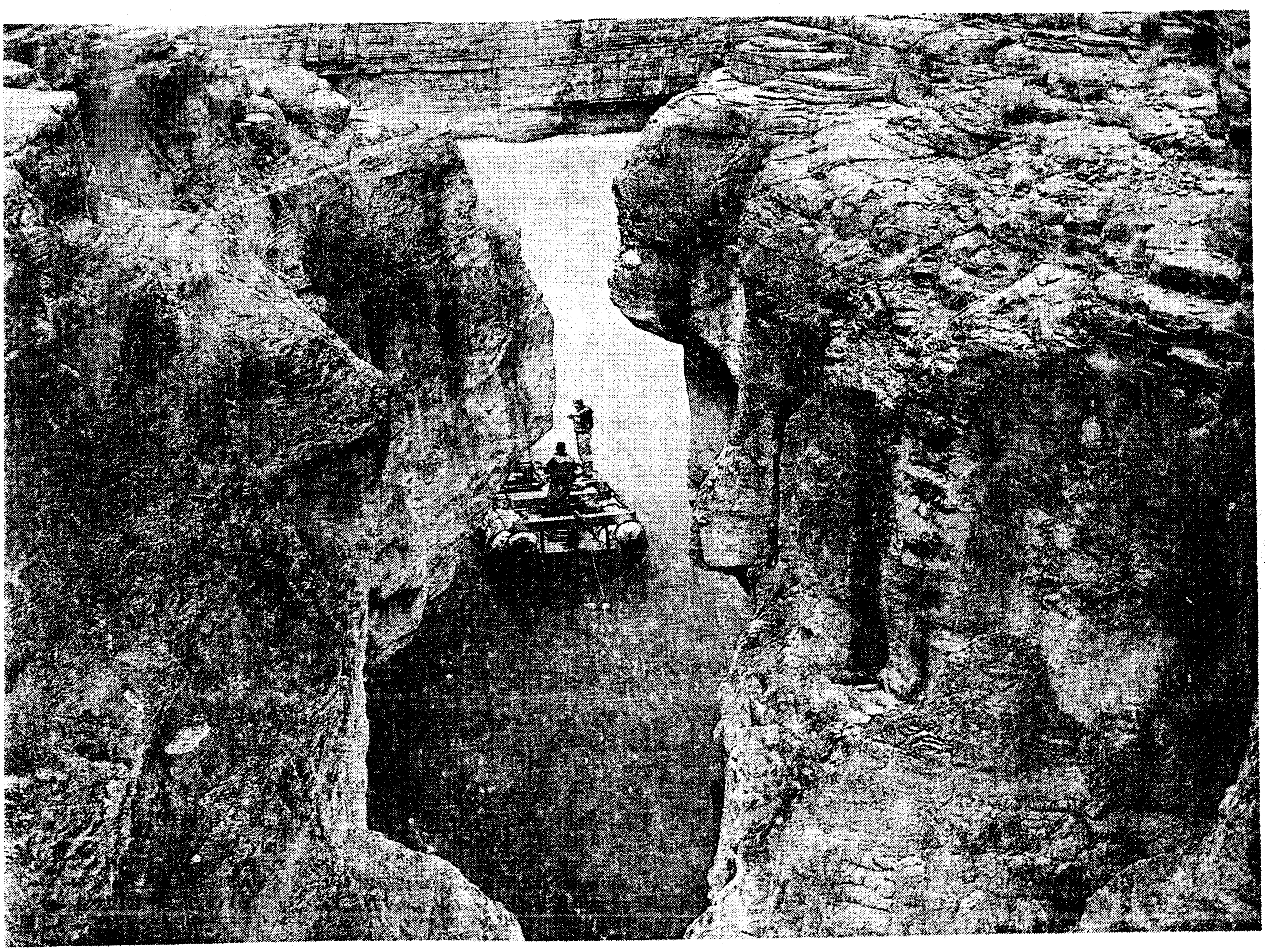
EFFECTS OF VARIED FLOW REGIMES ON AQUATIC RESOURCES OF GLEN AND GRAND CANYONS



ARIZONA GAME & FISH DEPARTMENT
FINAL REPORT
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EFFECTS OF VARIED FLOW REGIMES ON AQUATIC RESOURCES OF GLEN AND GRAND CANYONS

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Reach 20	TL	=	2.5	+	0.13(days)
Reach 30	TL	=	4.2	+	0.06(days)
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ABSTRACT

INTRODUCTION

The closing of Glen Canyon Dam in March 1963 marked a change in temporal discharge patterns in the Colorado River in Glen and Grand canyons. Prior to closure, there was little daily variation in discharge of the Colorado River in our study area. Rather, the variation was seasonal, largely due to snowmelt runoff with occasional summer floods and periods of drought. Since the onset of regulated flows, the seasonal pulse in discharge from snowmelt has continued, although much abated in most years. Much of the variation now occurs on a daily basis with dam releases dictated by needs for hydropower in the growing metropolitan areas of the southwestern United States.

This study was conducted as part of the Glen Canyon Environmental Studies (GCES), a multidisciplinary effort to gain knowledge on the effects of current and proposed operations of Glen Canyon Dam on the resources of the Colorado River and its tributaries in Glen and Grand canyons. Objectives of the present study were as follows:

1. Determine the distribution, relative abundance, habitat utilization, reproductive activity, movement, growth, and food resource utilization of fishes of the Colorado River and its tributaries;

2. Determine the relative importance of the mainstem Colorado and its tributaries to life history stages of native and introduced fishes in the study area;

3. Assess the relative importance of natural reproduction and artificial propagation (stocking) to the maintenance of the trout fishery in the Glen Canyon tailwater;

4. Evaluate and predict the effects of daily flow fluctuations, due to operation of Glen Canyon Dam, on native and introduced fishes to include direct effects such as stranding, and those brought about by changes in water quality, habitat availability, and food resources.

WATER CHEMISTRY

During the course of this study mean and coefficient of variation of daily flows at Lee's Ferry, 26 km below the dam, varied from 3,487 cfs to 51,570 cfs and 0% to 100.5%, respectively.

Except during periods of flooding when spillway releases occur, discharge through the dam is drawn from the depths of Lake Powell, more than 60 m below surface at maximum stage. These waters are perennially cold, varying only from 6-12^{o}C, and seldom warm to more than 15.5^{o}C at Diamond Creek. Tributary inflows are generally warmer in summer and colder in winter than the mainstem, but their combined discharge is insufficient to affect the Colorado River.

Major ion proportions in the Colorado River are: Ca > Na > Mg > K; and SO4 > HCO_3 > Cl. Tributaries vary from dilute dolomitic waters with high proportions of Ca, Mg, and HCO_3 to saline sodium chloride waters, but they produced only a slight increase of Na and Cl proportions in the mainstream during this study. Mean conductivity values increased only from 709 uS to 744 uS between the upper and lower reaches of the study area.

Mean mainstream NO_3-NO_2 concentrations varied between 315 ug/l and 350 ug/l with no apparent downstream trend. Tributaries were more variable with means of 13-759 ug/l. Ammonia levels were generally <5% those of NO_3-NO_2 in the Colorado River and its tributaries. Soluble reactive and total phosphate mean concentrations exhibited a downstream increase in the mainstream. Mean values ranged from 11.0-171.5 ug/l for the former and 15.8-290.9 ug/l for the latter. Observed increases were attributable largely to inputs from the Paria and Little Colorado rivers.

Molar N/P ratios in the Colorado River suggest that this system, if nutrient limited in primary productivity, is limited by phosphorus. Such limitation may not occur frequently, however, except perhaps in the reach above the Little Colorado River. Below the Little Colorado, dissolved phosphorus concentrations increase, but this is accompanied by considerable reduction in light penetration during flooding.

DISTRIBUTION AND ABUNDANCE

The Colorado River below Glen Canyon Dam has changed from a system of endemic and warmwater species prior to and immediately after closure of the dam to a system dominated by coldwater and eurythermal fishes. Although some native species have persisted through the changing environment, many have been extirpated including Colorado squawfish, bonytail chub, roundtail chub, and, probably, razorback sucker. Most warmwater species present in 1963 have either disappeared or decreased in abundance. Rainbow and brown trout have increased due to stocking and a more favorable environment.

Water temperature, clarity, food abundance, fish stocking, tributary locations, and backwater abundance seem to be important factors to fish distribution in the river. Decreased water temperature has been considered one of the primary reasons for the extirpation of native fishes from regulated portions of the Colorado River. Rainbow trout were collected throughout the study area, though catch rates were highest in the tailwater. Stocking of fingerling rainbow trout and the relative abundance of food items may contribute to the abundance of trout in Reach 10.

Brown trout abundance in the river seems to have increased since the examination of fish distribution by Carothers et al. (1981). Most of the increase has occurred in reaches 30 and 40 above and below the confluence of Bright Angel Creek. Brook trout distribution declined with distance downriver. Their distribution appears to be controlled more by stocking and dispersal downriver than by natural reproduction.

Other introduced species such as common carp and fathead minnow were most abundant in the lower reaches of the river. This may be related to higher water temperature.

Adult and larval bluehead sucker and speckled dace were most abundant in the lower reaches. Most adult flannelmouth were collected in Reach 10, with juvenile and larval fish in the lower reaches. The lower portion of the river serves as an important nursery and rearing area, and as these fish grow they distribute throughout the river.

Adult humpback chub, though found in reaches 20-50, were generally captured in the proximity of the Little Colorado

River. Most y-o-y and subadult humpback chub were collected from reaches 30 and 50, where most backwaters occur.

Adult rainbow trout habitat use differed between reaches above and below the Little Colorado River, perhaps due to increased turbidity below the LCR. Rainbow trout fry selected habitats with low or no current. Brown trout were caught in areas without vegetation.

Carp preferred habitats with slower water velocity. Fathead minnow density was highest along runs with vegetation. Vegetation served to diminish current velocity and probably provided substrate for food resources. Fluctuating flows may affect population size, depending on the effect of creating warmwater, isolated and connected, backwaters for reproduction, and then flushing fish hatched in these environments back into the mainchannel.

The higher velocity runs and sidechannels and rubble substrate selected by bluehead sucker are probably feeding areas. When water levels drop, these shallow areas are probably exposed. Larval bluehead sucker were generally in shallow backwaters and may also be affected by changing water levels.

Backwaters, where flannelmouth sucker catch was greatest, may be feeding, resting and spawning habitats for this species. If water level fluctuates in late spring or early summer, survival and eventual recruitment of this species could be limited. Speckled dace were collected from a variety of habitats but seemed to be concentrated in backwaters and sidechannels where waters were warmer than the mainchannel.

Adult and subadult humpback chub were generally collected along cliffs and boulders in the mainchannel. Vegetation did not appear to be important. Y-o-y chubs were captured in sandy runs and backwaters. Although larvae of other native fishes were collected from mainchannel sites, no humpback chub larvae were found outside the LCR, and mainchannel water temperatures are probably lethal to larvae of this species. Mainchannel abundance may be dependent upon the carrying capacity and success of reproduction within the LCR.

Colorado River backwaters are important nursery and rearing areas for both native and introduced fishes (Valdez et al. 1986). Backwaters in our study area appear to be very important to fishes during the period of spring through early autumn. When backwaters cool to near or below mainchannel water temperature, abundance of fish decreases. Introduced fishes were generally more abundant than natives in backwaters.

Of native fishes found in backwaters, flannelmouth sucker and speckled dace showed a decline in CPUE and relative abundance during the October 1985 fluctuating flows, whereas humpback chub and bluehead sucker generally increased. Results could have been much different if fluctuating flows had occurred during summer when many of these species are in their larval stages. Larval fish have much less mobility and are more vulnerable to river currents than older, larger individuals.

TRIBUTARIES

Tributaries are important in maintaining both endemic and introduced fish species of the Colorado River. Trout were captured most frequently in winter and early spring when water temperatures were lowest. Most native fish were found in tributaries in late spring and summer when temperatures far exceeded those of the mainchannel.

Native fishes and the introduced trout species also demonstrated different use patterns by tributary type. Native fishes were most common in streams classified as major tributaries with low gradients and originating outside Grand Canyon, e.g. Paria and Little Colorado rivers and Kanab Creek. Conversely, trout preferred tributaries that are steep in gradient, relatively straight, and originate as springs in Grand Canyon, e.g. Tapeats, Bright Angel, and Shinumo creeks.

The Little Colorado River appears to be crucial to the long-term survival of humpback chub. No evidence was found to indicate that major spawning areas occur outside this tributary, although as has been noted in other studies, Shinumo and Havasu creeks could support limited reproduction. Mainchannel reproduction by humpback chub is at best extremely limited, or more likely nonexistent as a result of cold water temperatures. The mixing zone formed at the mouth of the Little Colorado River appears to provide a thermal intergrade between the cold mainchannel and the warm tributary. Our collections indicate this may be an important staging area for larval chubs before entering the mainstream.

MAINCHANNEL REPRODUCTION

Variation in water flow has been shown to affect trout spawning and may have been responsible for the temporal shift in reproductive activity observed during this study in Reach 10. Reaches below Lee's Ferry seemed less disrupted by changes in flow. Fry density in 3 of 4 reaches appeared related to proximity of tributary streams.

Brown trout population levels in the mainchannel may be controlled by reproduction in and recruitment from tributaries to the Colorado River. It appears brook trout numbers are maintained only through stocking.

Mainchannel reproduction by other introduced fish, including common carp and fathead minnow, appeared to occur only in backwaters, because mainchannel temperatures inhibit spawning. Mainchannel reproduction by native fishes also appears limited; however, this habitat serves as an important nursery and rearing area for fishes spawned in both tributaries and mainchannel. Most larval bluehead sucker were collected from backwaters in lower reaches. Concentrations of flannelmouth suckers in reproductive condition were often found at tributary mouths and in connected backwaters. Larvae were collected from the mainchannel only in reaches 40 and 50.

The Grand Canyon population of humpback chub spawns between March and June in the Little Colorado River. Mainchannel temperatures may not be warm enough to initiate spawning. Y-o-y chub were collected in lower reaches of the river, however, suggesting that spawning areas other than the LCR may be present.

MOVEMENT

Movement was examined by tag-recapture, oxytetracycline dye marks and fin clips.

The majority of tagged and recaptured fish were rainbow trout. Most movement appeared to be associated with reproduction; movement to and from tributaries during spawning season was observed for rainbow trout, brown trout, flannelmouth sucker and humpback chub.

Oxytetracycline dye marked fingerling rainbow trout were stocked at Lee's Ferry from October 1983 to April 1986. Rainbow trout were then sampled from all reaches to document dispersal of these stocked trout. Dye marked trout represent 61% of the sampled fish in Reach 10, but very few marked individuals were collected downriver. Natural reproduction is occurring in the Lee's Ferry area for all sampled fish 100 mm or smaller were not dyed. Rainbow trout that were not dyed constituted 27.5% of individuals checked in the creel.

FISH FOOD RESOURCES

Food resource utilization of fishes was examined by analysis of gut contents. Gut analyses were accomplished for fry of three species; rainbow trout, bluehead sucker, and flannelmouth sucker. Only adult rainbow trout guts were examined.

Immature chironomids were numerically predominant in fry guts of all three species. Zooplankton, primarily copepods and cladocerans, was of second highest proportion in flannelmouth sucker and mainstream rainbow trout fry, but other immature insects held this position in bluehead sucker fry. Proportion of zooplankton declined dramatically in rainbow trout fry collected below Reach 10.

Adult rainbow trout guts had high volumetric proportions of the filamentous green alga, *Cladophora glomerata*, immature insects (mainly chironomids and simuliids), or the amphipod, *Gammarus lacustris*, depending on the stream reach considered. Proportions of these major food groups also varied on a seasonal basis. *Gammarus* proportion increased dramatically during a period when dam releases were dropped deliberately. This suggests that the amphipod's susceptibility to trout predation can be affected by operations of Glen Canyon Dam.

AGE AND GROWTH

Length frequency distributions were used to estimate growth of fish because it was not possible to age fish by conventional scale and otolith methods. Growth rate of rainbow trout was highest in upper reaches of the Colorado River and decreased below the confluence of the Little Colorado River. Condition factors for rainbow trout also decreased with distance downstream from Glen Canyon Dam.

First year growth of humpback chub was estimated to be 70 mm based on length frequencies. Growth of adults (>250 mm) was estimated to be approximately 10 mm/yr. First year growth of bluehead and flannelmouth sucker was estimated to be approximately 70-100 mm based on length frequencies. Growth of adult suckers was variable but generally slow.

LEE'S FERRY FISHERY

A stratified creel survey was conducted at Lee's Ferry from January 1984 to May 1986, and past creel records were analyzed. Fishing pressure increased greatly from 1977 to 1983 and then decreased greatly during each year of our study. Catch rates for trout increased from 1977 to 1985 and then decreased in 1986, probably due to a change in fishing regulations.

Mean lengths of creeled rainbow trout decreased from 1977 to 1985, probably due to lack of stocking from April 1978 to August 1980, and higher angler harvest. Mean lengths increased in 1986, yet few large fish were checked at the creel station.

There were significant seasonal differences in catch rates for total trout and in mean lengths and condition factors for rainbow trout. Catch rates and mean lengths were greatest during winter coinciding with the rainbow trout spawn. Mean condition factors were lowest during winter.

Daily catch rates varied significantly with daily mean flow. Catch rates were highest when mean daily flows were less than 14,000 cfs. Daily catch rates also varied significantly with discharge categories which included effects of both mean and coefficient of variation of daily flow.

1. INTRODUCTION

The closing of Glen Canyon Dam in March 1963 produced a major change in temporal discharge patterns of the Colorado River in Glen and Grand canyons (Figure 1.1). During the predam period of measure, annual discharge volumes and maximum discharges varied greatly from year to year. Maximum flows exceeding 50,000 cubic feet per second (cfs) were common. For 20 years following the dam's closure, during which time Lake Powell was filling, regulated maximum flows exceeded 50,000 cfs in one year and 30,000 cfs in only two additional years. Since early 1983, however, a combination of high runoff from snowmelt and the high stage of Lake Powell has resulted in maximum flows at Lee's Ferry[1] between 45,000 cfs and 92,600 cfs. In contrast, minimum flows, both pre- and post-dam, have been in the range of 1,000-4,000 cfs during most recorded years.

Prior to the closure of Glen Canyon Dam, there was little daily variation in discharge of the Colorado River in the study area. Rather, the variation was seasonal, largely due to snowmelt runoff (April-June) with occasional summer floods and periods of summer drought. Since the onset of regulated flows, the seasonal pulse in discharge from snowmelt has continued, although much abated in most years. Much of the variation, however, now occurs on a daily basis with dam releases dictated by needs for hydropower in the growing metropolitan areas of the southwestern United States. This variation, which is reminiscent of tides in marine systems, has no known corollary in the evolutionary history of the native flora and fauna of the Colorado River.

During peaking power periods, minimal water is released from the reservoir at night when the demand for power is low, and discharge is increased dramatically during high demand daytime hours. Weekends and holidays are often characterized by extended periods of low flow.

[1]Throughout this report we will observe the spelling "Lee's Ferry" in reference to the sight formerly occupied by John D. Lee and used to ferry boats across the Colorado River. In this respect, we follow Rusho and Crampton (1981) and concur with their finding that the spelling "Lees Ferry" as commonly used is "...both in poor grammar and poor history, since no person named Lees was ever involved."

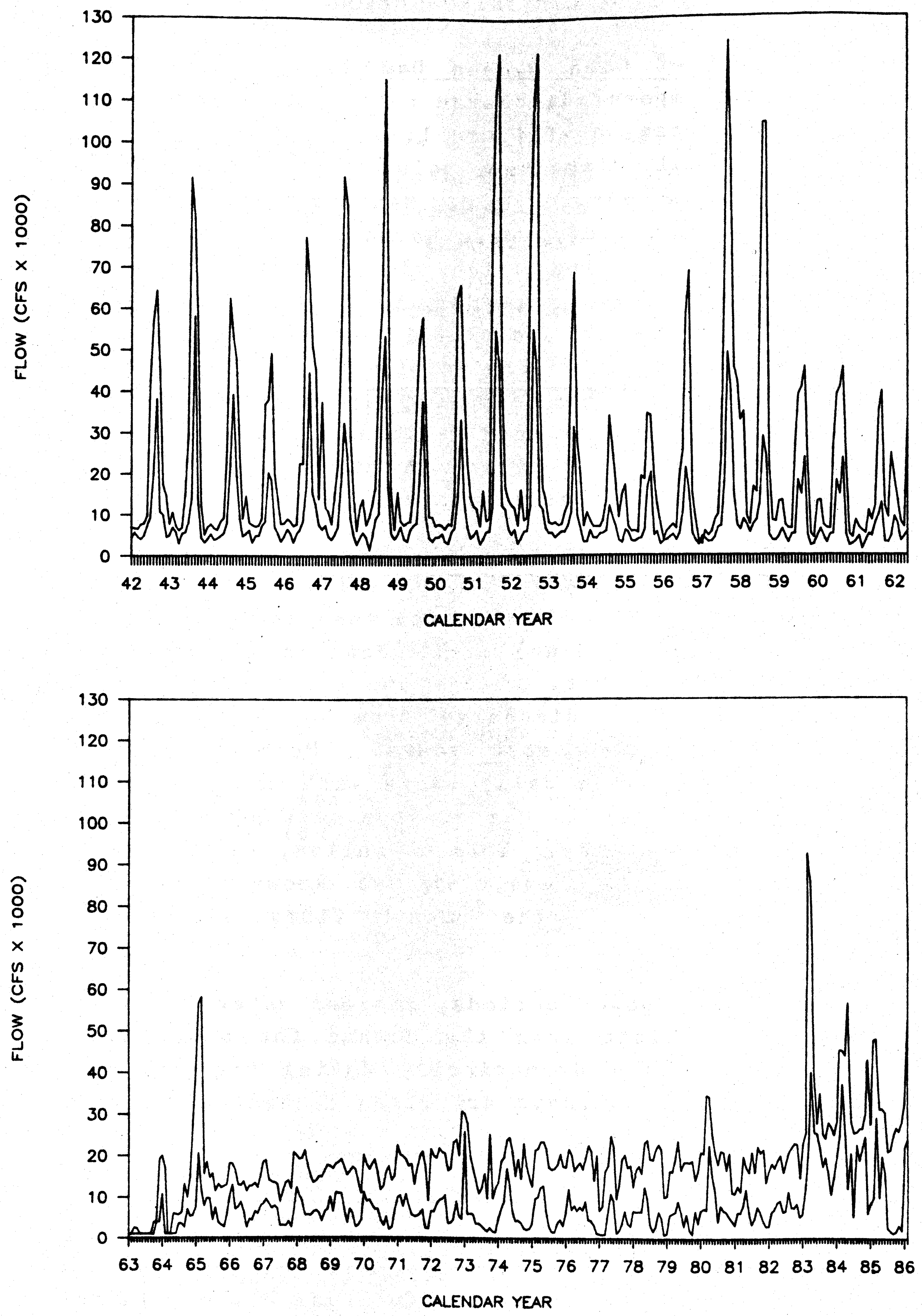


Figure 1.1. Minimum and maximum monthly flows measured at the Lee's Ferry gauging station for pre-dam 1942-62 (top) and post-dam 1963-86 (bottom) periods.

Fluctuating releases from reservoirs cause major changes in the physicochemical environment of receiving streams. Water velocity, depth, width, amount of wetted perimeter, temperature and other water quality variables are affected by varying flows, and these changes in turn impact the aquatic biota below dams. Variable flow patterns below dams impact the entire food chain from primary producers (Neel 1963) to invertebrates (Fisher and LaVoy 1972, Trotzky and Gregory 1974) to the fish fauna (Bauersfeld 1978, Becker et al. 1981).

In a 1956 U.S. Fish and Wildlife Service (FWS) report, recommendations were made to maintain a minimal instantaneous release of 8,000 cfs from Glen Canyon Dam. The proposal included a recommendation to maintain a variation in the rate of release of 50% or less within any one-hour period (Nelson et al. 1976). These recommendations were made without supportive biological data from the down river region. The Bureau of Reclamation (BOR) rejected both recommendations, though the Secretary of the Interior decreed a 1,000 cfs minimum.

The consequences of these actions or the effects of variable release patterns from Glen Canyon Dam have never been examined for the Glen and Grand canyon reach of the Colorado River. The present study provides the first comprehensive effort to understand the relationships between operation of Glen Canyon Dam and the aquatic resources below.

OBJECTIVES

The field aquatic portion of the Glen Canyon Environmental Studies began in April 1984 and ended in June 1986. This included 14 major river trips as well as shorter term data collection at important river locations.

An agreement between Arizona Game and Fish Department (AGFD) and BOR established broad objectives in an attempt to better understand the aquatic ecosystem and its relationship to fluctuating flows. The broad objectives of the present study were to: 1) determine the importance of the mainstream Colorado River and the impact of fluctuating flow levels within the Grand Canyon to the native and exotic aquatic species; 2) determine the importance of the tributaries to native and exotic fish life histories and determine tributary importance to the overall native and sport fisheries of the Canyon; 3) determine the effects of fluctuating flows on *Cladophora* life history; 4) determine the effects of fluctuating flows on phytoplankton and zooplankton life stages and the utilization and importance of these plankton to the fish species at various life stages throughout the study area; and 5) determine the importance of natural reproduction versus artificial propagation to the maintenance of the trout fishery in the Glen Canyon tailwater. In addition to these objectives, we were to include an analysis of potential alternative operating criteria consistent with Colorado River Storage Project (CRSP) requirements and to propose feasible alternatives.

The first objective was to collect baseline data on fish species composition and distribution in the Colorado River. This information allowed the more important second objective of comparing use of mainchannel and tributaries for spawning and nursery areas for larval fishes and rearing of older fish. Objective three was addressed through a combination of field and laboratory studies by researchers at Northern Arizona University. Because larval life stages of fishes may be dependent on zooplankton, objective four was included. A combination of plankton samples and larval fish gut analysis was incorporated to address this objective. The fifth objective was to establish whether rainbow trout in the Glen Canyon tailwater were naturally reproducing and, if so, how much they contributed to the creel. Other aspects of the ecosystem not covered in these objectives but considered important were also addressed.

The five discharge scenarios are based on the minimum release (8.3 million acre feet [maf]) established by law that must be released annually through Glen Canyon Dam. A release pattern based on 8.3 maf could have almost any combination of steady and fluctuating flows. A major factor that affected collection and analysis of data was the amount of runoff during the study period. Annual releases from the dam ranged from 16.6-21.1 maf during our study. Because of these high releases BOR was not able to provide the various flow patterns necessary to address all the questions raised in the study objectives. Most data collection occurred during periods of high steady releases. Only brief periods of fluctuations were provided during the study, and these generally came during autumn and winter.

Five alternative release patterns provided by BOR for evaluation are included in this report. As requested by BOR, discharges are listed in English units while all other measures are metric. This was done because of the wide acceptance of cubic feet per second (cfs) by the participating agencies. River miles throughout this report are considered locations, while distances between locations are in metric units.

2. STUDY AREA

The Colorado River was divided into an upper and lower basin by the Colorado River Compact of 1922 with Lee's Ferry as the boundary division between basins (Figure 2.1). The study area includes 26 km of renowned trout fishery in the upper basin above Lee's Ferry to Glen Canyon Dam and 384 km in the lower basin below Lee's Ferry to Diamond Creek.

The study area was divided into five reaches, numbered 10, 20, 30, 40, and 50, respectively (Table 2.1). These correspond to reaches established by the United States Geological Survey (USGS) in their study of sediment transport. The 26 km of river from Glen Canyon Dam to the Paria River constitutes Reach 10 and includes the first tributary below Glen Canyon Dam. Reach 20 extends from below the Paria River to just below the confluence of the Colorado and Little Colorado rivers. Reach 20 includes Nankoweap Creek and the Little Colorado River. The third reach, Reach 30, extends from that point to Bright Angel Creek near Phantom Ranch and the heart of the Grand Canyon. Tributaries in Reach 30 include Clear and Bright Angel creeks. Reach 40 begins below Bright Angel Creek and ends at National Canyon, River Mile (RM) 166.5. Reach 40 contains the most perennial tributaries, including Crystal, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks. Reach 50 begins at National Canyon and extends 109 km to above Diamond Creek. Reach 50 is the only one that does not contain a perennial tributary.

The river between Glen Canyon Dam and Diamond Creek has been classified into four categories (Howard and Dolan 1981). The first is wide valleys with freely meandering channel. This category is characterized by wide, shallow areas where cobble bars average 215 m in width compared to an average width of 129 m at average flood state (3,500 m^2/sec). Such areas include Reach 10, and the upper portion of reaches 30 and 50. The second classification is valleys of intermediate width. These are valleys constricted somewhat by resistant sandstone or limestone. Cobble bars in these areas are less abundant and limited to the wider portions of the river. The third type is narrow valleys in fractured igneous and metamorphic rocks. These are characterized by a narrow, steep-gradient channel and deep pools. The shoreline is often cliff, and cobble bars are rare. This area is often called the "granite narrows" and extends from RM 77 to RM 112. The last category is narrow valley in massive

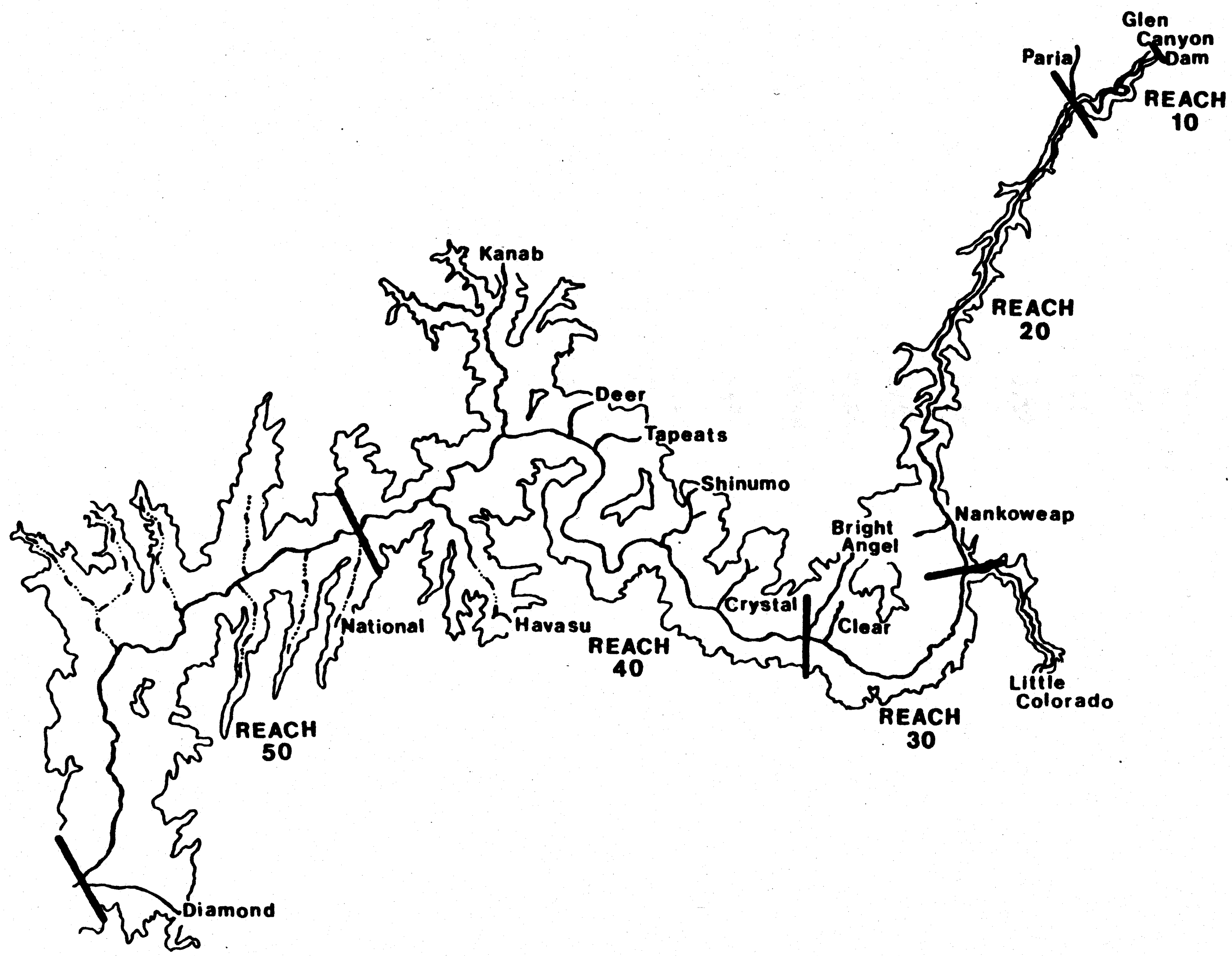


Figure 2.1. Map of study area including perennial flow tributaries.

Table 2.1. Description of sampling sites by reach, river mile, and distance from Glen Canyon Dam.

Sample Sites	Reach	River mile [a]	Distance (Km) from Glen Canyon Dam
Glen Canyon Dam	-	15.5	0
Lee's Ferry	10	0.0	24.9
Paria River	11	1.0	26.5
Nankoweap Creek	21	52.0	108.6
Little Colorado River	22	61.5	123.9
Clear Creek	31	84.0	160.1
Bright Angel Creek	32	88.0	166.5
Crystal Creek	41	98.0	182.6
Shinumo Creek	42	108.5	199.5
Tapeats Creek	43	134.0	240.5
Deer Creek	44	136.0	243.8
Kanab Creek	45	143.5	255.8
Havasu Creek	46	157.0	277.6
National Canyon	40 (above)	166.5	292.8
Diamond Creek	50 (below)	226.0	388.6

[a] After Stevens (1983).

limestone. These are often areas of constant width with sheer wall (cliff) for shoreline. Portions of Reach 40 fall within this classification.

The Colorado River between Lee's Ferry and Lake Mead drops 671 m in elevation. The river is a series of long runs and short steep rapids. These long runs have a water surface gradient near five feet (ft) in 10,000 (1.5/3048 m) (Leopold 1969). Rapids, which account for most of the drop in elevation, fall 5-17 ft per 1,000 (1.5-52/304.8 m). Mean velocity through the rapids is generally 11 to 15 feet per second (fps).

Tributaries to the Colorado River within this study area generally fit one of two categories described by Hamblin and Rigby (1968). The first category includes major streams with large drainages, low gradients and well developed meanders. The Paria and Little Colorado rivers and Kanab Creek fit this description. In general, substrate in this type stream consists of silt and clay.

The second type of tributary found in the study area is a generally short, relatively straight stream originating from springs and seeps issuing from various geologic formations within Grand Canyon. Gradient in these streams is generally steep, and, as a result, substrates are predominantly cobble, gravel, and sand. Nankoweap, Bright Angel, Deer, and Tapeats are good examples of this type of stream.

3. WATER CHEMISTRY

3.1 METHODS

Water quality parameters measured included discharge, temperature, water clarity, conductivity, major ion and nutrient (nitrogen, phosphorus, and silica) concentrations, pH, and dissolved oxygen levels. Mainstream discharge measurements were taken from the USGS continuous stage recorder at Lee´s Ferry, or were estimated from the BOR Stream Simulation and Reservoir Regulation (SSARR) model (See Graf et al. 1986). Tributary discharges were calculated from depth-velocity profiles made with a meter stick and Marsh-McBirney Model 201D current meter. Water temperature, conductivity, pH, and dissolved oxygen were measured in the field with a multiple-probe Hydrolab Model 9000 Surveyor II meter. Major ions and nutrients were analyzed at the BOR water quality laboratory in Salt Lake City, Utah. Instruments utilized for these analyses are given in Table 3.1. Appendix 3.1 provides a monthly schedule of locations where discharge, Hydrolab, major ion, and nutrient samples were taken. Because too many samples did not have coincident discharge and conductivity or ionic concentration measurements, values appearing in this report are not flow-weighted.

3.2 RESULTS

Discharge

Instantaneous discharge of the Colorado River at Lee´s Ferry varied between 1,160 cfs and 56,600 cfs during the period April 1984-May 1986 (USGS, Water Resources Data for Arizona, provisional data). Mean daily flows ranged from 3,487 cfs to 51,570 cfs, and the mean, median, and mode of mean daily flows were 26,233 cfs, 24,988 cfs and 25,000 cfs, respectively. The cumulative frequency hydrograph of mean daily flows for this period is roughly sigmoidal in shape with a lower plateau beginning near 14,000 cfs and an upper plateau at around 31,500 cfs (Figure 3.1). A secondary mode occurs at 42,000 cfs.

The cumulative frequency polygon of daily flow coefficient of variation ($CV=SD/\bar{x}$, half-hour intervals) during the same period rises precipitously in the range of 0% to 3% at which point slightly more than 50% of the observations have been included (Figure 3.1). Approximately 80% of all observations lie

Table 3.1. Instrumentation utilized for water chemistry analyses by Bureau of Reclamation water quality laboratory.

Water quality component	Instrumentation
Major cations	
Na, K, Ca, Mg	Atomic absorption
Major anions	
Cl, SO_4	Ion chromatograph
Alkalinity	Potentiometric titration
Nutrients	
SRP[a], NH_4, NO_3-NO_2, Silica	Flow injection analysis
NO_3	Ion chromatograph
Total phosphates[b]	Persulfate oxidation Ammonium molybdata/ ascorbic acid Narrow-band spectrophometer

[a] Soluble reactive phosphate
[b] 2 ml of HCl were added as preservative to all nutrient samples. This addition of strong acid undoubtedly solubilized some phosphate, thus increasing the SRP component.

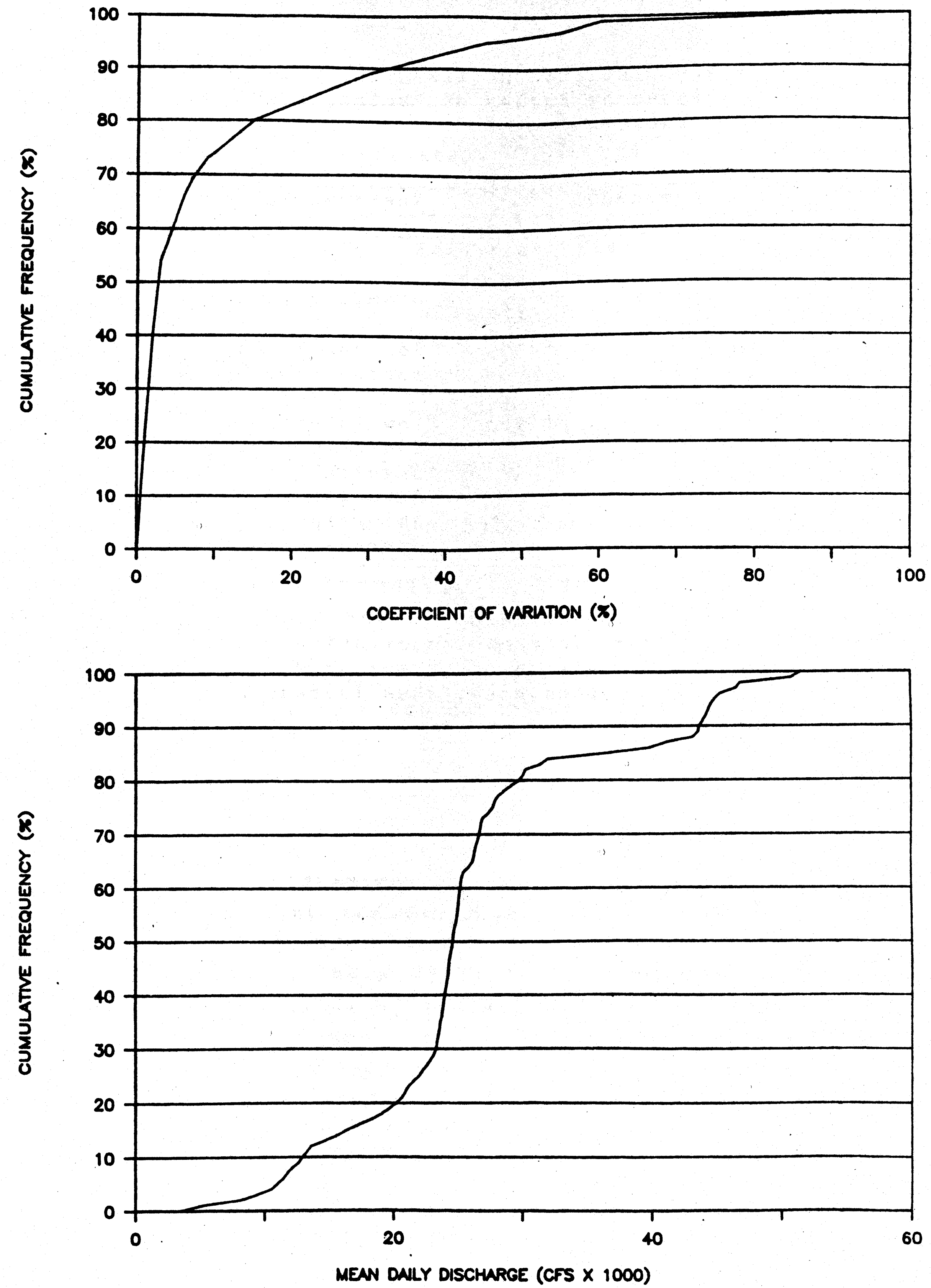


Figure 3.1. Cumulative frequency polygons for mean and coefficient of variation of daily discharge of the Colorado River at Lee's Ferry during 1984-86.

below a CV of 15%, and the remaining 20% of data points subtend a CV range from 15% to 100.5%.

The temporal pattern of the mean and CV of daily discharge at Lee's Ferry was summarized by categorizing these variables according to "breaks" in their cumulative frequency distributions. No a priori ecological significance was attached to boundaries of the classes of either mean or coefficient of variation in daily flow. The flow categories were assigned subjectively in order to allow a statistical approach to measuring the effects of previously undefined "fluctuating flows". Both measures were divided into low (L), intermediate (I), and high (H) classes as follows: mean flow 3,487-14,000 cfs (L); 14,001-31,500 cfs (I); 35,501-51,570 cfs (H); coefficient of variation 0-3.0% (L); 3.1-15.0% (I); 15.1-100.5% (H).

Three classes in the 3x3 matrix of coefficient of variation/mean daily flow were poorly represented during the period of the field study (Table 3.2). Graphical examples of half-hour interval discharges for representative days in the remaining six categories are given in Figure 3.2. Of 98 days for which mean daily flow did not exceed 14,000 cfs, only 3 days had a CV less than 15%. In contrast, during the 147 days when mean daily flows exceeded 31,500 cfs, only two days had a CV greater than 15%.

Daily discharges at Lee's Ferry during April and May 1984 were near 25,000 cfs, at which time they increased markedly to 40,000-45,000 cfs for a two month period. With the exception of brief periods during August 1984 and October 1984, flows were again near 25,000 cfs until March 1985. Excluding the October 1984 period, the CV of daily flows never exceeded 20% and most days had values of 10% or less (Figure 3.3).

From 12 to 15 August, 1984, discharge at Lee's Ferry increased to a maximum of 56,600 cfs due to a BOR test of a reconstructed dam spillway tunnel damaged during the 1983 flood (Collins 1984). During October 19-22, 1984, discharge from Glen Canyon Dam was deliberately dropped to near 5,000 cfs in order to produce a period of low flows for this study. The CV of daily flows increased to 61% in this interval, but this increase was attributable to the initial drop and subsequent increase on the first and final days of the period. CV for the intervening time did not exceed 1.1%.

Table 3.2. Frequency (days) of mean and coefficient of variation of daily discharge categories at Lee's Ferry USGS gauging station on the Colorado River during the period April 1, 1984-May 30, 1986. L=low; I=intermediate; H=high.

		Coefficient of variation[a]		
		L	I	H
Mean	L	2	1	95
Daily	I	269	192	81
Flow	H	115	30	2

[a] L=0-3%, I=3.1-15%, H=15.1-100.5%
[b] L=3,487-14,000 cfs, I=14,001-31,500 cfs, H=31,501-51,570 cfs

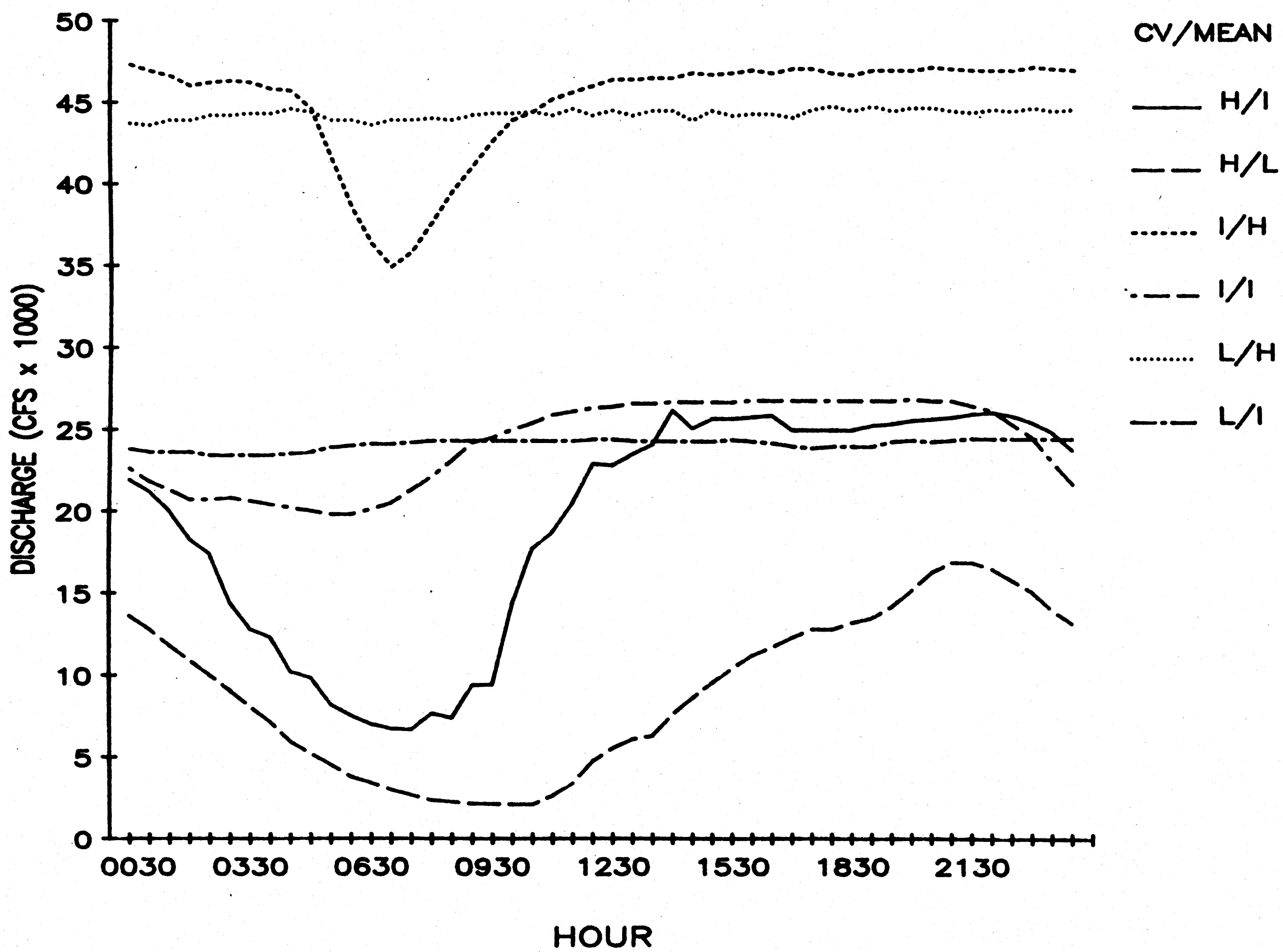


Figure 3.2. Half-hour instantaneous discharge records at Lee's Ferry for selected days during April 1984 to May 1986. CV = coefficient of variation; where L = 0-3%, I = 3.1-15%, and H = 15.1-100.5%. MEAN = mean of daily flow classes; where L = 3,487-14,000 cfs, I = 14,001-31,500 cfs, and H = 31,501-51,570 cfs.

