	R. M. 575.6	02241-02291	green
	R. M. 575.1	02292	green
	R. M. 568.6	02293-02303	green

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
	R. M. 557.6	02304-02333	green
	R. M. 551.6-544.6	02336-02357	green
	R. M. 524.1-523.6	02359-02367	green
	R. M. 509.1	02368-02432, 02434-02596, 00577, 00610	green
	R. M. 500.6	02597-02642	green
	R. M. 493.6	02643-02662	green
	R. M. 485.6	02664, 02676-02677	green
	R. M. 484.1	02677-02694	green
	R. M. 451.6-450.6	02702-02707	green
Summer 1978	Paria River	01595-01604, 01663-01669	yellow
	R. M. 659.6	01670-01683	yellow
	R. M. 647.6	01684	yellow
	R. M. 627.1	01692-01693	yellow
	R. M. 597.1-595.6	01700-01719, 01721-01741	yellow
	R. M. 581.6	01743-01791, 01793-01808	yellow
	R. M. 579.6	01819	yellow
	R. M. 574.6-572.6	01821-01823, 01828-01835	yellow

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
	R. M. 556.6-555.6	01836-01837, 01867-01869, 01889-01892	yellow
	R. M. 554.6	01894-01897	yellow
	R. M. 548.6-546.6	01925, 01901-01919	yellow
	Kanab Creek	01929-01934, 01948	yellow
	R. M. 524.6-522.1		
	R. M. 512.6-508.6	01963-02000, 04001-04100, 04145-04300, 04101-04133, 04134-04144	yellow
	R. M. 498.6-495.6	04301-04332	yellow
	R. M. 494.6	04333-04349	yellow
	R. M. 492.6	04350-04363, 02633	yellow
	R. M. 478.6	04365-04368	yellow
	R. M. 454.6	04369-04418	yellow
	R. M. 243.6-244.6	04425-04426	yellow
	R. M. 242.6	04419-04424	yellow
Fall 1978	R. M. 520.6	04752-04759	blue

(continued)

Appendix 6-1 (cont.). Tagging data and collecting dates and localities for fishes of the Colorado River and its tributaries between Lee Ferry (R.M. 688.6) and Separation Rapids (R.M. 450.6) during 1977 - 1978.

Season	Locality	Tag No.	Tag Color
	R. M. 510.1	04682-04669, 04601-04655, 04675, 04763-04775, 04676-04681	blue
	R. M. 508.6	04459-04475, 04656-04658, 04660-04674, 04442-04449, 04776-04802	blue
	R. M. 494.6-491.6	04760-04762	blue
	R. M. 506.6-504.6	04816-04822	blue
	R. M. 468.6-466.6	04835-04836	blue
CHANNEL CATFISH:			
Spring 1978	R. M. 627.4	02171-02173	green
RIO GRANDE KILLIFISH:			
STRIPED BASS:			
Spring 1978	R. M. 451.6-250.6	02708-02713, 02715	greed

Appendix 7-1. Summary of creel census statistics (weekday versus weekend): Bright Angel Creek, Coconino County, Arizona.

	1977				1978							
Month	Nov		Dec		Jan		Feb		Mar		Total	
Time of Week	Mid	End	Mid	End	Mid	End	Mid	End	Mid	End	Mid	End
#Days ✓/mo.	5	0	2	1	2	3	3	2	2	0	14	6
Total Anglers	30		12	15	6	35	10	8	10		66	58
% Male	96		71	100	83	82	90	83	100		91	87
% Female	4		29	0	17	18	10	17	0		9	13
% Resident	42		71	57	83	100	80	100	67		60	90
% Non-Resident	58		29	43	17	0	20	0	33		40	10
# Succ. Anglers	21		7	7	4	14	6	5	6		44	26
% of Total	70		58	47	67	40	60	63	60		67	45
Total Person Hours	104.13		31.68	54.60	24.00	135.10	25.20	24.64	19.20		204.21	214.34
Lg x Ang Day(w)	3.47		2.64	3.64	4.00	3.86	2.52	3.08	1.92		3.08	3.66
# Fish Caught	60		41	31	4	23	8	8	30		143	62
# Fish Kept	44		16	14	4	23	8	8	4		76	45
CPPH	0.58		1.29	0.57	0.17	0.17	0.32	0.32	1.56		0.70	0.29
RBT/Hr	0.41		0.51	0.26	0.17	0.17	0.24	0.32	0.16		0.35	0.21
GBT/Hr	0.01		0.00	0.00	0.00	0.00	0.08	0.00	0.05		0.02	0.00
x Fish Lg. (km)	432		402	470	463	437	271	411	252		398	443