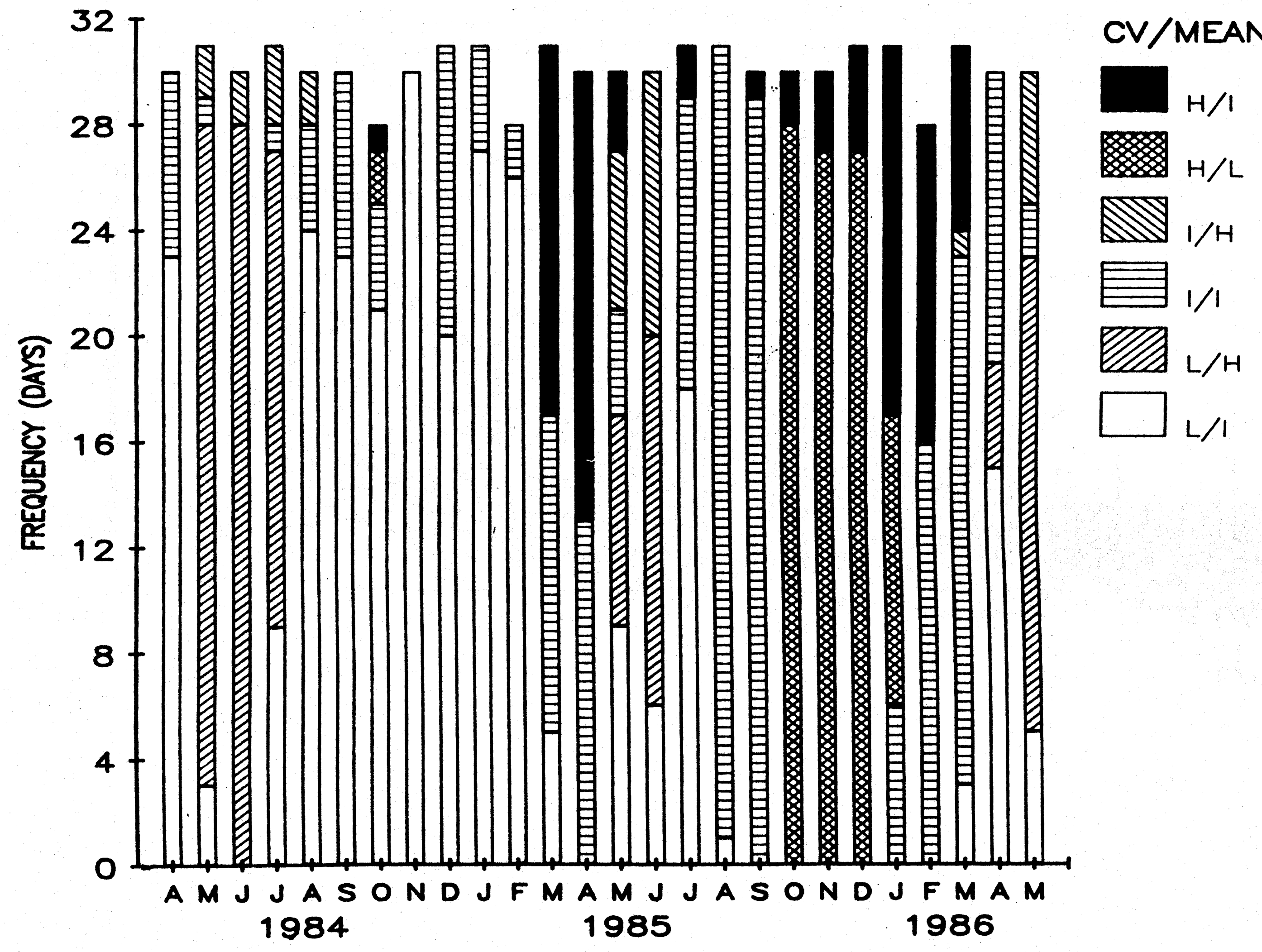


Figure 3.3. Monthly frequency distribution of coefficient of variation (CV) and mean of daily flows at Lee's Ferry during April 1984 to May 1986. CV and MEAN L, I, and H values given in figure 3.2.

March and April 1985, were months dominated by intermediate flows with high daily variation. During May and June 1985, discharges were greater than 40,000 cfs for most days and variation in flow declined. July-September 1985, was a transition period of declining mean discharge and increasing daily variation in flows. The most sustained period of highly fluctuating flows experienced during the study occurred from October 1985 to mid-January 1986, with CVs for most days exceeding 20%. Mean daily flows varied from ca. 6,500 cfs to 15,500 cfs during this time, and the range from minimum to maximum instantaneous discharge often exceeded 20,000 cfs. Mid-January to mid-March was a period of transition to lower variation in instantaneous discharge, while mean daily flows remained in the range of 18,000-24,000 cfs. For the remainder of the field study period, mean flows increased to compensate for high inflows to Lake Powell and CVs were generally <10%.

Tributary discharge measurements (Table 3.3) were taken somewhat sporadically, and certain values seem inordinately high when compared with previous records (USGS 1953, Johnson and Sanderson 1968, Huntoon 1974). Little Colorado River measurements were not made during this study, but base flow from springs in the lower reach of this tributary is known to be about 223 cfs (Johnson and Sanderson 1968).

Water Clarity

Secchi disc readings were taken at varying intervals through the study area on 10 field trips. Two trips, September 1984, and July 1985, illustrate the extremes of changes in water clarity through the 360 km corridor from Lee's Ferry to Diamond Creek (Figure 3.4). In September 1984, the Secchi disc reading decreased from 300 cm below the Paria River to 6 cm at RM 230, whereas in July 1985, the decline was from 580 cm at Lee's Ferry to 75 cm at RM 212. Major contributors to these declines were the Paria and Little Colorado rivers, both of which carry large amounts of suspended sediments even at moderate flows (Cole and Kubly 1976, USGS 1982). During the September trip Paria River flows near the mouth varied between 8 cfs and 69 cfs, while Little Colorado discharges at Cameron, Arizona ranged from 40-2340 cfs. In contrast, during the latter field trip Paria River flows were only 2.9-8.3 cfs, and the Little Colorado ranged from no flow to 26 cfs (USGS, Water Resources Data for Arizona, provisional data).

Table 3.3 Discharge measurements (cfs) of selected Colorado River tributaries in Glen and Grand canyons, during 1984-1986.

	1984				1985						1986		
	Apr	Jun	Sep	Dec	Feb	Apr	May	Jan	Oct	Dec	Feb	Apr	May
Paria River			7.9			33.9						34.4	12.2
Nankoweap Creek			0.9	3.6	1.4	8.5	5.6				0.8	1.9	
Clear Creek				3.8		13.3					3.6	2.4	3.6
Bright Angel Creek			30.4	26.6	25.1	72.1	43.3				30.9	35.5	
Crystal Creek			1.5	1.4	2.0	7.8	4.0					1.7	5.0
Shinumo Creek			13.0			108.0					10.5	16.5	
Tapeats Creek		138.3		124.0	101.6			173.3			78.4	102.6	281.9
Deer Creek											12.6	16.0	
Kanab Creek	8.6	3.7	8.6	11.6				7.0		2.8		38.0	6.0
Havasu Creek										69.5	60.6		207.4

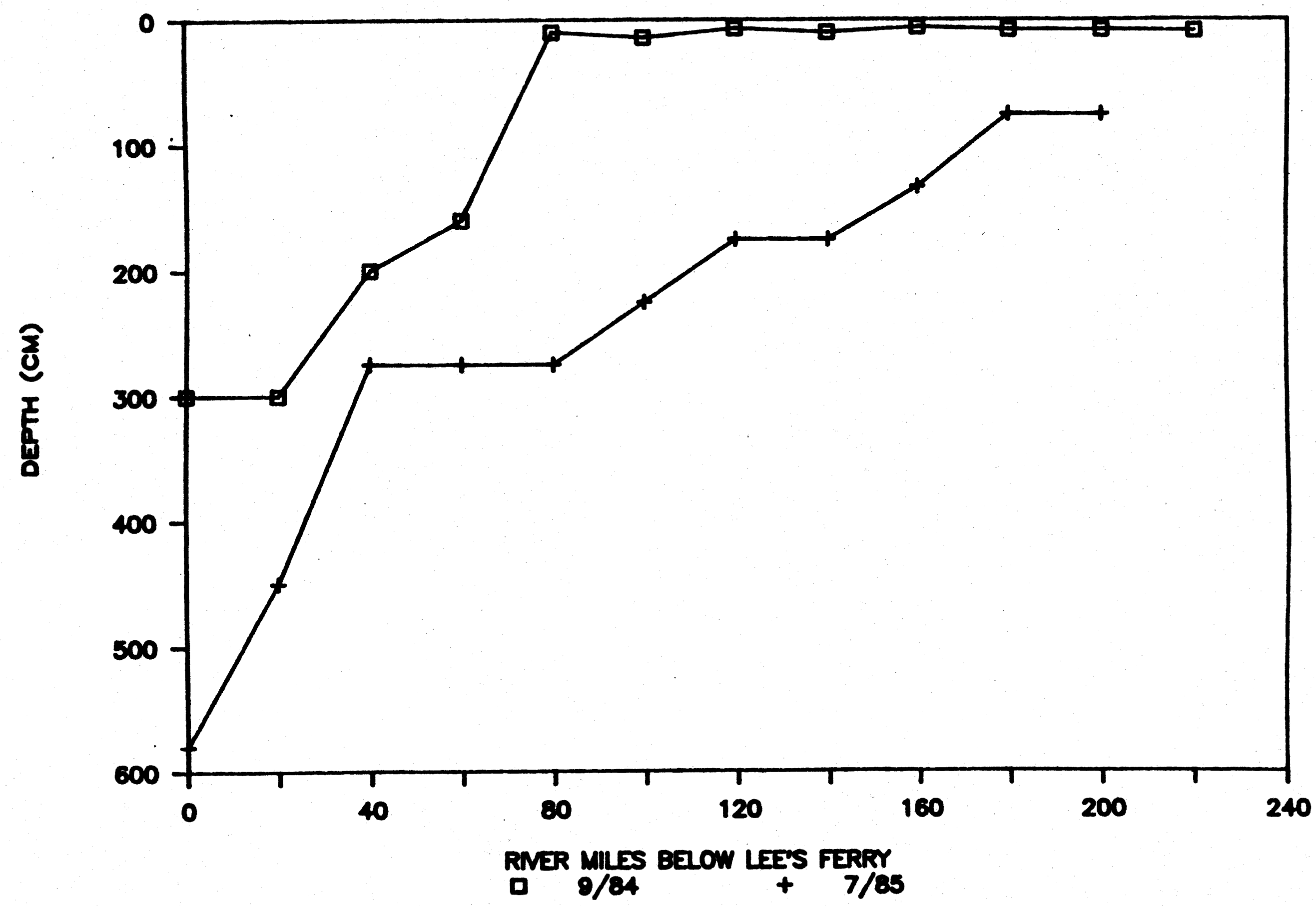


Figure 3.4. Secchi disc readings in the Colorado River below Lee's Ferry (RM 0) during September 1984 and July 1985.

The period during the course of an average year in which water clarity in the Colorado River is strongly affected by suspended sediments has not been determined. There is, however, evidence that this period is extensive enough to have a strong inhibitory effect on primary production by phytoplankton and benthic algae. During the course of the present study, Secchi disc readings declined to less than 10 cm below the LCR during 7 of 10 field trips. If this is representative of the temporal duration of turbid water below the LCR, primary productivity in this reach may well be restricted by limited light during much of the year.

Water Temperature

Waters discharged through Glen Canyon Dam from Lake Powell are drawn from a maximum depth of more than 60 m when the reservoir is full. These deep hypolimnetic releases are consistently cold, varying only between 6°C and 12°C at Lee's Ferry, even though air temperatures range from below freezing to near 40°C. In the 385 km study reach through Glen, Marble, and Grand canyons, mainchannel Colorado River water temperatures do not change dramatically (Table 3.4, Figure 3.5). The maximum increase measured during the present study, from 8.7°C to 15.3°C, occurred in May 1984. A slight decline of <1°C was indicated in December 1984 and 1985.

Backwater water temperatures were strongly related to flow regime, i.e. the degree of exchange with cold, mainchannel waters, particularly during summer months (Figure 3.6). When flows declined sufficiently to isolate backwaters from the mainchannel, the diel range of backwater temperature increased dramatically. In some backwaters, e.g. RM 194, flow regime apparently surpassed seasonal changes in ambient air temperature and amount of solar insulation as the major factor controlling temperatures.

Seasonal temperature variation in most tributaries was decidedly more pronounced than that of the mainchannel Colorado (Table 3.4. Figure 3.5). Maximum summer temperatures often exceeded those of the mainstream by 10°C or more, and minimum winter temperatures were near freezing. Observed seasonal variation was most pronounced in the Paria River and Nankoweap Creek, both of which have low modal flows and are highly exposed to solar insulation in their lower reaches. Tributaries exhibiting little seasonal variation, such as the LCR, Havasu

Table 3.4. Mean, standard deviation, and coefficient of variation of temperature, dissolved oxygen, pH and conductivity sampled in Colorado River mainstem and tributaries, 1984-86.

	Water Temperature (^oC)				Dissolved Oxygen (mg/L)			
Location	n	Mean	SD	CV	n	Mean	SD	CV
Reach 10	14	9.7	1.4	14	13	9.2	1.2	12
Reach 20	46	9.8	1.5	15	45	10.5	1.1	10
Reach 30	17	10.6	1.7	16	19	10.8	0.8	7
Reach 40	41	11.1	1.5	14	44	11.2	1.1	10
Reach 50	31	11.5	2.1	18	29	11.2	1.1	10
Paria R.	12	16.6	8.8	53	12	8.8	1.9	22
Nankoweap Ck.	10	15.9	9.4	59	10	9.4	1.9	20
L. Colorado R.	12	18.0	5.2	29	12	8.6	1.2	14
Clear Ck.	7	18.3	7.8	43	7	9.5	2.1	22
Bright Angel Ck.	11	15.3	6.5	42	11	9.8	1.4	14
Crystal Ck.	12	18.5	7.5	40	12	9.2	1.9	21
Shinumo Ck.	12	15.4	6.1	40	12	9.7	1.4	14
Tapeats Ck.	13	13.0	2.1	16	13	10.4	0.9	9
Deer Ck.	11	14.6	1.9	13	11	9.9	1.1	11
Kanab Ck.	13	16.4	6.0	43	12	9.2	1.2	13
Havasu Ck.	12	18.2	4.2	23	12	9.2	1.0	11

	pH				Conductivity (uS/cm)			
	n	Mean	Min	Max	n	Mean	SD	CV
Reach 10	14	8.07	7.50	8.30	14	709	69	10
Reach 20	32	8.12	7.70	8.67	45	701	69	10
Reach 30	14	8.05	7.78	8.35	19	751	74	10
Reach 40	34	8.11	7.72	8.57	43	740	86	12
Reach 50	16	8.20	7.84	8.61	28	744	69	9
Paria R.	10	7.54	6.80	8.67	11	1177	333	28
Nankoweap Ck.	8	8.31	7.70	8.92	10	596	59	10
L. Colorado R.	10	7.95	7.49	8.47	12	3898	906	23
Clear Ck.	6	8.52	8.43	8.68	7	370	65	18
Bright Angel Ck.	10	8.38	7.87	8.94	10	303	51	17
Crystal Ck.	10	8.46	8.10	9.04	12	1015	322	32
Shinumo Ck.	10	8.37	7.87	9.02	12	297	78	26
Tapeats Ck.	11	8.38	7.87	8.98	13	304	34	11
Deer Ck.	9	8.40	7.94	9.02	11	351	37	11
Kanab Ck.	9	8.37	8.20	8.80	13	1327	207	16
Havasu Ck.	8	8.47	8.30	8.70	12	704	27	4

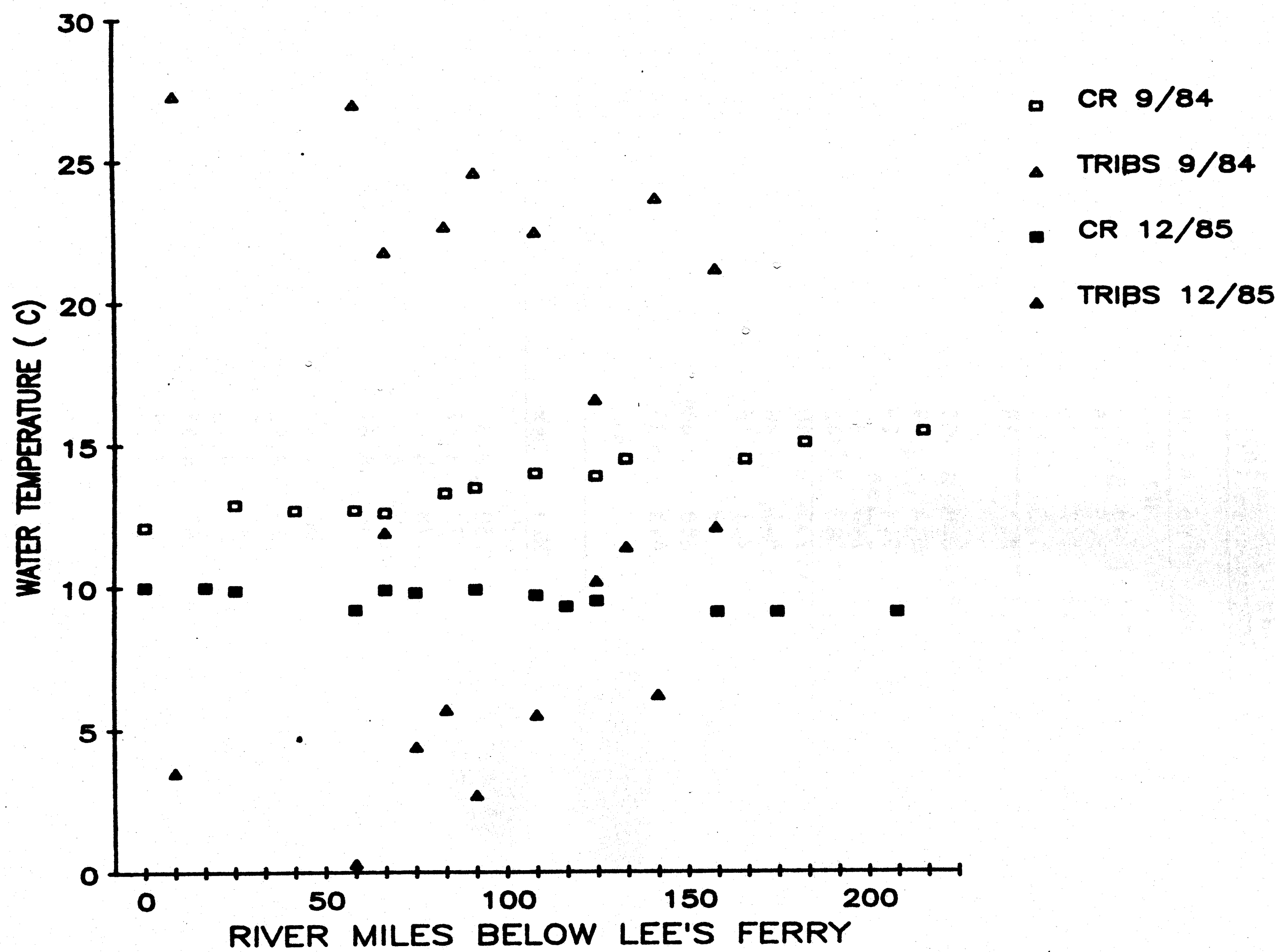


Figure 3.5. Water temperature (^{o}C) of the Colorado River and its tributaries during September 1984 and December 1985.

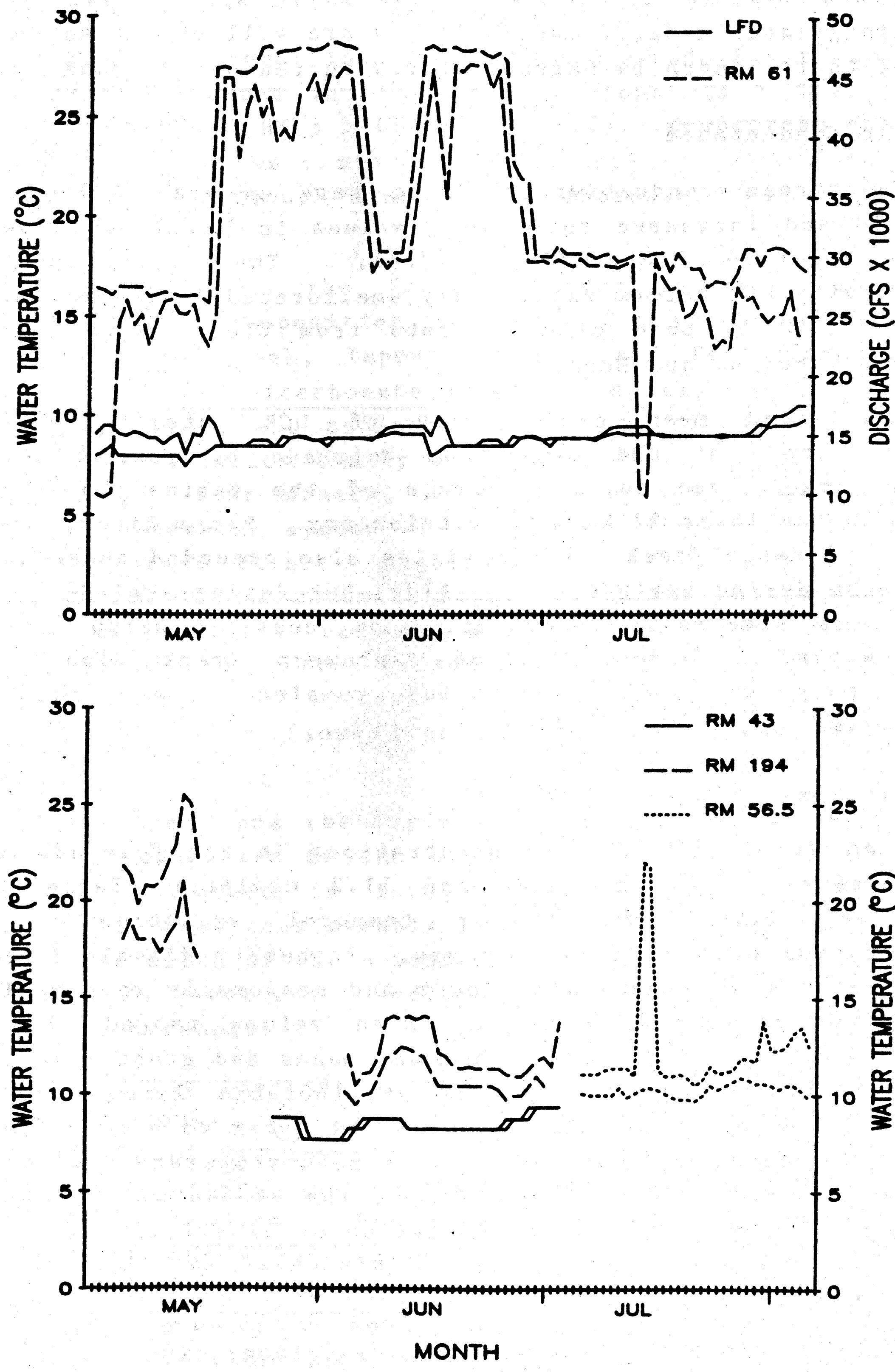


Figure 3.6. Daily minimum and maximum discharge of Colorado River at Lee's Ferry (LFD; top) with corresponding minimum and maximum water temperatures at mainchannel RM 61 (top) and backwaters RM 43, RM 56.5, and RM 194 (bottom).

Creek, and Tapeats Creek are fed by major spring systems that maintain greater modal flows, and they are well protected through much of their length by narrow, deeply entrenched canyons.

Specific Conductance

Mainstream conductivity levels were generally lowest in Reach 10 and increased to highest values in Reach 30 below the Little Colorado River (Table 3.4). The effect of high conductivity LCR waters was largely ameliorated in lower Reach 30 and Reach 40 by more dilute inputs from Clear, Bright Angel, Shinumo, Tapeats, and Deer creeks.

Unweighted mean conductivity of LCR water (3,898 uS) surpassed that of the mainstream Colorado by more than five times, largely due to the effects of the saline Blue Spring series in the lower 22 km of the tributary. Paria River, Crystal Creek, and Kanab Creek conductivities also exceeded those of the mainstream during periods of low flow, but during periods of high flow these streams had conductivities near or below Colorado River water. Conductivity of Nankoweap Creek also varied considerably with discharge, but remained lower than the mainstream.

Dissolved Oxygen

Mean dissolved oxygen concentrations in the Colorado River varied between 10.5 mg/liter and 11.2 mg/liter (Table 3.4). There was little spatial or temporal variation in the concentration of this dissolved gas. Tributary dissolved oxygen concentrations were generally lower and seasonally more variable than those in the mainstream. Mean values ranged from 8.6 mg/liter to 10.4 mg/liter. Both lower means and greater seasonal variation in tributaries may be attributable largely to the effects of temperature on the capacity of water to hold dissolved oxygen. Correlation coefficients for mean temperature with mean dissolved oxygen ($r = -0.78$, $P < .01$) and standard deviation of mean temperature with standard deviation of dissolved oxygen ($r = 0.88$, $P < .01$) were highly significant in the measured tributaries.

Percent saturation values of dissolved oxygen were not calculated on a consistent basis during this study. Occasional checks of extreme values, however, suggested that these levels ranged from 72% to 105% saturation, and no evidence of oxygen depletion or severe oversaturation was indicated.

Major Ions

Mean ionic proportions (meq %) in Colorado River water above Lee's Ferry occurred in the order: cations--Ca > Na > Mg > K, and; anions--SO4 > HCO3 > Cl (Figure 3.7). Downstream changes in these proportions were minor in all samples analyzed during the present study, although a noticeable increase occurred in Na and Cl.

Tributaries to the Colorado River in Grand Canyon are diverse in ionic composition (Figures 3.8 and 3.9). Bright Angel Creek, Shinumo Creek, Tapeats Creek, and Deer Creek contain calcium-magnesium bicarbonate waters with very low quantities of sodium, chloride, and sulfate, and may be classified as dilute dolomitic tributaries (Kubly and Cole 1979). These tributaries, and at least four others, arise as springs issuing from the karstic groundwater system of the Kaibab Plateau north and west of the Colorado River. Havasu Creek and Nankoweap Creek are impure dolomitic waters with higher dissolved solids and greater amounts of sulfate, sodium, and chloride than the previous group. The former stream arises from south of the mainstream as a series of seeps and springs flowing out of the Supai formation, whereas the latter flows from the Kaibab Plateau east to the Colorado River.

Kanab Creek and the Paria River are sulfate waters similar in ionic composition to the Colorado River, but they exceed the mainstream Colorado in total dissolved solids during modal flows. Both have considerably larger drainage systems than other tributaries north of the mainstream and derive their high sulfate content from gypsiferous sediments that comprise large portions of their watersheds.

The Little Colorado River arises in the White Mountains of eastern Arizona. It is an intermittent to ephemeral stream through much of its lower reaches, but becomes perennial some 20 km above the mouth due to inflow from the Blue Spring series (Johnson and Sanderson 1968). Outflow from Blue Springs, about 223 cfs, is the major contributor to modal flow of the Little Colorado in this reach. The issuance from the springs is a saline sodium-chloride water, which also contains significant amounts of calcium and carbonate. Except when the Little Colorado is in flood, much of the calcium carbonate from Blue Spring precipitates, leaving the river at its mouth even more enriched in sodium and chloride (Kubly and Cole 1979).

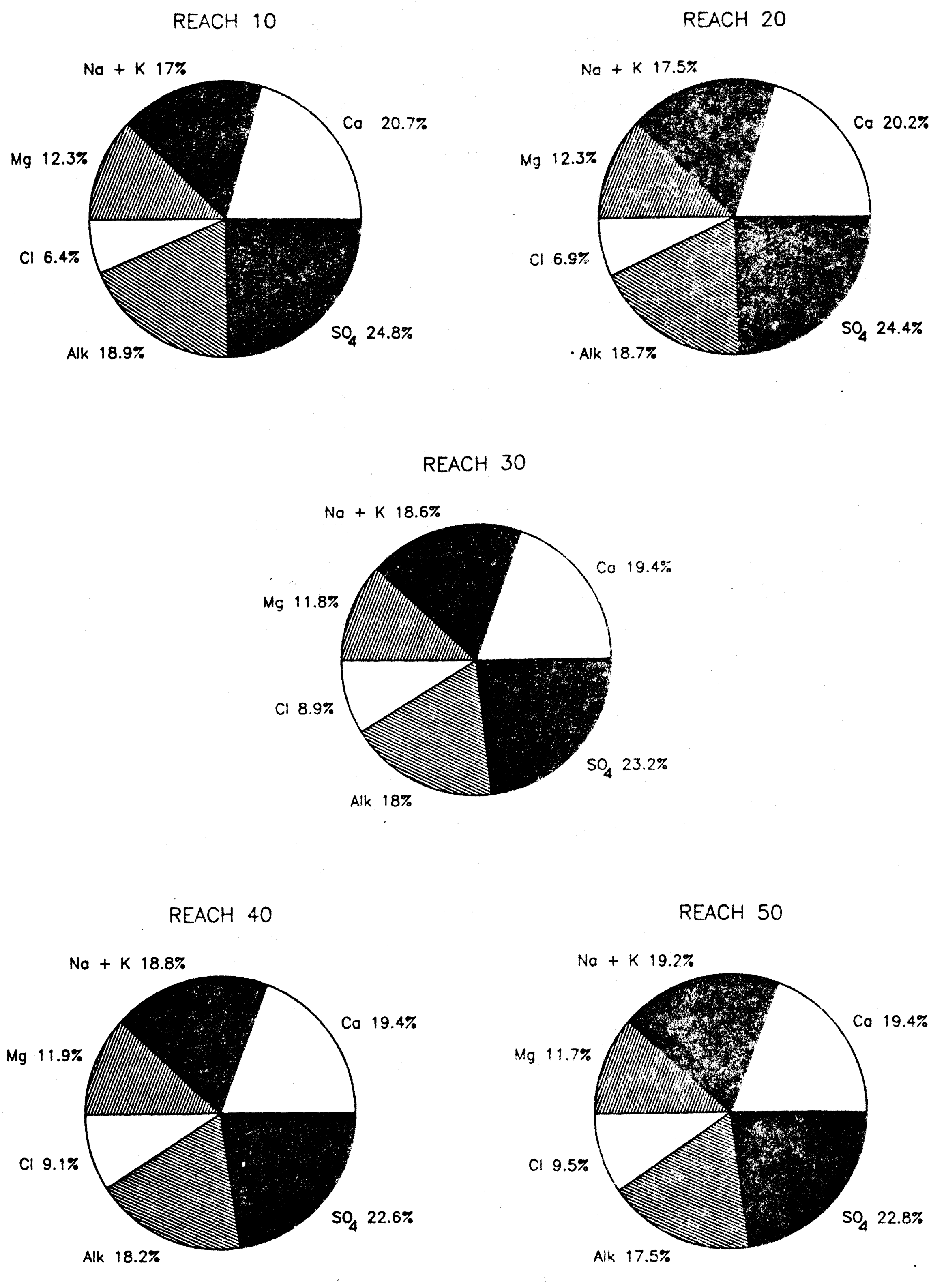


Figure 3.7. Major ion composition (meq %) in Reaches 10-50 of the Colorado River. Na and K combined (K always less than 1.5%).

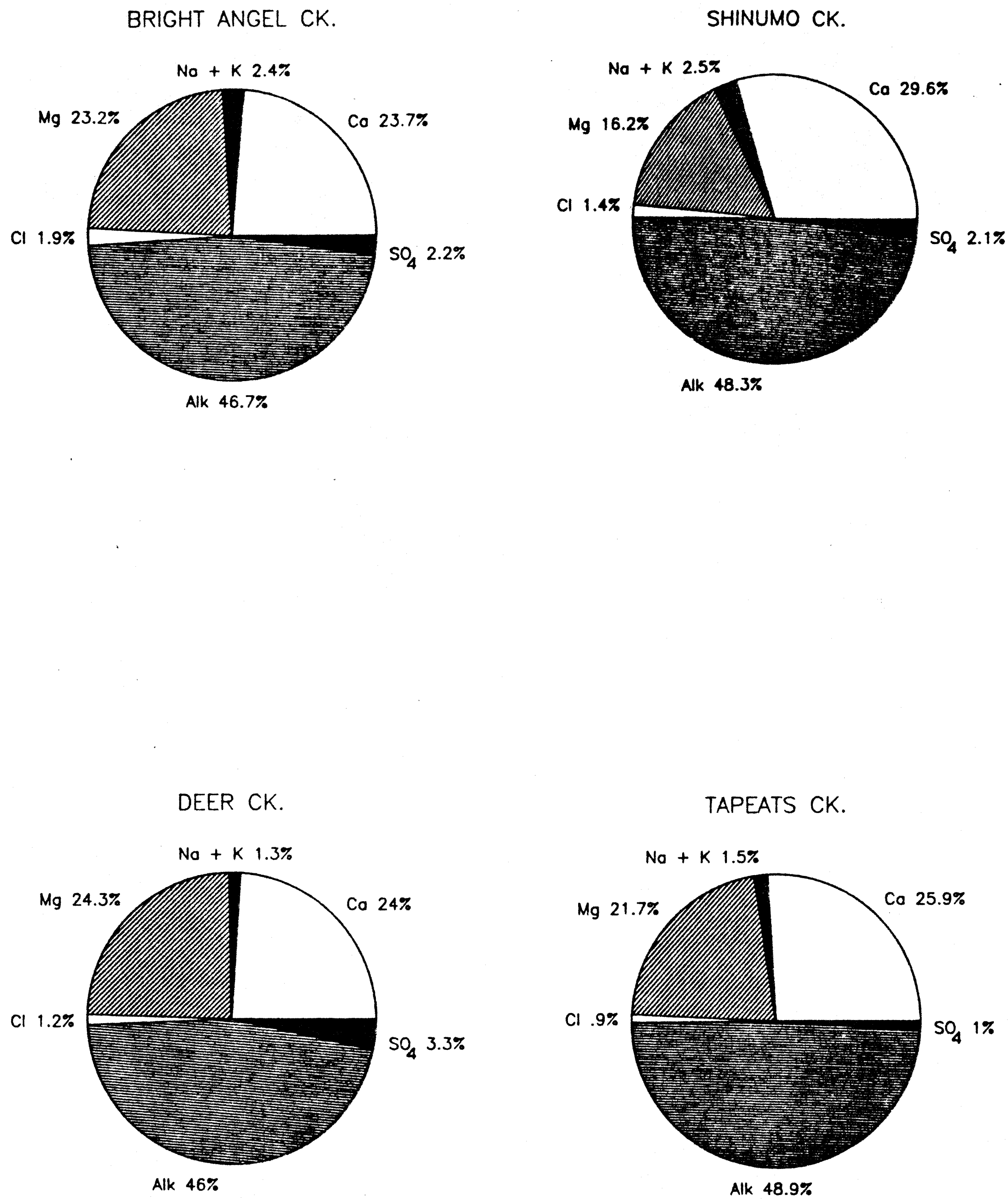


Figure 3.8. Major ion composition (meq %) in dilute dolomitic tributaries of the Colorado River. Na and K combined (K always less than 1%).

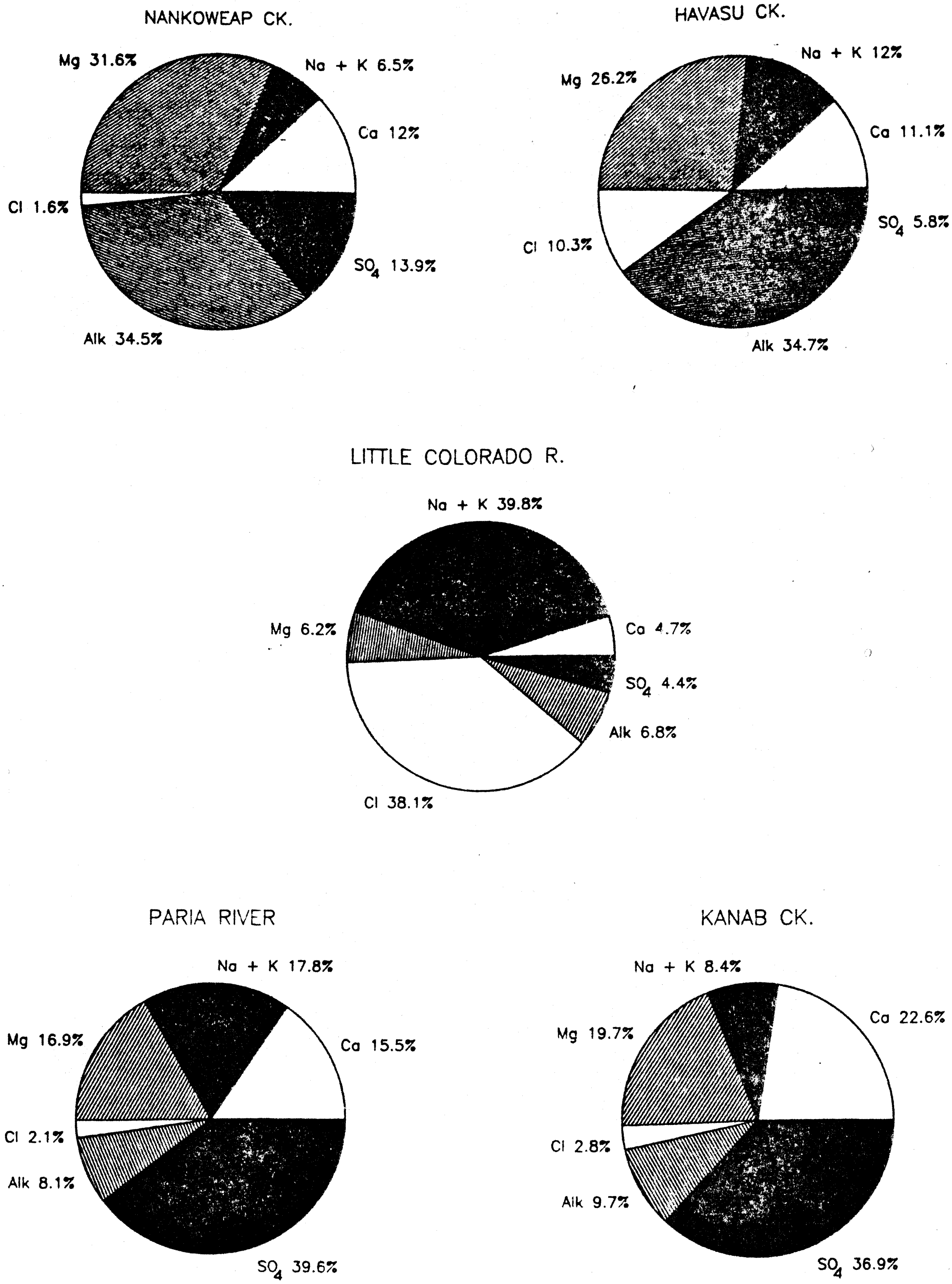


Figure 3.9. Major ion composition of impure dolomitic (Nankoweap and Havasu), sulfate (Paria and Kanab), and saline sodium chloride (Little Colorado River) tributaries of the Colorado River. Na and K combined (K always less than 1.5%).

Macronutrients

Ammonia concentrations in the Colorado River and its tributaries were generally less than 50 ug/liter and were lower than the level of detection (5 ug/liter) in many samples (Table 3.5). Only Reach 50 in the mainstream had a mean ammonia concentration lower than that of any tributaries. Most dissolved inorganic nitrogen was present in all streams as nitrate and nitrite (not separated in analysis). Mean mainstream concentrations varied between 315 ug/liter and 350 ug/liter with no apparent downstream trend (Table 3.5). Tributaries exhibited a much wider range in mean concentrations (13-759 ug/liter), but were generally lower than mainstream samples. Nankoweap Creek and Bright Angel Creek were decidedly low in nitrate-nitrite when compared with all other streams, whereas the Paria River held a mean concentration more than two times that of the mainstream.

Exact comparisons of soluble reactive and total phosphate concentrations, or of soluble reactive phosphate and nitrogen compound concentrations, could not be made in this report, because a small amount of concentrated HCl was added to all nutrient samples (See Table 3.1). For this reason, all soluble reactive phosphate samples may well contain some phosphate which was solubilized by the added acid. All results and discussion of phosphate levels should be considered with respect to the effect of this source of error.

There was a downstream increase in soluble reactive and total phosphate in Colorado River samples during this study (Table 3.5). Little change was evident between Reach 10 and Reach 20, even though the Paria River provided the highest tributary concentrations of phosphates to the mainstream. The only other major tributary to enter the Colorado River above Reach 30, the Little Colorado River, had a mean phosphate concentration approximately one-third that of the Paria River, but the former stream typically discharges 10 times as much water annually to the mainstream (USGS 1982). All remaining tributaries had mean concentrations of soluble reactive and total phosphates that were lower than those of mainstream reaches receiving their inflows.

The ratio of total/soluble reactive phosphate in reaches 10 and 20 and in all tributaries except the Paria and Little Colorado rivers was less than 2:1. In reaches 30-50 this ratio was >2:1 and in the two tributaries it was >10:1. High

Table 3.5. Ammonia (NH_3-N), nitrate-nitrite (NO_3-NO_2-N), soluble reactive phosphate (SRP-P), and total phosphate concentrations (TP-P) by Colorado River reach and selected tributaries in Glen and Grand canyons during 1984-86. Concentrations as N and P in ug/L. Ammonia and SRP samples below the level of detection (<5 kg/L) were given values of 2 ug/L for statistical calculations.

	NH_3-N					NO_3-NO_2-N				
Reach	n	Mean	SE	Min	Max	n	Mean	SE	Min	Max
10	8	10.0	5.5	<5	45	8	318.4	38.3	147	419
20	28	10.6	4.4	<5	124	28	337.9	15.5	38	445
30	11	14.5	4.5	<5	51	11	348.9	17.2	215	420
40	23	10.6	3.6	<5	68	23	315.6	22.0	105	495
50	15	7.1	2.1	<5	29	15	350.1	18.6	223	427
11	4	7.2	3.1	<5	14	4	759.0	36.9	657	830
21	6	6.3	3.2	<5	22	6	13.0	9.2	<5	59
22	7	8.6	6.1	<5	45	8	206.4	14.0	145	253
32	7	2.6	0.6	<5	6	7	16.0	6.0	<5	38
42	1			<5		1			42	
43	8	4.2	1.4	<5	13	8	91.5	7.8	73	123
44	8	3.4	0.7	<5	7	8	130.7	21.7	<5	225
45	7	4.6	2.0	<5	16	7	267.6	85.4	8	654
46	7	3.7	0.9	<5	8	7	148.8	29.6	<5	252

	SRP-P					TP-P				
Reach	n	Mean	SE	Min	Max	n	Mean	SE	Min	Max
10	8	11.0	0.7	9	14	8	15.8	1.9	9	24
20	28	11.8	0.6	5	19	28	15.9	1.1	9	32
30	11	59.8	43.8	6	497	10	178.2	109.2	9	962
40	23	101.6	51.9	<5	1030	23	283.6	103.6	9	1560
50	15	171.5	70.8	8	1020	15	290.9	101.9	20	1430
11	4	89.5	56.4	11	257	4	1007.5	759.1	50	3270
21	6	7.2	0.8	5	10	6	9.5	0.2	9	10
22	8	34.2	11.0	8	94	8	350.0	175.4	9	1360
32	7	36.3	7.8	<5	1030	7	49.8	11.1	17	85
42	1			42		1			65	
43	8	55.1	5.1	35	79	7	61.8	9.1	37	96
44	8	35.4	7.9	7	72	7	42.7	10.9	9	85
45	7	18.3	7.6	5	63	7	27.1	8.8	11	71
46	7	21.7	2.5	9	29	7	25.3	3.4	9	38

total/soluble reactive phosphate ratios in the Paria and Little Colorado rivers are undoubtedly associated with the high degree of turbidity these streams exhibit during periods of runoff from their respective watersheds. Turbidity is engendered largely from clay particles that are known to be important sources of phosphorus in the Colorado River (Watts and Lamarra 1983) and in many other aquatic systems (Stumm and Morgan 1981).

Mean molar N/P ratios in the mainstream Colorado were nearly equal in reaches 10 and 20, but declined downstream largely due to increasing phosphorus concentrations (Figure 3.10). Reaches 10 and 20 had mean N/P ratios greater than 15, suggesting that the Glen Canyon tailwater may be phosphorus limited if nutrients become limiting to primary production (Miller et al. 1978). Phosphorus is known to limit primary productivity in both the Colorado River above Lake Powell (Watts and Lamarra 1983) and in the reservoir (Gloss et al. 1980a). Paria River and Kanab Creek were the only tributaries with N/P ratios >15.

Silica concentrations in the Colorado River varied little during the course of this study (Table 3.6). Mean values differed by only slightly more than 1 mg/liter among the five reaches. Tributaries were evenly divided between those with higher and lower means than the grand mean for the mainstream (8.9 mg/liter). The most concentrated water, that of Havasu Creek, had a mean silica concentration two times that of mainstream reaches. There was no evidence for seasonal depletion of silica in either the Colorado River or its tributaries.

3.3. DISCUSSION

The effect of Glen Canyon Dam on downstream water quality and the biota of the Colorado River varies depending on the parameter of interest, the period of time involved, and the organisms affected by the outflow. Water temperatures, ionic concentrations and proportions, sediment loads, water clarity and seasonal differences in discharge all exhibit less variation in these deep hypolimnion release waters than in free flowing waters of the predam period (USGS 1922 et seq., USGS 1941 et seq., Kubly and Cole 1979, Paulson and Baker 1983). Daily discharge variation, however, is considerably greater under dam regulated releases and causes diurnal stage fluctuations of much greater magnitude than those of the predam era (Dolan et al. 1974, Turner and Karpiscak 1980).