GLOSSARY

abiotic	pertaining to or characterized by the absence of life or living organisms
AC alternating current	an electric current that reverses direction at regular intervals
alcove	any recessed space
algae	any of numerous chlorophyll-containing plants of the phylum, Thallophyta, ranging from unicellular to multicellular forms, occurring in fresh or salt waters
alkali	any of various bases, the hydroxides of the alkali metals and of ammonium, that neutralize acids to form salts and turn red litmus paper blue
alluvial	deposits formed by finely divided material laid down by running water
ambient	completely surrounding
amorphous	irregular form, no visible differentiation in structure
analytical balance	a balance of precision used especially in quantitative chemical analysis
angler	a person who fishes with hook and line as hobby or sport
anion	a negatively-charged particle or ion
annulus	a concentric growth ring (circulus) on the scale of a fish
anterior	situated in or toward the front
armoring	a process of erosion where large gravel and ruble become exposed
base flow	the discharge, entering stream channels from ground water or other delayed sources
bed scour	a place in a stream bed swept (scoured) by running water, generally leaving a gravel bottom

benthic	pertaining to or living on the bottom
bimodal distribution	distribution having two modes
biomass	total weight of organisms per unit area
branchio stegal rays	rays of a gill cover
Bright Angel Shale Formation	a rock formation of the Cambrian era found in the Grand Canyon consisting of a sequence of fine-grained, light greenish gray silty shale
caliper	an instrument for measuring thickness and internal or external diameters inaccessible to a scale, consisting usually of a pair of pivoted legs adjustable at any distance
carbonate waters	waters containing a salt or ester of carbonic acid
carnivore	flesh eating
caudal	of or pertaining to a tail
cations	a positively charged ion
cellulase	an enzyme which hydrolyses cellulose
cellulose	a carbohydrate, forming the main part of plant cell walls
census	enumeration of a population
centrifuge	an apparatus that rotates at high speed and by centrifugal force separates substances of different densities
Chinle Formation	a formation found in the Grand Canyon from the Triassic era, consisting of a thick sequence of shales displaying a variety of colors, such as blue, purple, green, pink, gray, maroon, and brown, weathering into an intricate network of gullies
climate	the composite or generally prevailing weather conditions of a region, averaged over a series of years
coliform bacteria	bacteria found as commensals in the large intestine of man and animals consisting of Genera <u>Escherichia</u> or <u>Aerobacter</u>
colonization	to form a collection of organisms living together

community	any assemblage of populations living in a prescribed area or physical habitat
contamination	to render impure or unsuitable by contact, a mixing with something unclean, bad, etc
concave	curved like, a segment at the interior of a circle or hollow sphere
conductance	the ability of a conductor to transmit current
confluence	a flowing together of two or more streams, their place of junction
conglomerate	rounded, water-worn fragments of rock or pebbles cemented together by another mineral substance
convex	having a surface that is curved or rounded outward
correlation	interdependence of characters, particularly of quantitative characters, measured by correlation coefficient which is plus or minus one if characters are exactly interrelated, and zero if entirely unrelated
cotyledon	the seed leaf, primary or first leaf of an embryonic sporophyte
creel census	a census of fish already caught by fishermen
DC direct current	an electric current of constant direction, having a magnitude that varies little
debris fan	a gently sloping, fan-shaped mass of debris forming a section of a very low cone commonly at a place where there is a notable decrease ingradient
density (population)	population size in relation to some unit of space
depauperate	dwarfed, stunted, poorly developed
dessication	the act of drying thoroughly; depriving of moisture