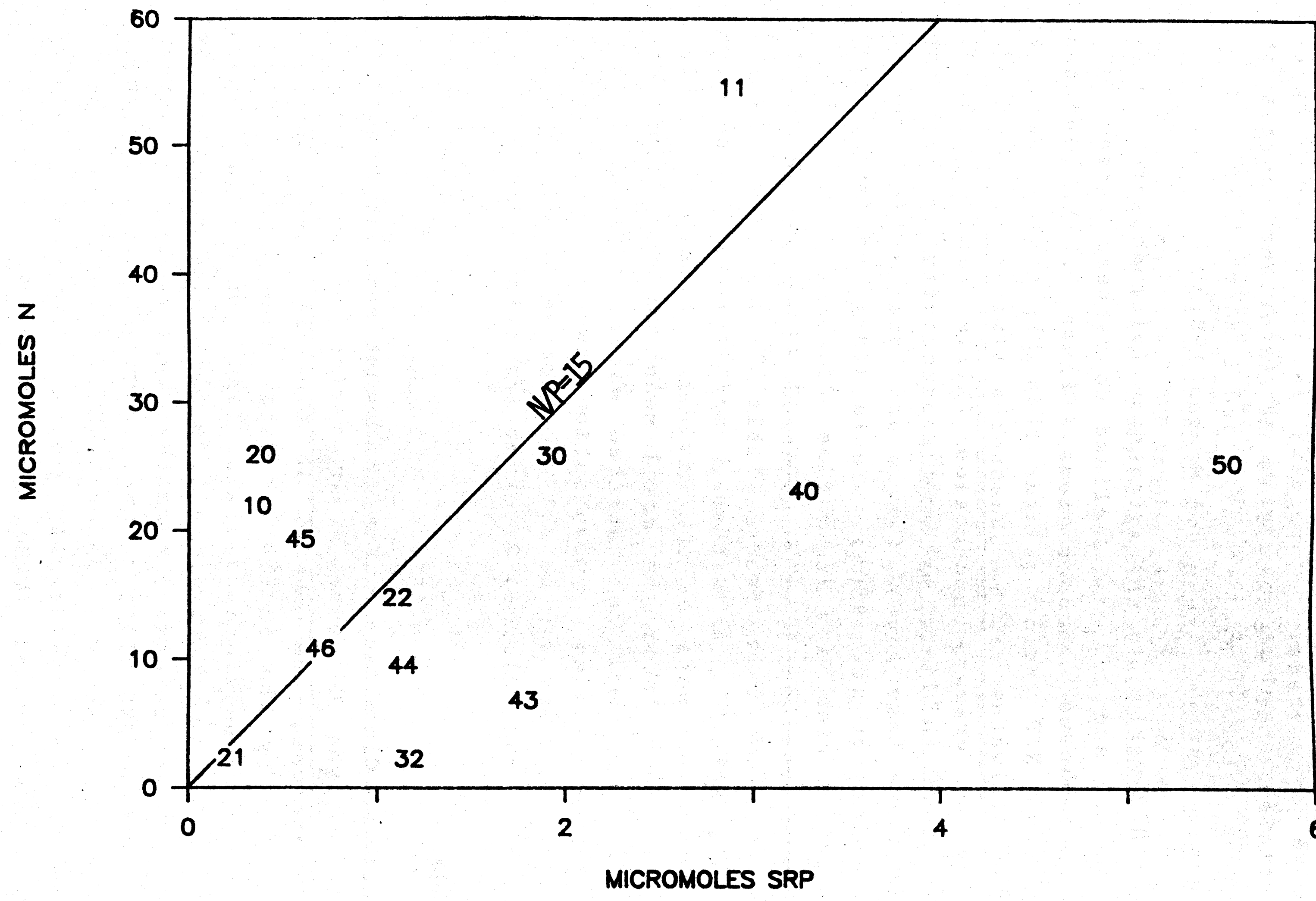


Figure 3.10. Mean molar dissolved inorganic nitrogen/soluble reactive phosphate (N/P) ratios from Colorado River Reaches (10 thru 50) and tributaries (11, 21, 22, 32, and 43-46) during 1984-86.

Table 3.6. Silica concentrations by Colorado River reach and selected tributaries during 1984-86. Mean concentrations as mg/L.

Reach	N	Mean	SE	Min	Max
10	9	8.9	0.21	8.2	10.0
20	19	9.1	0.13	8.0	10.0
30	6	9.2	0.16	8.5	9.6
40	11	8.1	0.54	7.7	10.1
50	7	9.1	0.22	8.4	10.1
11	3	10.7	0.45	9.6	11.3
21	5	8.4	0.29	7.5	9.3
22	6	15.2	0.84	10.6	16.5
32	5	6.3	0.25	5.3	7.0
42	1			5.6	
43	5	6.9	0.15	6.3	7.3
44	5	8.0	0.22	7.0	8.4
45	5	9.2	0.45	7.6	10.6
46	4	18.2	0.12	17.8	18.4

Combined tributary inputs to the Colorado River between Lake Powell and Lake Mead comprise <5% of the inflow to the latter reservoir in average flow years (Thomas et al. 1963); thus, mainstream major ion chemistry through Glen and Grand canyons is related closely to that of waters issuing from the dam (See Reynolds and Johnson 1974, Kubly and Cole 1979). When mainstream flow declines to ca. 5,000 cfs or less during periods of low regulated discharges, however, highly saline Blue Spring waters from the Little Colorado River assume increasing importance in determining the total dissolved solids (TDS) and major ion composition of downstream Colorado River waters (Cole and Kubly 1977).

Lake Powell is known to act as an efficient sediment trap and phosphorus sink (Gloss et al. 1980b, Evans and Paulson 1983) removing much of the nutrient load of its outflow waters to the Colorado River in Glen and Grand canyons. Another consequence of the removal of suspended sediments, however, is greatly increased water clarity and light penetration downstream of the reservoir. As a result, the Glen Canyon tailwater is, from all appearances, an autotrophic reach that exports large amounts of particulate organic matter to lower reaches in the form of *Cladophora* and benthic invertebrates. In addition, the reservoir apparently serves as the major source of downstream plankton (Haury 1986), which provides a food source to higher trophic levels.

The Little Colorado River is the only appreciable source of suspended sediment to the mainstream Colorado in Grand Canyon, although the Paria River and Kanab Creek produce occasional floods carrying large amounts of suspended matter (Cole and Kubly 1976). Since total phosphate concentrations are closely related to the amount of suspended sediment in the Colorado River (Gloss et al. 1980b, Evans and Paulson 1983, Watts and Lamarra 1983) and suspended sediment content is inversely related to light penetration (Cole and Kubly 1976, present study), the Little Colorado probably has a major effect on the trophic nature of the mainstream. Elevated phosphate levels increase the potential for higher primary productivity in a river potentially limited by this nutrient, but diminished light levels may well override this potential and move the system toward heterotrophy and a detritus food base. The outcome is further complicated by the fact that this tributary is for periods of time a clear stream carrying water much higher in salinity than that of the mainstream.

4. MAINCHANNEL DISTRIBUTION, HABITAT UTILIZATION AND BACKWATER EXAMINATION

4.1 METHODS

During the course of the study fish were captured by several methods to sample lifestages of the fishes in a variety of different mainchannel habitats (Table 4.1). Individuals were classified by lifestage according to length:

All trout - less than 75mm - y-o-y
Humpback chub - less than 50mm - y-o-y
All other native fishes - less than 25mm - y-o-y

Electrofishing

A 7.0 m aluminum framed pontoon raft powered by a 30 horsepower outboard motor was specially designed for electrofishing. The raft was equipped with a livewell, a Honda 4500 watt 240V AC generator, Coffelt VVP-15, a pulsator (Vectormax) made and designed by Norm Sharber, two 30.5 cm stainless steel spherical electrodes, spotlights, and shocking lights. Each pulsator was set at 260 volts, 60 pulses/second, and a pulse width of 25%.

During each electrofishing session, effort and catch data were recorded. Catch data included species captured, life stage, and habitat characteristics of area sampled electrofishing. Fish less than or equal to 200 mm were classified as adults and those >200 m as adults. This was done to determine if smaller individuals select different habitats than larger adults. Habitat characteristics were divided into habitat type (run, eddy, backwater, and sidechannel), shoreline substrate (cliff, boulder, rubble, gravel, and sand), and presence or absence of vegetation. Electrofishing sessions lasted approximately one hour or until about 100 fish were collected. Fish were often transported over a mile from their original capture site to a processing area. This may have caused movement as a result of releasing large numbers of fish in a small area.

Trammel nets

Trammel nets were used at mainchannel sites during 1984 and tributary sites throughout the study. Trammel nets were 30.5 m x

Table 4.1. Sampling methods used to capture fishes in the mainchannel, April 1984 - June 1986.

Species	Life Stage	Size (mm)	Electro-fishing	Larval Seine	Seine	Trammel
Rainbow trout	Y-O-Y	<75		X	X	
	Subadult	>75-199	X		X	
	Adult	$\geq$200	X		X	X
Brook trout	Y-O-Y	<75				
	Subadult	>75-199	X			
	Adult	$\geq$200	X			X
Brown trout	Y-O-Y	<75		X		
	Subadult	>75-199	X			
	Adult	$\geq$200	X			X
Common carp	Y-O-Y	<75				
	Subadult	75-199	X		X	
	Adult	$\geq$200	X		X	X
Fathead minnow	Y-O-Y	<25		X	X	
	Adult	$\geq$25	X		X	
Bluehead sucker	Y-O-Y	<50		X	X	
	Subadult	50-199	X		X	
	Adult	$\geq$150	X		X	X
Flannelmouth sucker	Y-O-Y	<50		X	X	
	Subadult	50-199	X		X	
	Adult	$\geq$200	X		X	X
Humpback chub	Y-O-Y	<50		X		
	Subadult	50-199	X		X	
	Adult	$\geq$200	X		X	X
Speckled dace	Y-O-Y	<25		X	X	
	Adult	$\geq$25	X		X	

2.4 m, 7.6 m x 2.4 m, and 7.6 m x 2.4 m with a 2.5 cm or 5.1 cm inner mesh and a 25.4 cm outer mesh. Effort was recorded by net nights. One net night = 30.5 m x 2.4 m trammel net set for 12 hours. Trammel nets were set in late afternoon and pulled during early morning. Fish were placed in 18.9 l buckets and brought to a processing station where they were immediately examined. Fish were released at least 90 m from the net to prevent immediate recapture.

Seining

Backwaters and tributaries were sampled by seining. The dimensions of the bag seine used were 7.6 m x 1.8 m with a 2.4 m bag. Mesh size was 6.3 mm on the wings and 3.2 mm in the bag. Smaller areas were surveyed with a 1.2 m x 0.9 m with 3.2 mm mesh seine. Effort was recorded in square meters of area sampled by habitat type (connected or isolated backwater). Collected fish were examined and documented after each seine haul.

Larval Seining

Larval seines and dip nets were used to sample shallow areas in the mainchannel. Larval seines were 10.0 m x 1.0 m with 0.8 mm mesh. Two types of dip nets were used. Larval dip nets were 30.5 cm wide and had a 0.8 mm mesh. Standard dip nets were 45.7 cm wide and had 3.2 mm mesh. Effort was measured by square meters of area sampled by habitat type. Water temperature, depth, velocity, substrate type, and presence of cover were recorded when fish were captured.

Fish examination

Fish collected by electrofishing and trammel netting were anesthetized with tricaine methane sulfonate (MS-222), identified to species, measured to the nearest millimeter (total length) and weighed to the nearest gram with an Ohaus C-3000 Port-O-Gram electronic balance. Fish were classified by sex and maturity when expressible gametes were present. Each fish was given a fin clip designating the reach of capture. Fish larger than 250 mm in total length were also tagged with a FD68B floy tag. Each tag had a unique 6 digit number and was attached to the left side of the fish below the dorsal fin with a Dennison Mark II tagging gun. Electrofishing and hooking injuries, presence of tubercules, floy tag, and fin clip recaptures were documented.

The River Mile of the release site was recorded and fish were then released. When possible, 20 rainbow trout stomach and head samples were collected from each reach during a river trip. Stomach samples were preserved in 10% formalin for gut content analysis. Head samples with the first few vertebrae attached were preserved in ethyl alcohol for tetracycline dye analysis (See Table 7.6 for stocking records of marked fish).

Larval fish collected by dip netting and seining were examined immediately after capture. These fish were identified to species and measured to the nearest millimeter (total length), and preserved in 3-5% formalin. Larval native fish were tentatively identified in the field (Snyder 1981), and subsamples were sent to the Larval Fish Laboratory at Colorado State University for verification. Juvenile and adult fish were handled as described earlier.

Data were analyzed using Statistical Package for the Social Sciences (SPSS x 1983). A Shannon-Weaver diversity index (Shannon and Weaver 1963) was computed for fish species by river reach. Data were categorized by month, season, or year depending on sampling frequency and variation. Months were grouped into the following: Spring (March-May), Summer (June-August), Autumn (September-November) and Winter (December-February). This seasonal categorization attempted to group life stages and processes of fishes into a single season. Effort data for the major sampling techniques are presented in Appendix 4.1.

Video Habitat Analysis

Habitat and shoreline categories were classified from video tapes shot from a helicopter approximately 30 m above the water surface. Videos were taken during summer and autumn 1985 at discharge of 4,800 cfs and 28,000 cfs. These represent a low flow and a flow near the mode for the entire study. For further information on specific methods, See Anderson et al. (1986). The analysis of the video tapes were in two phases. First, the classification of the habitat (eddy, run, backwater, and side channel) and shoreline (cliff, boulder, rubble, and sand) variables. For the shoreline analysis, gravel and rubble were combined because of resolution at 30 m. The second analysis consisted of total counts by reach and flow of habitats considered important and unique for various phases of a fishes life history. Reaches 30 and 40 were further divided to show habitat differences within a designated reach. Hard rock gorge comprises the lower half of Reach 30 and upper half of Reach 40.

4.2 RESULTS

A total of 35,500 fishes was captured, representing 20 species (Table 4.2). Of these species, five were native and 15 were introduced.

Species diversity in the mainchannel was low. Diversity was lowest in reaches 10 and 20, 0.30 and 0.20, respectively. Greater diversity was found in Reach 30 (0.77) and Reach 50 (0.63).

Introduced fishes were more abundant than native fishes in mainchannel collections of adults and subadults. Percentage of introduced fishes captured by electrofishing ranged from 81.5% in Reach 50 to 97.7% in Reach 40 (Figure 4.1). Rainbow trout was the most abundant fish species collected by electrofishing in all reaches, although carp CPUE was near that of rainbow trout in Reach 50.

Native fishes were better represented in larval seine CPUE data, although introduced species remained dominant throughout the five reaches. Introduced fishes represented between 53.1% (Reach 40) and 97.9% (Reach 20) of the catch in (Figure 4.2). Rainbow trout and fathead minnow were the most abundant introduced fishes. Speckled dace was the most abundant native species.

In backwater seining, introduced fish were not always the most abundant. Native fishes represented 89.7% of the catch in Reach 20 and 63.5% in Reach 30 (Figure 4.3) In reaches 40 and 50, introduced fish, dominated by fathead minnow, were most abundant.

Native fishes were dominant in three of the four reaches where fish were captured by trammel netting. Flannelmouth sucker was the predominant native fish, while rainbow trout was the dominant introduced species.

DISTRIBUTION

Introduced Species

Rainbow trout catch per unit effort (210.3/100 min) by electrofishing in Reach 10 was almost twice that of other reaches

Table 4.2. Scientific and common names of fish captured between April 1984 - June 1986 in Colorado River between Glen Canyon Dam and Diamond Creek.

Scientific Name	Common Name	Abbreviation
Salmonidae		
Salmo clarki	Cutthroat trout	CTT
Salmo gairdneri	Rainbow trout	RBT
Salmo trutta	Brown trout	BRT
Salvelinus fontinalis	Brook trout	BKT
Cyprinidae		
Cyprinus carpio	Common carp	CRP
Gila atraria	Utah chub	UTC
Gila cypha	Humpback chub	HBC
Notemigonus crysoleucas	Golden shiner	GS
Pimephales promelas	Fathead minnow	FHM
Rhinichthys osculus	Speckled dace	SD
Catostomidae		
Catostomus discobolus	Bluehead sucker	BHS
Catostomus latipinnis	Flannelmouth sucker	FMS
Xyrauchen texanus	Razorback sucker	RBS
Ictaluridae		
Ictalurus melas	Black bullhead	BBH
Ictalurus natalis	Yellow bullhead	YBH
Ictalurus punctatus	Channel catfish	CCF
Cyprinodontidae		
Fundulus zebrinus	Plains killifish	RGK
Percichthyidae		
Morone saxatilis	Striped bass	STB
Centrarchidae		
Lepomis cyanellus	Green sunfish	GSF
Micropterus salmoides	Largemouth bass	LMB

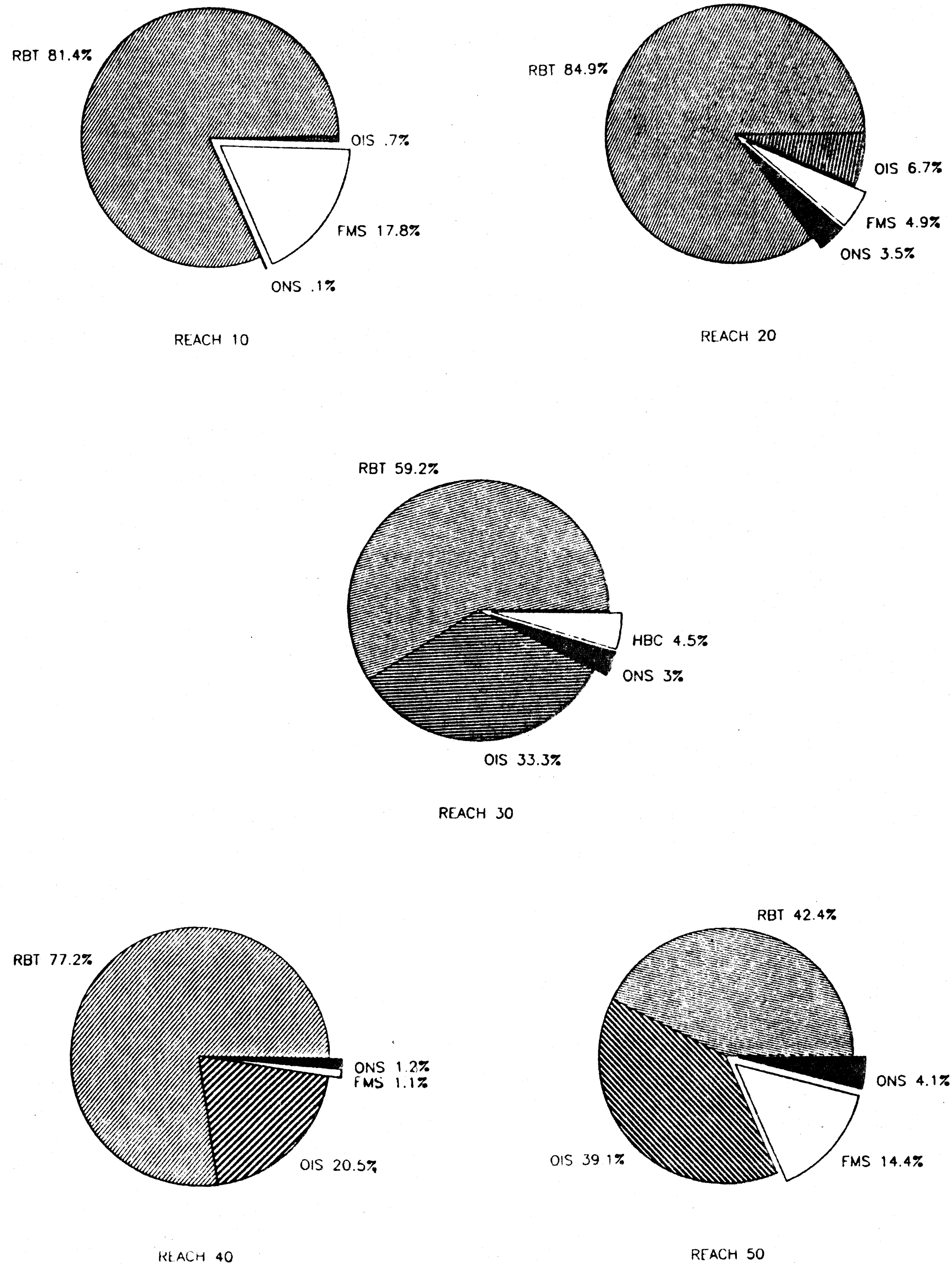


Figure 4.1. Species composition by reach from electrofishing effort during April 1984 to May 1986. Native species are identified by raised portions.

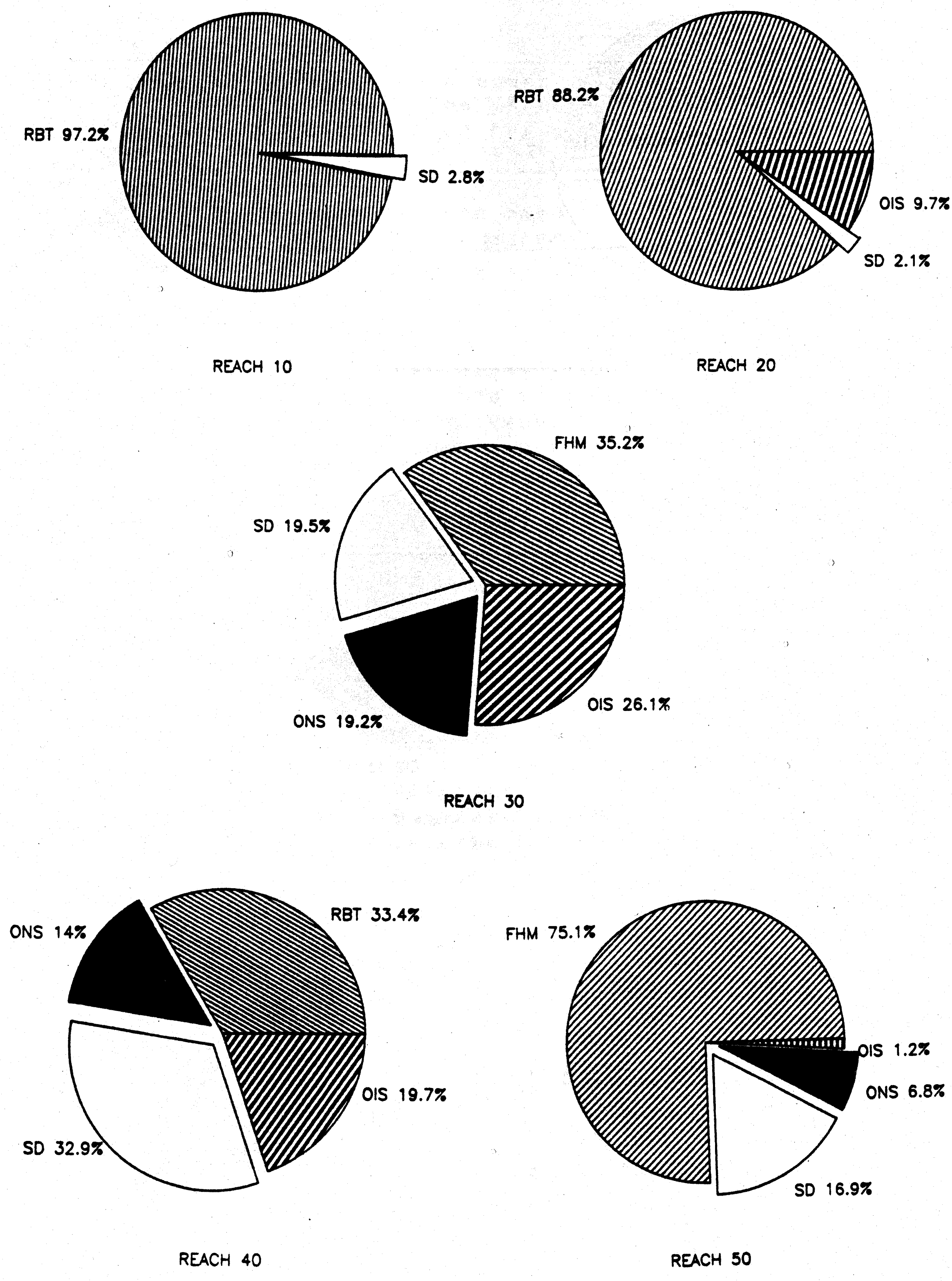


Figure 4.2. Species composition by reach from larval seining effort during April 1984 to May 1986. Native species are identified by raised portions.

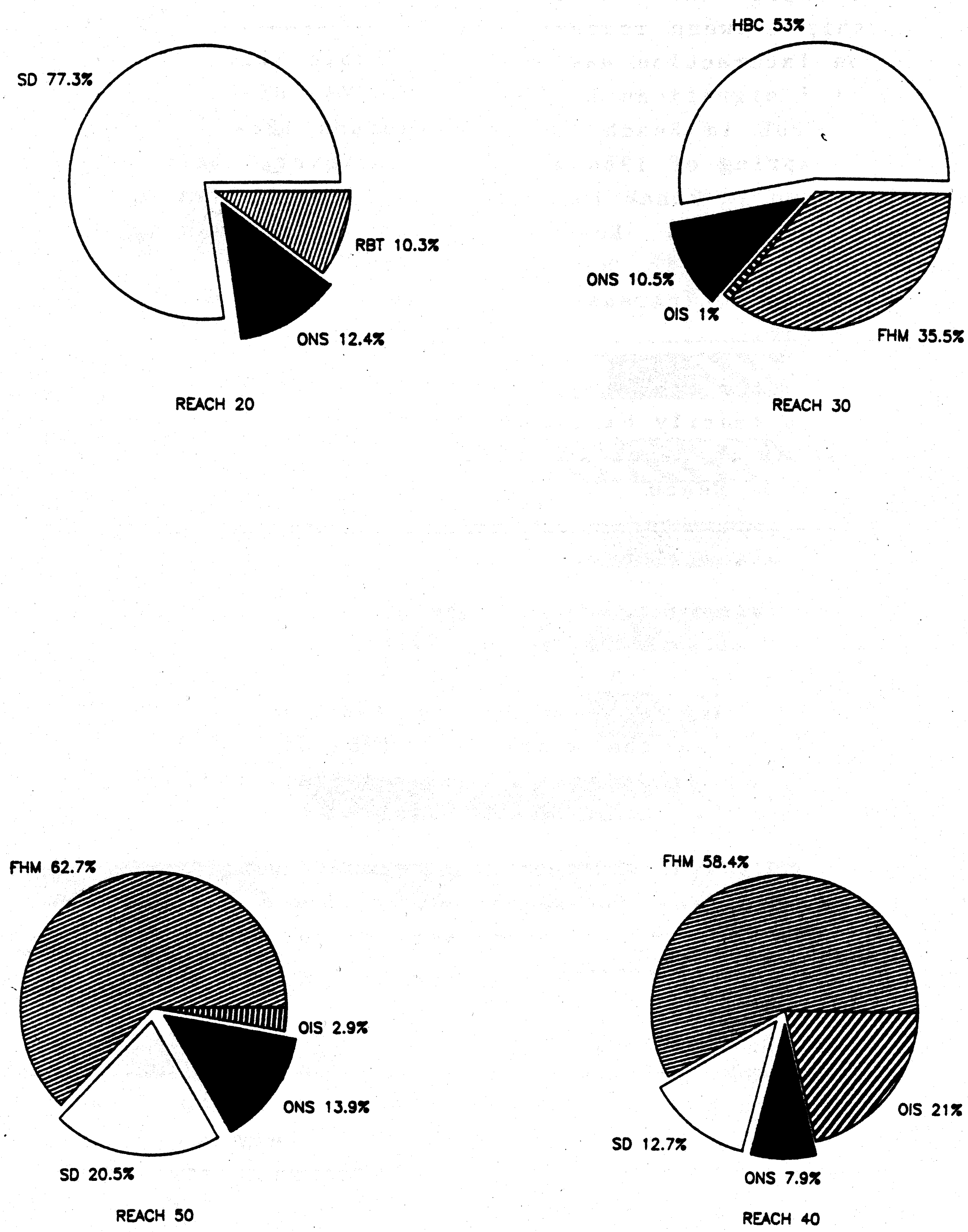


Figure 4.3. Species composition by reach from seining effort during April 1984 to May 1986. Native species are identified by raised portions.

(Figure 4.4). Reach 50 had the lowest CPUE at 25.8/100 min. Not only were there reach differences in rainbow trout CPUE but, the relationship between reaches changed by season. When the reach and season interaction was examined (Table 4.3), CPUE of rainbow trout varied significantly (Two-way ANOVA; df=20, 314; F=2.5436; P<.001). CPUE in Reach 10 during autumn 1984 was greater than during the spring of 1984 and 1985. However, there was no clear seasonal trend in Reach 10. Reaches 20 and 30 showed no seasonal differences in CPUE. Reach 40 showed an increase in CPUE until autumn 1985 when it began a steady decline. This decline corresponds to an increase in CPUE in Reach 50 during autumn and winter 1985/86.

Distribution of rainbow trout collected by seining represented primarily backwater habitats. The highest catch rate was 3.0/100 m^2 in Reach 40 (Figure 4.5). No rainbow trout were collected from Reach 10 using this method. Seasonally, the highest catch occurred during summer 1984. The lowest catches were in autumn and winter.

CPUE of rainbow trout with the larval seine showed a similar distribution pattern to electrofishing. Catch ranged from 93.0/100 m^2 in Reach 10 to 6.2/100 m^2 in Reach 50 (Figure 4.6). CPUE did not vary between spring 1985 and 1986, but showed differences between the winters of 1984/85 and 1985/86 (Figure 4.7), though not significant (One-way ANOVA; df=3, 263; F=1.6794: P>.05).

Catch of rainbow trout by trammel netting in 1984 was highest (91.7/12 h) in Reach 10, followed by Reach 40 with 35.2/12 h (Figure 4.8). No fish were captured by trammel netting in Reach 50, and netting in the mainchannel was discontinued after 1984.

The catch of brown trout by electrofishing was concentrated around Reach 30 (Figure 4.4). Reach 30 CPUE was highest at 11.7/100 min, and none were captured in Reach 10. Brown trout were not captured seining backwaters, and only one was collected (Reach 40) with the larval seine. Trammel netting catch was highest (27.9/12 h) in Reach 30 (Figure 4.8). Seasonal patterns in CPUE were not observed (Table 4.4).

CPUE electrofishing for brook trout decreased from the upper to lower reaches (Figure 4.4). CPUE was 10.4/100 min in Reach 10 and none were captured in Reach 50. Catch generally decreased through the period of the study. Seasonally, CPUE was lowest

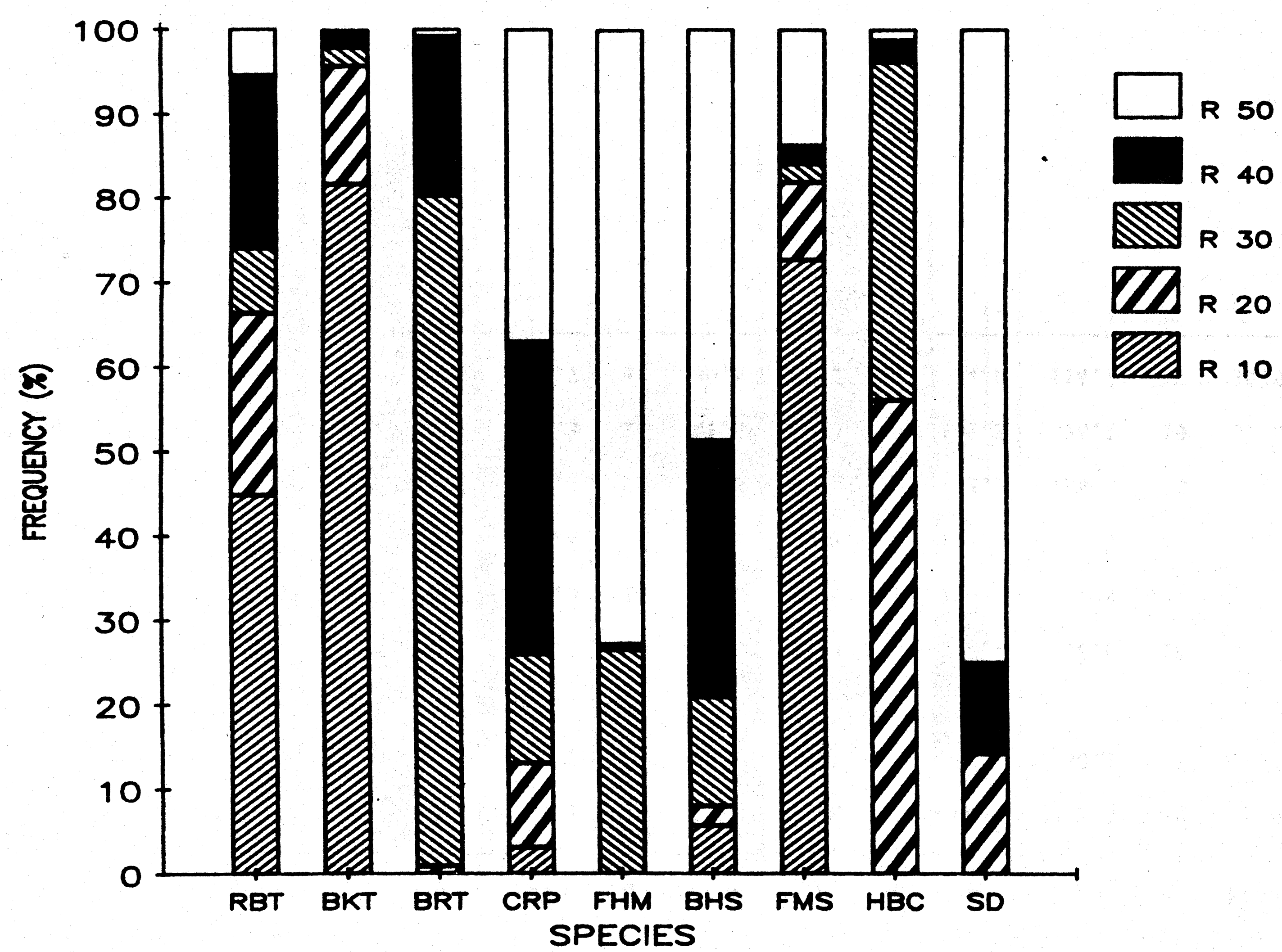


Figure 4.4. Relative abundance of fish species captured by electrofishing from April 1984 to May 1986. R = reach.

Table 4.3 Rainbow trout catch per unit effort (Catch/100 min) electrofishing in reaches 10-50 from April 1984-May 1986. N represents the number of electrofishing samples.

Season	10			20			30			40			50		
	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
Spring 1984	84.4	79.2	9	30.6	46.1	9	47.8	27.8	2	44.7	32.5	9	5.9	6.3	8
Summer 1984				65.6	75.2	5	25.8	21.1	5	76.2	30.1	3	17.2	17.5	3
Autumn 1984	289.3	321.6	26										0.0	0.0	3
Winter 1984/85	216.4	165.1	8	101.2	89.4	15	31.9	23.5	8	124.4	96.6	18	19.9	16.9	10
Spring 1985	106.8	56.5	10	90.6	77.3	18	34.8	20.5	8	100.6	79.9	21	17.4	21.9	7
Summer 1985	366.9	523.5	9	118.9	53.6	6	64.3	28.8	2	163.6	146.9	16	17.0	28.3	11
Autumn 1985	112.2	73.5	3	92.3	96.1	7	39.3		1	142.5	134.5	3			
Winter 1985/86	121.9	6.7	5	153.7	139.3	20	41.5	36.0	5	101.6	74.1	19	51.6	47.0	14
Spring 1986	150.1	87.0	7	88.3	93.7	12	30.3	47.5	4	94.8	114.1	12	36.5	48.3	6

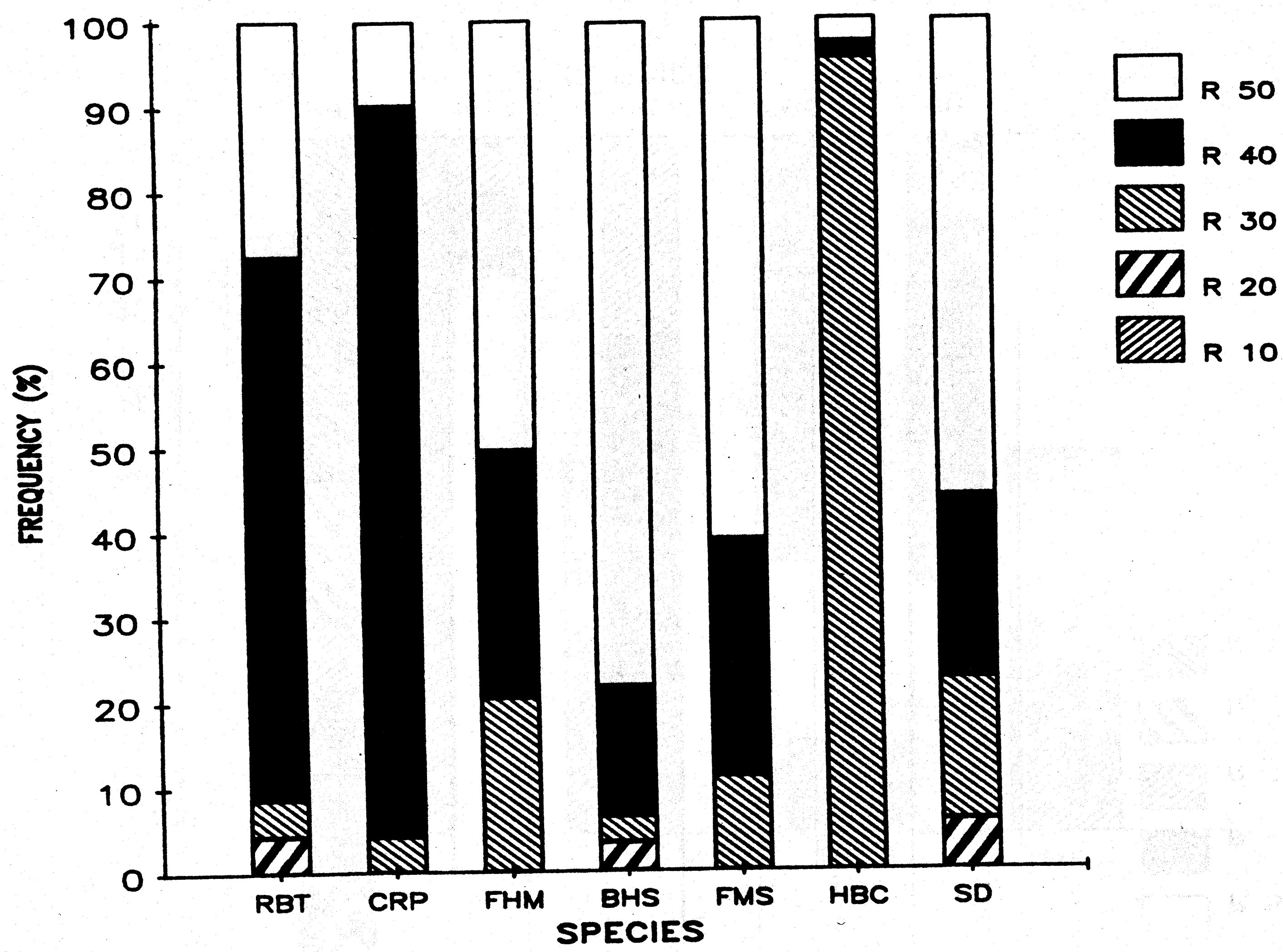


Figure 4.5. Relative abundance of fish species captured by bag seine from April 1984 to May 1986. R = reach.

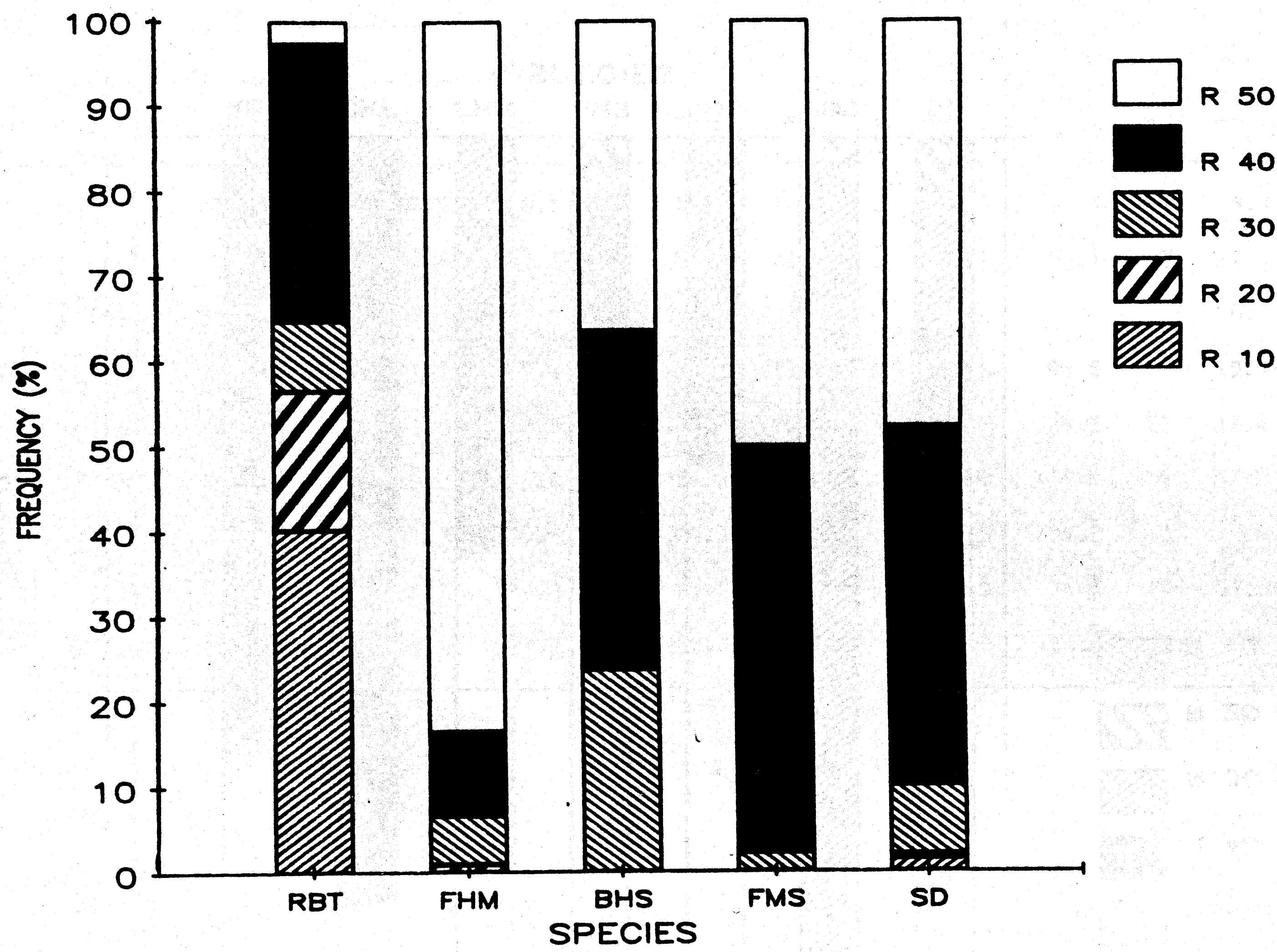


Figure 4.6. Relative abundance of fish species captured by larval seine from April 1984 to May 1986. R = reach.

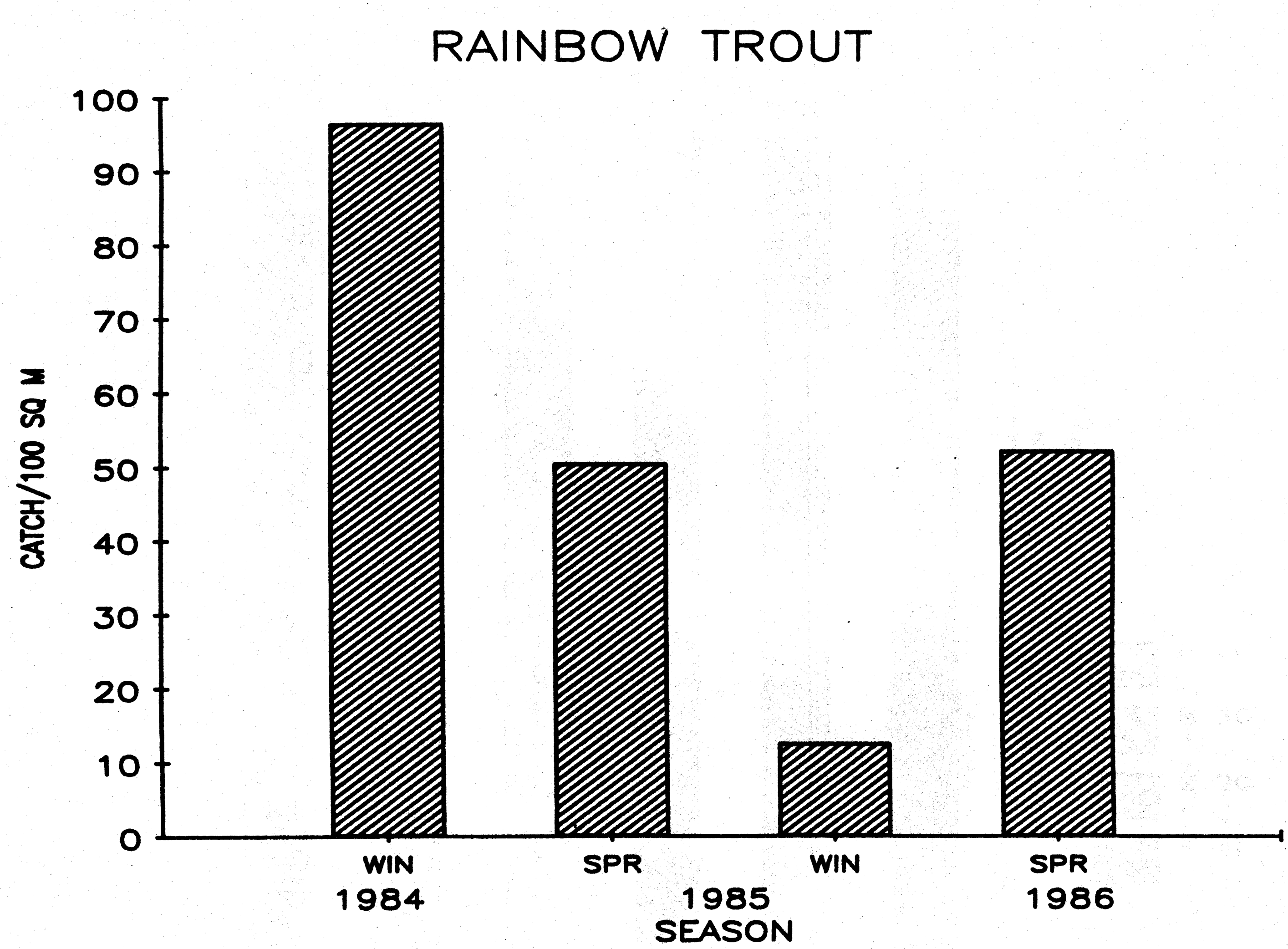


Figure 4.7. Rainbow trout catch per unit effort using larval seines from winter 1984 to spring 1986, all reaches combined.

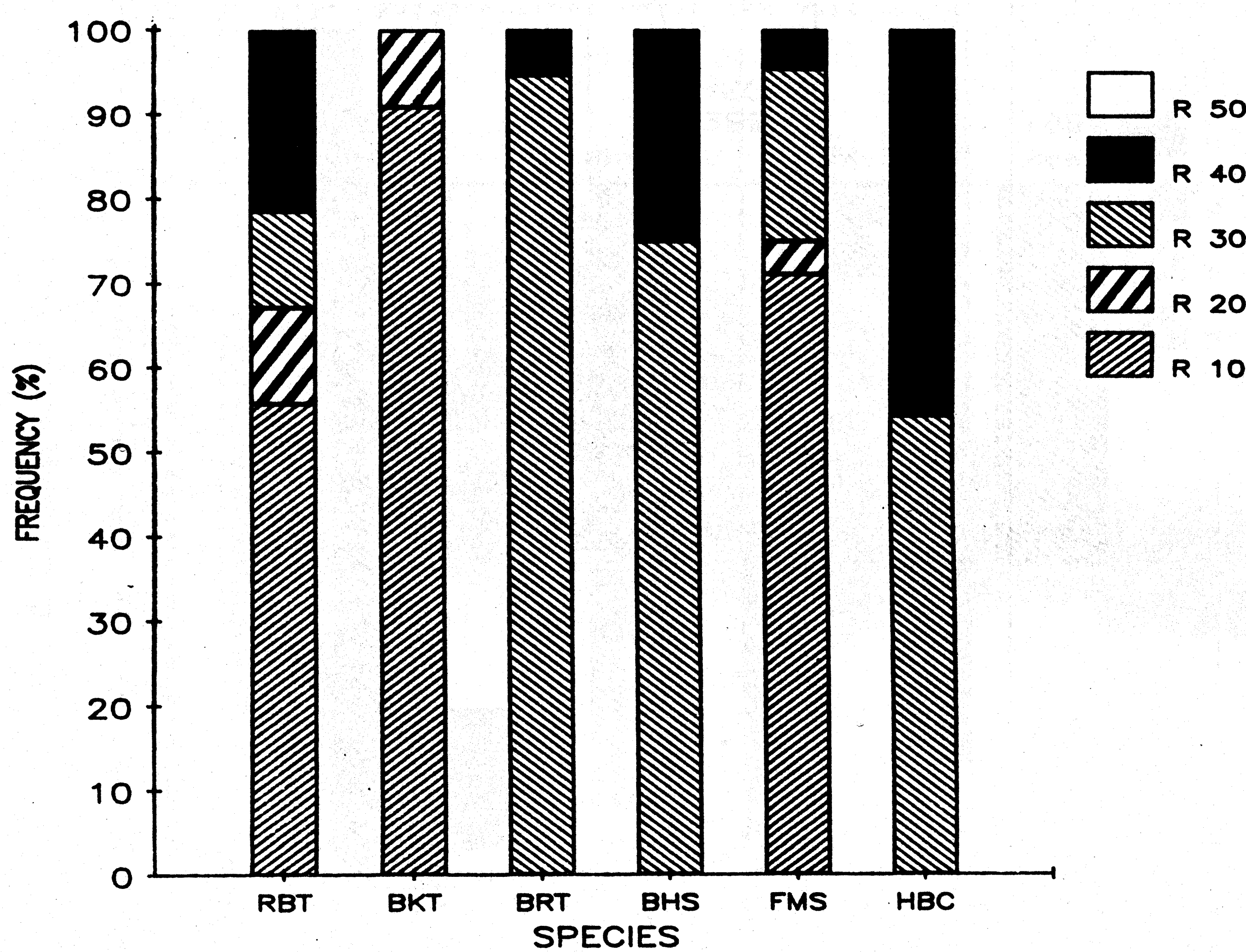


Figure 4.8. Relative abundance of fish species captured by trammel net from April 1984 to May 1986. R = reach.

during summer and highest in autumn (Table 4.4), but within seasons, catch generally declined from one year to the next. Brook trout were not captured by seining or larval seining, but were captured with trammel nets in Reach 10 (41.7/12 h) and Reach 20 (4.2/12 h) (Figure 4.8).

Carp CPUE electrofishing increased from the upper to lower reaches (Figure 4.4). CPUE in Reach 10 was 1.9/100 min, only 3.1% of electrofishing CPUE for carp in the entire river. Reaches 40 and 50 had the highest catch rates of 22.4/100 min. The greatest seasonal difference in carp CPUE was between spring and autumn (Table 4.4). The interaction of reach and season CPUE was significant (Two-way ANOVA; df=20, 314; F=2.77; P<.001). All carp collected by seining were below the Little Colorado River in reaches 30-50. Reach 40 had the highest catch rate of 6.1/100 m2 (Figure 4.5). Carp were captured by trammel netting only in Reach 40 (26.1/12 h) (Figure 4.8).

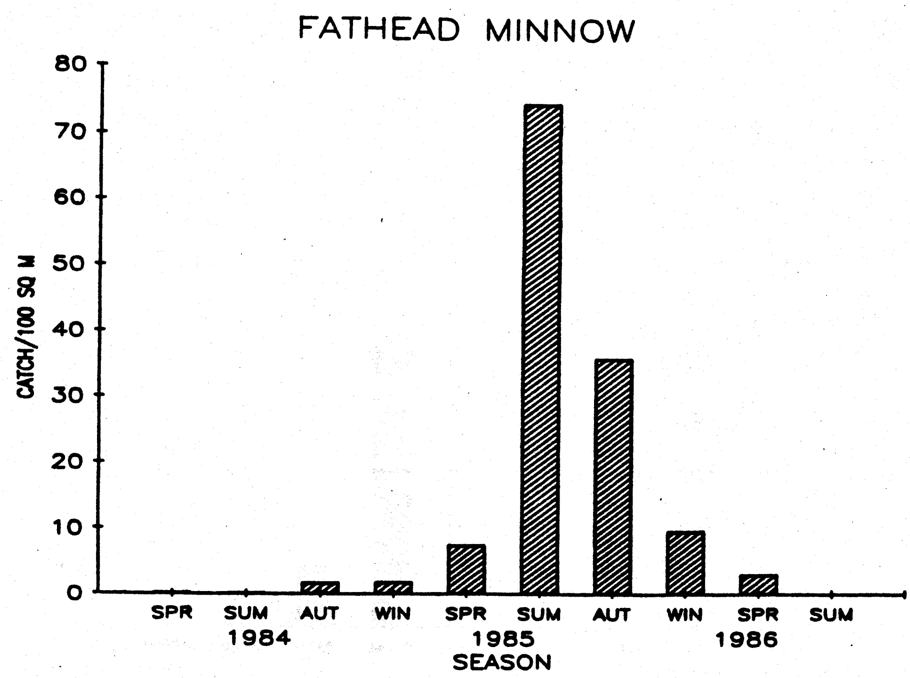
Fathead minnow were collected by electrofishing in the lower reaches. Catch was greatest in Reach 50, 1.2/100 min, and in Reach 30 below the Little Colorado River, 0.4/100 min (Figure 4.4). No seasonal trend was evident (Table 4.4). Fathead minnow were captured by seining in reaches 30-50. The highest CPUE, 44.1/100 m2, was in Reach 50 (Figure 4.5). Catch in 1985 was highest in summer and declined through the remainder of the year (Figure 4.9). CPUE by larval seining was also variable between seasons and years (Figure 4.9).

Native Species

Bluehead sucker CPUE by electrofishing generally increased down river (Figure 4.4). The highest CPUE was in Reach 50 (1.7/100 min). Seasonally, bluehead sucker CPUE electrofishing was greatest during summer 1985 (Table 4.4). Seine data were similar, with catch increasing down river (Figure 4.5). CPUE ranged from 0 in Reach 10 to 4.6/100 m^2 in Reach 50. Seining CPUE was highest during spring and summer 1984 and 1985 (Figure 4.10); however, no bluehead suckers were captured seining (n=39 sampling efforts) in spring 1986. Larval sucker CPUE was greatest in Reach 40, 22.9/100 m^2, and Reach 50, 20.9/100 m^2 (Figure 4.6). Larval suckers with recorded CPUE were not captured in reaches 10 or 20. Larval seine CPUE was low in both winter 1984/85, 1.9/100 m^2, and winter 1985/86, 1.2/100 m^2 (Figure 4.10). Catch varied between spring 1985 and spring 1986.

Table 4.4. Electrofishing catch per unit effort (Catch/100 min) from April 1984-May 1986, all reaches combined.

Species		1984				1985			1986	
		Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Brown trout	Mean	1.5	1.0	0.0	2.0	3.5	1.3	0.4	2.4	1.7
	SD	6.6	2.6	0.0	5.1	9.9	5.9	1.1	7.3	8.9
	n	37	16	27	59	65	44	15	63	41
Brook trout	Mean	4.1	0.2	12.6	4.2	1.4	0.3	4.5	1.3	0.7
	SD	6.1	0.7	16.9	15.5	2.7	0.9	8.9	3.9	1.6
	n	37	16	27	59	65	44	15	63	41
Common carp	Mean	27.0	27.5	2.0	12.1	14.3	9.0	2.9	6.1	15.6
	SD	41.0	49.9	5.0	17.7	31.6	13.0	4.2	8.4	20.1
	n	37	16	27	59	64	44	15	63	41
Fathead minnow	Mean	1.4	2.2	0.0	<0.1	0.1	0.0	0.1	0.1	0.1
	SD	7.1	8.2	0.0	0.2	0.4	0.0	0.5	0.6	0.7
	n	37	16	27	59	65	44	15	63	41
Bluehead sucker	Mean	0.2	0.2	0.0	0.6	0.4	2.5	0.9	0.3	0.9
	SD	0.7	1.0	0.0	3.0	1.1	4.1	1.7	0.9	2.6
	n	37	16	27	59	65	44	15	63	41
Flannelmouth sucker	Mean	18.6	4.9	14.3	9.4	29.8	6.7	9.0	7.2	13.9
	SD	64.1	16.6	24.0	48.9	222.7	31.4	19.3	26.3	47.3
	n	37	16	27	59	64	44	15	63	41
Speckled dace	Mean	0.1	0.6	0.0	<0.1	0.1	1.0	0.6	0.4	0.3
	SD	1.1	1.6	0.0	0.2	0.7	1.9	2.0	1.4	1.4
	n	37	16	27	59	65	44	15	63	41



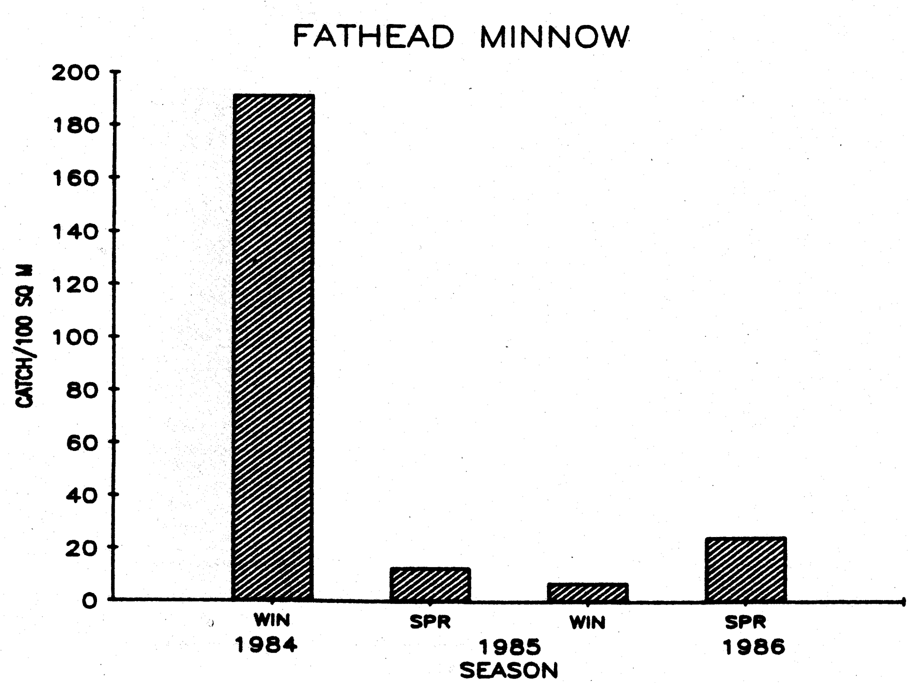
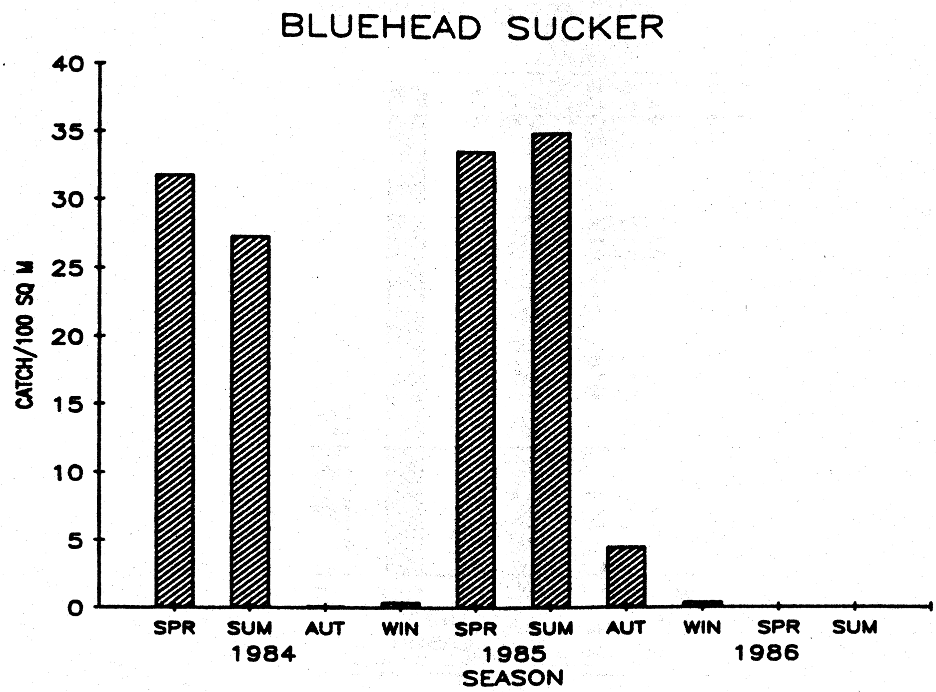


Figure 4.9. Fathead minnow catch per unit effort using bag seine (top) and larval seine (bottom), all reaches combined.



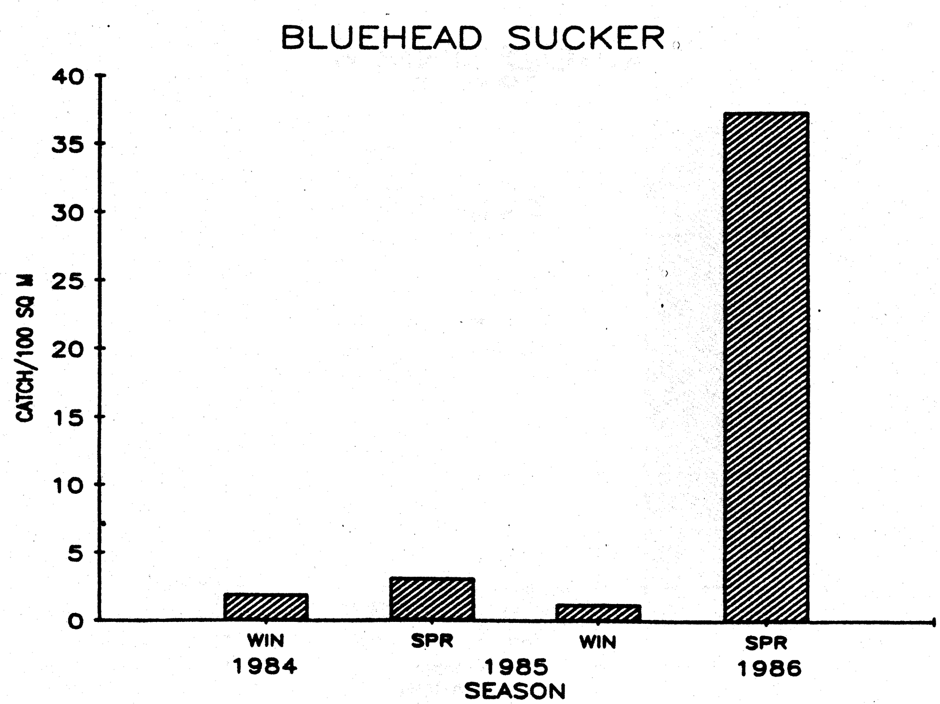


Figure 4.10. Bluehead sucker catch per unit effort using bag seine (top) and larval seine (bottom), all reaches combined.

Trammel netting CPUE for bluehead suckers was highest in Reach 30; few, however, were captured in any reach with trammel nets (Figure 4.8).

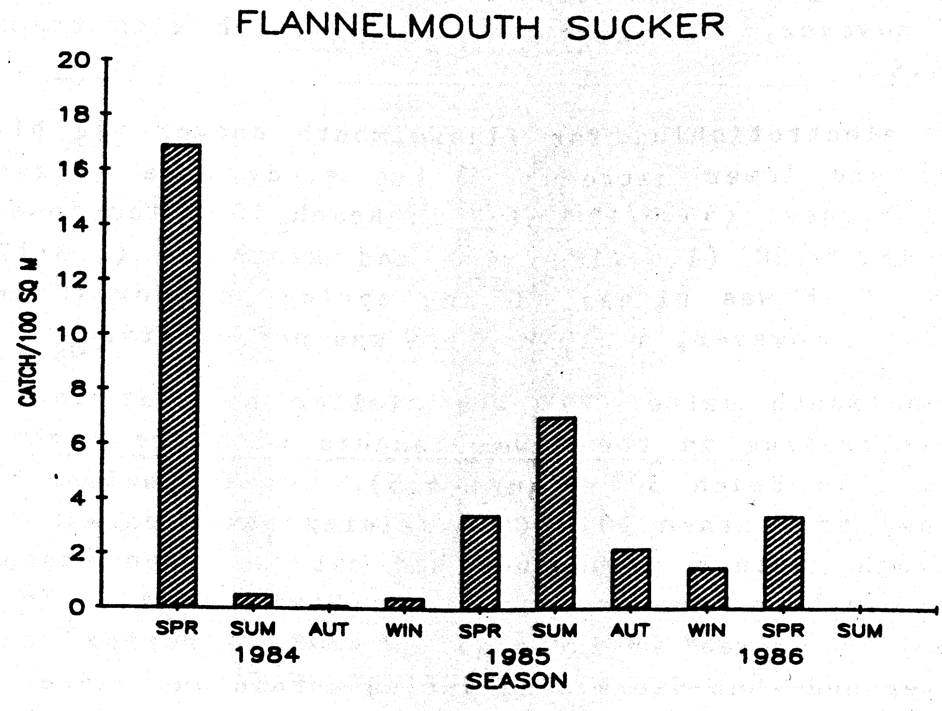
CPUE electrofishing for flannelmouth sucker was highest in the upper and lower extremes of the study area (Figure 4.4). Catch was highest (46.0/100 min) in Reach 10. The lowest CPUEs were in Reach 30 (1.41/100 min) and Reach 40 (1.3/100 min). Generally, CPUE was highest during spring and lowest in summer (Table 4.4). However, a clear trend was not observed.

Flannelmouth seine CPUE was similar to that for bluehead sucker, increasing in the lower reaches with the highest CPUE, 4.4/100 m^2, in Reach 50 (Figure 4.5). No flannelmouth suckers were seined from Reach 10. CPUE seining was greatest in spring 1984, though capture techniques had not yet been standardized, and catch may have been overestimated (Figure 4.11). The pattern for 1985-1986 showed an increase in CPUE in spring, continuing into summer and then decreasing during autumn and winter.

Larval flannelmouth sucker CPUE was greatest in reaches 40 (8.5/100 m^2) and 50 (8.9/100 m^2) (Figure 4.6). The greatest CPUE for larval fish occurred in spring 1986 (Figure 4.11), though there was no significant difference between seasons (One-way ANOVA; df=3, 272; F=1.0077). Flannelmouth sucker CPUE by trammel netting was greatest in Reach 10 (225.0/12 h) and Reach 30 (64.6/12 h) (Figure 4.8).

Most humpback chub captured by electrofishing were in the vicinity of the Little Colorado River (Figure 4.4). Ninety-six percent of all chub captured by electrofishing were from reaches 20 and 30. No chub were collected from the tailwater, Reach 10. Trammel netted fish were captured in reaches 30 and 40 with little difference in CPUE between the two reaches (Figure 4.8). In seining backwaters, 95.4% of all humpback chub were captured in Reach 30 (Figure 4.5). Most of these were captured in October 1985. The only chub captured by larval seining were from Reach 50, 3.8/100 m^2. Insufficient numbers precluded evaluation of CPUE by season.

The highest CPUE electrofishing for speckled dace was in Reach 50, 1.3/100 min (Figure 4.4). Dace were also captured by electrofishing in reaches 20 and 40. Though there were seasonal differences in CPUE electrofishing, no clear pattern emerged (Figure 4.4). CPUE of speckled dace in seined backwaters



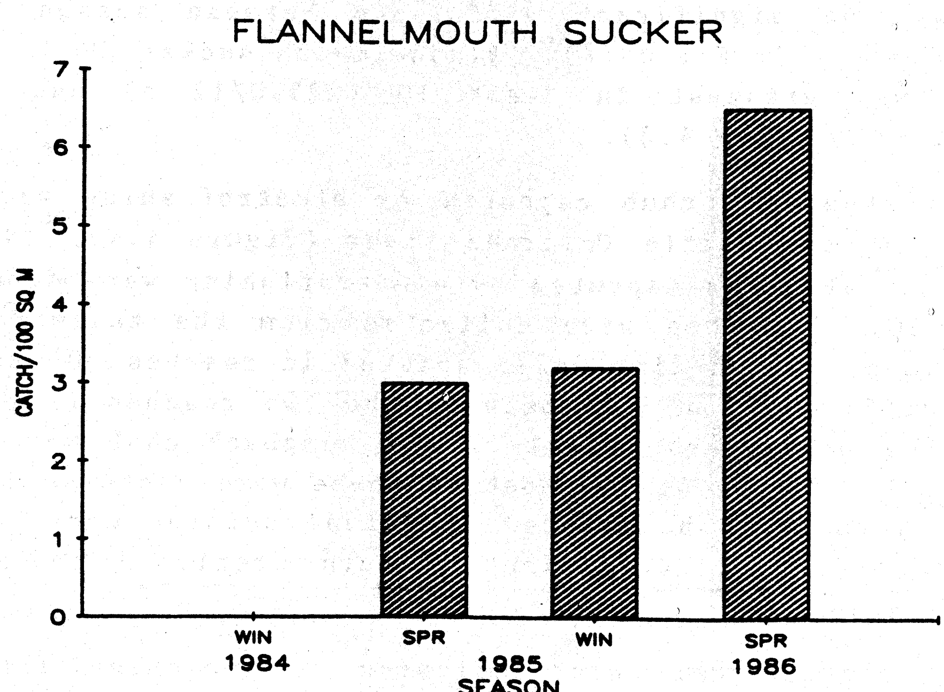


Figure 4.11. Flannelmouth sucker catch per unit effort using bag seine (top) and larval seine (bottom), all reaches combined.

increased from upper to lower reaches. The highest CPUE was in Reach 50 (14.4/100 m^2) and none were seined from Reach 10 (Figure 4.5). Catch rates from larval seining was highest in Reach 50 (83.6/100 m^2) and lowest in Reach 20 (0.9/100 m^2) (Figure 4.6). Significant differences in dace CPUE occurred between seasons (One-way ANOVA; df=3 274; F=4.6128; P<.01). The greatest catch was in winter 1984/85, 56.7/100 m^2, and spring 1986, 64.2/100 m^2 (Figure 4.12).

B. HABITAT UTILIZATION

Fishes were collected by electrofishing from a variety of mainchannel habitats including, runs, eddies, backwaters, and sidechannels and a variety of substrates including sand, gravel, rubble, boulders, and cliffs. Use by the different species often changed from one reach to the next.

Introduced Species

Adult rainbow trout CPUE was greatest in runs in reaches 10 and 20 and in backwaters in reaches 30, 40, and 50 (Table 4.5). Adults were found near gravel substrate in sampling above the Little Colorado River and larger rubble and boulders below. Adult CPUE was highest in presence of vegetation in all reaches except Reach 50.

Subadult rainbow trout were most abundant in eddies in reaches 10 and 30 and backwaters in reaches 40 and 50. In Reach 40, CPUE was similar across all habitats. Subadult CPUE was greatest for rubble and boulder in all reaches. Subadults were near vegetation in reaches above the Little Colorado River, but not in reaches below.

A comparison was made of CPUE of rainbow trout in runs, eddies, and backwaters during steady and fluctuating flows (Table 4.6). Because of differences in habitat use above and below the Little Colorado River, these reach data were combined into two groups. Winter 1984/85 was tested against winter 1985/86 using ANOVA. Winter was used because it was the only season characterized by both steady (1984/85) and fluctuating (1985/86) flows. By limiting analysis to one season we hoped to control for seasonal differences and test for only flow type. The only significant differences in habitat use were for adults in eddies and backwaters above the LCR (ANOVA P<.05). However, adult catch during fluctuating flows was higher in all habitat types while

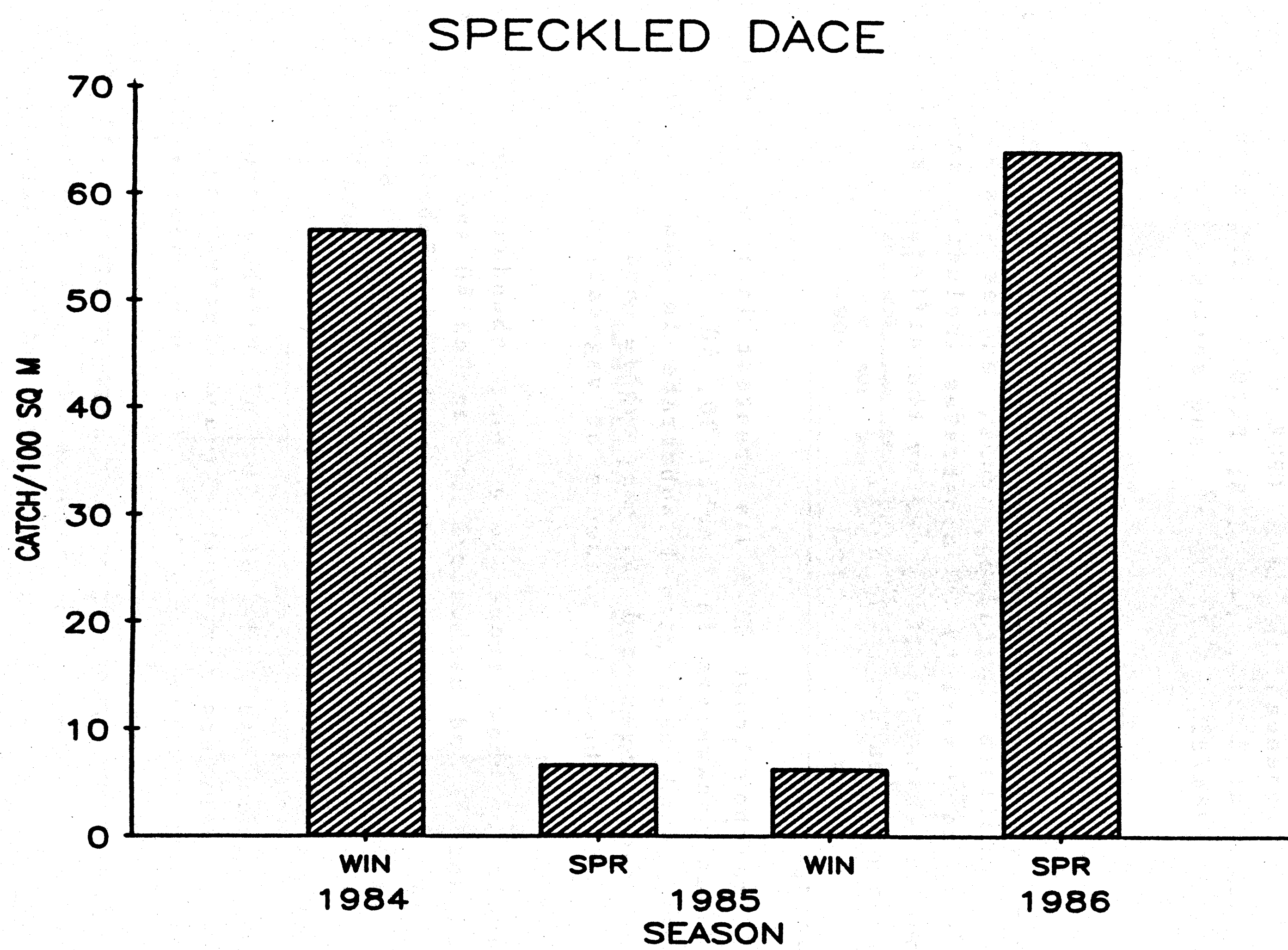


Figure 4.12. Speckled dace catch per unit effort using larval seines from winter 1984 to spring 1986, all reaches combined.

Table 4.5. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of rainbow trout adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	**136.5**	32.8	97.6	18.2	67.1	78.2	151.3	**165.5**	78.6	**100.4**	69.4
	SE	18.6	5.2	31.5	18.2	14.5	10.3	35.2	57.0	10.5	10.8	12.5
	Subadult	35.2	**39.7**	11.4	0.0	23.1	**48.6**	30.4	14.7	22.8	35.1	**40.3**
	SE	6.2	20.7	4.2		6.6	13.8	10.0	7.5	4.9	6.5	22.6
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	**92.5**	59.8	84.8	33.3	55.4	86.1	89.1	**159.1**	53.6	**90.1**	64.4
	SE	10.5	5.6	8.8	21.1	12.5	10.6	15.0	59.0	5.9	9.8	8.0
	Subadult	**10.1**	7.2	4.2	4.2	6.2	8.0	**12.1**	3.0	5.9	6.5	**7.9**
	SE	2.0	1.3	4.2	4.2	1.7	1.4	3.7	3.0	1.4	1.3	1.4
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(69)	(57)	(69)
30	Adult	20.0	29.9	**71.2**		26.5	**47.9**	20.0	21.4	29.7	**30.3**	26.9
	SE	4.4	4.5	29.8		4.9	11.9	7.4	14.9	5.4	6.8	3.6
	Subadult	3.9	**7.0**	0.0		4.5	8.7	4.4	0.0	**11.6**	**15.2**	7.2
	SE	1.1	1.4			1.2	2.5	3.4		3.5	5.9	1.8
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	61.9	58.8	**103.6**	23.1	42.0	69.8	**70.3**	36.8	70.1	**63.5**	60.5
	SE	6.3	5.1	49.9	5.2	4.2	6.3	13.4	22.1	7.6	6.5	5.1
	Subadult	36.5	34.5	**41.1**	40.4	17.1	38.9	52.1	**53.4**	34.5	**44.4**	35.7
	SE	52.8	3.2	18.0	32.4	2.9	3.7	8.4	21.9	4.0	4.8	3.4
		(89)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(104)	(110)
50	Adult	12.9	8.5	**13.5**	0.0	3.4	9.4	**19.5**	2.9	13.3	7.7	**11.9**
	SE	3.0	1.5	9.5		1.2	1.8	5.8	2.9	2.6	1.4	2.0
	Subadult	15.0	9.8	**21.8**	450.0	5.3	12.3	16.0	**31.4**	12.9	**12.1**	11.9
	SE	0.2	1.9	10.6	0.0	2.6	2.4	4.1	21.0	2.5	2.6	2.3

Table 4.6. Comparison of rainbow trout electrofishing catch per unit effort (CPUE) and effort (minutes) during a steady flow period (winter 1984/85) and a fluctuation period (winter 1985/86) in different habitat types. The number of samples from each habitat type is represented by n.

			Steady				Fluctuation				ANOVA		
Area	Habitat	Life stage	Mean CPUE	SE	Total Effort	n	Mean CPUE	SE	Mean Effort	n	F	DF	P
Above LCR [a]	Run	Adult	76.8	15.1	432	38	137.2	22.4	577	54	2.7	1,90	.107
		Subadult	36.1	9.6	432	38	11.0	3.2	577	54	3.3	1,90	.074
	Eddy	Adult	40.2	7.4	542	41	65.4	10.9	716	51	6.0	1,90	.016[b]
		Subadult	15.4	3.8	542	41	8.9	4.0	716	51	0.1	1,90	.781
	Backwater	Adult	20.6	16.1	34	6	185.7	87.0	32	11	5.1	1,15	.039[b]
		Subadult	5.6	5.6	34	6	2.3	2.3	32	11	2.0	1,15	.183
Below LCR [a]	Run	Adult	24.2	3.8	575	75	48.5	8.3	631	80	3.4	1,153	.069
		Subadult	27.6	5.8	575	75	19.3	3.3	631	80	0.2	1,153	.688
	Eddy	Adult	38.2	5.2	1515	97	42.9	6.0	1920	98	0.1	1,193	.753
		Subadult	29.6	3.8	1515	97	15.4	2.2	1920	98	2.8	1,193	.094
	Backwater	Adult	73.3	63.6	16	3	86.9	55.0	26	11	1.3	1,12	.277
		Subadult	66.7	66.7	16	3	12.1	9.3	26	11	1.4	1,12	.257

[a] LCR = Little Colorado River confluence.
[b] $P<.05$

catch of subadults declined. It appeared that adult use of the electrofished habitats was not adversely affected, but that subadults may move to deeper water and areas less affected by fluctuating flows.

Brook trout adults were captured in reaches 10-40. These fish were captured most often in eddies with the exception of Reach 10 where sidechannel CPUE was highest (Table 4.7). Adults showed no defined pattern in substrate CPUE, though CPUE was highest near cliffs in two of four reaches. Adults were captured near vegetation in all reaches.

Subadults were most often caught in eddies in reaches 10 and 20, and were not captured below the Little Colorado River. They were captured in boulders and in the absence of vegetation in both reaches.

Brown trout adults in most reaches were generally captured in runs (Table 4.8). However, in Reach 30 where brown trout were most abundant, backwaters and cliff shores had by far the greatest CPUE. In other areas substrate varied from cliffs in Reach 20 to boulder in Reach 50. In reaches where CPUE along cliff was highest, CPUE was also greatest in absence of vegetation. Among other substrate types, CPUE was always highest in the presence of vegetation.

Subadults, which were captured in low numbers in all reaches except 30, were also found in backwaters. However, catch rates by substrate were different for subadults; rubble was the most common substrate selected. CPUE was highest in vegetation in reaches 20 and 30, but highest in the absence of vegetation in all other reaches.

Adult carp CPUE was highest in the slower water velocity habitats of backwaters and eddies in all five reaches (Table 4.9). Carp density by substrate was variable. CPUE was greatest over boulder and sand in the reaches of higher CPUEs. In all reaches adult carp CPUE was greater in vegetation.

Habitat selection for the few subadult carp collected was similar to adults. Like adults, they were ubiquitous across substrate types except gravel. Differences between adults and subadults appeared in CPUE for vegetation. Subadult carp CPUE was highest in the absence of vegetation in two of three reaches.

Table 4.7. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of brook trout adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	3.7	1.9	0.0	**4.6**	0.6	1.5	**3.1**	1.8	3.9	**4.1**	1.08
	SE	1.4	0.8		4.6	0.4	0.6	1.6	1.8	1.6	1.5	0.4
	Subadult	2.8	**2.9**	0.0	0.0	0.4	**4.1**	2.0	0.0	0.3	2.2	**2.3**
	SE	1.2	1.3			0.4	1.4	0.9		0.3	0.8	1.1
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	0.7	**1.2**	0.0	0.0	**1.4**	1.1	1.0	0.0	1.3	**2.1**	0.7
	SE	0.2	0.3			0.9	0.3	0.9		0.6	0.8	0.2
	Subadult	0.0	**0.0**	0.0	0.0	0.0	**0.1**	0.0	0.0	0.0	0.0	**0.0**
	SE		0.0				0.1					0.0
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	0.0	**.1**	0.0		0.0	**0.2**	0.0	0.0	0.1	**0.1**	0.1
	SE		0.1				0.2			0.1	0.1	0.1
	Subadult	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	0.0	**.1**	0.0	0.0	**0.2**	0.1	0.0	0.0	0.0	**0.1**	0.1
	SE		0.1			0.1	0.1				0.1	0.1
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											

Table 4.8. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of brown trout adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**	0.0
	SE											
	Subadult	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**	0.0
	SE											
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	**0.1**	0.0	0.0	0.0	**0.2**	0.1	0.0	0.0	0.0	0.0	**0.1**
	SE	0.1	0.0			0.2	0.0					0.1
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	9.0	9.6	**54.6**		**19.6**	19.1	14.1	0.0	4.1	8.1	**12.2**
	SE	2.8	2.5	31.2		6.1	6.9	7.6		1.9	3.2	3.5
	Subadult	1.9	1.4	**13.6**		2.1	1.5	**3.2**	0.0	1.1	**3.1**	1.4
	SE	0.9	0.5	9.8		0.6	0.7	2.2		0.3	1.6	0.4
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	**2.3**	2.1	0.0	0.0	2.5	3.2	1.2	**5.0**	2.2	**2.8**	2.5
	SE	0.5	0.5			0.6	0.7	0.8	5.0	0.9	1.0	0.4
	Subadult	0.2	**0.4**	0.0	0.0	**0.4**	0.4	0.2	0.0	1.0	0.3	**0.3**
	SE	.1	0.1			0.2	0.1	0.1		0.1	0.1	0.1
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	0.0	**0.1**	0.0	0.0	0.0	**0.1**	0.0	0.0	0.0	**0.2**	0.0
	SE		0.1				0.1				0.2	
	Subadult	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0
	SE		0.0			0.0	0.0				0.0	

Table 4.9. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of carp adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	1.2	1.4	**9.6**	4.2	2.1	**3.1**	1.0	0.9	2.8	**2.7**	0.7
	SE	0.4	0.7	4.1	4.2	1.2	1.7	0.6	0.9	1.0	0.8	0.4
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	1.2	**4.7**	0.6	2.4	2.4	2.1	4.5	**9.1**	3.2	**4.4**	1.5
	SE	0.7	1.2	0.6	2.4	1.1	0.5	2.4	9.1	0.9	1.1	0.4
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	2.2	**4.9**	4.6		4.0	1.8	1.4	0.0	**4.4**	**6.5**	1.4
	SE	1.0	1.1	4.6		2.3	0.7	1.2		1.3	1.7	0.6
	Subadult	0.1	0.3	**1.5**		0.0	**1.8**	0.0	0.0	0.2	0.4	**1.5**
	SE	0.1	0.3	1.5			1.7			0.2	0.3	1.5
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	9.8	**20.6**	11.7	2.4	10.2	**17.5**	11.0	0.0	17.2	**27.4**	13.0
	SE	2.4	2.6	11.7	2.4	1.7	2.7	3.5		2.8	5.5	1.6
	Subadult	0.3	**0.5**	0.0	0.0	0.1	0.3	0.0	0.0	**0.7**	**1.1**	0.2
	SE	0.2	0.2			0.1	0.2			0.3	0.4	0.2
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	6.8	12.2	**20.2**	0.0	10.9	8.2	13.1	0.0	**14.4**	**13.1**	8.6
	SE	1.7	1.9	14.1		6.0	1.6	4.4		2.2	1.9	0.2
	Subadult	0.0	**0.6**	0.0	0.0	**0.4**	0.2	0.4	0.0	0.4	**0.5**	0.2
	SE		0.2			0.4	0.1	0.4		0.2	0.2	0.2

Native Species

Bluehead sucker CPUE for adults was not conspicuously highest for any one habitat type, though faster current runs and sidechannels seemed important in some reaches (Table 4.10). CPUE was highest near gravel in Reach 10, but not in any other reach. In Reach 50, where CPUE of blueheads was greatest, the highest CPUE occurred over rubble substrate. Sand never contained the highest density for adults in any reach, though some fish were captured over sand in all reaches. CPUE was highest in the absence of vegetation in all reaches.

CPUE was generally highest in runs for subadult bluehead suckers. Their densities by substrate seemed to vary by reach. CPUE was highest with sand and cliff in Reach 40 and boulder and sand in Reach 50 where subadult abundance was greatest. With the exception of Reach 40, subadults followed a pattern similar to adults and CPUE was highest in the presence of vegetation.

Catch rates for flannelmouth sucker adults in Reach 10 differed from all other reaches (Table 4.11). CPUE was highest in Reach 10 backwaters. They were captured in runs in all reaches, though runs never contained the highest CPUE in any reach. In Reach 10, CPUE near sand substrate was twice that of any other substrate. Cliff, gravel, and rubble CPUE were similar, while CPUE in boulder was the lowest of all substrate types. CPUE was highest in the absence of vegetation except in Reach 10.

Subadults were generally collected from eddies and runs over sand. In contrast to adults, subadult CPUE was higher in the presence of vegetation in all reaches except Reach 50.

Habitat information for adult humpback chub was reported from reaches 20-40. In reaches 20 and 40 adult CPUE was highest in eddies and in Reach 30 in runs (Table 4.12). In reaches 30 and 40, adults were captured along cliffs, although in Reach 20 the catch was higher in boulders. In all cases adult CPUE was highest in the absence of vegetation.

Subadult CPUE by habitat followed that of adult humpback chubs, though in Reach 50 subadults were caught in eddies. Substrate selection was more variable with the highest CPUEs over sand, rubble, and near cliffs. Adults and subadults were not captured over gravel. Subadult CPUE was highest in absence of vegetation with the exception of Reach 50.

Table 4.10. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of bluehead sucker adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(74)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	**1.0**	0.0	0.0	0.0	0.0	0.0	3.1	**3.6**	0.1	0.2	**1.0**
	SE	0.5						1.8	3.6	0.1	0.2	0.6
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(71)	(152)	(140)	(171)
20	Adult	0.0	**0.2**	0.0	0.0	0.0	**0.2**	0.0	0.0	0.0	0.0	**0.2**
	SE		0.2				0.1					0.2
	Subadult	**0.1**	0.0	0.0	0.0	0.0	0.0	**0.1**	0.0	0.0	0.0	**0.1**
	SE	0.1					0.0	0.1				0.0
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	**0.4**	0.3	0.0		0.2	0.4	**0.5**	0.0	0.3	0.2	**0.6**
	SE	0.3	0.1			0.1	0.3	0.5		0.2	0.2	0.3
	Subadult	0.0	**0.0**	0.0		**0.1**	0.0	0.0	0.0	0.0	0.0	**0.0**
	SE		0.4			0.1	0.0					0.0
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	0.1	0.4	0.0	**50.0**	**1.0**	0.5	0.2	0.0	0.7	0.7	**0.9**
	SE	0.4	0.1		20.4	0.7	0.2	0.2		0.4	0.3	0.5
	Subadult	**0.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	**0.1**	0.0
	SE	0.1	0.0			0.0				0.1	0.1	0.0
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	1.4	0.6	**1.5**	0.0	0.0	1.1	**2.3**	0.0	0.5	0.7	**1.1**
	SE	0.5	0.2	1.5			0.4	1.3		0.3	0.3	0.5
	Subadult	**0.4**	0.2	0.0	0.0	0.0	**0.4**	0.0	0.0	0.2	0.2	**0.3**
	SE	0.2	0.2				0.2			0.2	0.1	0.3

Table 4.11. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of flannelmouth sucker adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	33.4	11.2	**182.3**	40.9	20.3	4.6	19.8	20.0	**48.7**	**41.8**	20.7
	SE	10.7	4.8	105.4	40.9	15.3	1.9	7.0	11.9	13.8	13.1	6.7
	Subadult	**0.3**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**	**0.3**	0.0
	SE	0.1								0.3	0.3	
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	3.0	2.0	1.4	**46.4**	0.1	1.0	0.8	**18.2**	6.2	2.2	**5.9**
	SE	1.8	1.6	1.4	46.4	0.1	0.6	0.5	12.2	3.0	0.9	3.1
	Subadult	0.0	0.0	**4.2**	0.0	0.0	0.0	0.0	0.0	**0.1**	**0.0**	0.0
	SE			4.2						0.1	0.0	
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	2.3	1.1	**9.1**	0	**2.3**	1.4	0.0	0.0	1.2	0.5	**1.9**
	SE	1.7	0.4	9.1		1.2	0.8			0.8	0.3	0.8
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	0.3	0.5	**10.0**	8.4	0.5	0.6	0.8	0.0	**1.6**	0.8	**0.8**
	SE	0.1	0.2	8.4	4.4	0.2	0.2	0.7		0.8	0.4	0.3
	Subadult	0.0	**0.1**	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**	**0.2**	0.0
	SE	0.0	0.1				0.0			0.1	0.1	
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	0.6	**0.7**	0.0	0.0	0.3	**0.7**	0.4	0.0	0.6	0.5	**0.6**
	SE	0.4	0.3			0.3	0.5	0.4		0.3	0.4	0.3
	Subadult	**0.5**	0.4	0.0	0.0	0.5	**1.0**	0.3	0.0	0.2	0.0	**1.2**
	SE	0.3	0.3			0.6	1.0	0.2		0.1		0.9

Table 4.12. Mean and standard error (SE) of electrofishing catch per unit effort (catch/100 min) of humpback chub adults and subadults by habitat, substrate, and the presence or absence of vegetation in Reach 10-50. Values in parentheses () represent n, the number of times each category was sampled. Bold values represent highest catch rate among habitat, substrate, and vegetation categories.