detritus	aggregate of fragments of a structure, as of detached or broken-down tissues
diatom	a unicellular form of alga, with walls empreg--nated with silica
dicotyledon	a plant with two seed-leaves
dilute, dilution	to make a liquid thinner or weaker by the addition of water, or the like
dinoflagellate	any of numerous plantlike flagellates of the order *Dinoflagellata*, which are important elements of plankton
disarticulate	to separate at a joint
discharge	rate of flow at a given instant in terms of volume per unit of time
dispersal	the actual scattering or distributing of organisms on the earth's surface
distribution	range of an organism or group in biogeographical divisions of the globe
diurnal	active in the daytime; opening during the day only; occurring every day
diurnal inundation	to flood or overspread with water every day
diversity index	of a community, the ratio between number of species and number of individuals
dolomitic	containing the mineral calcium magnesium carbonate, $CaMg(CO_3)_2$
dorsal	lying near back, surface farthest from axis
Dox Formation	a Precambrian formation found in the Grand Canyon composed of red siltstones, shales, and sand-stone lenses. Abundant ripple marks and mudcracks, slope forming; intruded by dark greenish gray basalt sills and dikes
drainage basin	a part of the surface of the lithosphere that is occupied by a drainage system or contributes surface water to that system

dredge	a dragnet or other contrivance for gathering material or objects from the bottom of a river, bay, etc
ecology	the branch of biology which deals with the inter-relationships between living things and the relationship between organisms and their environment
ectoparasite	a parasite that lives on the exterior of an organism
eddy	a current of water running contrary to the main current, especially one moving in a circle
effluent	anything that flows forth; a stream flowing out of another or forming the outlet of a lake
electrofishing	the collecting of fish using electricity
electrode	a conductor through which a current enters or leaves an electric devise
electromagnetic	the phenomena associated with the relations between electric current and magnetism
enteric	of or pertaining to the enteron, intestinal
enzyme	a catalyst produced by living organisms and acting on one or more specific substrates
ephemeral	a short-lived plant or animal species
equilibrium	a state of rest or balance due to the equal action of opposing forces
erosion	the process by which the surface of the earth is worn away by the action of water, glaciers, waves, wind
evaporation	the extraction of moisture or liquid from, so as to make dry, or reduce to a denser state
exotic	a foreign plant or animal, introduced or non-endemic
extant	in existence, not destroyed or lost
fauna	the animal life of a locality or region

fecundity	the capacity in female animals of producing many offspring, fertility; rate at which an individual produces offspring, usually expressed only for females
flash flood	a sudden and destructive rush of water down a narrow gully or over a sloping surface
flood plain	a nearly flat plain along the course of a stream that is naturally subject to flooding
flow regimes	a range of stream flows with similar bed forms resistant to flow, and made of sediment transport
fluvial terrace	a terrace formed by a sedimentary deposit consisting of material transported by, suspended in or laid down by a river stream
fly	a fishhook dressed with hair, feathers, silk, tinsel, etc., so as to resemble an insect or small fish for use as a lure, or bait
forage (foraging)	the seeking or obtaining of food
formalin	an aqueous solution of 40 percent formaldehyde, used as a preservative
frequency	the number of items occurring in a given category
fry	the young of fish
fulcrum	point of articulation on opercule of fish
fyke net	a bag-shaped fish trap
galvanonarcosis	with the progressive increase of the density of an electrical current passed through the water, fish swim towards the anode but before reaching, are stunned and lie still on their side and keep still, facing the anode
galvanotaxis	response or reaction to electrical stimulus
geomorphology	the study of the characteristics, origin, and development of land forms

germination	beginning of process of initial development
gill net	a net, suspended vertically in the water, whose meshes catch entering fish by the gills
gonad	a sexual gland, either ovary or testes of ovotestis
gonadal somatic index (Carlander 1966)	gonadal weight to body weight ratio
gradient	any departure from the horizontal; a grade; a slope; frequently used in connection with the slope of streams
granite	a granular igneous rock composed chiefly of feldspars and quartz, usually with one or more other minerals
growth increment	an addition or increase in growth
habitat	the locality or external environment in which a plant or animal lives
headwaters	the upper tributaries of a river
helgramites	a long-lived carnivorous aquatic larva of a large North American insect (Corydalus cornutus) or of various related insects that is much used as a fish bait by anglers - also called dob son
herbarium	a collection of dried plants systematically arranged
hectare	a unit of land measure equal to 100 acres or 10,000 square meters
heterogeneous	unlike, dissimilar, not uniform
histogram	a graph of a frequency distribution in which rectangles with bases on the horizontal axis are given widths equal to the class intervals and heights equal to the corresponding frequencies
homogeneous	of uniform composition
hydraulic resistance	resistance to the wearing action of water

hypolimnion	a zone of water in a lake extending from thermocline to the bottom, with temperature fairly uniform and cold
icthyafauna	the fish life of a locality or region
importance value	three values (relative density, relative frequency and relative dominance of species) summed for cach species in a community
increment of growth	an addition or increase in size or development
indicators	a plant, animal or microrganism species which is characteristic of a certain environmental stage
inflow	the act of inflowing; water that flows in
intermittent stream	streams which flow only at certain times when it receives water from springs, or surface fed, as melting snow in mountainous areas
interneural ray	sharp bones attached to dorsal fin rays
inundation (periodic)	the periodic flooding or overflowing of water
invertebrates	animals backboneless, without a spinal column
ion	an electrically charged atom or group of atoms, as a cation or positive ion, which is created by electron loss, and is attracted to the cathode in electrolysis, or as an anion, or negative ion, which is created by an electron gain and is attracted to the anode
isometric	of, pertaining to, or having equality of measure
juvenile	immature, young animal
karst	limestone dissolved by rain or rivers forming caves or underground river channels are produced into which the surface drainage sinks by rifts and swallow-holes which have been dissolved out and land is left dry and barren
kilo	prefix meaning 'thousand' used in metric system
larvae	an embryo which becomes self sustaining and independent before it has assumed the characteristi features of its parents

lateral line	longitudinal line at each side of body of fishes, marking position of sensory cells
leaching	to cause water or other liquid to percolate through something, resulting in the removal of soluable constituents
linear regression	statistical technique for determining the relationships between two or more variables
litoral	zone between high and low water marks
logistic	dealing with the procurement, maintenance, and movement of equipment, supplies, and personnel
lure	a decoy, live or artificial bait used in angling
macrophyte	a member of the macroscopic plant life, especially of a body of water
marginal vegetation	vegetation situated on the border or edge
marsh	a tract of low wet land, often treeless and periodically innundated
mass	a fundamental property of a body, giving a measure of the acceleration the body will have when a given force is applied; considered constant
Mauv Limestone Formation	a rock formation found in the Grand Canyon of the Cambrian era, occurs beneath the Redwall Limestone, and consists of a sequence of alternating gray limestone and greenish gray calcareous siltstone
mesophytic	an organism living under moderate moisture conditions, intermediate between xerophyte and hydrophyte
meter	the fundamental unit of length in the metric system, equivalent to 39.37 U.S. inches
metamorphic rock	all rocks that have formed in the solid state in response to pronounced changes of temperature, pressure, and chemical environment, which take place below the shells of weathering and cementation
microbial	a microorganism, a pathogenic bacterium

microflora	a small, or strictly localized flora
modal length	most common length
Moenkopi Formation	a formation found in the Grand Canyon from the Triassic era, consisting of many thousands of layers of dark, reddish brown shale and siltstone, and shale with white gypsum beds
monsoon	any persistent wind established between water and adjoining land
monocotyledon	having one cotyledon or embryo-lobe
monospecificity	one species
morphology	the structure and form of organisms
native	a plant or animal produced or occurring naturally in a particular region
niche	all the components of the environment with which the organism or population interacts
nocturnal	foraging and moving around only at night
nonparametric	not involving the estimation of parameter values of a distribution function
non-point source (of water pollution)	diffuse surface or subsurface accumulation of pollutants from natural processes, both controllable and uocontrollable, or human activities and the transporation of those pollutants to surface water and ground water. Nonpoint source pollution does not arise from a discrete or identifiable facility
normal distribution	a theoretical frequency distribution represented by a normal; bell-shaped curve
nutrient	a substance usable in metabolism
operculum	gill-cover of fishes
organic matter	matter of compounds which contain carbon
ovary	the essential female reproductive gland
overstory	the layer of foliage in a forest canopy; its trees