		Habitat				Substrate					Vegetation	
Reach	Life Stage	Run	Eddy	Backwater	Side Channel	Cliff	Boulder	Rubble	Gravel	Sand	Present	Absent
		(79)	(58)	(18)	(2)	(31)	(62)	(48)	(14)	(71)	(78)	(64)
10	Adult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
	Subadult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
		(159)	(165)	(24)	(6)	(80)	(162)	(76)	(11)	(152)	(140)	(171)
20	Adult	0.0	**0.1**	0.0	0.0	0.0	**0.1**	0.0	0.0	0.0	0.0	**0.0**
	SE		0.0				0.1				0.0	0.0
	Subadult	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	**0.0**
	SE		0.0							0.0		0.0
		(61)	(72)	(11)	(0)	(48)	(59)	(30)	(7)	(64)	(57)	(69)
30	Adult	**0.1**	0.0	0.0		**0.2**	0.0	0.0	0.0	0.0	0.0	**0.1**
	SE	0.1				0.2						0.1
	Subadult	**0.7**	0.7	0.0		1.3	0.0	**2.8**	0.0	1.8	0.3	**1.0**
	SE	0.6	0.3			1.1		2.3		1.6	0.2	0.6
		(172)	(203)	(12)	(6)	(156)	(191)	(72)	(10)	(151)	(148)	(209)
40	Adult	0.1	**0.1**	0.0	0.0	**0.1**	0.1	0.0	0.0	0.0	0.0	**0.1**
	SE	0.1	0.0			0.1	0.0				0.0	0.0
	Subadult	0.0	**0.1**	0.0	0.0	**0.2**	0.0	0.0	0.0	0.0	0.0	**0.1**
	SE		0.1			0.2						0.1
		(59)	(120)	(13)	(1)	(57)	(105)	(62)	(7)	(111)	(109)	(110)
50	Adult	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SE											
	Subadult	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**	**0.1**	0.0
	SE		0.0							0.1	0.1	

Larval Seine

Rainbow trout fry were most often captured in runs followed by eddies (Appendix 4.2). The highest CPUE for fry was over sand and especially in habitats providing cover. Rainbow trout were captured at a mean depth of 23.6 cm and in water velocity lower than for any other species (Table 4.13).

Fathead minnows were found in the deepest water of any species sampled with the larval seine. They were also found in water velocities higher than any other species except humpback chub. Fathead minnow CPUE for habitat type was highest in runs. CPUE in substrate was greatest on sand, and they were captured in cover.

Larval bluehead sucker were most often encountered in backwaters, over gravel and in association with cover. They were found in water with a mean depth of 21.7 cm and a mean velocity of 0.23 ft/sec. Mean water temperature was near 15^{o}C (Figure 4.13).

Flannelmouth sucker larvae were found in habitats similar to bluehead sucker. The exception was that flannelmouth suckers were not necessarily in cover. Depth, velocity, and temperature were all near, but slightly lower than those of bluehead sucker habitats (Table 4.13, Figure 4.13).

Of the humpback chub juveniles captured, the highest CPUE was in runs over sand and near cover. Depth and velocity measurements were taken from the habitat of only one captured individual. Mean water temperature where fish were captured was 15.2^{o}C. This temperature is warmer than that for other native fishes except speckled dace.

Speckled dace was the only species that had its greatest density in sidechannels. Like other native fish, speckled dace were collected over gravel and near cover. They were captured at water depths similar to those where fathead minnow were taken. Mean water temperature (26.78^{o}C) where dace were captured was greater than for any other species.

Habitat Availability

Changes in the relative amounts of habitat types occurred when discharge was dropped from 28,000 cfs to 4,800 cfs. The frequency of eddies generally increased in all reaches (Table

Table 4.13. Mean depth and velocity for larvae, fry and other small fishes collected with larval seine in mainchannel Colorado River.

	Depth			Velocity		
Species	Mean	SD	n	Mean	SD	n
Rainbow trout	23.6	12.6	159	0.1	0.2	135
Fathead minnow	27.4	15.3	114	0.3	1.0	78
Bluehead sucker	21.7	11.5	58	0.2	0.2	24
Flannelmouth sucker	23.6	13.5	33	0.2	0.2	26
Humpback chub	24.0		1	0.3		1
Speckled dace	26.7	13.4	105	0.2	0.1	51

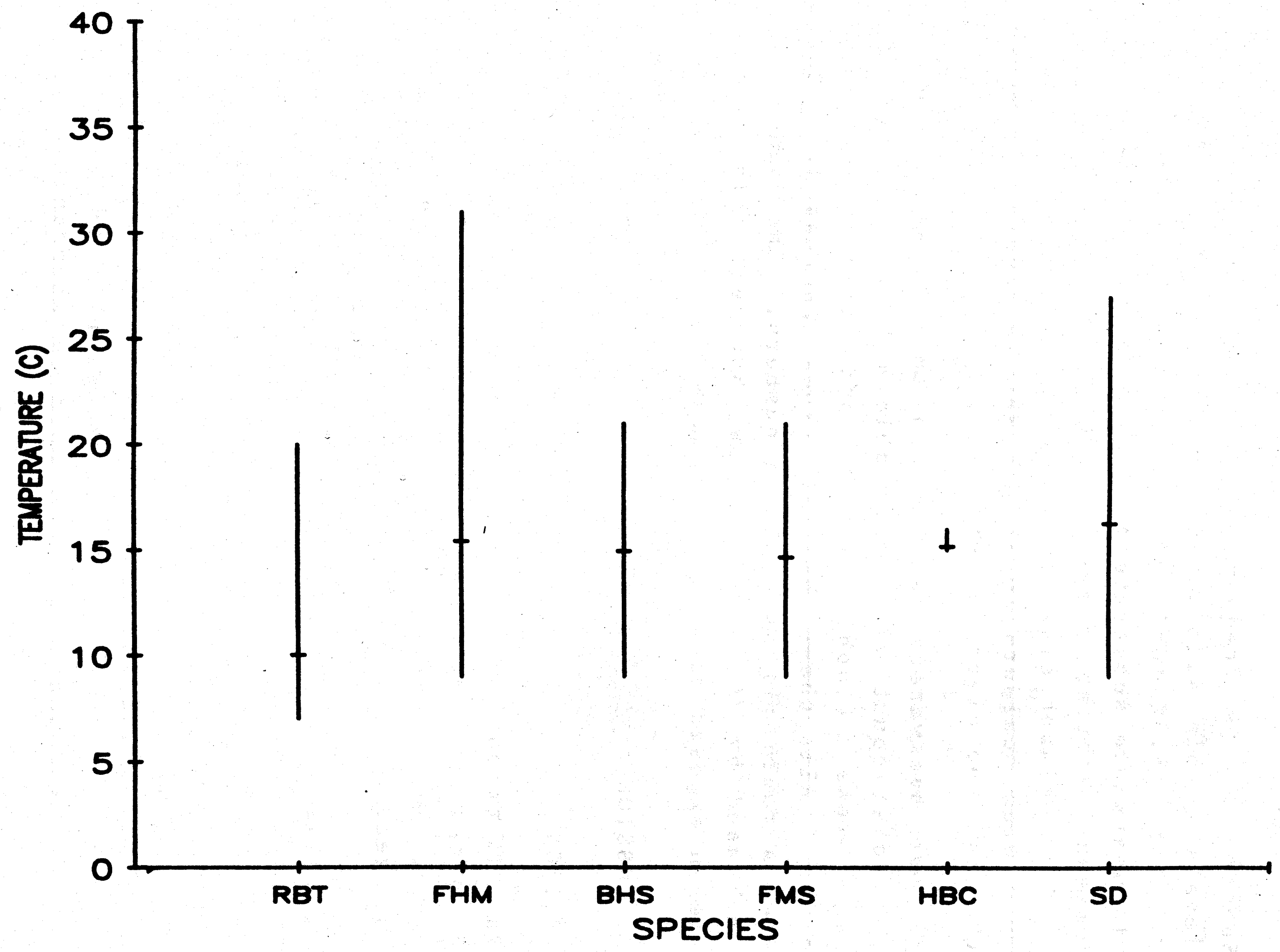


Figure 4.13. Mean and range of water temperatures (^{o}C) at capture sites for fishes collected by larval seine.

4.14). The relative percent of eddies for the entire river increased slightly from 52.9% of the habitat type to 59.3%. Runs decreased from 44.0% to 36.3% and probably corresponding to a decrease in water velocity associated with a decrease in discharge.

Substrate type frequencies changed little between the two flow levels (Table 4.15). The greatest change was a decrease from 25.1% to 18.5% for cliffs to and an increase from 6.7% to 12.4% in nearshore substrate being rubble. Table 4.16 represents the dominant habitat classes combining habitat and substrate types. The dominant class in reaches 10 and 20 above LCR changed from runs with boulders to eddies with boulders. Reaches below the LCR showed no clear patterns.

Because backwaters represent a small area of the Colorado River, a total count was done (Table 4.17). Included are other spawning areas (cobble bars) and unique habitat (side channels). All these habitat types increased. Backwaters exhibited a four-fold increase in numbers. The number of cobble bars increased by 745% at low flow; however, this represents an increase in exposed rainbow trout spawning areas.

4.3. DISCUSSION

DISTRIBUTION

The distribution of fishes in Glen and Grand canyons has been reported from prior to the construction of Glen Canyon Dam to the present time (Table 4.18). Differences in sampling methods, gear types, and effort make comparisons among studies difficult. However, these studies do show a change from warm water species prior to and immediately after closing of the dam to a system dominated by cold water and eurythermal fishes. Although some native species have persisted through the changing environment, many have been extirpated, including Colorado squawfish, bonytail, roundtail chub, and probably the razorback sucker. Introduced species such as red shiner, black bullhead, channel catfish, green sunfish, bluegill, and largemouth bass have either disappeared or decreased in abundance. Rainbow and brown trout, coldwater species, have increased due to stocking, natural reproduction, and a more favorable environment.

Water temperature, clarity, relative food abundance, fish stocking, location of tributaries, and abundance of backwaters

Table 4.14 Frequency and percent (%) occurrence of nearshore river habitats at high and low flows, from Anderson et al. (1986).

Reach	Flow level	n	Eddy	Backwater	Run	Side channel
10	High	28	12 (42.9)	0 (0)	16 (57.1)	0 (0)
	Low	50	33 (66.0)	2 (4.0)	14 (28.0)	1 (2.0)
20	High	118	49 (41.5)	3 (2.5)	65 (55.1)	1 (0.8)
	Low	113	68 (60.2)	0 (0)	45 (39.8)	0 (0)
31	High	28	13 (46.4)	0 (0)	13 (46.4)	2 (7.1)
	Low	23	7 (30.4)	2 (8.7)	11 (47.8)	3 (13.0)
32	High	20	12 (60.0)	1 (5.0)	7 (35.0)	0 (0)
	Low	39	16 (41.0)	2 (5.1)	18 (46.1)	3 (7.7)
41	High	46	28 (60.9)	0 (0)	16 (34.8)	2 (4.3)
	Low	51	31 (58.8)	0 (0)	20 (39.2)	1 (2.0)
42	High	108	58 (53.7)	2 (1.9)	47 (43.5)	1 (0.9)
	Low	143	88 (61.5)	1 (0.7)	53 (37.1)	1 (0.7)
50	High	118	72 (61.0)	5 (4.2)	41 (34.7)	0 (0)
	Low	122	72 (59.0)	8 (6.6)	38 (31.1)	4 (3.3)
TOTAL	High	466	244 (52.4)	11 (2.4)	205 (44.0)	6 (1.3)
	Low	518	307 (59.3)	13 (2.5)	188 (36.3)	10 (1.9)

4.14). The relative percent of eddies for the entire river increased slightly from 52.9% of the habitat type to 59.3%. Runs decreased from 44.0% to 36.3% and probably corresponding to a decrease in water velocity associated with a decrease in discharge.

Substrate type frequencies changed little between the two flow levels (Table 4.15). The greatest change was a decrease from 25.1% to 18.5% for cliffs to and an increase from 6.7% to 12.4% in nearshore substrate being rubble. Table 4.16 represents the dominant habitat classes combining habitat and substrate types. The dominant class in reaches 10 and 20 above LCR changed from runs with boulders to eddies with boulders. Reaches below the LCR showed no clear patterns.

Because backwaters represent a small area of the Colorado River, a total count was done (Table 4.17). Included are other spawning areas (cobble bars) and unique habitat (side channels). All these habitat types increased. Backwaters exhibited a four-fold increase in numbers. The number of cobble bars increased by 745% at low flow; however, this represents an increase in exposed rainbow trout spawning areas.

4.3. DISCUSSION

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Water temperature, clarity, relative food abundance, fish stocking, location of tributaries, and abundance of backwaters

Table 4.15 Frequency and percent (%) occurrence of nearshore river substrates at high and low flows, from Anderson et al. (1986).

Reach	Flow level	n	Cliff	Boulder	Rubble	Sand
10	High	28	6 (21.4)	12 (42.9)	4 (14.3)	6 (21.4)
	Low	50	6 (12.0)	16 (32.0)	16 (32.0)	12 (24.0)
20	High	118	32 (27.1)	57 (48.3)	4 (3.4)	25 (21.2)
	Low	113	14 (12.4)	59 (52.2)	14 (12.4)	26 (23.0)
31	High	28	5 (17.9)	4 (14.3)	5 (17.9)	14 (50.0)
	Low	23	0 (0)	10 (43.5)	6 (26.1)	7 (30.4)
32	High	20	9 (45.0)	8 (40.0)	0 (0)	3 (15.0)
	Low	39	10 (25.6)	15 (38.5)	6 (15.4)	8 (20.5)
41	High	46	19 (41.3)	18 (39.1)	5 (10.9)	4 (8.7)
	Low	51	23 (45.1)	17 (33.3)	4 (7.8)	7 (13.7)
42	High	108	38 (35.2)	44 (40.7)	2 (1.9)	24 (22.2)
	Low	143	35 (24.5)	77 (53.8)	3 (2.1)	28 (19.6)
50	High	118	8 (6.8)	49 (41.5)	11 (9.3)	50 (42.4)
	Low	122	8 (6.6)	42 (34.4)	21 (17.2)	51 (41.8)
TOTAL	High	466	117 (25.1)	192 (41.2)	31 (6.7)	126 (27.0)
	Low	518	96 (18.5)	226 (43.6)	64 (12.4)	132 (25.5)

Table 4.16. Percent occurrence of dominant habitat classes (greater than 10% of all habitats) defined by nearshore habitats and shoreline substrates for high and low flows at selected reaches, from Anderson et al. (1986).

Reach	High Flow		Low Flow	
	Habitat Class	%	Habitat Class	%
10	run/boulder	28	eddy/boulder	26
	eddy/boulder	14	run/rubble	16
	eddy/cliff	14	eddy/sand	14
	eddy/sand	11	eddy/rubble	14
	run/rubble	11	eddy/cliff	12
	run/sand	11		
20	run/boulder	32	eddy/boulder	30
	eddy/boulder	16	eddy/sand	23
	run/cliff	14	run/boulder	22
	eddy/cliff	13	run/rubble	10
	eddy/sand	13		
31	eddy/sand	32	run/boulder	26
	run/sand	18	eddy/sand	17
	run/rubble	14	eddy/boulder	13
	eddy/cliff	14	run/rubble	13
32	eddy/cliff	30	run/boulder	20
	eddy/boulder	25	eddy/boulder	15
	run/cliff	15	eddy/cliff	13
	run/boulder	15	eddy/sand	13
41	eddy/cliff	33	eddy/cliff	27
	eddy/boulder	22	eddy/boulder	18
	run/boulder	17	run/cliff	18
42	run/boulder	24	eddy/boulder	27
	eddy/cliff	21	run/boulder	27
	eddy/sand	17	eddy/sand	17
	eddy/boulder	16	eddy/cliff	17
	run/cliff	14		
50	eddy/sand	33	eddy/sand	35
	run/boulder	23	eddy/boulder	18
	eddy/boulder	19	run/boulder	16
			run/rubble	14

Table 4.17 Total number and number per mile (in parentheses) of spawning and nursery habitats from selected reaches at high and low flows, from Anderson et al. (1986).

Reach	Flow level	Sample miles	Spawning and Nursery Habitat: Backwater	Isolated backwater	Cobble bar	Side channel	Total
10	High	9.0	1 (0.1)	0 (0)	2 (0.2)	2 (0.2)	5 (0.6)
	Low	15.0	17 (1.1)	5 (0.3)	19 (1.3)	5 (0.3)	46 (3.1)
20	High	61.5	26 (0.4)	3 (0.05)	0 (0)	2 (0.03)	31 (0.5)
	Low	59.0	103 (1.7)	22 (0.4)	14 (0.2)	15 (0.2)	154 (2.6)
31	High	15.5	3 (0.2)	0 (0)	1 (0.1)	6 (0.4)	10 (0.6)
	Low	11.0	62 (5.6)	17 (1.5)	9 (0.8)	7 (0.6)	95 (8.6)
32	High	10.8	1 (0.1)	0 (0)	0 (0)	0 (0)	1 (0.1)
	Low	6.5	16 (2.5)	2 (0.3)	1 (0.1)	0 (0)	19 (2.9)
41	High	22.2	1 (0.04)	0 (0)	1 (0.04)	3 (0.1)	5 (0.2)
	Low	22.2	34 (1.5)	2 (0.1)	4 (0.2)	1 (0.04)	41 (1.8)
42	High	52.0	33 (0.8)	0 (0.6)	2 (0.04)	8 (0.1)	43 (0.8)
	Low	56.5	40 (0.7)	5 (0.1)	2 (0.04)	4 (0.1)	51 (0.9)
50	High	58.5	122 (2.1)	1 (0.02)	5 (0.1)	10 (0.2)	138 (2.4)
	Low	58.5	225 (3.8)	23 (0.4)	43 (0.7)	29 (0.5)	320 (5.5)
TOTAL	High	229.5	187 (0.8)	4 (0.02)	11 (0.05)	31 (0.1)	233 (1.0)
	Low	228.7	497 (2.2)	78 (0.3)	92 (0.4)	61 (0.3)	728 (3.2)

Table 4.18. Present and historical fish species occurrence and relative abundance in the Colorado River, Glen Canyon to Separation Canyon. Abundance values are: A = abundant, C = common, LC = locally common, and R = rare.

Species	1958-59[a]	1967-68[b]	1968[c]	1967-73[d]	1975[e]	1976[f]	1977-78[g]	Present
Threadfin shad	-	-	-	-	-	R	-	-
Cutthroat trout	-	-	-	-	-	-	A	R
Rainbow trout	-	A	C	C	C	C	A	A
Brown trout	-	R	-	-	-	-	C	C
Brook trout	-	-	-	-	-	-	C	C
Common carp	C	A	C	C	C	A	A	A
Utah chub	R	-	-	-	-	-	-	R
Humpback chub	-	C	R	R	R	R	LC	R
Virgin spinedace	-	-	-	-	-	-	R	-
Golden shiner	-	-	-	-	-	-	R	R
Red shiner	-	-	C	-	-	R	-	-
Fathead minnow	A	-	A	R	A	-	C	A
Woundfin	-	-	-	-	-	-	R	-
Colorado squawfish	R	R	-	-	-	-	-	-
Speckled dace	A	-	C	A	A	A	C	A
Bluehead sucker	C	C	C	C	A	C	C	C
Flannelmouth sucker	C	A	C	C	A	C	C	C
Razorback sucker	R	-	-	-	-	-	R	R
Black bullhead	C	R	R	-	R	-	R	R
Yellow bullhead	-	-	-	-	-	-	-	R
Channel catfish	A	A	A	R	R	-	C	R
Plains killifish	R	-	-	-	C	C	C	R
Mosquitofish	R	-	-	-	-	R	-	-
Striped bass	-	-	-	-	-	-	R	R
Green sunfish	C	C	-	-	-	R	R	R
Bluegill	R	-	-	-	-	R	R	-
Largemouth bass	R	C	-	-	-	R	R	R
Black crappie	-	R	-	-	-	-	-	-

[a] McDonald and Dotson 1960
[b] Stone and Rathbun 1968
[c] Miller and Smith 1968
[d] Holden and Stalnaker 1975
[e] Minckley and Blinn 1976
[f] Suttkus et al. 1976
[g] Carothers et al. 1981

all seem to be important factors to fish distribution within the river. Water temperature has been considered the primary cause for extirpation of native fishes from regulated portions of the Colorado River (Holden and Stalnaker 1975, Behnke and Benson 1980). The displacement of native fishes from Colorado River tailwaters is common (Vanicek et al. 1970).

Species diversity throughout the five reaches was low and did not appear to relate directly with habitat diversity. Reach 50 had the highest species diversity, but a corresponding low habitat diversity. Although habitat diversity was low, Reach 50 contained an estimated 45.5% and 61.5% of all backwaters at 4,800 and 28,000 cfs, respectively. It is typical for warmer water to contain a more diverse fauna. However, in this system there is very little warming from the dam to above Lake Mead (See Chapter 3), and backwaters and tributaries represent the only warm water habitats available. Therefore, backwater location and abundance may contribute more to species distribution and diversity than other factors. Because these habitats warm in the spring and summer, they may provide essential spawning and rearing habitats for species that might otherwise disappear from the system.

Introduced Species

Rainbow trout were collected throughout the study area, though catch rates were highest in the tailwater from the dam to Lee's Ferry. Rainbow trout have replaced native fish populations in other tailwaters (Vanicek et al. 1970). Annual stockings of fingerling rainbow trout and the relative abundance of aquatic invertebrates and other food items (Leibfried and Blinn 1986) may contribute to their abundance in Reach 10. The stocking of rainbow trout downstream ended in 1971 (Persons et al. 1985), and present populations are attributable to reproduction in the tributaries and main channel. Downstream movement from Reach 10 was minimal during the present study (See Chapter 7) and does not account for trout below Lee's Ferry.

Brown trout abundance in the river seems to have increased since the examination of fish distribution by Carothers et al. (1981). Most of their increase in abundance seems to have occurred in reaches 30 and 40, immediately above and below Bright Angel Creek. Fish in the mainchannel may represent individuals moving from the creek. Water temperature and clarity make habitats in Reach 10) less suitable for brown trout (Scott and Crossman 1973, Gosse and Helm 1982).

Brook trout distribution was fairly predictable as abundance declined with distance traveled down river. Temperatures in the tailwater more nearly approximate the optimal temperature for brook trout. Distribution appears to be controlled by stocking and dispersal down river, rather than by reproduction.

Carp distribution was the inverse of brook trout. Catch increased from upper to the lower reaches. This may be related to temperature preference. The preferred temperature of carp has been reported to be 18.5-23.0°C (Jester 1974). Temperatures in Reach 50 are not near that optimum but are the warmest mainchannel temperatures ($\bar{x}$=11.5°C) in the study area.

Fathead minnow, like carp, were most abundant in the lower reaches. The variation in fathead abundance by seasons reflects its short life span and high reproductive potential (Carlander 1969).

Native Species

Adult and larval bluehead suckers were most abundant in the lower reaches. Riverine suckers are less abundant in tailwaters than in unregulated streams (Swink and Jacobs 1983). Bluehead suckers were not captured in the first 17 miles below Flaming Gorge Dam (Vanicek et al. 1970).

Flannelmouth suckers, unlike other native fish, were most abundant in Reach 10. In general, large adult flannelmouth suckers were in Reach 10, while juvenile and larval fish were in the lower reaches. Larval suckers are known to drift from spawning grounds to their nursery areas (Valdez and Ryel 1986). The lower portion of the river may serve as a nursery and rearing area, and as these fish grow, they disperse throughout the river, concentrating in Reach 10. By comparison, flannelmouth suckers are the only native fish present in the Flaming Gorge tailwater (Vanicek et al. 1970). Abundance and persistence of this species may be linked to the integrity of backwaters used as nursery areas in reaches 40 and 50.

Speckled dace, like other native fishes, were most abundant in the lower reaches. Thought to be primarily associated with tributary streams (Carothers et al. 1981), they were abundant in Reach 50, an area with no tributaries. Presumably, warmer backwaters and sidechannels provide habitat necessary for the different life stages of the speckled dace.

Adult humpback chub, though found in reaches 20-50, were generally captured in the proximity of the Little Colorado River. Kaeding and Zimmerman (1983) also found adult humpback chub a short distance upstream and downstream from the Little Colorado River. Adults were collected from the Glen Canyon tailwater in 1967 (Suttkus and Clemmer 1977), but none were captured there during the present study. Most y-o-y and subadult humpback chub were collected from reaches 30 and 50, where most backwaters in the study area occur.

HABITAT UTILIZATION

Rainbow trout habitat selection differed above and below the Little Colorado River. Greater turbidity below the Little Colorado River may affect habitat selection by fish. Gradall and Swenson (1982) found that in moderately turbid water fish use overhead cover less than in clear water. Subadult preference for lower water velocity accounts for differences in habitat from that of adults (Gosse and Gosse 1985). Anderson et al. (1986) reported differences in relative percent of habitat for reaches 10-50 at 4,800 cfs compared to 28,000 cfs. If adult and subadult habitats change at different water stages, forced crowding or alteration of an individuals choice of habitat may result.

Rainbow trout fry selected habitats with low or no current velocity. Persons et al. (1985) showed that as discharge changes, habitat suitable for fry changes from one river location to another. If discharge fluctuates, theoretically fry could be displaced downstream daily. Discharge patterns during the present study inhibited our ability to test this hypothesis. Rainbow trout fry were not displaced down river under the fairly steady flow regime during this study.

Like rainbow trout, catch for adult and subadult brown trout in Reach 30 was highest in backwaters. Brown trout, unlike rainbows, were caught in areas lacking vegetation; this may reflect their more piscivorous nature. Those species captured near vegetation may be feeding on food falling into the river. In this portion of Reach 30, backwater and cliff abundance were similar at the two flow levels examined (Anderson et al. 1986). The narrow, sheer cliff environment of this stretch of river changes very little with water stage. However, during high discharge water velocity increased and surged in and out of backwaters. This could affect habitat of fish and their food base.

If sampling was representative of actual habitat selection of fishes, then brook trout and rainbow trout are using different habitat types. Brook trout were in eddies and along cliff and boulders, though they prefer cold headwater streams (Scott and Crossman 1973). Cliff frequency was the same at both flow levels, while boulder frequency was highest during low flow. These represent shoreline substrates. Therefore, boulder frequency may not change with flow or may decrease at lower discharges. Water velocity in mainchannel habitats was not measured although it may be an important factor in determining overall habitat suitability.

Carp, known for its adaptability, preferred habitats with slower water velocity and did not seem to select any one substrate type. The ubiquitous nature of carp may account for its distribution among habitat types. Carp abundance and distribution may be regulated by water temperature rather than habitat type (See Chapter 3).

Fathead minnow density was highest along runs where they were captured in vegetation. Vegetation served to break the current velocity and probably also provided food. Fathead minnows were found in the river prior to the construction of Glen Canyon Dam and have persisted since its closure. Fluctuating flows may affect population size by creating warm backwaters for reproduction (See Chapter 6), and later flushing the young fish hatched in these environments into the river.

The higher velocity runs and sidechannels with rubble substrate selected by bluehead sucker probably serve as feeding areas for these "scrapers." When water levels drop many of these shallow areas are exposed. Larval bluehead suckers were generally in shallow backwaters and may also be affected by changing water level.

Backwaters, where flannelmouth sucker catch was greatest, may have been feeding, resting, and spawning habitats for this species. Few were observed in these habitats during the day, but nighttime electrofishing in backwaters often resulted in very high catch rates. Like other natives, larvae were generally in lentic, sand or gravel bottom backwaters. These habitats form and disappear as river stage changes. If water level fluctuates in late spring or early summer, survival and eventual recruitment could be limited.

Speckled dace were collected from a variety of habitats but seemed concentrated in backwaters and sidechannels, habitats warmer than the main channel. Water flow and temperature in sidechannels may resemble tributaries, where speckled dace are seasonally abundant.

Generally, adult and subadult humpback chubs were collected along cliff and boulders in mainchannel habitats, and vegetation did not appear important in habitat selection. In humpback chub populations in the Green and Upper Colorado rivers, individuals are believed to prefer deep, swift areas with large boulders and sheer cliff (Valdez 1980, Tyus et al. 1982, Valdez and Clemmer 1982).

Y-o-y humpback chub were captured in sandy runs and backwaters similar to those reported in the upper basin (Holden 1978, Valdez and Clemmer 1982). Holden (1978) reported y-o-y humpback chub preferred depths of 0.6 m and velocities from 0.0-0.15 meters per second (m/sec) (0.0 - 0.49 ft/sec). Valdez and Clemmer (1982) report slightly different results for juveniles from Black Rocks and Westwater Canyon in the Upper Colorado River. The few y-o-y were captured at a similar velocity, but in shallower water. The mean temperature for captured y-o-y chub of 15.2°C is well below their optimum (Bulkley et al. 1981). Although larvae of other native fishes were collected from mainchannel sites, no humpback chub larvae were found outside of the Little Colorado River. Mainchannel temperatures, which are lethal to chub ova (Hamman 1982), may limit the distribution of humpback chub, and mainchannel abundance may be dependent upon the carrying capacity and success of reproduction within the Little Colorado River. Historically, when spring and summer mainchannel temperatures approximated those in the Little Colorado River, larvae may have utilized mainchannel habitats as nursery areas.

BACKWATER EXAMINATION

4.1. METHODS

Prior to the change in the release pattern of Glen Canyon Dam from high steady flows to a regime with daily fluctuations in October 1985, three teams of biologists were flown to stations in reaches 30, 40, and 50. Each team worked a concentrated area of backwaters, sampling fishes prior to fluctuation and during the first few days of fluctuating flows. Stations were located in areas of known importance to native fishes based upon earlier results from this study. After the short sampling trip, a regularly scheduled trip was made through the canyon between October 6-15, and most of these backwaters were again seined.

Backwaters were sampled using 7.6 x 1.8 m seines with 3.2 and 6.4 mm mesh. All stations were sampled with 3.2 mm mesh seines but not all sites were sampled with 6.4 mm mesh seines. Collected fish were identified, measured to the nearest millimeter, weighed when appropriate, given a fin clip unique to the backwater, and then released back into that same backwater. The fin clips were used to determine fish movement during fluctuating flows. Water temperature was measured to the nearest degree centigrade using a hand held thermometer.

Backwaters were classified as connected (with access to the river) or isolated (closed off from the river). A series of backwaters was sampled within each station during steady flows and again each day after the water began fluctuating. However, some backwaters present at one flow level were no longer backwaters at another flow level. A backwater present at low water might be an eddy at higher water, while a backwater at high water might be dry at lower water. Hydrographs near each study site were estimated using the Bureau of Reclamation Stream Simulation and Reservoir Regulation (SSARR) model (See Graf et al. 1986).

4.2. RESULTS

Releases from Glen Canyon Dam fluctuated between 1,960-26,500 cfs from September 29 to October 4, 1985 (Figure 4.14). At the Reach 30 station lows occurred between 2100-2200 h with peak flows occurring between 0400-1100 h. The Reach 40 station experienced low flows from 1700-1900 h, while Reach 50 was lowest between 0000-0200 h. High flows for Reach 40 were at 0200-0500 h and for Reach 50 at 0900-1200 h. Because of the time of day low flows occurred at these stations, very few backwaters were sampled at their lowest water level. Lowest water discharges occurring in reaches 30, 40, and 50 were 5,000, 6,150, and 6,340 cfs, respectively. Because of flow attenuation, stations nearer the dam experienced greater fluctuations.

In all reaches, water temperature changed very little in connected backwaters during steady and fluctuating flows (Table

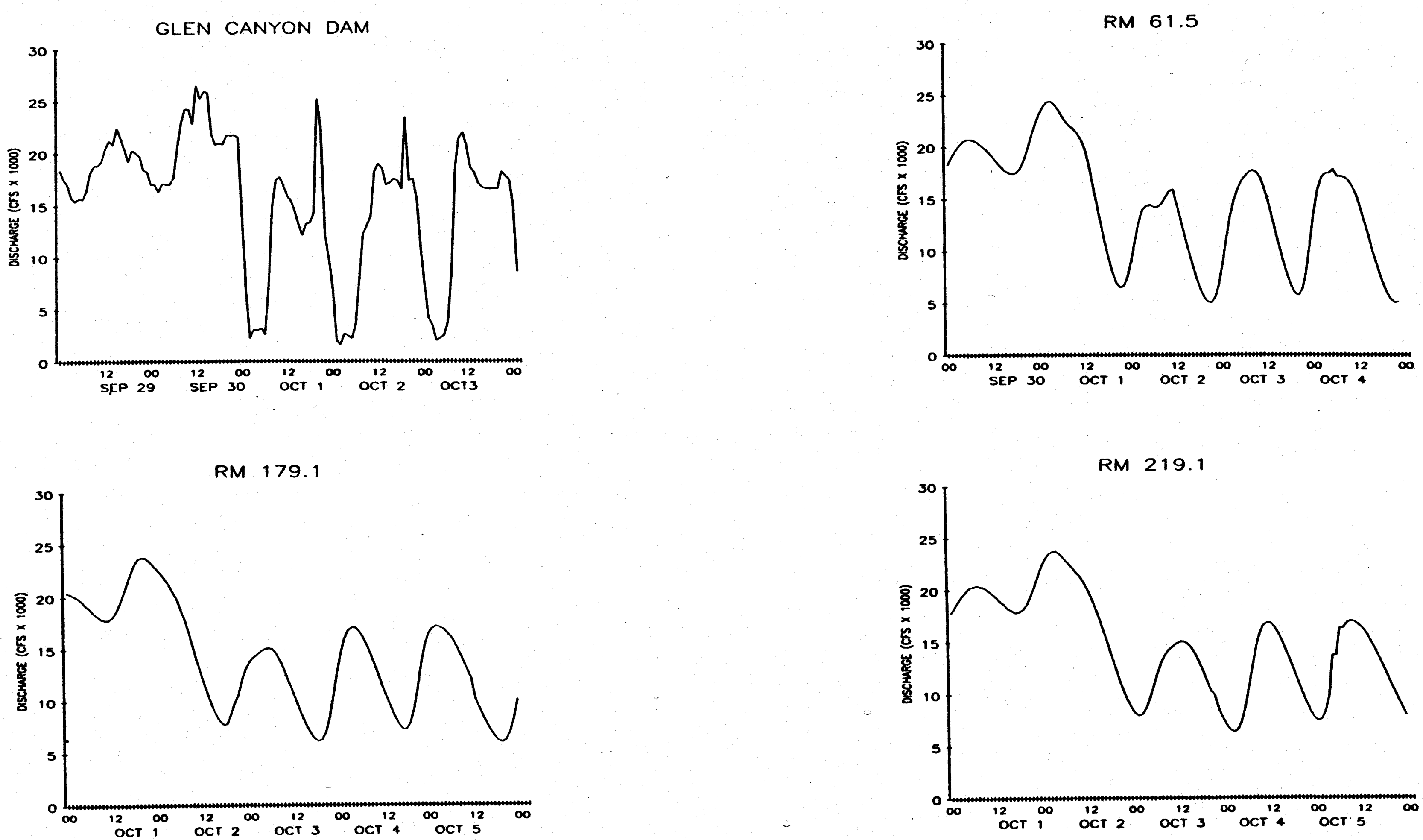


Figure 4.14. Discharge from Glen Canyon Dam and flows estimated from the SSARR Model near sites in reaches 30-50 from September 29 thru October 5, 1985 (backwater examination period).

4.19). However, temperatures in isolated backwaters were warmer than connected backwaters, averaging between 16.5-19.0°C. Mean mainchannel temperatures varied between 11.5-14.0°C, with warmer temperatures occurring in the lower reaches.

Nine fish species were captured during the sampling period. Fathead minnow (62.7 %) and humpback chub (30.4 %) were respectively most abundant in the catch from connected backwaters in Reach 30 during stable flows (Figure 4.15). Speckled dace, channel catfish, rainbow trout, and common carp made up the remaining 6.9%. After flows began fluctuating, fathead minnow (19.2%), the predominant species, was replaced by humpback chub (69.6%). Isolated backwaters created by changing water levels contained fathead minnow, humpback chub, and speckled dace.

Catches in connected backwaters of Reach 40 during steady flows were again predominately fathead minnows (55.6%) (Figure 4.16. They were followed by rainbow trout (19.1%), speckled dace (18.8%), flannelmouth sucker (3.8%), bluehead sucker (1.9%), and humpback chub (0.8%). When connected backwaters in this reach were sampled during fluctuating flows, fathead minnows (69.0%) remained predominant. Speckled dace (9.2%), bluehead sucker (5.4%), rainbow trout (4.7%), flannelmouth sucker (4.6%), common carp (1.3%), humpback chub (0.8%), and a single Plains killifish (0.4%) were also present. Only one isolated backwater was sampled in this reach, and it contained no fish.

Reach 50 was the only sampled area where fathead minnow was not the predominate species (Figure 4.17). Speckled dace (53.9%) comprised the majority of the catch in connected backwaters during steady flows. The remainder was made up of fathead minnow (35.4%), flannelmouth sucker (7.6%), bluehead sucker (1.8%), and humpback chub (1.3%). During fluctuations, bluehead suckers (41.9%) were predominant. Fathead minnow (38.4%) and speckled dace (13.9%) were also abundant. Isolated backwater catches were made up of speckled dace (76.0%), bluehead sucker (12.0%), and fathead minnow (12.0%). The fishes found in isolated backwaters in reaches 30 and 50 were those most abundant in connected backwaters during fluctuating flows.

To better understand the relationship between backwater type, reach of the river, flow, and catch per unit effort (CPUE) and mean length data were calculated for each species. CPUE for rainbow trout in reaches 30 and 40 connected backwaters decreased

Table 4.19. Water temperature of connected and isolated backwaters during steady (S) and fluctuating (F) flows from September 30 - October 5, 1985, at selected sites in the Grand Canyon.

Reach	Backwater type	Flow	Mean temperature	SD	N
30	Connected	S	12.2	1.25	11
	Connected	F	13.5	1.52	18
	Isolated	F	17.0	3.46	3
40	Connected	S	13.7	0.75	16
	Connected	F	14.0	2.01	10
	Isolated	F	16.5	-	1
50	Connected	S	14.0	-	1
	Connected	F	14.0	0.00	4
	Isolated	F	19.0	-	1

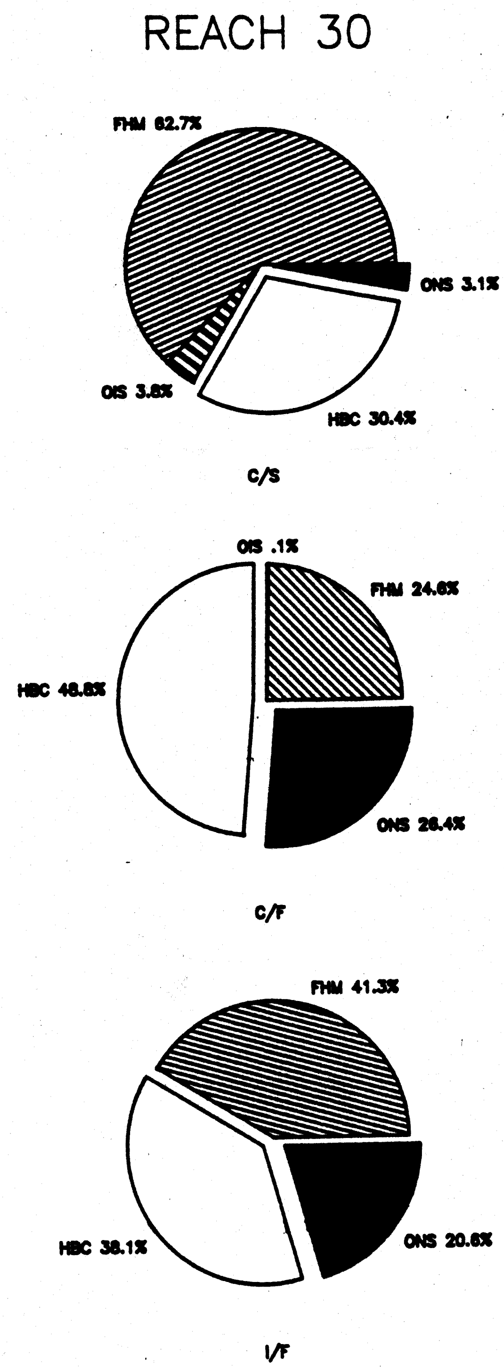


Figure 4.15. Species composition of fish seined from backwaters in Reach 30 before and after the onset of fluctuating flows in October 1985.

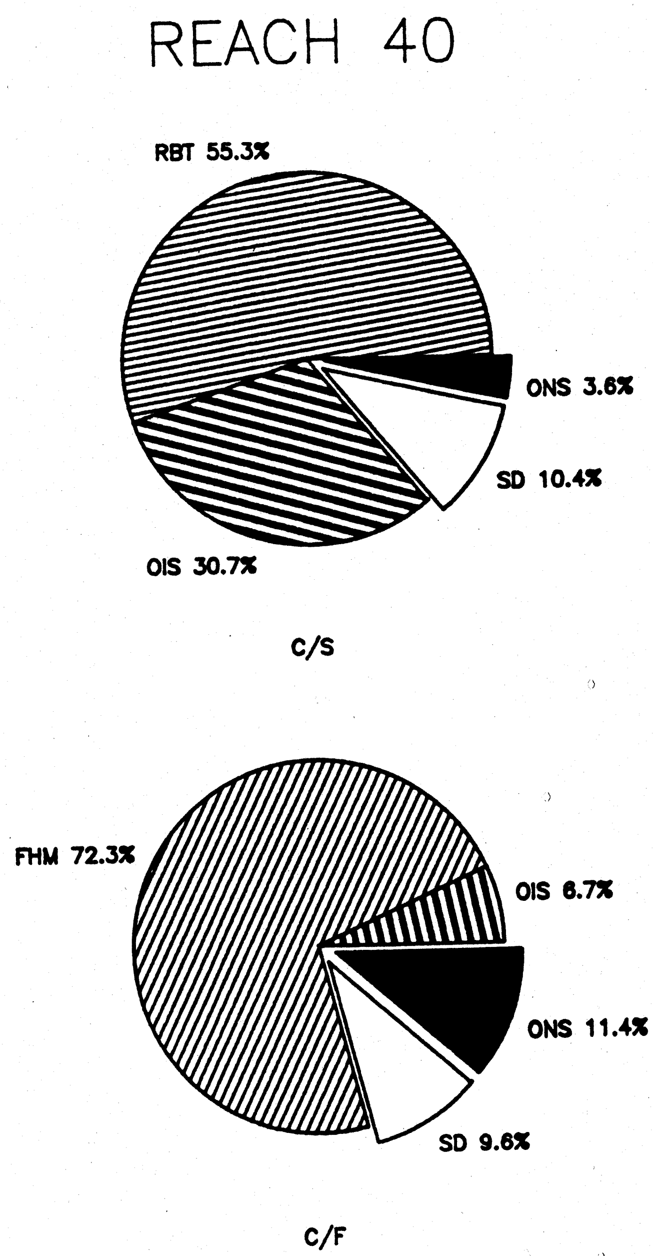


Figure 4.16. Species composition of fish seined from backwaters in Reach 40 before and after the onset of fluctuating flows in October 1985.

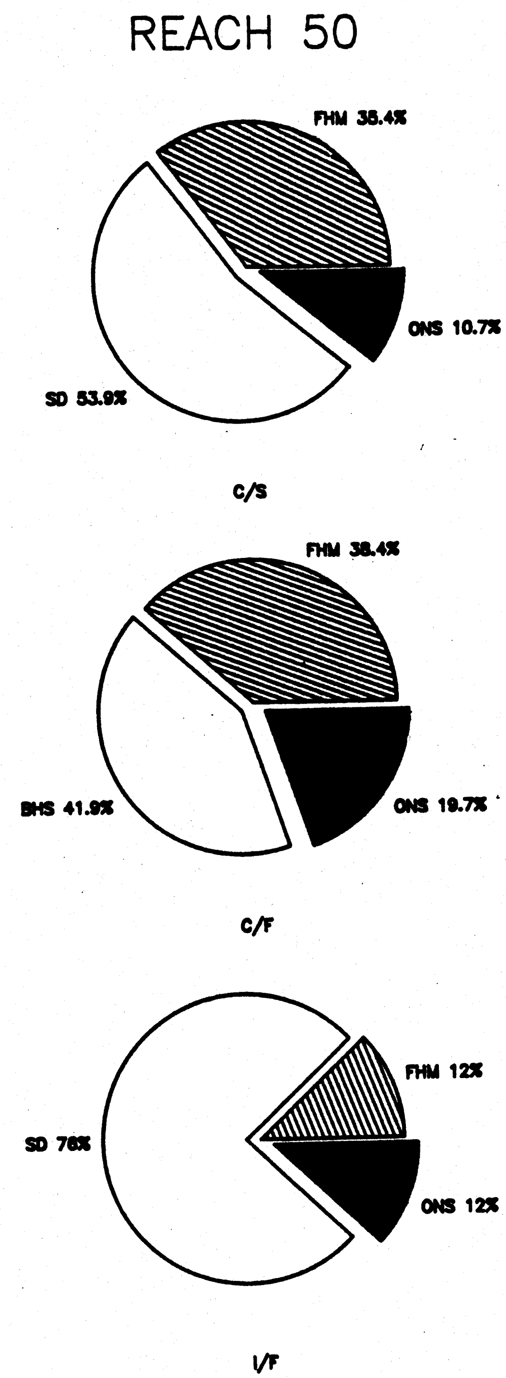


Figure 4.17. Species composition of fish seined from backwaters in Reach 50 before and after the onset of fluctuating flows in October 1985.

when flows fluctuated (Figure 4.18). No trout were collected in Reach 50. Rainbow trout was the only species showing a significant difference (ANOVA $p<.005$) between steady and fluctuating flows (Table 4.20). Fathead minnow showed a similar pattern to rainbow trout, decreasing in CPUE (Figure 4.19) after fluctuations. Flannelmouth sucker were collected only from reaches 40 and 50 (Figure 4.20). They showed the same pattern as rainbow trout and fathead minnow, decreasing in CPUE after water began fluctuating. No flannelmouth suckers were found in isolated backwaters. CPUE of bluehead sucker in connected backwaters increased during fluctuations in reaches 40 and 50 (Figure 4.21). CPUE for bluehead sucker was highest in an isolated backwater in Reach 50. Humpback chub CPUE decreased in both reaches 40 and 50, but increased from 14.1 fish/100 m^2 to 44.0 fish/100 m^2 in Reach 30 (Figure 4.22). Speckled dace showed a similar pattern to humpback chub, decreasing in CPUE in reaches 40 and 50, while increasing in CPUE in Reach 30 (Figure 4.23). The highest CPUE for speckled dace occurred in an isolated backwater. When CPUE by species was compared between reaches, fathead minnows, humpback chub, and rainbow trout were all significant (ANOVA $p<.05$) (Table 4.21).

Except for rainbow trout, mean length of species collected in isolated backwaters was less than connected backwaters prior to and during fluctuating flows. Mean length of rainbow trout decreased from 259.8 mm to 252.1 mm in connected backwaters during water level fluctuations. Only one rainbow trout (317.0 mm) was found in an isolated backwater during this period. Fathead minnows also showed a slight decrease in mean length from 45.3 mm to 43.2 mm after fluctuations. Fathead minnows ($\bar{x}$=33.8 mm) were smaller in isolated than connected backwaters. Flannelmouth sucker mean length decreased from 80.1 mm to 59.8 mm in connected backwaters after the initiation of fluctuating flows. Bluehead sucker mean length decreased from 75.4 mm to 57.1 mm in connected backwaters when flows began fluctuating. Individuals in isolated backwaters were smaller yet, averaging 33.7 mm. Though humpback chub mean length increased from 104.8 mm to 115.5 mm in connected backwaters during fluctuations, only small chub ($\bar{x}$=54.0 mm) were found in isolated backwaters. Mean length of speckled dace captured in connected backwaters increased from 59.3 mm to 67.4 mm after fluctuations began. Dace collected from isolated backwaters were smaller ($\bar{x}$=26.3) than those collected in connected backwaters during both flow types.

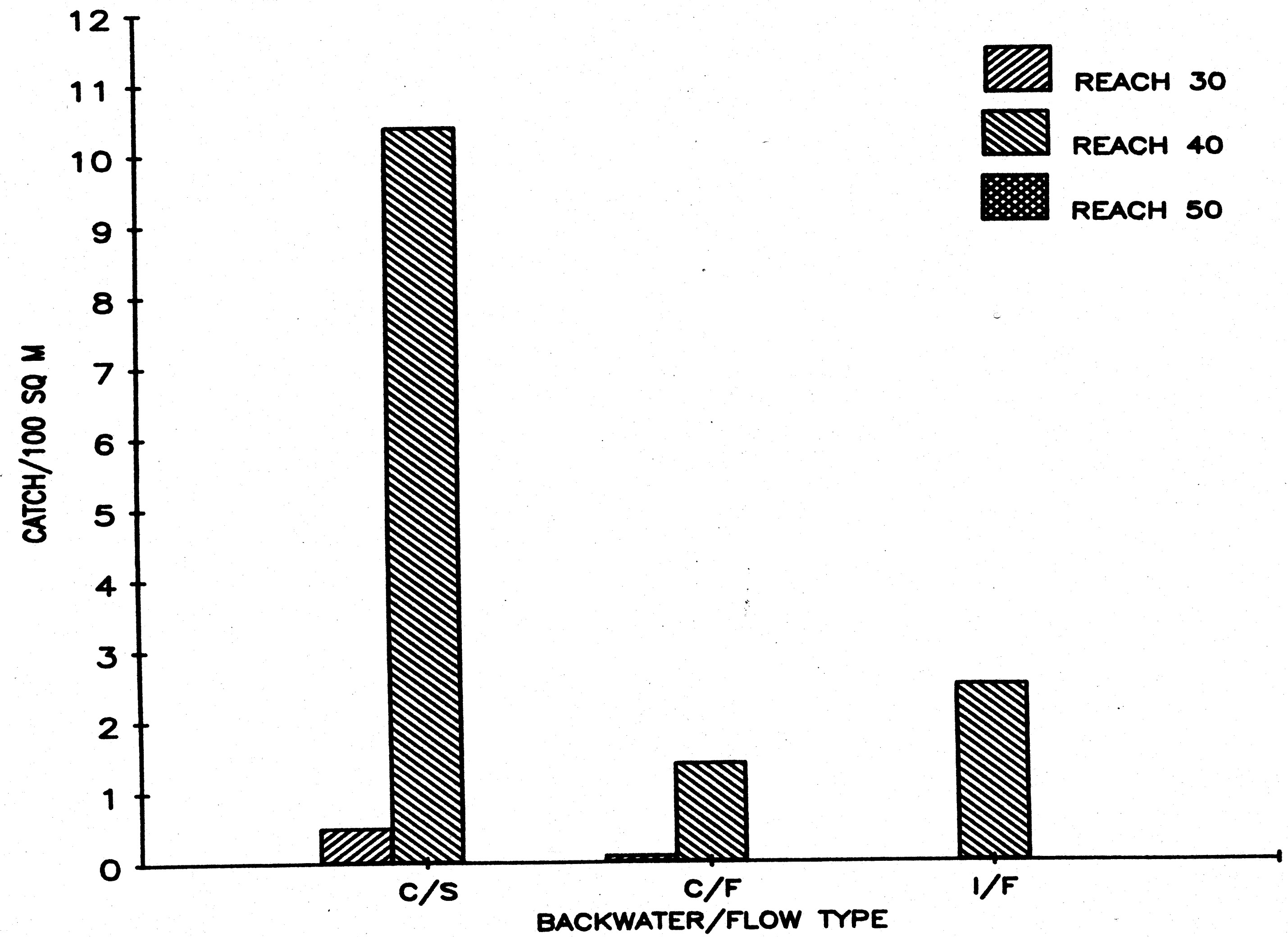


Figure 4.18. Rainbow trout catch per unit effort at selected sites during October 1985 backwater examinations.

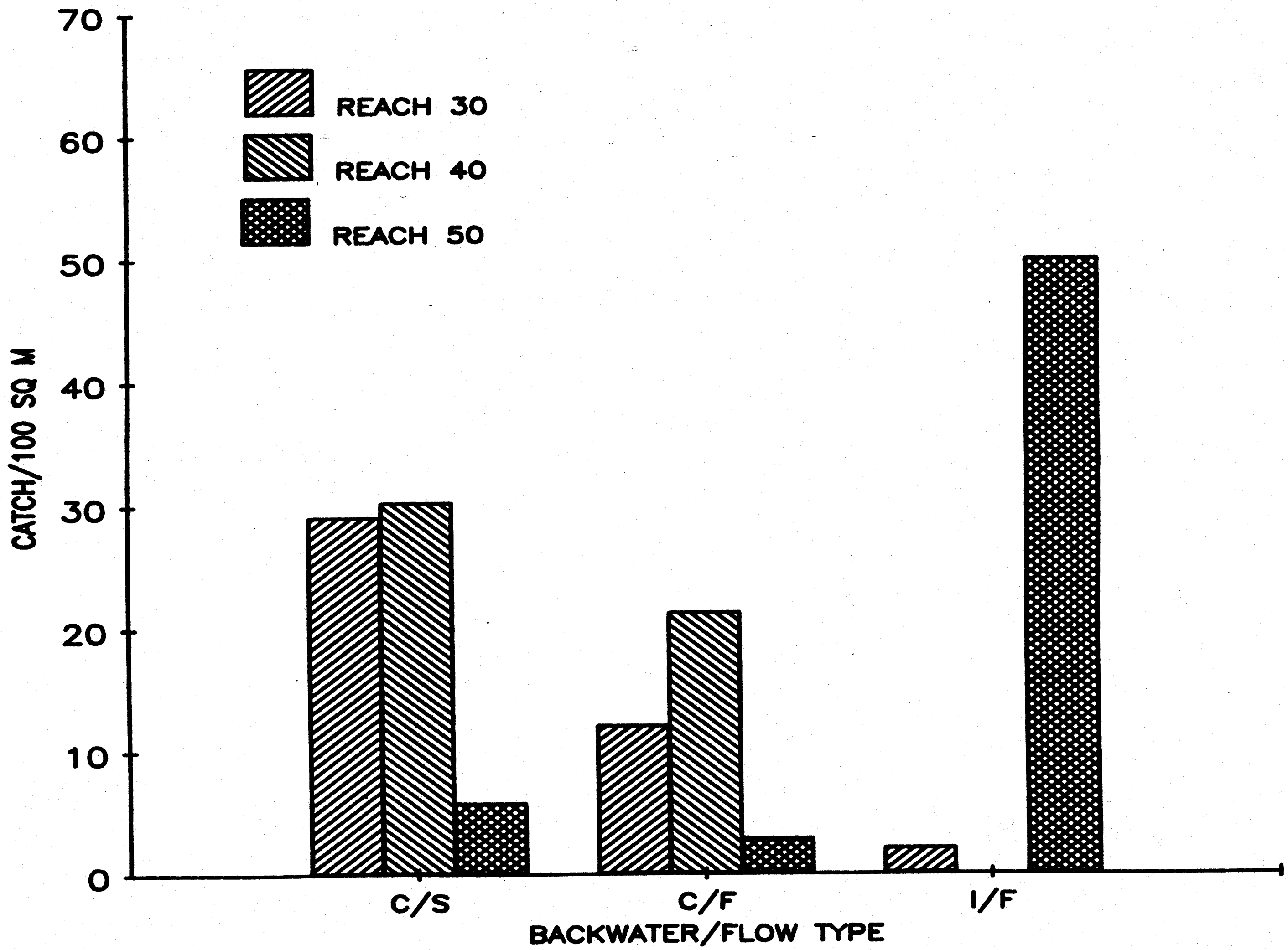


Figure 4.19. Fathead minnow catch per unit effort at selected sites during October 1985 backwater examinations.

Table 4.20. One-Way analysis of variance (dF = 2, 79) of catch per unit effort (CPUE) in backwaters before and after fluctuations.

Species	F	Significance
Rainbow trout	8.48	P<.005
Fathead minnow	0.06	N/S
Flannelmouth sucker	0.00	N/S
Bluehead sucker	0.76	N/S
Carp	2.20	N/S
Humpback chub	0.22	N/S
Speckled dace	0.32	N/S

Table 4.21 One-Way analysis of variance (dF = 2, 53) of catch per unit effort (CPUE) by river reach.

Species	F	Significance
Rainbow trout	5.56	P<.05
Fathead minnow	8.09	P<.001
Flannelmouth sucker	0.23	N/S
Bluehead sucker	0.28	N/S
Carp	0.57	N/S
Humpback chub	14.71	P<.001
Speckled dace	0.15	N/S

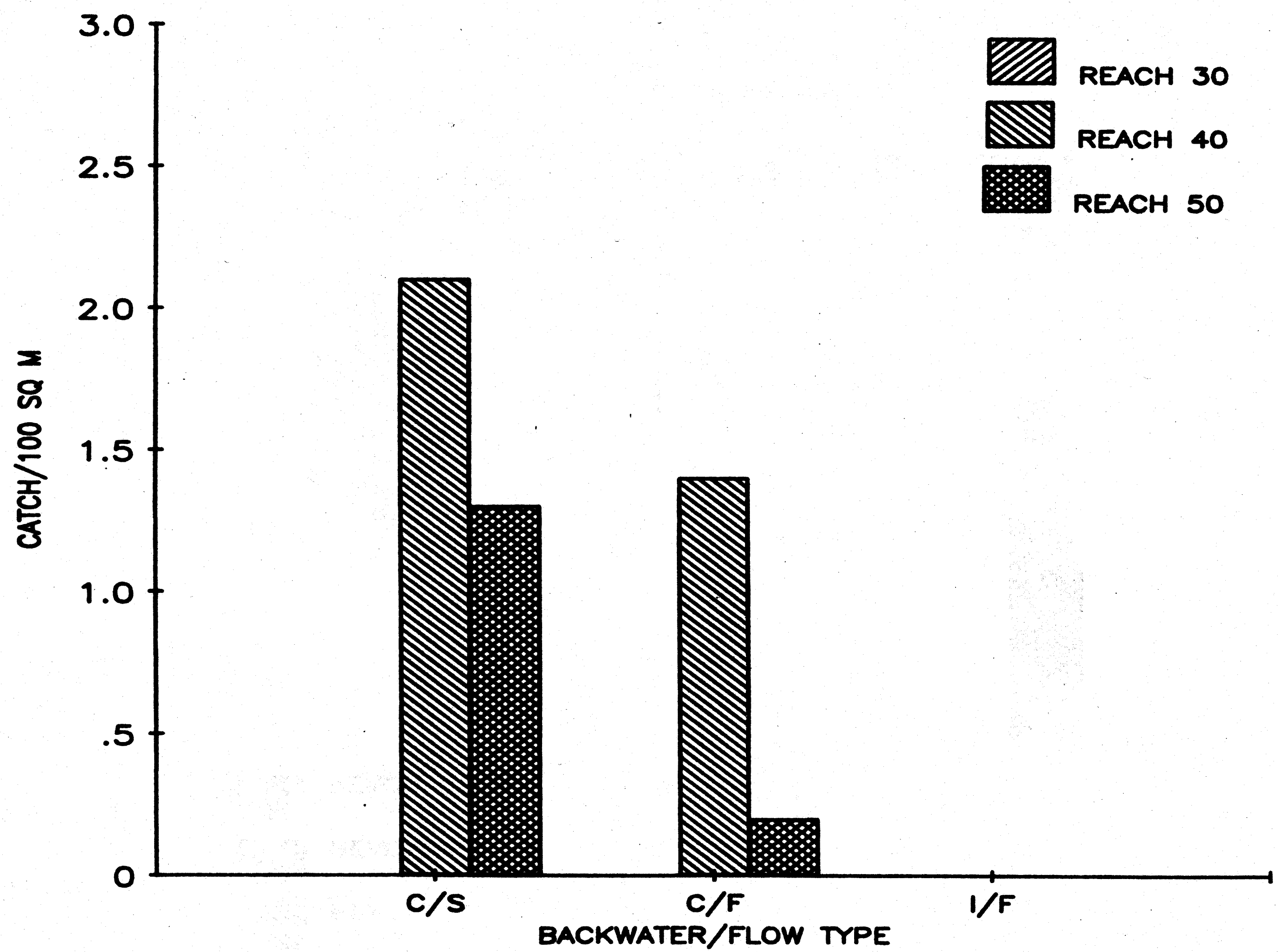


Figure 4.20. Flannelmouth sucker catch per unit effort at selected sites during October 1985 backwater examinations.

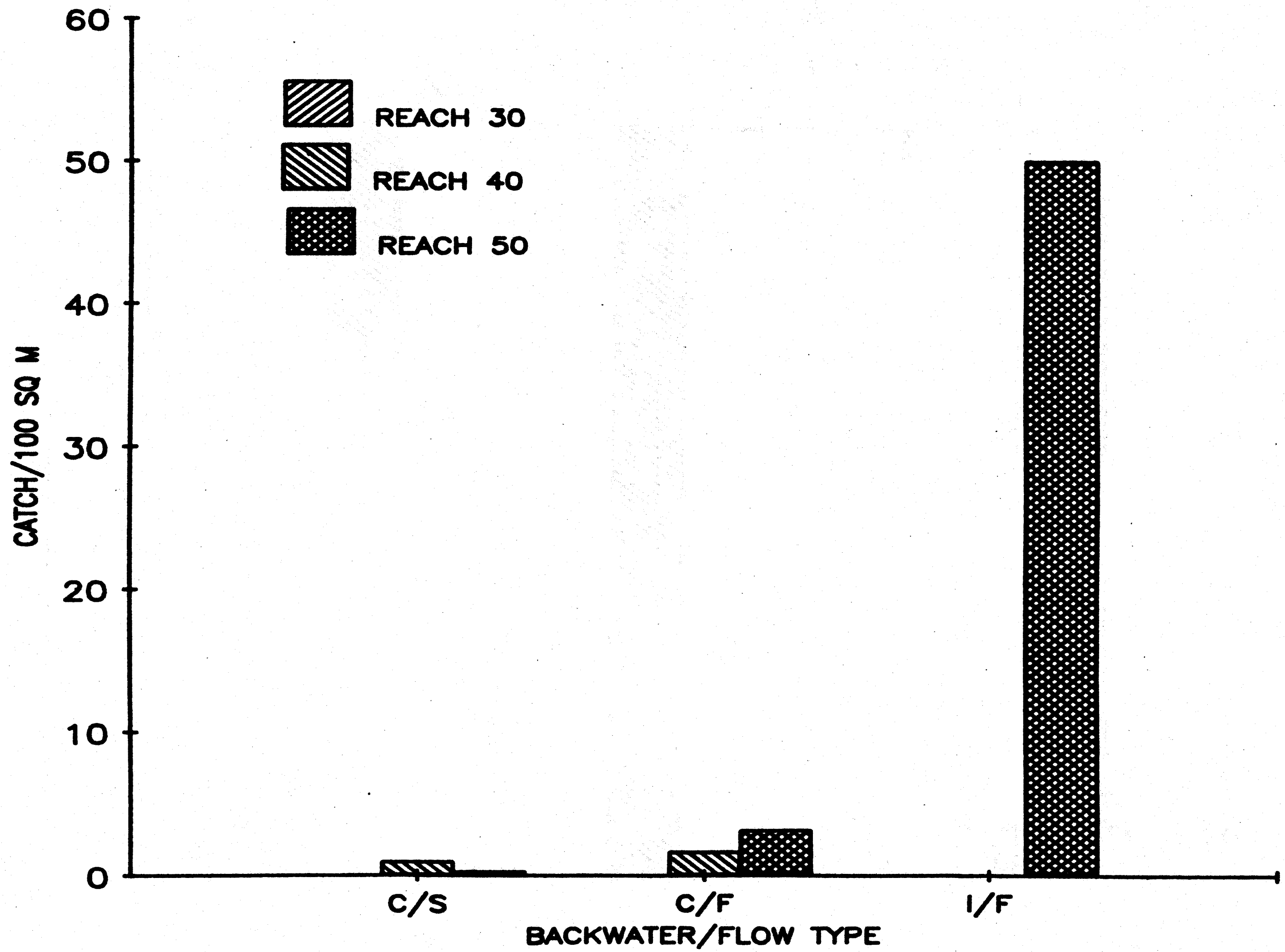


Figure 4.21. Bluehead sucker catch per unit effort at selected sites during October 1985 backwater examinations.

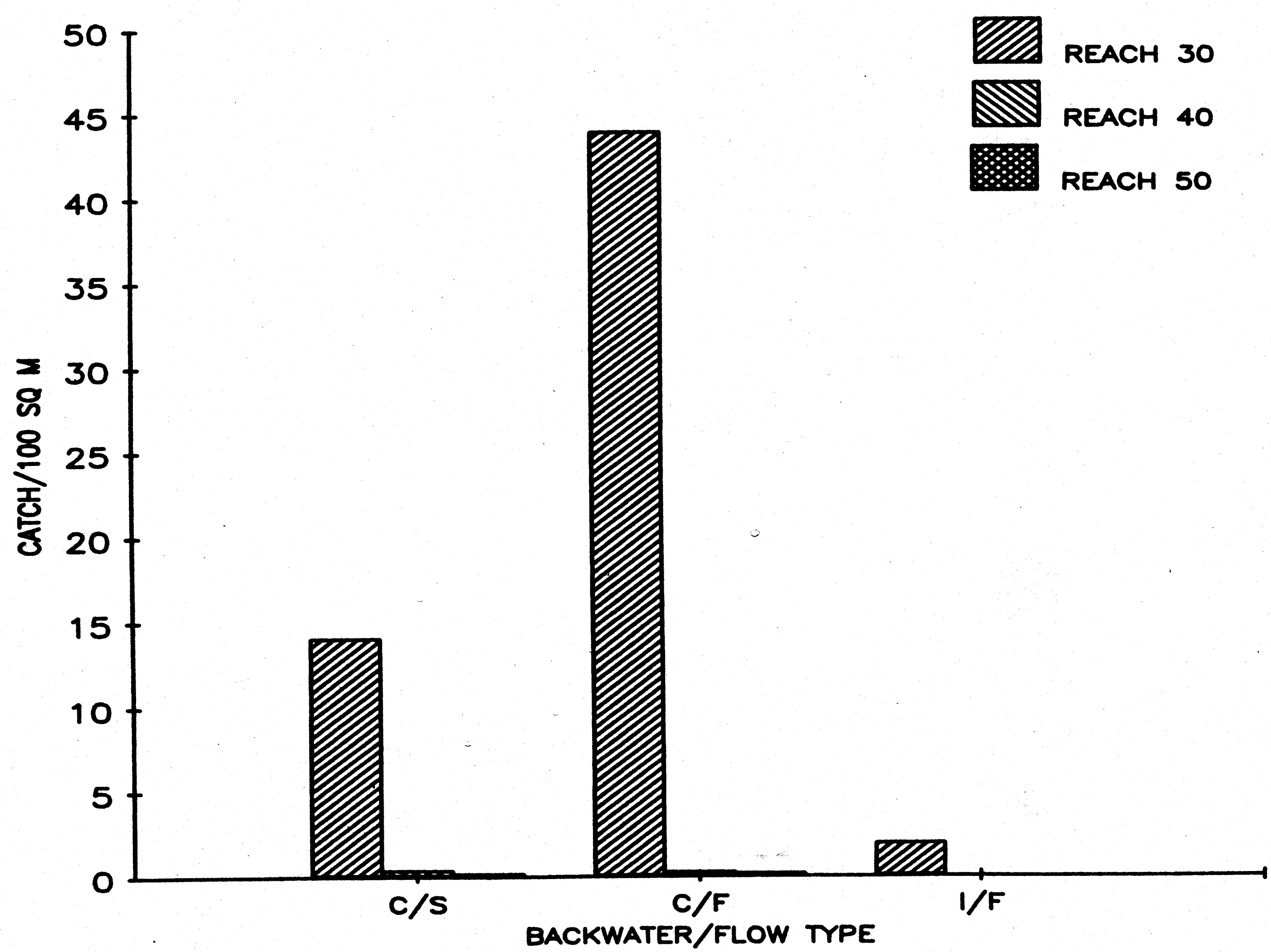


Figure 4.22. Humpback chub catch per unit effort at selected sites during October 1985 backwater examinations.

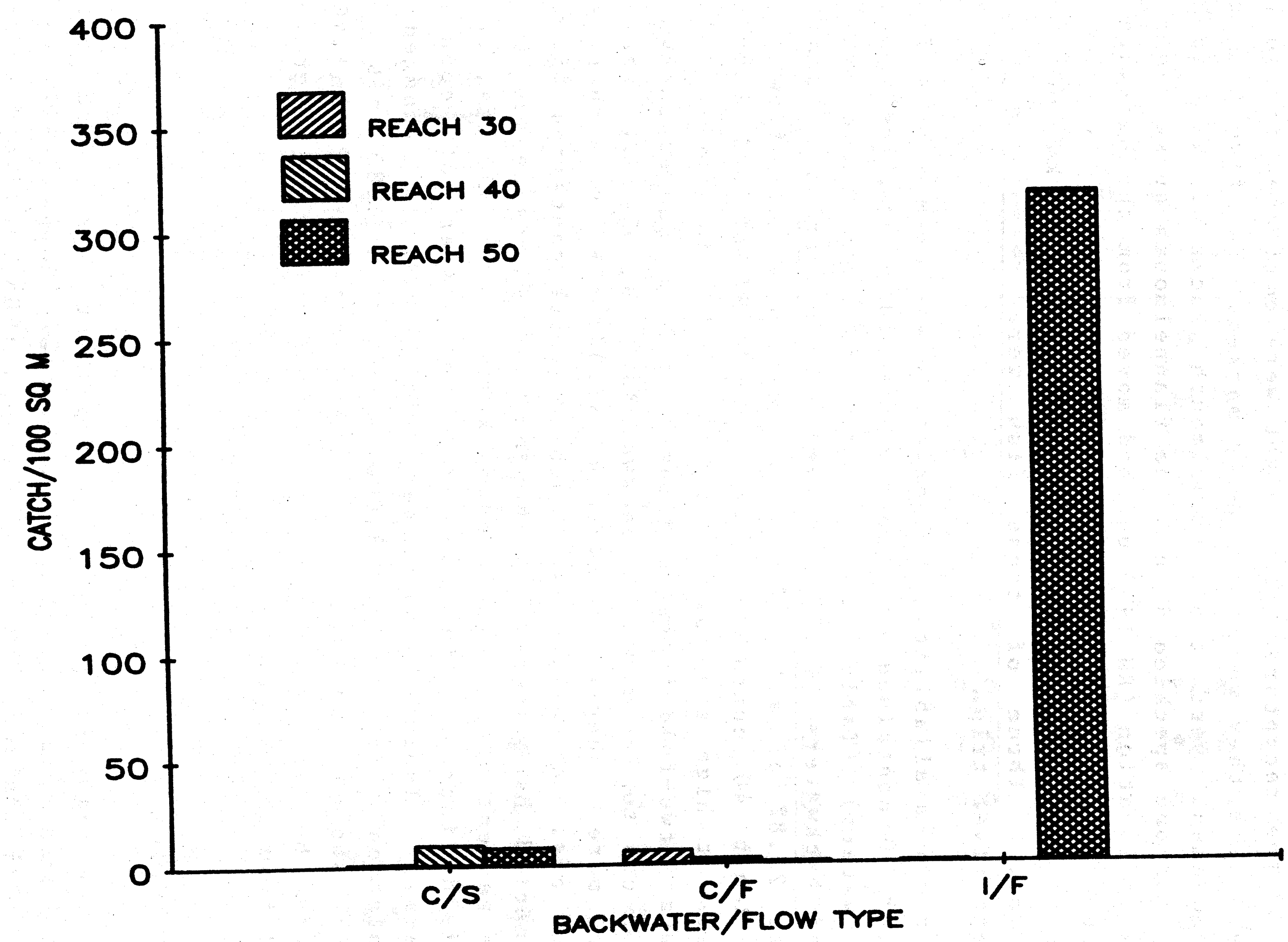


Figure 4.23. Speckled dace catch per unit effort at selected sites during October 1985 backwater examinations.

Because of the season and water temperature, no larval fishes were collected in backwaters during this portion of the study.

Thirteen fish were recaptured during fluctuating flows and five of these were subsequently recaptured on a river trip (Table 4.22). Of the recaptured fish, eight were collected in the same backwater where they were originally marked. The five fish that showed movement were two flannelmouth suckers, two fathead minnows, and one speckled dace. One flannelmouth sucker remained at the same location (RM 194) but had moved from the backwater to the mainchannel. The four remaining recaptures (31% of the recaptures) had moved down river between 1.3-20.7 km (mean 10.3 SD 8.0 km). Three of these fish were recaptured on the subsequent river trip.

When the availability of backwaters was examined at 28,000 cfs, Reach 30 contained only four connected backwaters (2.1% of all backwaters) (Table 4.23). At 4,800 cfs there were 78 connected backwaters (15.7%), a twenty-fold increase. Reach 30 contained 21.8% of all isolated backwaters at low flow (4,800 cfs). Reach 40 contained 18.2% and 14.9% of all connected backwaters at high and low flows, respectively. However, this represents a two-fold increase going from 34 connected backwaters at 28,000 cfs to 74 connected backwaters at 4,800 cfs. Reach 50 contained more connected backwaters (65.0%) than any other reach at 28,000 cfs. At 4,800 cfs, Reach 50 still contained 45.0% of all connected backwaters. Although Reach 50 decreased in the relative percent of all connected backwaters at 4,800 cfs, it had a two-fold increase in the absolute number of connected backwaters. Isolated backwaters in Reach 50 changed in representation from 25.0 at 28,000 to 30.0% at 4,800 cfs. The video work showed no isolated backwaters in reaches 30 and 40 at 28,000 cfs, because these habitats disappear quickly after being isolated from the river.

4.3. DISCUSSION

Colorado River backwaters are important nursery and resting areas for both native and introduced fishes (Holden 1977, Valdez and Wick 1981, Valdez 1982, Archer et al. 1985, and Valdez et al. 1986). Backwaters in our study area appear to be very important to fishes on a seasonal basis. When backwaters cool to near or below mainchannel temperature, abundance of fish in these

Table 4.22. Recapture data of fish tagged during backwater examinations under steady and fluctuating flows from September 30 - October 14, 1985.

Species	Tagging Data				Recapture Data			
	Date captured	River mile	Site	Length (mm)	Days since tagging	Distance traveled (Km)	River Mile	Site
Bluehead sucker	10-3-85	178.5	CBW	43	1	0.0	178.5	CBW
Humpback chub	7-30-85	65.0	CBW	189	2	0.0	65.0	CBW
Humpback chub	10-2-85	192.0	CBW	58	1	0.0	192.0	CBW
Humpback chub	10-3-85	192.0	CBW	64	10	0.0	192.0	CBW
Fathead minnow	9-30-85	65.0	CBW	55	3	0.0	65.0	CBW
Fathead minnow	9-30-85	65.0	CBW	55	2	0.0	65.5	CBW
Fathead minnow	10-2-85	191.6	CBW	62	12	10.0	197.8	CBW
Fathead minnow	10-3-85	197.0	CBW	56	11	1.3	197.8	CBW
Flannelmouth sucker	10-1-85	194.0	CBW	92	13	0.0	194.0	MCH
Flannelmouth sucker	10-2-85	192.0	CBW	84	12	9.3	197.8	CBW
Flannelmouth sucker	10-3-85	178.5	CBW	92	1	0.0	178.5	CBW
Speckled dace	10-2-85	165.6	CBW	27	2	20.7	178.5	CBW
Speckled dace	10-2-85	198.3	CBW	80	1	0.0	198.3	CBW

CBW - Connected Backwater, MCH - Mainchannel

Table 4.23. Number (n) and percent of backwater types at two discharge levels in reaches of backwater examinations.

Flow (cfs)	Backwater type	Reach[a]	n	Percent
28,000	Connected	31	3	1.6
		42	33	17.7
		50	122	65.2
4,800	Connected	31	62	12.5
		42	40	8.1
		50	225	45.3
4,800	Isolated	31	17	21.8
		42	5	6.4
		50	23	29.5

a Reach codes used by LAnderson et al. 1986 differ than those used in this study. Reach 31 represents the upper half of Reach 30, and Reach 42 corresponds to the lower half of Reach 40. These designations exclude the hard rock gorge sections of Reaches 30 and 40.

habitats decreases. Archer et al. (1985) found that y-o-y squawfish planted in backwaters in early October had moved out by late November. By October, y-o-y native fishes have reached a size where they are fairly mobile though limited in their ability to move upstream. It is therefore difficult to draw conclusions as to short- and long-term responses of young fishes to fluctuating waters levels based on this short examination.

In October, when backwater temperatures were decreasing to near river temperature, it appeared that flows had little effect on backwater temperature. Depth may also contribute to backwater temperatures, but this was not considered.

As in other backwater studies along the Colorado River (Valdez et al. 1986), introduced fishes generally were the most abundant species in backwaters. Fathead minnows, which thrive in pond environments, seem to prefer and do well in backwaters. However, during fluctuating water levels, CPUE of fathead minnows decreased and those remaining in backwaters were smaller. In general, all introduced fishes showed this same pattern. Larger individuals are more mobile and may have moved to areas of the mainchannel less affected by changing water levels.

Of the native fishes found in backwaters, flannelmouth sucker and speckled dace showed a decline in CPUE and relative abundance during fluctuating flows, while humpback chub and bluehead sucker generally increased. Valdez (1982) found more introduced fishes in isolated pools than native fishes. He hypothesized that native fish are adapted to changes in flow and can exit backwaters before they become isolated. However, it may be that species like fathead minnow and speckled dace may take advantage of warmer temperatures in isolated backwaters for feeding and reproduction. Another possibility is that the small individuals of the species prefer not to leave the backwater environment for the harsher mainchannel and become isolated from the mainchannel as a result.

From the few fish we recaptured there was no clear trend toward movement from or remaining at a single location. It would be difficult to separate movement caused by flow and habitat changes from movement that is dispersal from areas of high concentration or movement as a result of handling. At least a few individuals were able to survive movements of up to 20.7 km. If fish were continually forced to relocate because of changes in habitat due to flow, however, the resultant mortality might be high.

We were only able to look at a point in time for a limited size range of fish. Had environmental conditions allowed fluctuating flows 3-4 months earlier, when many of these fish were in their larval stages, results could have been different. Larval fish have much less mobility and are more vulnerable to river currents and could be forced to move downstream from one backwater to the next with each daily cycle in flow. Each time the fish would be subjected to mortality from predators, starvation, damage from river currents, or being carried into an unfavorable habitat. This could result in only the individuals in the most preferred habitats (backwaters that remain backwaters at all flow levels) surviving.

From video footage at 28,000 and 4,800 cfs there was a change in absolute numbers of backwaters as well as many backwaters disappearing while new ones are formed. Smaller fish may have less chance of finding or being carried into another backwater. Holden (1977) stated that preferred habitat for y-o-y humpback chub were connected backwaters with no current and a maximum depth of two ft (0.6 m). In the reach immediately below the Little Colorado River, a 0.6 m drop in water elevation was common during the fluctuating flows in October.

The question remains that even if y-o-y fishes are moved in and out of backwaters during fluctuating water levels, is this constant movement beneficial or will it result in slow growth, instantaneous or delayed mortality, and eventual reduction in population levels. Until more is known about effects of flows on the larval stages of these fishes, this and other questions remain unanswered.

5. TRIBUTARIES

INTRODUCTION

One of the major objectives of this study was to determine the importance of tributaries in maintaining aquatic resources of Glen and Grand canyons. To accomplish this, the 11 major tributaries were selected as sampling areas. One factor dictating these tributaries be sampled is that they are perennial sources of water input to the mainchannel Colorado River. Another selection factor is that earlier studies within these canyons, examined one or more of them (Johnson and Sanderson 1968, Carothers and Aitchison 1972, Cole and Kubly 1976, Czarnecki et al. 1976, Minckley 1978, Carothers et al. 1981).

Data for describing the tributaries were collected from two major sources. Unless otherwise cited, elevation changes, point of origin, and point of entry to the Colorado River were taken from the appropriate USGS topographic map. Geologic information is from the map of the Eastern Part of the Grand Canyon National Park (Grand Canyon Natural History Association 1980).

A brief description of the tributaries sampled is as follows:

Paria: The Paria River enters the Colorado River from the north within RM 1 below Lee's Ferry. It originates in the Escalante Mountains in southern Utah and flows a distance of approximately 88 km. Gradient is relatively flat when it enters the Colorado River with a decline in elevation of less than 24.4 m within the last 2 km of flow. Discharge estimates taken during this study ranged from 7.9 to 34.4 cfs. As the Paria River enters Glen Canyon it bisects the Shinarump Conglomerate, Chinle and Moenkopi formations. The drainage covers approximately 3652 km^2 in southern Utah and northern Arizona.

The substrate in the vicinity of the confluence consists primarily of silt and clay. The vegetation along the margin of the Paria River consists primarily of salt cedar (*Tamarix chinensis*).

Nankoweap Creek: Nankoweap Creek enters the Colorado River from the west within RM 52. It originates between Kibbey Butte and Bradly Peak and flows a distance of approximately 14 km. The point of origin for this creek is within 1 km of the origin for

Bright Angel Creek. The gradient as it enters the Colorado River is among the steepest for the 11 tributaries, dropping approximately 97.5 m within the last 2 km of flow. Discharge estimates taken during this study ranged from 0.9 to 8.5 cfs. Geologic formations bisected are: Bright Angel Shale, Coconino Sandstone, Cardenas Lava and, Galeros Formation.

The substrate found in Nankoweap Creek upstream from the confluence consists primarily of a mixture of cobble gravel and silt. There is a large cobble bar formed in the mainchannel that extends both above and below the mouth of Nankoweap Creek. The vegetation in the vicinity of the confluence is sparse, consisting of arrowweed (Tessaria sericea) and salt cedar.

Little Colorado River: The Little Colorado River provides the greatest water input of any of the Glen or Grand Canyon tributaries. This tributary originates on Mount Baldy in the White Mountains and flows approximately 412 km through eastern and northern Arizona. It enters the Colorado River at RM 61. The gradient is relatively flat as it enters the Colorado, with a decline in elevation of less than 24.4 m within the last 2 km of flow.

This tributary is often dry at the Highway 89A crossing near Cameron, Arizona (approximately 70 km upstream from the Colorado River). Johnson and Sanderson (1968) noted that a series of springs between 5 and 21 km upstream from the confluence with the Colorado River provides the major water input to the Little Colorado River. Blue Springs, located approximately 21 km upstream from the confluence, has the greatest water output.

Major geologic formations bisected by the Little Colorado River are the Tapeats Sandstone and the Bright Angel Shale. The area drained by this tributary is slightly greater than 141,100 km^2.

The substrate of the lower portion of this tributary is primarily a mixture of clay and silt, with several areas where travertine deposits have formed. The vegetation in this area is variable, consisting of areas dominated by cattails (Typha domingensis), long stretches of bare ground, and scattered areas of salt cedar and mesquite (Prosopis juliflora).

Clear Creek: Clear Creek originates on the Walhala Plateau and flows at least intermittently over a distance of approximately 21 km. It flows from the north to the confluence with the Colorado River in RM 84. The gradient over the last 2 km of flow is also among the steepen of the tributaries with a decline in elevation of approximately 73.2 m over this distance. During this study discharge measurements ranged from 2.4 to 13.3 cfs.

Over the course of flow, Clear Creek bisects the geologic formations that comprise the Vishnu Group.

The substrate in the lower portion of this tributary is primarily a mixture of sand and silt. The overstory vegetation of the area consists primarily of willows (Salix spp.), although species other than those in what is described as the new riparian zone by Carothers et al. (1981) are present.

Bright Angel Creek: This creek originates near Greenland Lake and flows to the south a distance of approximately 20 km. Major sources of water input to this tributary are Roaring Springs (approximately 16 km upstream) and Angel Spring (approximately 19 km upstream). Phantom Creek, which enters Bright Angel approximately 2 km from the confluence with the Colorado River, is also a source of water input. During this study, discharge from Bright Angel ranged from 25.1 to 72.1 cfs. Confluence with the Colorado River is within RM 87. The gradient over the last 2 km of this tributary is moderate, declining approximately 48.8 m over this distance.

The geologic formations bisected by this tributary are those that comprise the Vishnu, Unkar, and Tonto groups.

The substrate in the lower portion of this tributary is primarily a mixture of boulders-cobble-gravel. Vegetation in this area is sparse, primarily consisting of salt cedar and mesquite.

Crystal Creek: Crystal Creek originates in the Hindu Amphitheater and flows approximately 11 km to its confluence with the Colorado River within RM 98. Most of the stream flow is from two springs, Dragon and Crystal, which are located approximately 8 and 10 km from the confluence, respectively. The gradient of this creek is very steep, with a decline in elevation of approximately 97.6 m over the last 2 km. During this study, discharge measurements ranged from 1.4 to 7.8 cfs.

Over the course of flow, this creek also bisects the geologic formations that comprise the Vishnu and Unkar groups.

The substrate in this area is dominated by a mixture of rubble, sand, and silt, although there are a few areas dominated by gravel. Overstory vegetation consists of a mixture of salt cedars and willows.

Shinumo Creek: This tributary originates within the Shinumo Amphitheater and flows approximately 20 km to the confluence with the Colorado River within RM 108. The point of origin is South Big Springs. Several springs that enter Shinumo Creek are located approximately 13 km from the confluence. Gradient for this creek is relatively steep, with elevation declining approximately 91.4 m over the last 2 km of flow. During this study, flows ranged from 10.5 to 108.0 cfs. The major geologic formations bisected by this creek are those comprising the Unkar group.

The substrate in the area upstream from the confluence is dominated by sand with some gravel interspersed. Vegetation is sparse, consisting of a few overhanging salt cedars.

Tapeats Creek: Tapeats Creek originates in the Tapeats Amphitheater and is formed by a number of springs, the largest of which is Tapeats Spring located approximately 10 km from the confluence with the Colorado River within RM 133. Springs originating from Monument and Crazy Jug points also provide water to Tapeats Creek. Thunder River, formed by Thunder Springs, flows into Tapeats Creek approximately 3 km from the confluence. Huntoon (1974) reported that this creek had the highest discharge into the Colorado River of any tributary originating from the north side of Grand Canyon. Discharge measured during this study ranged from 78.4 to 281.9 cfs. Gradient as it approaches the Colorado River was extremely steep, with a decline in elevation of approximately 97.5 m in the last 2 km of flow.

Tapeats Creek bisects the geologic formations comprising the Unkar and Tonto groups.

The substrate in the area upstream from the confluence is primarily a mixture of cobble gravel and boulder. The overstory vegetation of the area consists primarily of willow and mesquite.

Deer Creek: This tributary enters the Colorado River from the north near RM 136. It originates from a number of springs formed in the southern portion of the Kaibab Plateau and is approximately 15 km long. Vaughn and Deer springs are the major sources of water for Deer Creek. The gradient of the last 2 km is the most precipitous of the tributaries studied with a decrease in elevation of 195.1 m. Only two discharge measurements were taken at the mouth of this tributary and were 12.6 and 16.0 cfs.

This tributary bisects three geologic formations: Redwall limestone, Tonto, and Vishnu groups.

The substrate in the area above the confluence is dominated by a mixture of sand and gravel. There is minimal vegetation in the area.

Kanab Creek: Kanab Creek is one of the longest tributaries that enters the Colorado River within Grand Canyon. It originates on the Pausagunt Plateau in southern Utah and flows south approximately 105 km to the confluence at RM 143. Gradient as Kanab Creek enters the Colorado River is relatively flat, with approximately a 24.4 m decrease in elevation over the last 2 km. Discharge measurements taken during this study ranged from 2.8 to 38.0 cfs.

The Tonto Group, Redwall and Temple Butte formations are the major geologic formations bisected by Kanab Creek.

The substrate in the area above the confluence is dominated by a mixture of sand and gravel. Vegetation is limited, consisting of scattered salt cedars.

Havasu Creek: The majority of the water that makes up Havasu Creek flows from Havasu Springs, which is approximately 15 km upstream from the confluence with the Colorado River in RM 156. Gradient over the last 2 km of the tributary is moderate with a decline in elevation of approximately 48.8 m. Discharge measurements in this study ranged from 60.6 to 207.4 cfs. Havasu Creek bisects the same geologic formations as Kanab Creek.

The substrate of Havasu Creek consists of boulders and sand with small areas of gravel. The vegetation is a well developed example of the new riparian vegetation with interspersed mesquite, salt cedar and willows.

5.1. METHODS

Tributary Fish Sampling

Electrofishing of tributaries was accomplished with a bank shocker. This equipment utilized a gasoline-powered Honda EX 800 generator producing 110 volts of alternating current (AC). The power output was modified by a pulsator that converted AC to pulsed direct current (DC). DC output ranged from 120-240 volts at 60 pulses/second with a pulse width of 50 percent. Two 30.5 m extension cords, each equipped with a 25.4 cm Coffelt diamond shaped electrode, were used to apply current to the water.

Effort was recorded as minutes of actual shocking effort. An observer with a stopwatch recorded the effort expended. All fish netted were placed in a 18.9 l bucket and held until completion of an area survey. Fish were then weighed, measured, and marked as described in Chapter 4.

Minnow traps, hoop nets, and trotlines were used with limited success. Fish captured using these techniques were added to totals for the species but effort was limited and, therefore, catch per unit effort is not reported.

Substrate samples were collected from five tributaries that appeared to be used by spawning fish, especially the salmonids. A plastic bucket with a capacity of approximately 20 l, with the bottom removed, was forced into the substrate over and adjacent to redds. All substrate found within the bucket was removed, dried and weighed. Samples were then passed through a series of sieves with decreasing mesh diameter, with the remaining substrate reweighed, allowing calculation of the percent of the sample that is smaller than the sieve size. All other gear types used in sampling tributaries are discussed in Chapter 4.

5.2. RESULTS

To evaluate seasonal use of tributaries, CPUE estimates were derived for several different gear types. Success varied between species and methods. Electrofishing was most effective in tributaries containing rainbow trout with seining and trammel nets providing better data for native species.

Two factors made data interpretation difficult: a high number of cases where no fish were caught and times when large numbers were caught in a single sample that resulted in wide variances. As a result, few tests resulted in significant differences, however, trends were apparent.

Rainbow trout were collected in all tributaries sampled electrofishing (Table 5.1). CPUE was highest in smaller tributaries such as Clear and Deer creeks where fish, during and after spawning, were concentrated and vulnerable to our sampling gear. Catch in Bright Angel and Tapeats Creeks is underestimated because of the difficulty in sampling these fast flowing, large tributaries.

Temporal shifts in tributary use by rainbow trout were also evident. As mean water temperature in Bright Angel Creek declined from summer to winter, CPUE increased. Catch did not follow temperature in Tapeats Creek where temperatures were moderate (Figure 5.1). Rather the highest CPUEs were before and during the spawning period.

Seine data indicated seasonal use patterns for flannelmouth suckers and bluehead suckers. For the three tributaries where case numbers exceeded 15, use occurred almost exclusively during spring and summer (Table 5.2). In Kanab Creek, CPUE estimates for flannelmouth suckers ranged from a high of 10.8 fish/100 m^2 in spring, declined to 0.54 fish/100 m^2 in summer, declined again to less than 0.01 fish/100 m^2 in autumn and raised to 0.51 fish/100 m^2 in winter. Similar patterns were observed in the Paria and Little Colorado rivers.

Tributary use by humpback chub was almost entirely restricted to the Little Colorado River. Seining was successful in the Little Colorado River and Kanab Creek, although no effort was recorded for the one humpback chub captured in Kanab Creek. CPUE was highest in the summer (4.79 fish/100 m^2) followed by spring (1.18 fish/100 m^2). Trammel nets were also used successfully to capture humpback chubs in the Little Colorado River and Shinumo Creek. Overall CPUE estimates for trammel netting were 1.75 and 33.2 fish/12 h in Shinumo and the Little Colorado River, respectively.

Seasonally, humpback chub CPUE for both seining and trammel netting showed similar use patterns to the other native fish discussed. With both techniques, CPUE was highest in summer followed by spring, with very low estimates in autumn and winter.

Table 5.1. Electrofishing catch per unit effort (catch/10 min.) for rainbow trout within several tributaries of the Colorado River, 1984-86.

Tributary	Mean	SE	n[a]
Paria River	4.55	-	1
Nankoweap Creek	5.29	1.97	3
Clear Creek	14.60	5.37	4
Bright Angel Creek	4.82	1.11	1
Crystal Creek	2.42	1.27	3
Shinumo Creek	2.00	-	1
Tapeats Creek	13.31	3.96	1
Kanab Creek	1.85	38.1	2
Deer Creek	44.76	-	1
Havasu Creek	4.57	-	1

[a] Number of times electrofished.