oviposit — to discharge eggs from the body

Paleozoic — one of the eras of geologic time. Comprises the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian and Permian systems

parameter — a determining factor, characteristic, etc

parasite — an organism living with or within another to its own advantage in food and/or shelter

parr — the young of certain fishes

pathogenic — disease-producing

pectoral — of the chest or breast; thoracic region

pectoral spines — spines located in chest region of many fish

pelagic — ocean water inhabiting

perennial — something that is continual, recurrent

petri dish — a shallow, circular glass or plastic dish with a loose-fitting cover, used for culturing bacteria and other microorganisms

ph — the negative value of the power to which 10 is raised in order to obtain the concentration of hydrogen ions in gram-molecules per liter, ph of a neutral solution being 7; ph of acid solutions is smaller than 7, ph of alkaline solutions being greater than seven

phenology — recording and study of periodic biotic events, as of flowering, breeding, migration, etc., in relation to climate and other factors

photoperiod — the interval in a 24-hour period during which a plant or animal is exposed to light

photosynthesis — carbon assimilation, requiring presence of chloroplasts and light, and consisting in synthesis of carbohydrates from carbon dioxide

physico-chemical — parameters pertaining to physical chemistry

piscivorous — fish-eating

pollution	foul, unclean, dirty contamination
polyploid	with a reduplication of the chromosome number, as triploid, tectraploid, etc., having three, four, etc., times the normal haploid or gametic number
point bars	one of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank
ponar grab samples	benthic invertebrate sampler
pool-rapid (morphology)	a sequence found in river systems where a rapid is preceded and followed by a small body of standing water
population	group of individuals of any one kind of organism
posterior	situated behind or at the rear of
potassium permanganate	a dark-purple solid, KM_uO_4 used as an oxidizing agent
precipitation	the discharge of water, out of the atmosphere
predator (predacious)	habitually preying upon other animals
primary productivity	rate at which radiant energy; stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances which can be used as food materials
primary radius	measurement taken from center of origin or point of attachment to margin of structure
pupae	the third or chrysalis stage of insect life; insect enclosed in a case during stage in metamorphosis preceding imago
pyloric sphincter	between mid-gut and hind-gut of insects; between stomach and duodenum of vertebrates
rapid	stretches in a river where the water plunges down rocky ledges or over-accumulations of loose rocks
reach	an extended portion of water, as in a straight portion of a stream or river; a level stretch

Redwall Limestone Formation	a rock formation found in the Grand Canyon of the Mississippian era, is one of the most distinctive and prominent formations within the Grand Canyon. The Redwall Limestone is medium gray on fresh exposures, but colored by a superficial red stain from overlying formations
regenerated	to renew or restore (a lost, removed or injured part)
relative density	$\frac{\text{number of individuals of species X}}{\text{total individuals of all species}} \times 100$
respiration	gaseous interchange between an organism and its surrounding medium
rhizome	a root-like subterranean stem, commonly horizontal in position, which usually produces roots below and sends up shoots progressively from the upper surface
riffles	a shallow extending across the bed of a stream; a rapid of comparatively little fall
riparian	frequenting, growing on, or living on the banks of streams or rivers
river bed	all the space ordinarily covered by water and lying between the lands on each side of the stream
river channel	the deepest portion of a river through which the main volume or current of water flows
riverine	of or pertaining to a river
saline	the amount of mineral substances, (common salts and others) left by evaporating water
salt	any of a class of compounds that are formed by the replacement of one or more hydrogen atoms of an acid with elements or groups; and that usually ionize in solution
scales	a flat, small, plate-like external dermal or epidermal structure, covering fish
schist	a medium or coarse-grained metamorphic rock, with a foliated structure, split up in thin, irregular plates
scour	erosion, especially by moving water
sediment	material in suspension in water or recently deposited from the waters of streams, lake, or seas