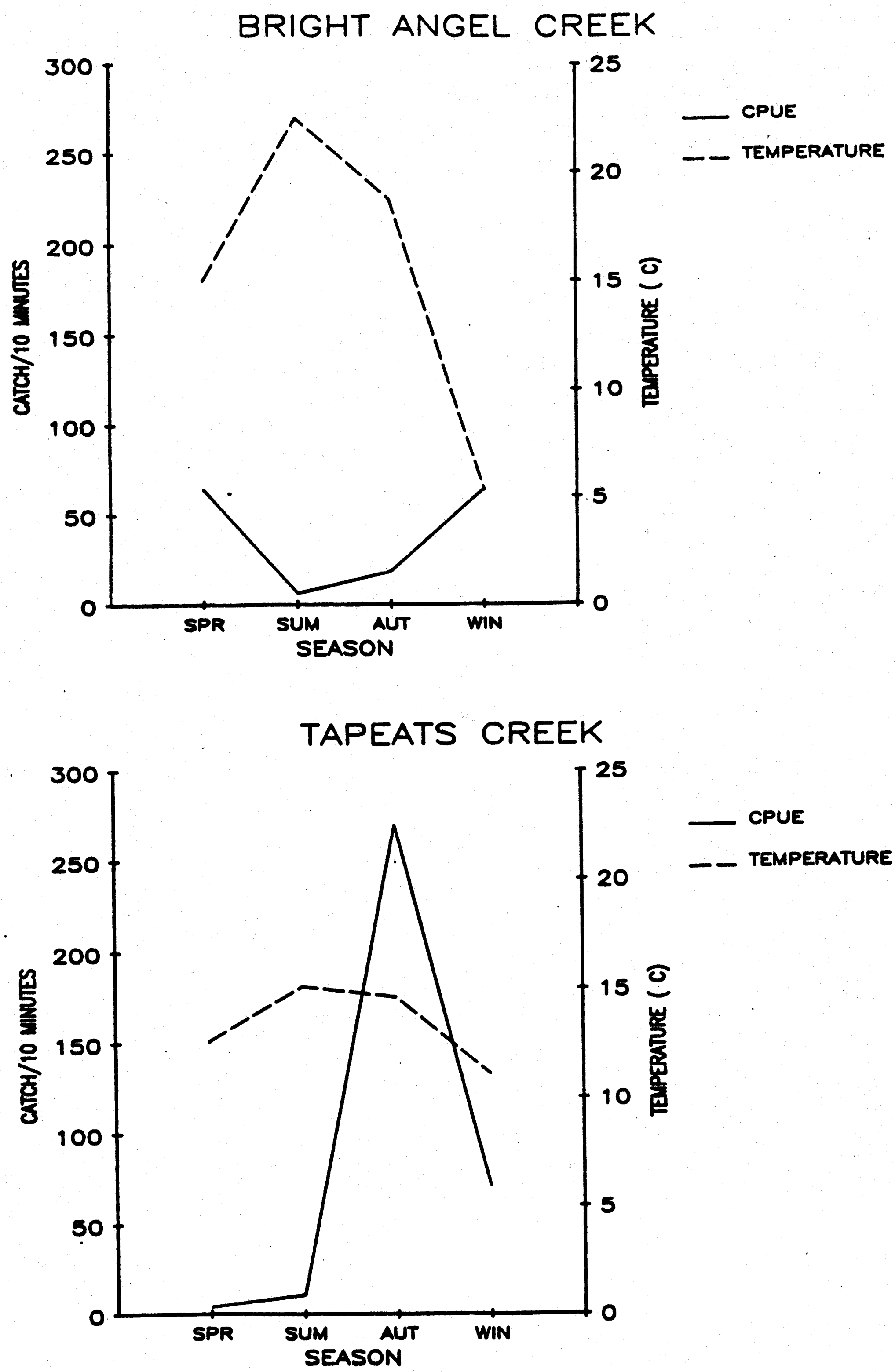


Figure 5.1. Rainbow trout catch per unit effort (catch/10 minutes) and water temperature (°C) by season for Bright Angel and Tapeats Creeks (all years combined).

Table 5.2. Seine catch per unit effort (catch/100m^2) estimates by season for flannelmouth sucker, bluehead sucker and humpback chub, 1984-86. All tributaries combined, data primarily from Paria River, Little Colorado River, and Kanab Creek.

Species	Season	Mean	SD	Cases
Flannelmouth sucker	Spring	10.06	36.30	25
	Summer	0.37	0.86	24
	Autumn	0.00	0.00	11
	Winter	0.28	0.48	19
Bluehead sucker	Spring	32.57	93.66	23
	Summer	73.23	178.34	21
	Autumn	14.20	45.05	11
	Winter	0.48	0.81	19
Humpback chub	Spring	1.18	5.46	23
	Summer	45.85	165.00	11
	Autumn	0.00	0.00	11
	Winter	0.49	1.42	19

When total numbers are considered, similar patterns are found. On river trips during 1984, 3,296 fish were caught using all gear types, except larval seines (Appendix 5.1). The total catch was dominated by four species; speckled dace (1,126), rainbow trout (698), humpback chub (614), and flannelmouth sucker (595). In aggregate, these species comprised 90.2% of the collections. Three species, plains killifish, golden shiner, and black bullhead were represented by a single collection.

In 1985, 2,547 fish were collected from tributaries (Appendix 5.2). Four species dominated the collections in 1985. These were bluehead sucker (930), speckled dace (516), humpback chub (409), and flannelmouth sucker (402). In aggregate, these species represented 88.7% of the catch. Brown trout (8) and carp (9) were the least frequently captured fish.

Fewer river trips were made in 1986. Decreased effort is reflected in reduced number of fish collected (1,745) (Appendix 5.3). With the exception of a sampling trip to the Little Colorado River and Havasu Creek in June 1986, no tributaries were sampled in spring or summer, 1986. Both of these are seasons that previously had resulted in high capture rates for native fish. Humpback chub were most abundant (632) followed by rainbow trout (473), speckled dace (279), and flannelmouth sucker (224). These four species comprised 92.1% of the catch. Fathead minnow (1), carp (5), and brown trout (7) were infrequently caught.

Because of the seasonal patterns in water temperature in most tributaries (See Chapter 3) there is little overlap in use by native and introduced species (Figure 5.2). Natives comprise most fish in the tributaries in spring (89%) and summer (96%) with trout the most abundant group in winter (68%). Autumn is a transition period where both native and trout are inhabiting the tributaries.

Table 5.3 presents the y-o-y fish data collected in tributaries. There were seven species for which we were able to document reproduction in the tributaries as indicated by the presence of y-o-y fish. Rainbow trout was the most frequently captured fish (35.1%) followed by humpback chub (25.4%), bluehead sucker (24.9%). Flannelmouth sucker, speckled dace, brown trout, and fathead minnow comprised the remaining 14.6%.

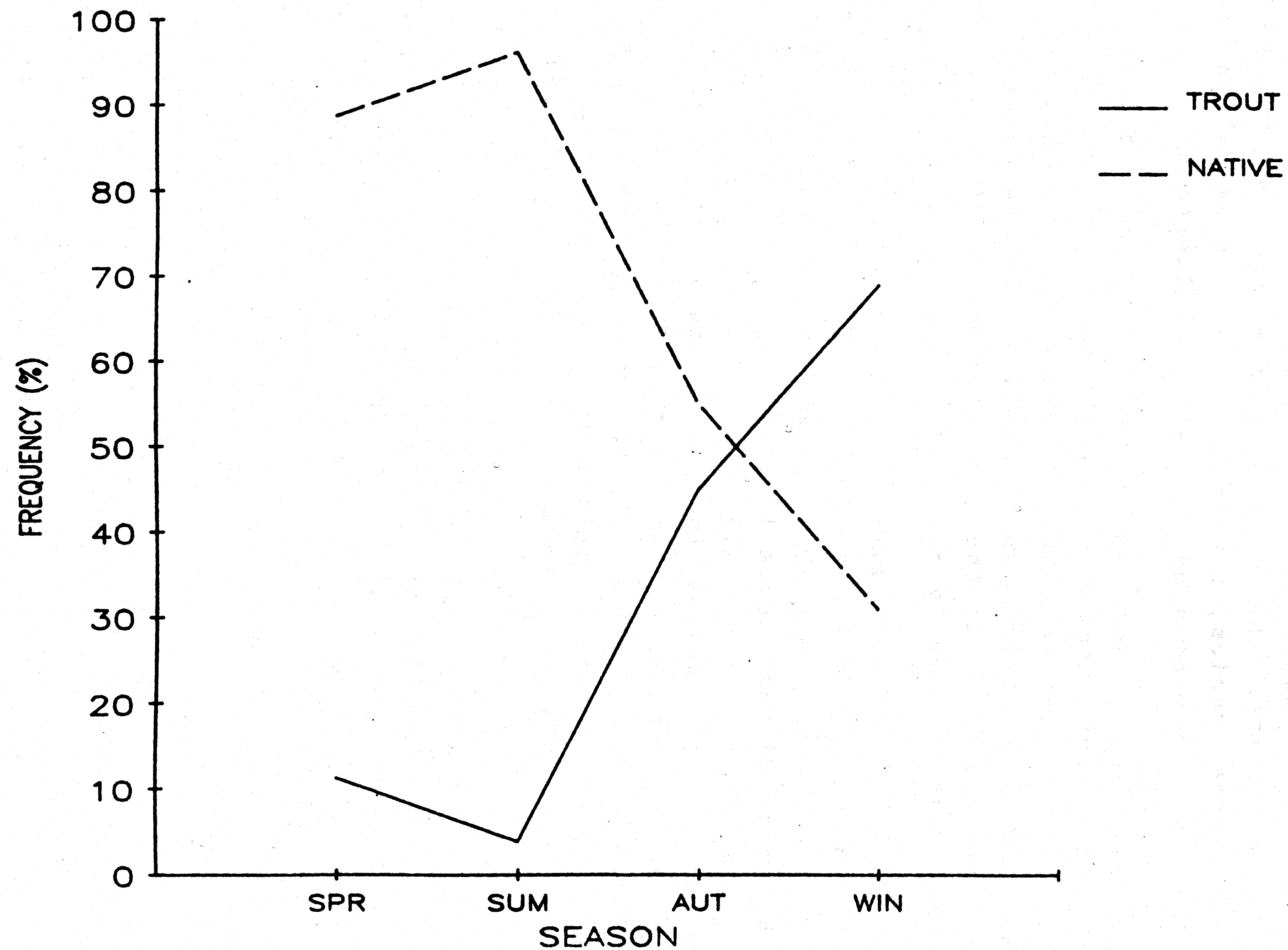


Figure 5.2. Relative frequency of all trout species and native species (flannelmouth sucker, bluehead sucker, humpback chub, and speckled dace) by season from tributaries (excluding fish captured by larval seine).

Table 5.3. Locations (tributaries) and number (in parentheses) of Y-O-Y fish species collected from 1984-86 using all gear types (except the larval seine).

Sampling Period	Humpback Chub	Rainbow Trout	Flannelmouth Sucker	Speckled Dace	Bluehead Sucker	Fathead Minnow	Brown Trout
Spring 1984		Nankoweap (64) Clear (79) Bright Angel (5) Crystal (5) Tapeats (1)	LCR (6)	Kanab (22)			Nankoweap (18)
Summer 1984	LCR[a] (12)	Nankoweap (3) Clear (9) Shinumo (4) Tapeats (4)	LCR (1)	Paria (3) Nankoweap (1) Crystal (1) Kanab (5)			
Autumn 1984				Nankoweap (1) Bright Angel (2) Kanab (1)			
Winter 1984/85							
Spring 1985	LCR (147)	Clear (4) Crystal (2)	Kanab (2)		Paria (2) Kanab (4)		
Summer 1985	LCR (136)	Tapeats (2)	LCR (4) Kanab (1)	LCR (4) Kanab (7)	LCR (161) Kanab (28) Deer (2)	LCR (1) Kanab (1)	
Autumn 1985							
Winter 1985/86		Tapeats (6) Deer (10) Havasu (2)					
Spring 1986	LCR (1)	Nankoweap (39 Clear (65) Bright Angel (16) Crystal (6) Tapeats (85) Deer (6) Havasu (1)	LCR (8)	Havasu (2)	LCR (9) Crystal (4) Havasu (33)		Bright Angel (2)
Summer 1986	LCR (52)	Shinumo (16)	LCR (101)	LCR (6)	LCR(92) Shinumo (5)		

[a] Little Colorado River

Rainbow trout spawning was verified in eight of 11 tributaries examined. Spawning by natives occurred primarily in Paria River, Little Colorado River, and Kanab Creek. However, bluehead sucker used a variety of other tributaries including Deer, Crystal, Shinumo, and Havasu creeks.

To further evaluate which tributaries supported spawning and which periods were important, reproductive conditions of adults were examined (Table 5.4). These data indicate that in 1984, the peak of trout spawning occurred in December. During December 84.4% of adult trout checked in Nankoweap Creek were classified as ripe. Several other tributaries showed similarly high ratios of ripe fish (Clear Creek, 4/7; Tapeats Creek, 70/106; Deer Creek, 41/47). In several tributaries, up to 28.6% of the trout examined in December 1984 were spent. Ripe fish were found in Nankoweap and Shinumo creeks as late as April 1985.

Although the number of fish examined in the autumn and winter 1985 spawning season was reduced, it appeared that with the exception of Nankoweap Creek, peak of spawning occurred in December 1985 also. No ripe or spent trout were found in Nankoweap in December 1985. It appeared that the peak of spawning in Nankoweap occurred in February 1986.

Flannelmouth sucker spawning generally occurred during spring, although ripe fish were captured during most seasons. Ripe fish were collected in Paria and Little Colorado rivers and Shinumo, Kanab, and Havasu creeks. A high percentage (97.5% or 40 of 41) of ripe flannelmouth suckers were captured in Paria River in February 1986 (Table 5.5).

Table 5.6 presents the data collected on spawning condition for bluehead suckers. These data indicate the peak of spawning for bluehead suckers was variable, but late spring and early summer were the time frames where most spawning occurred. Little Colorado River, Kanab, and Shinumo creeks are the three tributaries where the majority of bluehead sucker spawning occurred.

Channel catfish in ripe condition were located in the Little Colorado River throughout the late spring and summer except in August (Table 5.7). This introduced predator seems to reach spawning condition, but recruitment seems limited.

The data collected pertaining to substrate composition, indicate that in most cases the percentage of particles less than

Table 5.4 Reproductive condition (R = ripe, S = spent) of rainbow trout collected in tributaries from 1984-86. Numerators are the number of fish found in spawning condition. Denominators are the total number sampled.

Sampling Period	Nankoweap	Clear	Bright Angel	Crystal	Shinumo	Tapeats	Deer	Kanab
Spring 1984	2/3 S	0/2			0/1	1/7 R		0/4
Summer 1984						0/5		0/7
Autumn 1984					1/1 R	0/4		
Winter 1984/85	86/106 R	4/7 R 13/106 S	18/29 R 2/7 S	10/20 R 2/29 S	4/20 S	79/116 R	48/54 R 10/116 S	0/1 3/54 S
Spring 1985	19/27 R			1/3 S	1/3 R	1/3 S	0/2	1/15 S
Summer 1985						0/2		
Winter 1985/86	301/368 R 45/368 S	1/3 R	1/4 R 2/4 S	0/4	2/2 R	0/1		
Spring 1986	1/1 R				0/5			
Summer 1986					0/5			

Table 5.5 Reproductive condition (R = ripe, S = spent) of flannelmouth suckers collected in tributaries from 1984-86. Numerators are the number of fish found in spawning condition. Denominators are the total number sampled.

Sampling Period	Paria	Little Colorado	Shinumo	Tapeats	Kanab	Havasu
Spring 1984	0/1	0/108	0/31	0/7	0/162	
Summer1984	0/3	0/22	0/38	0/2	1/35 R	
Autumn 1984			0/1	0/1		
Winter 1984/85			0/1			
Spring 1985	12/120 R	8/213 R	1/16 R		2/13 R	
Summer 1985					0/3	
Winter 1985/86	40/41 R	3/7 R				
Spring 1986		1/24 R	1/1 R		0/30	
Summer 1986		1/185 R	6/12 R			3/39 R

Table 5.6 Reproductive condition (R = ripe, S = spent) of bluehead suckers collected in tributaries from 1984-86. Numerators are the number of fish found in spawning condition. Denominators are the total number sampled.

Sampling Period	Little Colorado	Bright Angel	Shinumo	Deer	Tapeats	Paria	Havasu	Kanab
Spring 1984	0/10		0/2					13/19 R
Summer 1984		0/1	1/43					10/21 R
Autumn 1984		0/2			1/4 R			0/1
Winter 1984/85								0/9
Spring 1985	18/43 R 1/43 S	1/3 R	0/47	1/1 R		1/4 R		34/82 R
Summer 1985			1/2 R					
Autumn 1985								0/1
Winter 1985	2/16 R	0/1						0/1
Spring 1985	0/5		5/11 R					
Summer 1986	0/17		14/35 R				8/23 R	

Table 5.7 Reproductive condition (R = ripe, S = spent) of channel catfish collected from the Little Colorado River from 1984-86. Numerators are the number of fish found in spawning condition. Denominators are the total number sampled.

Sampling period		Reproductive condition
1984	Autumn	1/1 R
1985	Spring	2/6 R
	Summer	12/28 R
1986	Spring	1/2 R
	Summer	3/5 R

3.4 mm (fines) were generally less in redds than they were the adjacent areas (Table 5.8). Redds were sampled in Nankoweap, Clear, Bright Angel, Shinumo, and Tapeats creeks. Samples were collected by Matt Kondolf as part of the Glen Canyon Environmental Studies.

5.3. DISCUSSION

Based upon the surveys conducted as part of the Glen Canyon Environmental Studies, the tributaries are important in maintaining the aquatic resources of the Colorado River. Both the native and introduced fish species use the tributaries, at least seasonally as spawning and nursery areas.

One important question revolves around the seasonal use of these tributaries to the continued survival of any one of these species. The humpback chub is a species that appears to rely heavily on the Little Colorado River for successful spawning sites and as a staging area (and nursery area) for fish prior to entry into the mainchannel Colorado River. It appears that water temperature may control tributary use by fish. In April 1984 water temperature at the interface of the Little Colorado and Colorado rivers was 8.9°C, and 14.0°C just upstream from the confluence with the mainchannel, and 18.2°C 125 m upstream from the confluence. The upstream Little Colorado River water temperature on May 17, 1984 was 23.4°C. By September 7, 1984 it had dropped to 21.8°C and was down to 9.6°C on December 22, 1984. Humpback chubs were very abundant in the Little Colorado River starting in spring when water temperatures began to rise. Both adults and y-o-y fish continued to be present until temperatures were reduced. In winter 1984-1985, when Little Colorado River water temperatures were cold, only a single humpback chub was captured in the mouth of the Little Colorado River.

The need for movement of humpback chubs into the warmer water to find suitable spawning conditions is supported by this and other studies. The Humpback Chub Recovery Plan (U.S. Fish and Wildlife Service 1979) indicates that water temperatures of at least 18°C are required before spawning occurs. Hamman (1982) reported that eggs deposited at higher temperatures (21-22°C) required less time to incubate than those deposited at lower (12-13°C) temperatures. More importantly, survival was directly related to water temperature. Survival rates ranged from 84% at

Table 5.8. Particle size composition (%) of spawning site substrates collected from various tributaries of the Colorado River.

Sample site	Substrate particle size (mm)				
	0.2-3.4	3.5-15	15.1-40	40.1-100	100.1-180
Redd					
A	3.1	14.0	41.3	25.9	15.7
B	1.4	2.6	18.0	47.1	30.9
C	4.9	4.4	29.0	31.3	30.4
D	14.1	24.2	23.4	22.8	15.5
E	3.5	12.8	20.6	34.4	28.7
F	1.3	17.0	26.7	43.8	11.2
G	1.0	7.4	22.8	26.0	42.8
H	4.8	10.0	11.7	38.6	34.9
I	2.3	8.5	6.8	20.0	22.4
J	2.3	9.1	38.5	16.0	34.1
Adjacent					
K	1.6	20.0	49.9	17.3	11.2
L	3.4	17.7	44.4	25.9	8.6
M	1.0	21.4	27.7	28.7	21.2
N	4.7	19.2	27.1	21.8	27.2
O	7.9	6.9	18.8	35.3	31.1
P	8.4	13.7	22.5	21.4	34.0
Q	1.9	5.1	22.3	42.3	28.4
R	6.8	13.8	22.6	17.6	39.2
S	10.6	8.7	37.7	19.0	24.0
T	10.1	8.5	34.4	24.7	22.3

19-20°C downward to only 12% at 12-13°C. This would at least imply that mainchannel spawning would be severely limited by cold water temperatures. Cold mainchannel temperatures may also be a thermal barrier limiting the ability of newly emergent chubs to move into the Colorado River. Berry (1986) examined the effects of cold shock on larval squawfish (Ptychocheilus lucius) and found that fish subjected to a 15°C change in 5 minutes suffered significant mortality. Larval fish subjected to a 10°C decrease exhibited behavioral changes. The difference in temperature between the mainchannel and Little Colorado River in May 1984 was 13°C and that difference increased in June. A larval fish would not have to suffer immediate immortality but only lose its ability to maneuver to be lost from the population.

Although the literature is somewhat conflicting, a study at the Bozeman Fish Cultural Development Center indicates that water temperature changes of 6°C, without tempering, resulted in mortality (U.S. Fish and Wildlife Service 1979).

With mainchannel temperatures in the range described by Hamman (1982) as limiting survival for humpback chub larvae, and the potential for stress resulting from migration to cold water, it may be important to maintain high, sustained flows during humpback chub spawning. This would allow maintenance of a mixing zone and provide larval humpback chubs with a thermal refuge. If widely fluctuating flows were to occur during the humpback chub spawning period, larval fish would have to move as the location of the mixing zone varied with river stage. These fluctuations would also reduce the ability of fish to select preferred temperatures as did fish in a study described by Cherry et al. (1977).

Archer et al. (1985) found that spawning in the upper Colorado River at Black Rocks, Colorado occurred in 1983 when water temperatures ranged from 12-17°C in late June. Flows during this time were high but on the declining edge during the study. In 1984, the peak of spawning occurred in July when the water had a daily maximum temperature range of 21-23°C. These two periods appear to be somewhat later than observed during this study, when the majority of the y-o-y humpback chubs were captured in spring 1985 and early summer 1986. Hamman (1982) found in a hatchery situation that spawning was initiated in early May with water temperatures of 19°C.

Based upon the results of this study and others (Suttkus and Clemmer 1977, Carothers et al. 1981, and Kaeding and Zimmerman 1983), it would appear that the Little Colorado River is the location where the vast majority of successful humpback chub spawning occurs. There is, however, some indication that spawning may occur in other tributaries. Suttkus and Clemmer (1977) indicated that they found three young humpback chubs in Shinumo Creek and concluded that Shinumo Creek was a marginal spawning site primarily because of the creek's small size. This conclusion was supported by this study when ripe humpback chubs were collected in Shinumo Creek.

It is questionable if humpback chub spawning occurs in any tributary other than Shinumo Creek and Little Colorado River, however, concentrations of adult humpback chubs have been observed in the mouth of Havasu Creek (Peter Warren pers. comm. verified by photograph slides by H. Maddux, AGFD). Immature fish were also collected in Reach 50 within 25 km downstream of Havasu Creek. Although it is possible that these y-o-y fish may have drifted from the Little Colorado River, it may be that they were produced in the vicinity of Havasu Creek.

The importance of maintaining this mixing zone (acclimation area) at the mouth of the Little Colorado River is magnified by the fact that the vast majority of the successful spawning occurred there. Having a single tributary where successful spawning occurs increases the potential to lose this population to a single catastrophe. The potential for this to occur results from the large watershed and the wide variety of land ownership.

It would appear that water temperatures also dictate the seasons when salmonids are able to utilize tributaries. Cherry et al. (1977) indicate that temperatures of 27°C approach or exceed the lethal limits for the three trout species found throughout the study area. In addition, trout exposed to high temperature (21-24°C) water sought refuge in cooler water. Scott and Crossman (1973) indicate that rainbow trout are most successful in habitats with temperatures of 21°C or slightly lower. During the three summer periods of the study, tributary water temperatures frequently exceeded 24.0°C and occasionally exceeded 27.0°C. Temperatures in this range would preclude trout use of the tributaries.

The temperature regimes found in the tributaries during the winter period correspond to the ranges reported as ideal spawning temperatures for rainbow trout (Scott and Crossman 1973), who indicate preferred spawning temperatures of 10-15°C. In December 1984 temperatures measured in most tributaries ranged from 10.0-12.0°C.

Hokanson et al. (1973) indicated the preferred temperature range for brook trout spawning was somewhat lower than that for rainbow trout, with an upper median tolerance limit for a normal hatch of 12.7°C, and an optimum temperature of approximately 6.0°C.

One of the factors that appears to influence use of the tributaries by spawning fish is mainchannel water levels. In winter 1984, when flows were classified as being high/sustained (See Chapter 3), December was the peak of trout spawning in most tributaries. In Nankoweap Creek, 98.9% of the fish were classified as being ripe or spent. This was based on a sample of 90 adult rainbow captured.

In December 1985, after the period with the longest sustained fluctuating flows that occurred in the study, no adult rainbow trout were observed in Nankoweap Creek. During the river trip in December 1985, it appeared the gravel bar formed by the outflow of Nankoweap Creek imposed a barrier to upstream movement by spawning adult fish. On the next trip in February 1986, flows had returned to normal rates (high sustained), and the largest number of spawning fish were observed when 345 of 365 rainbow trout were classified as being either ripe of spent. It appears that rainbow trout using Nankoweap Creek as a spawning area can adjust to short delays in spawning. Although the sample size was small for the other tributaries, it appeared that the peak of rainbow trout spawning occurred in the other tributaries during December 1985 (Table 5.4).

Based upon visual observations made during periods of low flow, it would appear that four major tributaries would be expected to be isolated by sustained periods of low flow. These are: Paria River, Nankoweap, Kanab, and Shinumo creeks. It should be noted that discharge rates measured during this study (Table 3.3) appear to be higher than those measured during previous studies (U.S. Geological Survey 1953, Johnson and Sanderson 1968). During periods of low discharge from tributaries, the effect of isolating those tributaries during low mainchannel flows would be magnified. We suggest that prolonged periods of sustained fluctuating flows would adversely effect spawning success.

Several studies have been conducted to evaluate the importance of a high percentage of fines (particles <3.35 mm) in controlling the success of trout spawning, including studies conducted to evaluate the role of particles size play in controlling emergence. Koski (1966) indicated that there was an inverse relationship between the percent of sediments less than 3.3 mm and survival of Coho fry from egg deposition to emergence. He found that eggs developed normally to the fry stage but were apparently unable to emerge from the gravel because of entrapment by small size sediment.

Phillips et al. (1975) conducted laboratory experiments where variables such as dissolved oxygen and rate of water flow were controlled, but the percent of sediments smaller than 3.0 mm was varied between 0 and 70% of the total spawning substrate. They also found that there was an inverse relationship between percent survival and percent sediment less than 3.0 mm. When the percent fines was 0%, steelhead fry survival was 94%, and when fines comprised 70%, survival was reduced to 18%. The greatest rate of reduction came when percent fines increased from 20% to 30% and survival decreased from 65% to 40%.

As indicated in this study (Table 5.8), none of the 11 redds sampled exceeded 20% in fines. Based upon these measurements, the tributaries assessed during this study provided good spawning substrate in at least a portion of the streambed. It should be noted that a study done by Adams and Beschta (1980) indicates that temporal variability can be caused by occasional flushing of sediments as a result of flooding incidents. As discussed earlier, this study appears to have been conducted during a period with high tributary discharge that may have an influence on the sediment composition.

Native fish use of tributaries was concentrated in three tributaries: Paria River, Little Colorado River, and Kanab Creek. These three are classified by Hamblin and Rigby (1968) as major tributaries typified by relatively low gradients. Other tributaries studied fell into the category described as steep gradient, relatively straight streams. With the exception of flood events, these streams carry clear water. These tributaries are used extensively by rainbow trout. Although there were exceptions to this trend, during this study, both native and introduced fish appeared to prefer distinct tributary types.

It is possible that the increased turbidity in the three major tributaries may contribute to this use pattern. Gradall and Swenson (1982) found that creek chubs (Semotilus atromaculatus) preferred highly turbid waters. Brook trout, while using this type of water did not prefer it. This may function to separate habitats and reduce predation on native fishes. Swenson (1978) found that high turbidity reduces interaction between walleye (Stizostedion vitreum), which prefer turbid water, and lake trout (Salvelinus namaycush), which avoid turbid areas. In contrast, rainbow smelt (Osmerus mordax) were made more available to walleye as a result of turbidity. Based upon these studies, a management strategy to enhance native fish populations would include maintenance of large, turbid mixing zones at the mouth of the major tributaries to partially segregate predators from natives and enhance the ability of fish to take advantage of the moderated temperatures. Flows that would facilitate access to the tributaries for trout spawning are also important.

6. MAINCHANNEL FISH REPRODUCTION

6.1. METHODS

Fish of reproductive size were examined for reproductive condition and either tagged and released or sacrificed for gonads, vertebra, and stomachs. Gonads from sacrificed individuals were classified as immature, maturing, mature, running ripe, or spent (Gupta 1975). Fish released were classified as running ripe (gametes easily expressed), spent (only residual gametes remaining), or unknown. Fish examined in the creel were classified as ripe or spent based on the physical appearance and weight of the ovaries. Because of the short time between running ripe and spent, these stages were combined for analysis except where noted. The ratio of ripe individuals to adult fish (>250 mm, except bluehead suckers, >150 mm) classified as unknown was used to estimate spawning season.

Female fish not cleaned before being checked at the creel station had their ovaries removed and weighed to the nearest 0.1 g. The Gonosomatic Index (GSI), expressed as the percentage of gonad weight to body weight, was calculated for each fish. Ovaries were labeled and preserved in 10% formalin. Three ova subsamples from each pair of ovaries were counted and then weighed using the gravimetric wet subsample method (Bagenal and Braum 1978). The mean weight per ovum was then divided into the total weight of the ovaries to estimate potential fecundity for that female.

To better locate spawning areas, native fish larvae and rainbow trout fry were sampled at intervals along the entire river and plotted as catch per unit effort by 16 km river sections. Mainchannel rainbow trout spawning areas were located by visual observation when possible. Sucker spawning areas were identified by collection of ripe adults and proximity of larval fish. Amount of mainchannel spawning area was not determined.

6.2. RESULTS

Rainbow Trout

Reaches 10 and 20 showed differences in spawning season between 1984/85 and 1985/86. In Reach 10, the peak in number of fish sampled in reproductive condition occurred in winter 1984/85 and declined in spring (Figure 6.1). However, the following year the peak was sustained into spring. In Reach 20, the peak occurred in autumn 1984 and declined through winter and spring. The percentage of fish in reproductive condition was lower in autumn 1985 than autumn 1984, even though winter and spring were similar during the two years.

Reaches 30 and 40 had a peak of fish in reproductive condition in winter of both spawning years (Figure 6.1). Reproduction continued into spring, though at a lower level.

There was no clear pattern in Reach 50 which had a peak in winter 1984/85 and another peak in summer 1985. Fewer rainbow trout were collected and examined in Reach 50 than in any other reach.

Creeled fish in Reach 10 (Lee's Ferry) provided a more extensive data base for examination of the reproductive pattern. For 1984/85, fish either mature or running ripe peaked in autumn at 15.1%, while spent fish represented only 1.1% (Figure 6.2). During the ensuing winter and spring, spent individuals exceeded ripe fish. In 1985/86 ripe fish exceeded spent fish in autumn and winter. It was not until spring that the number of spent fish (8.5%) was greater than ripe fish (6.2%).

The Gonosomatic Index (GSI) for ripe and spent fish varied little between years (Figure 6.3). In both years GSI peaked in winter at around 15%. Spent female's GSI decreased through the spawning season as residual ova were resorbed and ovaries decreased in size.

Mean estimated fecundity for 1984/85 was 3,164 ova/female with a range of 1,386-5,430 ova/female. Fecundity in 1985/86 ranged from 1,334-6,174 ova/female ($\bar{x}$=2,819 ova/female).

Rainbow trout fry were collected from above Lee's Ferry (Interval 1), to Interval 21 (Figure 6.4). Highest CPUE for rainbow fry occurred above Lee's Ferry. Other peaks in CPUE occurred at Interval 4, 5, 11, 12, 16, and 18. High densities in reaches 10 and 20 were not associated with tributaries and represent mainchannel spawning. Concentrations in reaches 30 and 40 were in close proximity to tributary streams. Few fry were collected in Reach 50, which has no tributary streams.

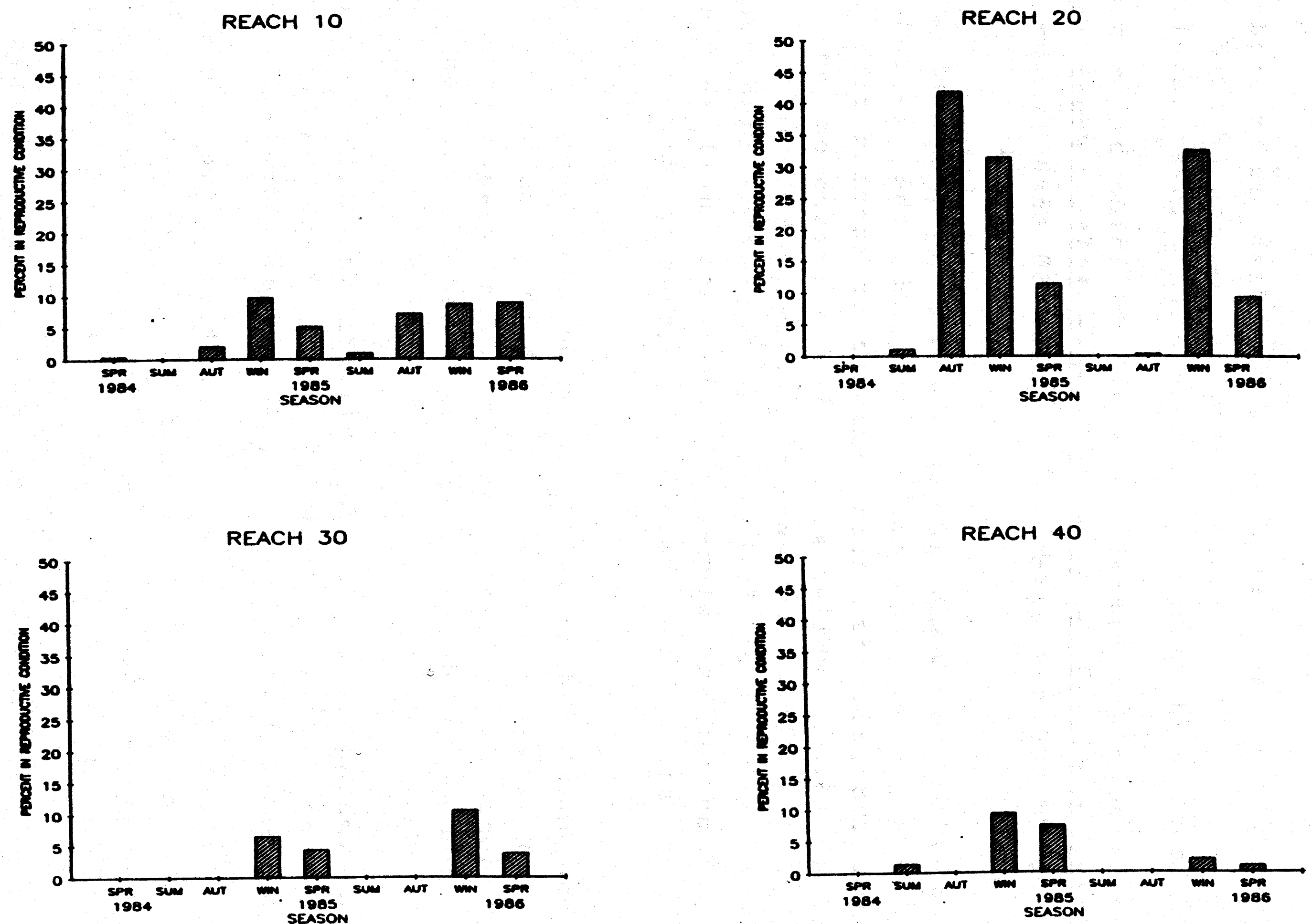


Figure 6.1. Percentage of adult rainbow trout with expressable gametes, reaches 10-40.

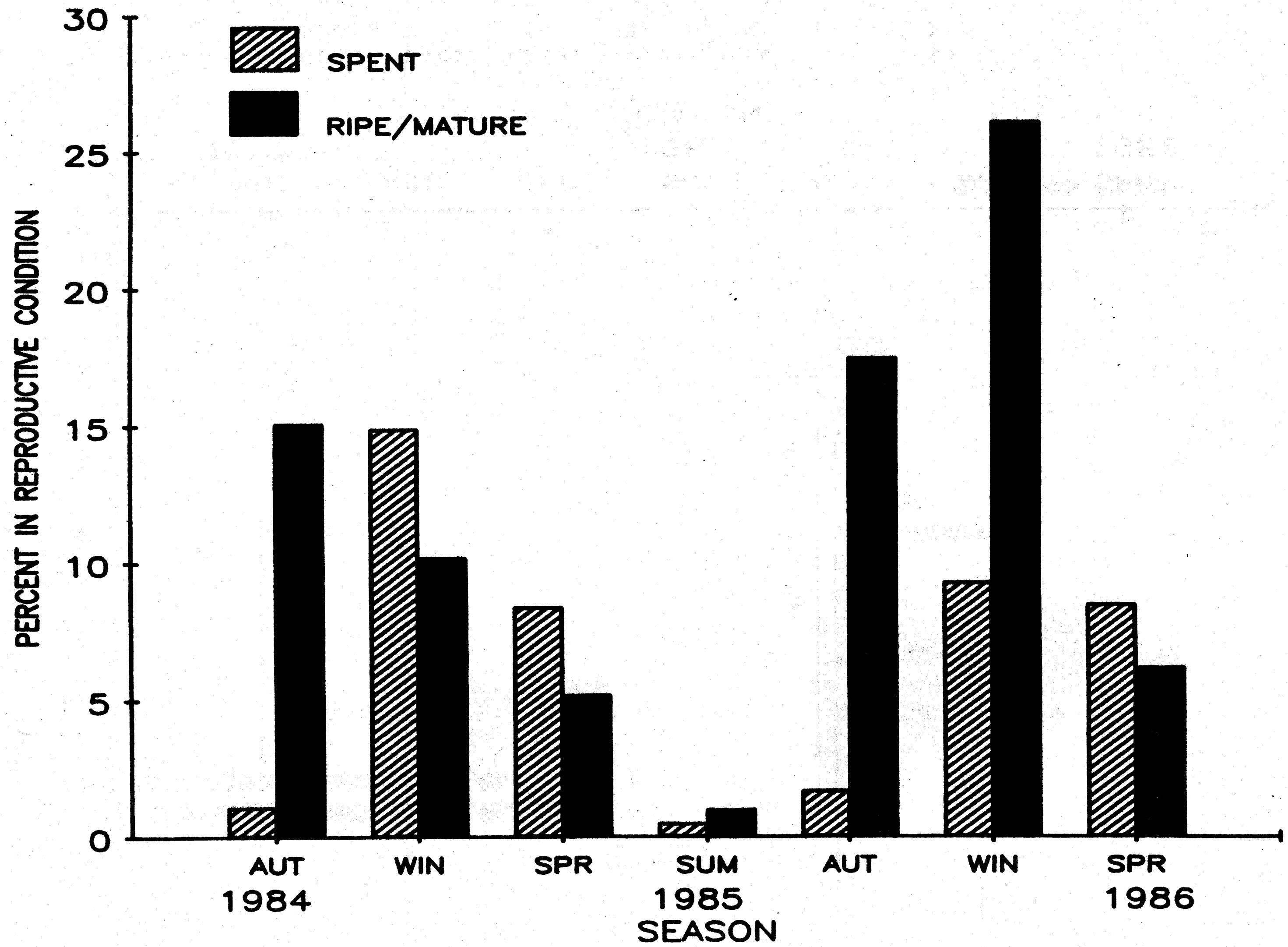


Figure 6.2. Percentages of ripe and spent rainbow trout creeled at Lee's Ferry from June 1984 to May 1986.

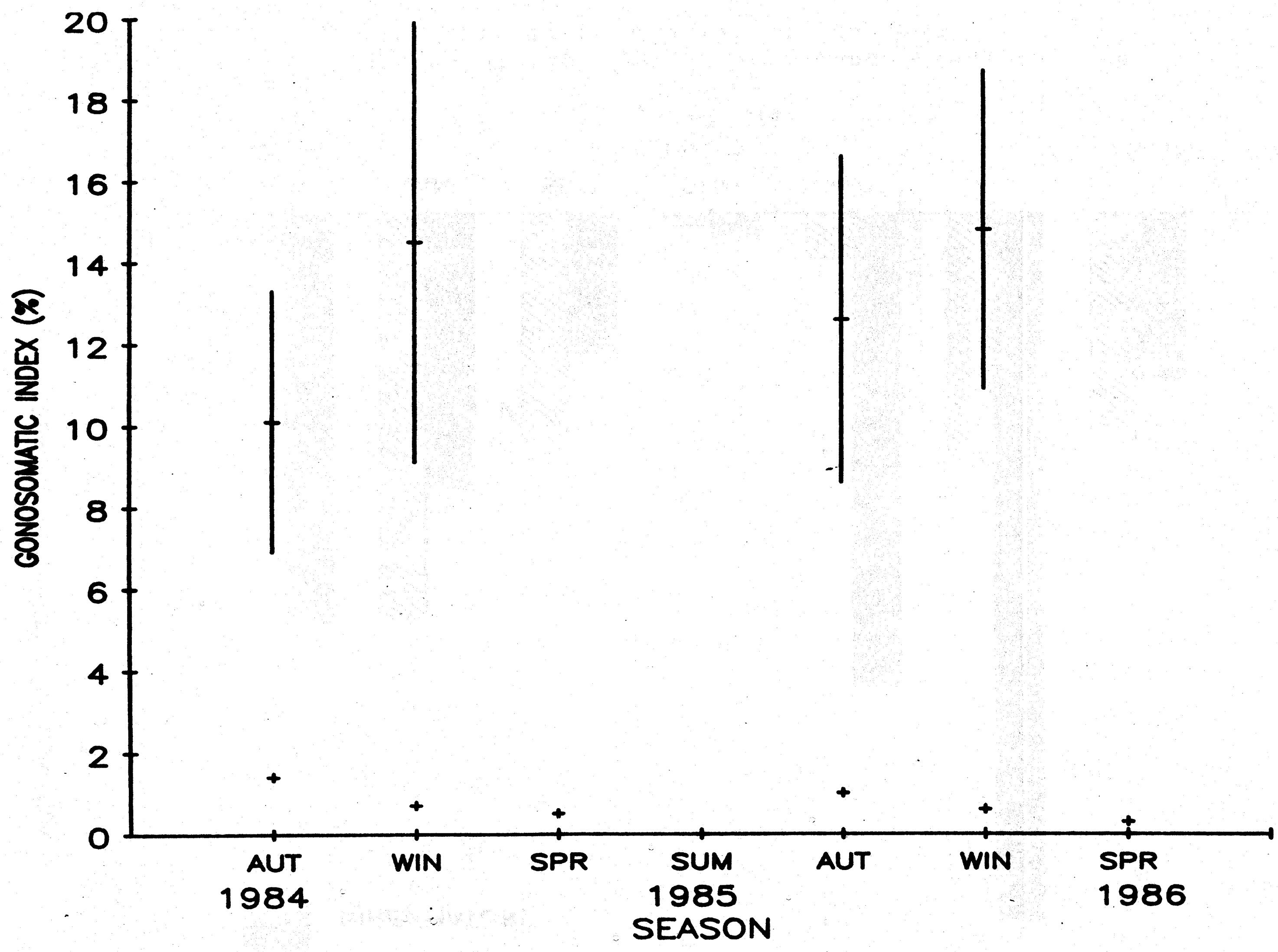


Figure 6.3. Gonosomatic index of creeled rainbow trout from Lee's Ferry, June 1984 to May 1986. Upper values include mean and range of fish in reproductive condition; lower values include mean and range of fish in spent condition.

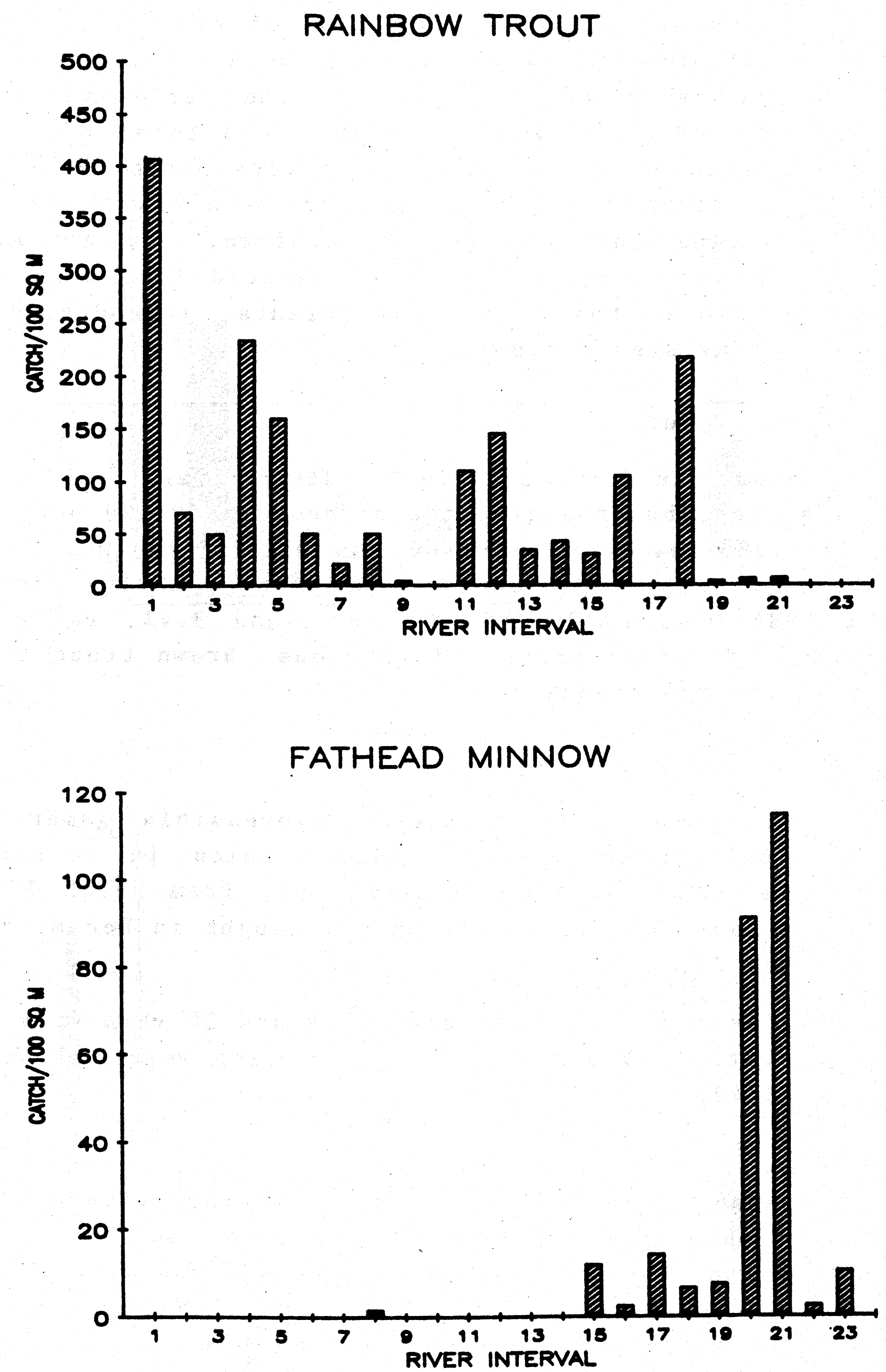


Figure 6.4. Catch per unit effort of y-o-y rainbow trout (<75mm) and fathead minnow (<25mm) captured by bag and larval seine at 16 km (10 mile) intervals.