sediment load	solid fragmental material, or a mass of such material, either inorganic or organic that originates from the weathering of rocks and is suspended in the water flow
seine	a fishing net that hangs vertically in the water, having floats at the upper edge and sinkers at the lower
shale	a laminated sediment in which particles are mostly of the clay grade
Shinarump Conglomerate Formation	a rock formation found in the Grand Canyon from the Triassic era, consisting of light gray sand-stone and conglomerate
silica	silicon dioxide, $Si02$
siltstone	a very fine-grained consolidated clastic rock com-posed predominantly of particles of silt grade
solubility	the quality or property of being capable of being dissolved
somatic	purely bodily part of animal or plant; germinal
spawn	to deposit eggs or sperm dfrectly in water, as fishes
species	a group of individuals of common ancestry which closely resemble each other structurally and physio-logically and, in nature, interbreed, producing fertile offspring
species diversity	of the total number of species in a trophic component, or in a community as a whole, a relatively small per-cent are usually abundant, and a large percent are rare. While the few common species, or dominants, largely account for the energy flow in each trophic group, it is the large number of rare species that largely determine the <u>species diversity</u> of trophic groups and whole communities
specific conductance	a measure of total dissolved salts
spring	water issuing through a natural opening in such quantity as to make a distinct current
spring alcove	notch in a valley wall from which a spring issues forth

standard deviation	a measure of dispersion in a frequency distribution equal to the square root of the mean of the squares of the deviation from the arithmetic mean of the distribution
statistical	the science that deals with the collection, classification, analysis and interpretation of numerical data
strata	a single sedimentary bed or layer
Streptococcus	any of several spherical bacteria of the genus Streptococcus, occurring in pairs or chains. Some pathogenic to man
submerged aquatic macrophytes	attached plants occurring at all depths within the photic zone but vascular angiosperms only to about 10 meters
substrate-substratum	the base or material on which an organism lives
sulfate water	water containing a salt or ester of sulfuric acid
surber-type stream bottom sampler	device for sampling stream invertebrates. Using a frame to mark out area to be measured, all debris is swept into a net and stones are picked up and scrubbed in mouth of net
suspended sediment	sediment which remains in suspension in water for a considerable period of time without contact with the bottom
sympatric	having the same, or overlapping areas of geographical distribution
talus, or scree	fragments are broken off by the action of the weather from the face of a steep rock
Tapeats Sandstone	a geologic formation of the Cambrian era is the most persistent rock bodies in the Grand Canyon. Weathers into a nearly vertical cliff, containing dark brown, light brown horizontal layers composed of coarse quartz sand grains
taxon	any definite unit in classification of plants and animals. A taxonomic unit
taxonomy	the law of classification as applied to natural history
temperate	moderate in respect to temperature; not subject to prolonged extremes of hot or cold weather

terrestrial	consisting of or pertaining to the land in distinction from water
tissue	the fundamental structure of which animal and plant organs are composed
transect	a line, strip or profile as of vegetation chosen for studying and charting
transverses	lying across or between
travertine	calcium carbonate, $CaCO_3$, of light color and usually concretionary and compact, deposited from solution in ground and surface waters
tributary	applied to any stream which directly or indirectly contributes water to another stream
topography	the relief features or surface configuration of an area
trammel net	a rectangular net made of a middle layer that is slack and of fine mesh so arranged that fish attempting to pass in either direction carry some of the fine net through the coarse and are thus pocketed
turbidity	unclear or murky because of stirred-up sediment; clouded; opaque
understory	a foliage layer lying beneath and shaded by the main canopy of a forest
variance	the square of the standard deviation
vascular plant	plant composed of, or provided with, vessels or ducts that convey fluids
vegetarian	non-flesh eating
velocity	rapidity of motion, swiftness, speed
ventral	situated on lower or abdominal surface
vertebrae	any of the bony or cartilaginous segments that make up the backbone
viable	capable of living, growing, and developing
vinal (thread)	any of various synthetic textile fibers that are long chain polymers composed of at least 50% by weight of vinyl alcohol units

volt	the meter-kilogram-second unit of electromotive force equal to the electromotive force that will cause a current of one ampere to flow through a conductor with a resistance of one ohm
watershed	the region drained by a river, stream, a drainage area
whirl packs	plastic bags used in field sampling of aquatic life
yearling	an animal in its second year of life
zoogeography	the study of the geographical distribution of animals

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