Rainbow trout were collected from Reach 10 and examined for a tetracycline dyemark (See Chapter 7). Of fish collected from creel and electrofishing surveys, 31% were negative for the dyemark. This number was adjusted for the percentage of fish stocked that tested positive for the dye. A total of 177 fish were examined prior to stocking and 157 were positive. The 31% natural reproduction figure was adjusted by a 88.7% figure for dyed fish entering the fishery. Therefore, our estimate of natural reproduction in Reach 10 was adjusted to 27.5%. It is important to note that this represents reproduction and recruitment during steady flows.

Brook and Brown Trout

Brook trout in reproductive condition were collected in winter and spring, but the greatest percentage (9.1%) occurred in the winter 1985/86. Brown trout were similar with highest percentage of fish in reproductive condition occurring during the winter of 1984/85 and 1985/86 at 1.8% and 3.4%, respectively (Figure 6.5). No brook trout and only one brown trout fry were collected in the mainchannel.

Common Carp

In 1,881 common carp examined, expressible gametes were detected in only eight (0.4%). Seven males in reproductive condition were collected in February 1985, from Reach 20. One other fish in reproductive condition was caught in December 1985, also from Reach 20.

Seven y-o-y carp were collected in Reach 50 (two from a deep isolated backwater). The remaining y-o-y carp were collected in reaches 30 and 40.

Fathead Minnow

Fathead minnow were not examined for reproductive condition, but distribution of individuals <25 mm gives an indication of spawning location. Most fathead minnows <25 mm were collected from lower reaches of the river (Figure 6.4). The only exception was the area immediately below the Little Colorado River. Highest CPUE of fathead minnow <25 mm occurred between RM 184 and RM 204. These high densities were generally in or adjacent to backwaters.

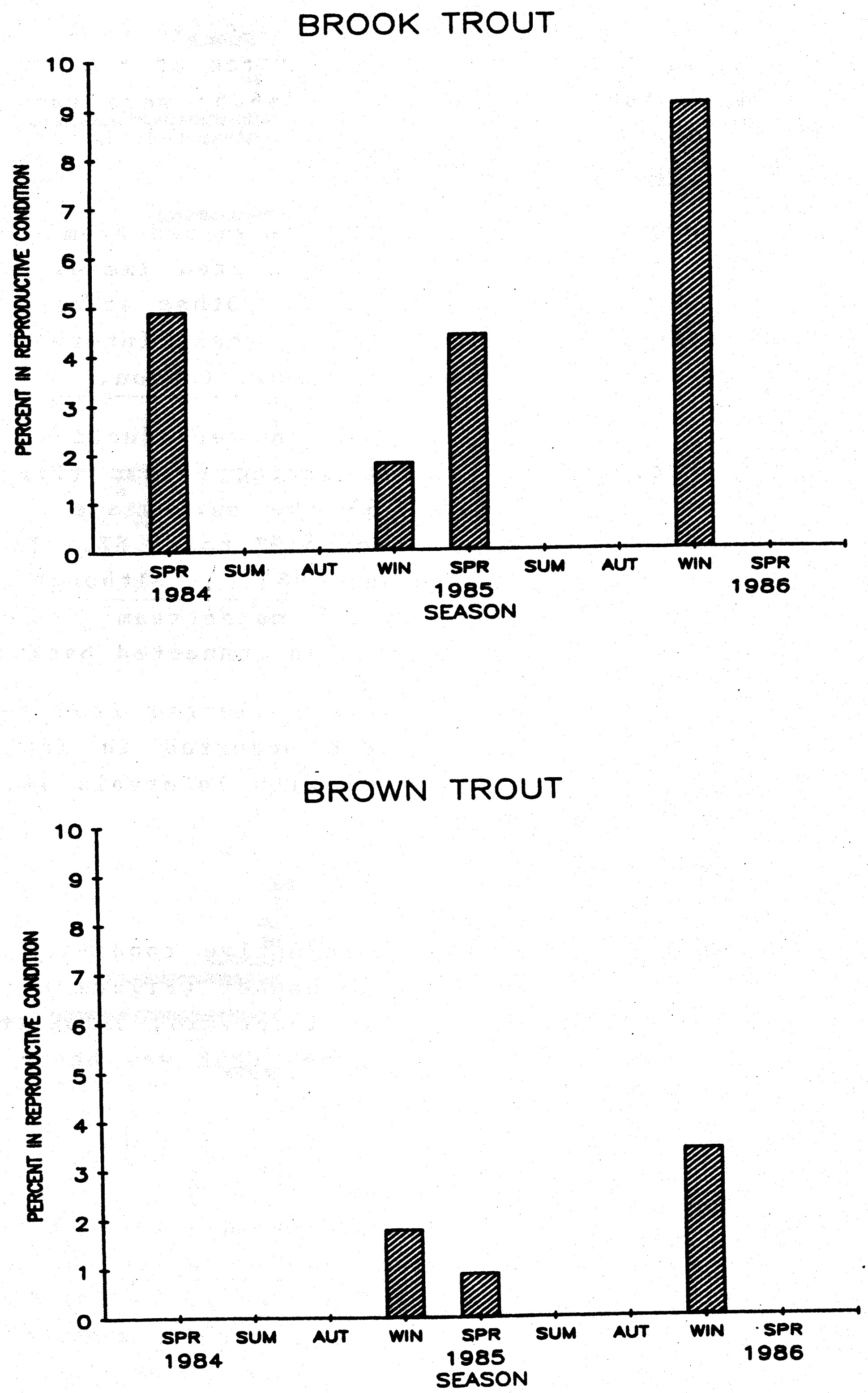


Figure 6.5. Percentage of adult brook trout and brown trout with expressable gametes from reaches 10-50 combined.

Suckers

Bluehead sucker were found in reproductive condition in the mainchannel during May 1985 and 1986. Three of four fish caught immediately below National Canyon (RM 166.5) were running ripe. All bluehead suckers caught in the mainchannel in reproductive condition were from reaches 40 and 50.

Two dead bluehead sucker larvae were seined from above Lee's Ferry. The first live larvae were collected immediately below the Little Colorado River (Figure 6.6). Other areas with peaks in CPUE were Interval 17 below Shinumo Creek, Interval 19 below Kanab Creek, and Interval 20 below National Canyon.

Flannelmouth suckers were found in reproductive condition throughout the study period except during autumn (Figure 6.7). From winter 1984/85 to spring 1985 the percentage of fish in reproductive condition increased from 5.9% to 15.8%. The highest peak (30.4%) occurred in spring 1986. Although fish in reproductive condition came from all mainstream habitats, the greatest concentration were collected in connected backwaters.

Flannelmouth sucker <25 mm were collected from reaches 40 and 50 (Figure 6.6). Highest CPUE occurred in Interval 19. Other peaks in CPUE were associated with Intervals 14, 18, 21, and 23.

Humpback Chub

No adult humpback chub in reproductive condition and very few y-o-y were captured in the mainchannel (Figure 6.6). Chub <50 mm were collected from five river intervals, below the Little Colorado River, in Interval 9. Highest CPUE was between RM 164 and RM 174 in Interval 19.

Speckled Dace

Speckled dace were not examined for reproductive condition. The most upstream mainchannel location where dace <25 mm were collected occurred at RM 6.5 above Lee's Ferry. No effort data were recorded, therefore this sample is not represented in Figure 6.15. The first down river location where dace were captured was near Nankoweap Creek (Figure 6.6). Highest CPUE for dace <25 mm (400.0 fish/100 m^2) was reported from RM 134-144 (Interval 16). Other peaks occurred between Interval 19 (54 fish/100 m^2) and Interval 20 (76.1 fish/100 m^2).

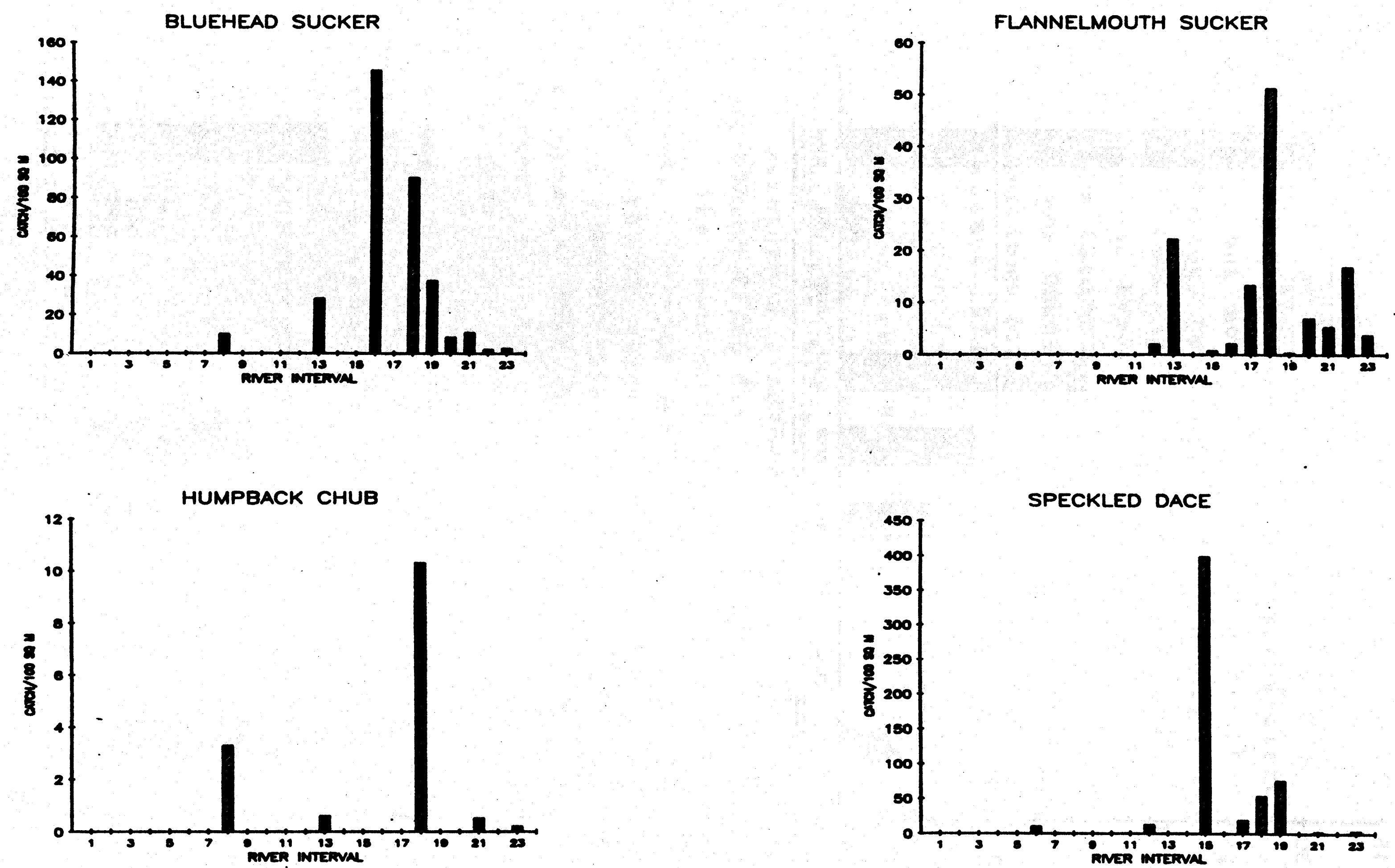


Figure 6.6. Catch per unit effort of y-o-y bluehead sucker (<25mm), flannelmouth sucker (<25mm), humpback chub (<50mm), and speckled dace (<25mm) captured by bag and larval seine at 16 km (10 mile) intervals.

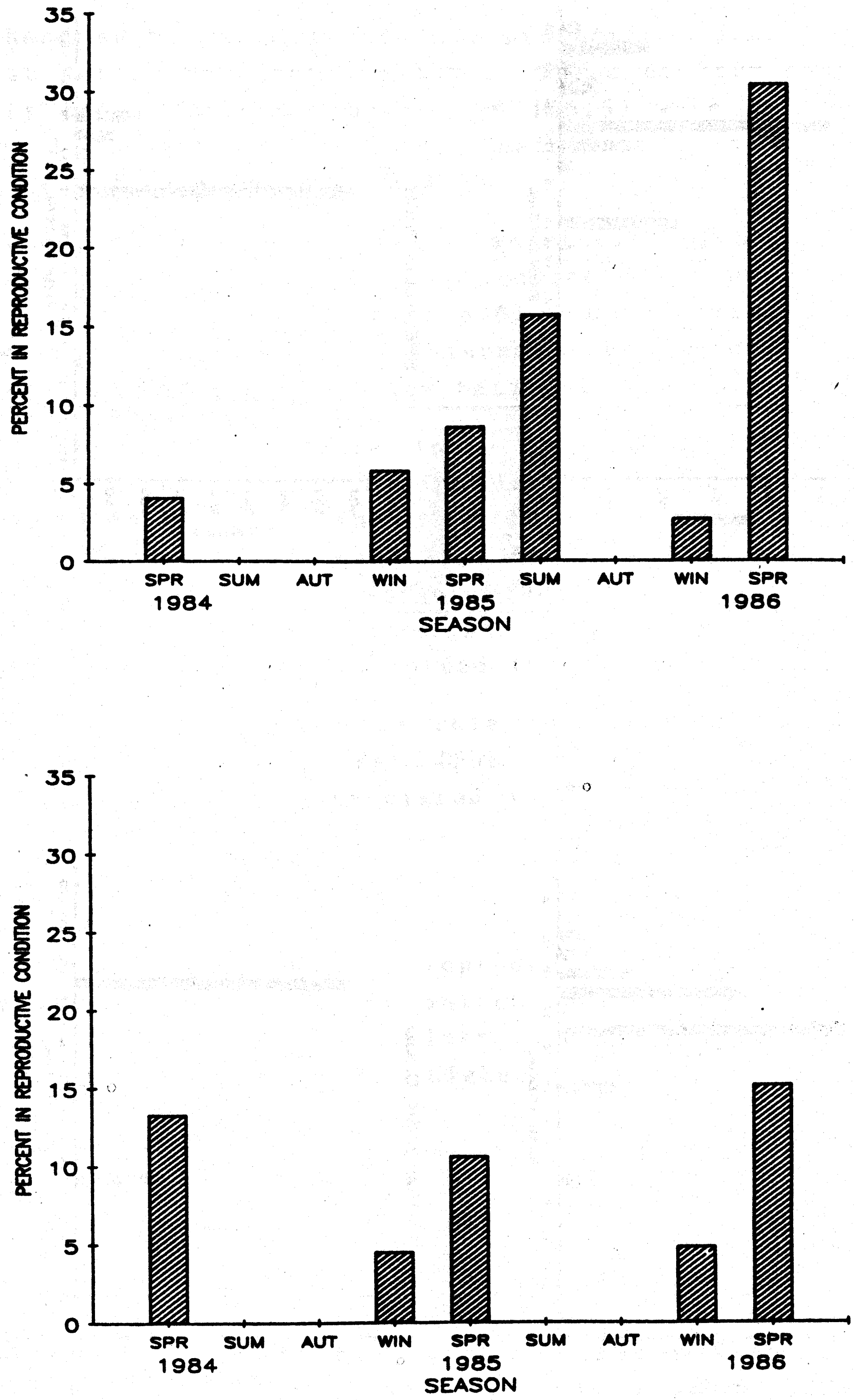


Figure 6.7. Percentage of adult flannelmouth sucker with expressable gametes in Reach 10 (top) and in reaches 20-50 (bottom).

6.3 DISCUSSION

Rainbow Trout

Trout reproduction below deep release western reservoirs has been suspected, but not verified, prior to this study. (Glen Canyon Dam, Persons et al. 1985; Flaming Gorge Dam, Steve Brayton, pers. comm.; Navajo Dam, Jack Kelly, pers. comm.). Rainbow trout that have become established since the closure of Glen Canyon Dam (Stone and Rathbun 1968) utilize the mainchannel for spawning (See Chapter 5). Tailwater temperatures are near the reported optimum (10.0-15.5°C) for spawning by rainbow trout (Scott and Crossman 1973).

Variation in water flow has been shown to affect trout spawning (Anderson and Nehring 1985), and may have been responsible for the temporal shift in reproductive activity observed during this study. Flows during winter 84/85 were steady and maintained trout access to spawning bars. However, flow during winter 85/86 fluctuated on a daily basis (See Section C). These daily fluctuations made gravel bars less accessible for spawning. Deeper gravel bars were less affected by fluctuations, though water velocities over the redds may have varied. When fluctuations ceased in spring and bars were again inundated, spawning fish and redds were observed. Fishing guides at Lee's Ferry observed this same pattern (Dale Whitmore and Terry Gunn, pers. comm.).

This temporal shift was evidenced by the creel from Reach 10, where most fish were in reproductive condition during winter 84/85, but not until spring 1986. Though reproduction in rainbow trout appears to have been affected by flow, gamete viability and success of the spawn were not measured. Fish resorb ova when conditions are unfavorable for spawning (Kukuradez 1968, Hokanson 1977), which can disrupt future oocyte development and inhibit spawning the following year. Therefore, restricted spawning due to prolonged periods of fluctuating flows could affect trout spawning for more than one year.

Fecundity for rainbow trout in the Glen Canyon tailwater was similar to that reported for domesticated trout (Leitritz and Lewis 1980, Moyle 1976) and to that reported in Grand Canyon (936-2994 ova/female, Carothers et al. 1981). There was little difference in fecundity between years, and flows apparently had no direct effect.

Reaches below Lee's Ferry seemed less disrupted by changes in flow. Spawning occurred in winter for all other reaches except 50. Reach 50 had few fish in reproductive condition, and few fry were collected. If mainchannel spawning occurred, it was limited. Fry density in three of four reaches appeared related to proximity to tributary streams.

Our observations were that in Reach 10 rainbows utilize available spawning gravels, but suitable sites are limited. With occasional spillway releases as seen in 1983 and 1984, spawning gravels may be decreasing in quantity and quality.

Brown Trout and Brook Trout

Most brown trout were collected from Reach 30 and were of a size reported by Carlander (1969) and Taube (1976) as mature. Only one brown trout fry was collected in the mainchannel (Reach 40). Brown trout prefer fairly shallow areas with fine gravels for spawning (Shirvell and Dungey 1983). The gorge environment where most of the brown trout were collected contained very few shallow water areas, and no spawning gravels were observed.

Brown trout may reach reproductive condition in the mainchannel and then move into Bright Angel and Phantom creeks to spawn (Minckley 1978). Those fish found in the mainchannel are probably a product of tributary spawning.

It appears that brook trout numbers are maintained only through stocking. This species was observed over gravel bars in early autumn, and individuals reached reproductive condition, but no fry were collected in the mainchannel. Hale (1970) found brook trout spawned in the laboratory at temperatures between 6.7-9.4°C. Hokanson et al. (1973) found the optimum hatching temperature was 6.0°C and that at 11.7°C, 50% of all eggs were nonviable. They concluded that a mean water temperature below 9.0°C is required to optimize spawning activity, gamete viability, and subsequent embryo survival. Mansell (1966) reported spawning occurring in water between 6.7-8.9°C. Because juvenile brook trout, though few in number, were collected throughout the study it may be that limited natural reproduction and recruitment are occurring. Whether successful spawning is occurring in the tributaries or mainchannel is unknown.

Other Introduced Species

Mainchannel reproduction by common carp and fathead minnow appears to occur only in backwaters. The reproduction seems to be limited by water temperature. Carp spawn at temperatures between 18.5-23.0°C (Shields 1957, Sigler 1958, Mauck and Summerfelt 1971, Jester 1974). Swee and McCrimmon (1966) reported that spawning ceased at temperatures below 16°C. Thus, mainchannel spawning is undoubtedly inhibited by cold water temperatures, and this activity is restricted to warmer connected and isolated backwaters.

Fathead minnow spawn in temperatures similar to carp. Carlander (1969) reported that spawning begins when temperatures reach 16°C. Most age 0 fish were collected in connected and isolated backwaters. Fathead minnow are fractional spawners and have been shown to spawn 16-26 times over a three month period (Gale and Buynak 1982). This condition allows fathead minnows to spawn quickly when temperatures in backwaters become suitable, and increases their chances for reproductive success when environmental conditions change on a daily basis. Being a fractional spawner may account for the abundance within lower reaches of the study area.

Native Fishes

Fishes endemic to the Colorado River evolved in a system with wide seasonal fluctuations in water temperature and volume (McDonald and Dotson 1960). The Glen Canyon Dam tailwater has changed from a reach with seasonal fluctuations in water temperature of 1-27°C prior to impoundment to a relatively constant 10°C. The extent of mainchannel reproduction that existed prior to impoundment in 1963 was never documented. In the present system, mainchannel reproduction appears limited. The mainchannel, however, serves as an important nursery and rearing area for native fishes spawned in both tributaries and mainchannel. The area between RM 154 and RM 184 contained the highest densities of larval and y-o-y fishes and may be especially important.

Bluehead sucker is a native fish species that uses tributaries and the mainchannel for spawning and nursery areas. Spawning occurs in water temperatures between 13-18°C (Minckley 1978). Mainchannel temperatures in lower reaches are within this range. Tributary temperatures during the spawning season are warmer and more closely approximate ideal spawning temperatures (See Chapter 4). Larval suckers were collected above and below the Paria River. Their presence above this first tributary suggests that ova develop and hatch in this area. However, both larvae collected were dead and, therefore, recruitment of larvae spawned in the cold tailwater is questionable.

The mainchannel at National Canyon (RM 166.5) was a collection site for both adult and larval suckers. Larvae were located in shallow water flowing over a cobble bar. Had water levels fluctuated during this period these larvae would have been stranded or displaced.

Most other collections of larval bluehead sucker were near tributary streams in which reproduction occurs. Turbidity in mainchannel waters often reduced our ability to locate other mainchannel spawning sites, which undoubtedly exist. Present data are insufficient to determine the contribution recruitment from mainchannel spawning has to the population.

Flannelmouth sucker spawn in water temperatures from 6-23^{o}C (Minckley and Blinn 1976, McAda 1977, Carothers et al. 1981). McAda and Wydoski (1985) found ripe males from early April through June and ripe females during May and June in the upper Colorado River. Flannelmouth suckers in ripe condition were collected throughout the year from the study area, though the peak in reproductive condition occurred in spring. Concentrations of fish in reproductive condition were often found at the mouths of tributaries and in connected backwaters.

Even though flannelmouth suckers in reproductive condition were found in all reaches, larvae were collected only in reaches 40 and 50. Mainchannel reproduction could not be verified during this study, but it appears to occur in backwaters in both upper and lower reaches.

Humpback chub in the Grand Canyon spawn between March and June in water temperatures of 16-20^{o}C (Suttkus and Clemmer 1977, Carothers et al. 1981, Minckley et al. 1981, Kaeding and Zimmerman 1983). Mainchannel temperatures near 11^{o}C observed during this study may be lethal to humpback chub ova. When ova were incubated at 12-13^{o}C, 12% hatched and only 15% of those survived to become feeding larvae (Hamman 1982). Bulkley et al. (1981) incubated ova at 20^{o}C and had 100% hatching. Mainchannel temperatures may not be warm enough to even initiate spawning.

If spawning were to occur, egg and larval mortality would greatly diminish any chance for recruitment. No spawning sites or larval humpback chub were found in the mainchannel. Y-o-y chubs were collected in lower reaches of the river, however, suggesting that spawning areas other than the Little Colorado River may be present.

Speckled dace fry were captured above Lee's Ferry and in Reach 50 in isolated and connected backwaters. Spawning has been reported to occur between 17-23°C in tributaries of the Colorado River (Carothers et al. 1981). These temperatures, though not available in the mainchannel, were present in backwaters where reproduction probably occurred.

CONCLUSIONS

Rainbow trout appear to have reacted to flow conditions during the spawning season as spawning in 1985/86 was later than that observed the previous year. Once flows returned to a high steady condition in 1986, trout moved onto cobble bars to spawn.

Native fishes in the mainchannel spawned during periods of steady flows. Bluehead suckers that spawn on shallow gravel bars would have been affected by fluctuating flows. No one has studied the effects of dewatering on bluehead ova.

Species that utilize warmer backwaters for spawning could be affected by dewatering and desiccation during periods of low flows. Backwaters that become isolated, warm, and then are reconnected to the mainchannel may benefit species that respond quickly to warmer water and reproduce.

7. MOVEMENT

7.1. METHODS

Movement data were collected for three native species (bluehead sucker, flannelmouth sucker, and humpback chub) and four introduced species (rainbow trout, brown trout, brook trout, and carp) by mark-recapture methods. Movement was classified as upstream, downstream, tributary/mainchannel exchange, tributary/tributary exchange, or none. Fish tagged and recaptured in the same tributary were classified as within tributary movement, although tagging and recapture often occurred in different years. Movement between mainstream reaches was also examined. Distances between capture and recapture represent the minimum distances individuals could have moved. We recognize that local movements (<1.6 km) may have been artifacts of our recording system for capture-recapture locations (See Chapter 4) and, thus, classified them as no movement. In order to exclude individuals carried downstream after tagging, same and next day recaptures were eliminated from the calculations.

Fish were captured using techniques discussed in Chapter 4. Floy and Carlin dangler tags (Appendix 7.1), fin clips (Table 7.1) and tetracycline dye were used to mark fish. Tag number, total length, weight, and River Mile where released were recorded for each fish.

Recapture information was obtained on subsequent sampling trips or from anglers. Date, location, length, weight, and tag number were recorded for recaptured fish. Angler information was often incomplete and few of these records could be used.

Tetracycline dye marks were used to monitor dispersal of stocked fingerling rainbow trout. Tetracycline administered in the food produces a yellow-green fluorescent band in bone tissue when viewed under an ultraviolet light (Weber and Ridgeway 1962). Hatchery rainbow trout were fed a marking diet (4 g active tetracycline/220 kg fish/day) in commercial fish food for 10 days prior to stocking. Fish were sampled prior to release to verify the presence of the dye mark.

Rainbow trout were collected for dye mark examination during Lee's Ferry creel surveys and by electrofishing throughout the five river reaches. Several anterior vertebrae were removed, stored in 70% ethanol, cleaned and then examined under an

Table 7.1. Fin clip codes used by reach, 1984-86.

Location	Reach	River mile	Tag
Lee's Ferry to Glen Canyon Dam	10	16-0	Right Pelvic & Adipose
Lee's Ferry to Little Colorado River	20	0-61.5	Left Pelvic & Adipose
Little Colorado River to Bright Angel Creek	30	61.5-87.5	Left Pelvic
Bright Angel Creek to National Canyon	40	87.5-166.5	Right Pelvic
National Canyon to Diamond Creek	50	166.5-225	Left Pectoral

ultraviolet light. Samples were coded positive, negative or undetermined for the dye mark.

On September 24, 1985, 943 tagged adult rainbow trout from Canyon Creek Hatchery were released at River Mile 7.5 in Reach 10 to determine dispersal. Mean total length of these fish was 377 mm (SD=18) and mean weight was 652 g (SD=7).

7.2. RESULTS

Movement

From April 10, 1984 to June 2, 1986, 14,760 fish (10 species) were tagged (Table 7.2). A total of 949 fish (seven species) was recaptured, including 29 humpback chub tagged during previous studies. One hundred and ten fish were recaptured the same or next day and were eliminated from the tag-recapture analysis.

The majority of tagged (65%) and recaptured (75%) fish were rainbow trout. The number of recaptures for the remaining six species varied from one to 71.

Forty-four percent of recaptured fishes exhibited downstream movement, 22% upstream movement, and 17% no movement. Six of the seven species moved between tributaries and mainchannel. Tributary/mainchannel exchange comprised 10.1% of movement and across reach movement accounted for 9.8%.

Tag-recapture

Rainbow trout

A total of 9,642 rainbow trout were tagged of which 641 (6.6%) were recaptured (Table 7.2). Movement (>1.5 km) away from release sites was observed for 58.1% of recaptures (Table 7.3). Distance moved ranged from 0.2 km to 152.0 km ($\bar{x}$=7.1, SD=16.4), which included 22 long distance upstream movements (>50 km). More individuals moved downstream (43.6%) than upstream (25.2%) (Figure 7.1). This species exhibited the highest mean daily movement rate of 0.2 km/day (SD=1.6).

Most tributary/mainchannel recaptures of rainbow trout occurred during the winter spawning season and involved seven of the 11 tributaries. All recaptures of individuals in the same

Table 7.2. Number of fish tagged, number recaptured, and percent recaptured for each species, by reach, 1984-1986.

Species[a]	Reaches	Number tagged	Number recaptured	Percent (%) recaptured
RBT	10-11	2781	169	6.0
BKT		105	9	8.6
CRP		57	1	1.8
FMS		742	39	5.3
BHS		9	0	0
RBT	20-22	3624	215	5.9
BKT		55	8	14.5
BRT		4	0	0
CRP		137	1	0.7
FMS		480	24	5.0
BHS		38	0	0
HBC		1000	41[b]	1.2
RBT	30,31	434	39	9.0
BRT		170	10	5.9
CRP		86	0	0
FMS		35	3	8.6
BHS		11	0	0
HBC		1	0	0
RBT	40-46	2568	207	8.1
BRT		116	9	7.8
CRP		884	42	4.8
FMS		341	3	0.9
BHS		162	1	0.6
HBC		7	0	0
RBT	50	234	11	4.7
BRT		2	0	0
CRP		530	7	1.3
FMS		109	2	1.8
BHS		23	0	0
HBC		1	0	0
Summary				
RBT	All	9641	641	6.6
BKT		160	17	10.2
BRT		292	19	6.5
CRP		1694	51	2.9
FMS		1707	71	4.2
BHS		243	1	0.4
HBC		1009	41[b]	1.2
Totals		14,746	841	32.0

a See Table 4.2 for abbreviations.
b Incl. 29 tagged during previous studies.

Table 7.3. Number of fish recaptured, percent moved, and mean distance moved, by species, 1984-1986.

Kilometers	Rainbow trout	Brook trout	Brown trout	Common carp	Flannelmouth sucker	Hump chub
0	145	1	6	11	12	3
0.2-1.5	92	3	1	2	2	
1.6-3.1	119	4	6	1	9	
3.2-6.3	84	4	3	5	12	
6.4-12.7	53	3	0	11	10	
12.8-25.6	29	0	2	10	5	
25.7-51.3	21	0	0	4	2	
51.4-102.8	20	0	0	1	2	
102.9-205.8	2	0	1	0	0	
205.9-412.0	0	0	0	0	2	
$\bar{x}$ distance moved (km)	7.1	3.4	9.0	10.6	16.9	0.
SD	16.4	3.1	27.8	12.1	43.6	1.
$\bar{x}$ distance moved/day (km)	0.21	0.06	0.03	0.06	0.18	0.
SD	1.6	0.2	0.8	0.2	0.6	<0.
Number	565	15	19	45	56	4
Percent Moved (≥1.6 km)	58.1	73.3	63.2	71.1	75.0	4.

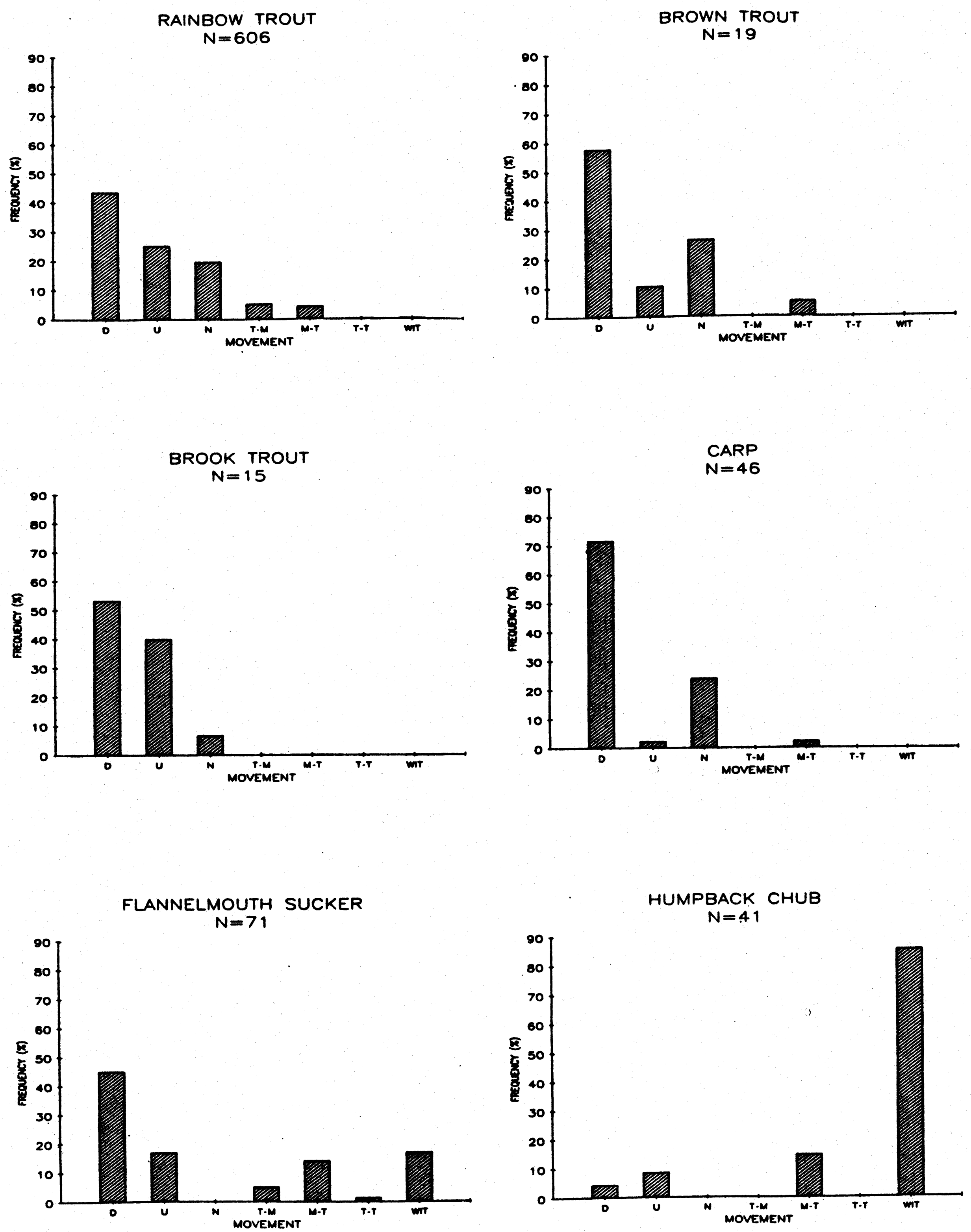


Figure 7.1. Relation of capture to tagging location for rainbow trout, brown trout, brook trout, carp, flannelmouth sucker, and humpback chub from the Colorado River and tributaries 1984-86. D=downstream, U=upstream, N=none, T-M=tributary to mainchannel, M-T=mainchannel to tributary, T-T=tributary to tributary, WIT=within tributary.

tributary where they were tagged occurred during winter. Only one tributary to tributary movement was observed; a rainbow trout was tagged in Shinumo Creek in December 1985 and recaptured two months later in Nankoweap.

Movement from downstream reaches into the Lee's Ferry area represented 4.7% of Reach 10 recaptures. Seven rainbow trout moved from Reach 20 into Reach 10, and one moved from Reach 40 into Reach 10. In contrast, only 1.4% of the fish recaptured in Reach 20 were tagged in Reach 10.

Brook trout, Brown trout, Common carp

The other three introduced species made up 14.6% of the total tagged and 9.9% of the recaptures (Table 7.2). All recaptured brook trout were in reaches 10 and 20. Brook trout had the highest recapture rate (10.2%) and one of the highest percentage of individuals that moved (73.3%). This species was seldom captured in tributaries and, therefore, movement involving tributaries was not evaluated. Likewise, only few trout or carp were tagged or recaptured in tributaries. However, carp exhibited the highest percentage of downstream movement of all recaptured species (71.7%) (Figure 7.1).

Flannelmouth sucker, Bluehead sucker, Humpback chub

Native fishes made up 20.1% of tagged and 13.4% of recaptured fish (Table 7.2). Over half of the tagged native fish were flannelmouth sucker. Most flannelmouth sucker (83.1%) moved away from capture sites; those that did not were recaptured in the same tributaries where they were tagged. We observed several long range movements to the Little Colorado River. Two flannelmouth sucker moved 212.5 km (22 months) and 236.7 km (six months) upstream from Reach 50, and one moved downstream 93.4 km (one month). Bluehead sucker made up only 0.1% of the total number of fish tagged; therefore, movement was not addressed.

All recaptured humpback chub were taken from the Little Colorado River during the spawning season in late spring to early summer. Six had moved from capture sites in reaches 20 and 30 into the Little Colorado River, moving 0.2 to 10.0 km ($\bar{x}$=0.5 SD=1.8).

Canyon Creek Hatchery Rainbow trout

A total of 86 (9.1%) Canyon Creek Hatchery rainbow trout were recaptured from September 1985 until May 1986 (Table 7.4). Mean number of days between stocking and date of recapture was 58 (SD=48.7). Twenty seven percent were recaptured at the release site, 43% moved downstream, including one to Bright Angel Creek, and 29% moved upstream. Mean daily movement rate was 0.1 km/day (SD=0.3).

Dye Mark

A total of 397,876 tetracycline marked rainbow trout were stocked at Lee´s Ferry between October 1983 and April 1986 (Table 7.5). Mean length was 125 mm (SD=75.0).

A total of 1,566 rainbow trout were examined for dye marks. The percentage of marked individuals declined dramatically below Reach 10, and no individuals examined for marks in Reach 50 were dyed (Figure 7.2). All dye marked fish below Reach 20 were collected from tributaries (Appendix 7.2).

The occurrence of natural reproduction in Reach 10 was confirmed by the presence of fry without dye marks (See Chapter 6). All fish sampled in the 50-100 mm size class (N=12) did not exhibit a mark. For all size classes, 39% of the sampled fish were not dyed.

Fin Clips

All captured fish were marked with a fin clip unique to the capture reach. Approximately 15,000 fish were marked with a fin clip only and less than 1% of recaptures were fin clip recaptures.

7.3. DISCUSSION

Tag-recapture: Introduced Species

Past studies on trout movement have provided variable results. Cargill (1980) observed little upstream or downstream movement from 470 wild rainbow trout in Valley Creek, Minnesota. Other species have also been shown to be sedentary, remaining within 0.8 km of release (Brown 1961). In contrast Bjornn (1971) reported upstream movement by juvenile salmon and

Table 7.4. Recapture data of Canyon Creek Hatchery rainbow trout released in Glen Canyon, September 1985 - May 1986.

	Tagged	Recaptured	
	Number	Number	Percent
Total	943	86	9.1
Movement			
Upstream		25	29.1
Downstream		37	43.0
None		23	26.7
To tributary		1	1.2
Mean distance moved per/day:		0.1 km/day	(SD=0.3)
Mean distance moved per/fish:		5.2 km	(SD=17.7)

Table 7.5. Stocking numbers and dates of oxytetracycline-marked rainbow trout at Lee's Ferry.

Stocking date	Number Stocked	Mean length (mm)
10/83	98,583	114
6/84	24,952	102
8/84	53,000	76
9/84	50,000	76
2/85	4,962	178
3/85	19,841	175
7/85	60,168	76
9/85	30,000	76
10/85	2,190[a]	305
4/86	53,180	76
	396,876	$\bar{x}$ = 125

[a] Includes Canyon Creek Hatchery rainbow trout

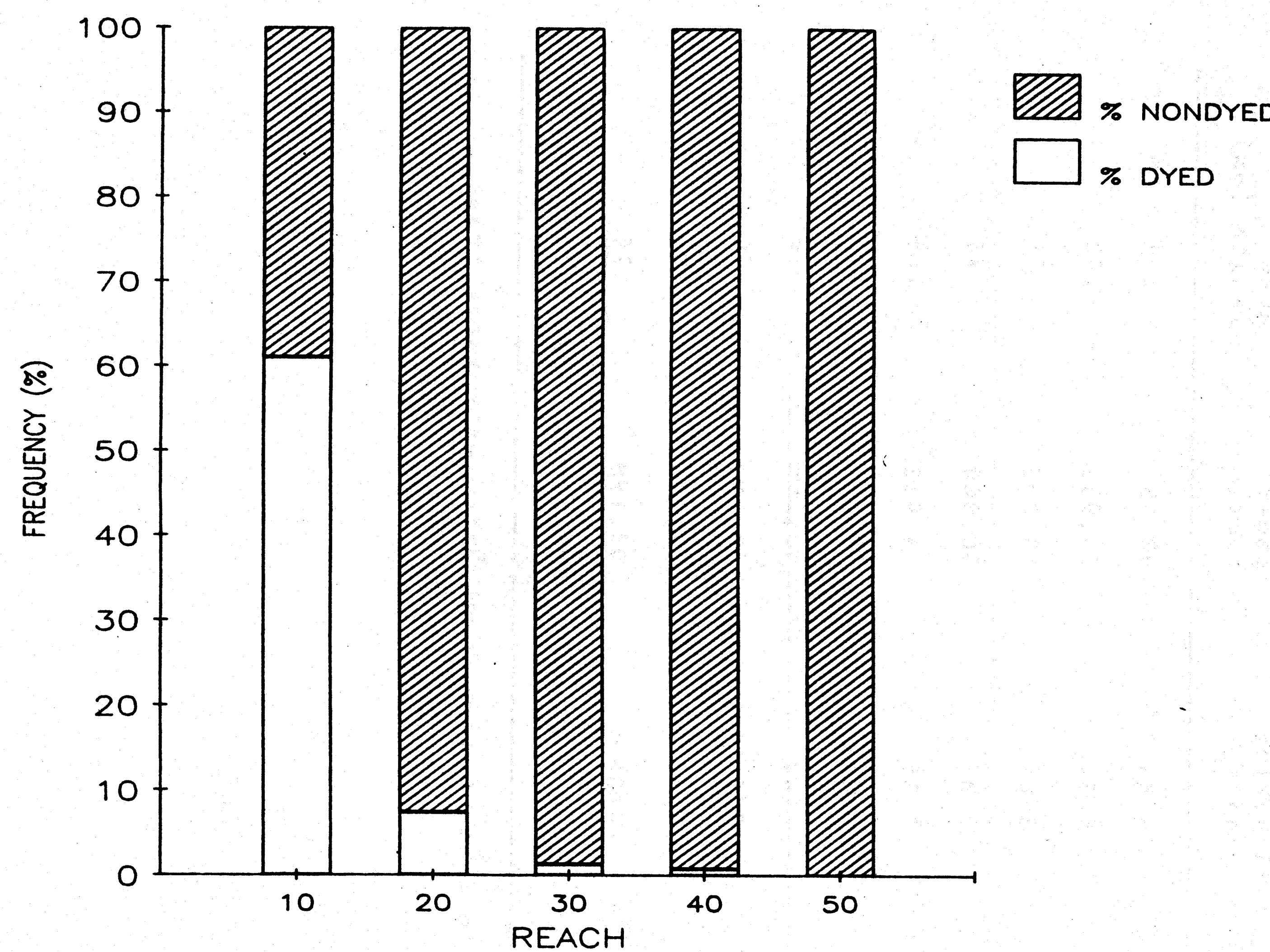


Figure 7.2. Relative frequency, by reach, of dyed and nondyed rainbow trout from Colorado River 1984-86.

trout occurred during summer, and downstream movement of all age classes occurred mainly during spring and autumn. Approximately 30% of the recaptured Gila trout in the Gila National Forest, New Mexico, were sedentary. Seventy-five percent of these were within 0.1 km of their original capture site (Rinne 1982).

Although a majority of the rainbow trout recaptured during this study showed movement, 42% of the recaptures were near the same location as tagging. Both upstream and downstream movement occurred frequently, and may have been due to the large size of the system.

The increase in tributary related recaptures during the winter seems related to rainbow trout moving into tributaries to spawn (See Chapter 5). Fluctuating flows during this period may affect accessibility to the tributaries by rainbow trout.

Brook trout exhibited the highest recapture rate of the study (10.2%), yet had the least number tagged. The high recapture rate may be in part because of their low abundance and limited distribution (See Chapter 4). A similar rate of 10.6% (over 33 years) was reported for wild brook trout in the Au Sable River in Michigan (Shetter 1968).

The amount of upstream and downstream movement documented for brook trout was similar and only 27% did not move from the tagging site. In contrast, Shetter (1968) reported 88% of the tagged trout to be within 1.6 km of the release site. No movement among reaches was observed.

Recapture rate of brown trout (6.5%) was lower than that for rainbow and brook trout. This may be due in part to the lack of returns for brown trout and to distribution being restricted largely to reaches 30 and 40.

Nearly 1,700 carp were tagged during this study, yet the recapture rate was fairly low (2.9%). Carothers et al. (1981) reported an even lower recapture rate of 0.9% during their 1977-1978 study. Although carp are not highly mobile, a few long-range movements have been recorded (Pflieger 1975). A tagged carp in Missouri moved 1,088 km upstream over a 28 month period (Pflieger 1975). In the Grand Canyon, a tagged carp traveled 425 km downstream (from Lava Falls to Lake Mead Marina) over a 4 month period (Carothers et al. 1981). Distances of 40, 42 and 52 km downstream were observed during our study.

Tag-recapture: Native Fish

Direction and distance moved by flannelmouth sucker were highly variable (second only to rainbow trout). Tributary/mainchannel exchange involved the Little Colorado and Paria rivers, and one incidence of tributary/tributary exchange occurred (Kanab Creek to Havasu Creek over a 23-month period). Most tributary movement was related to spawning (See Chapter 6). Similarly, Persons et al. (1985), captured flannelmouth sucker, tagged in the Little and Colorado and Paria rivers, in Reach 10. Spawning in these tributaries by flannelmouth sucker was also reported by Carothers et al. (1981).

The recapture rate for humpback chub during this study was similar to that previously reported in the Little Colorado River (Kaeding and Zimmerman 1983). Even though we were successful at capturing humpback chub in the Little Colorado River in the spring and early summer, present sampling gear and techniques were not effective at capturing individuals once they moved out of the Little Colorado River. However, six fish tagged in the mainchannel were recaptured in the Little Colorado River during their spawning period.

Canyon Creek Hatchery Rainbow trout

Recapture rate for rainbow trout stocked as adults was higher than for other tagged trout during this study. Once the stocked fish were discovered by anglers, the fishing pressure increased in the area of release. More than one quarter of the fish were recaptured in the release area. The remainder of these stocked trout moved throughout Reach 10. One was recaptured three months later 152 km downstream at Bright Angel Creek.

Dye Mark

The dye mark incidence (88.7%) for stocked fish during this study was similar to that previously reported (Weber and Ridgeway 1962, Bilton 1968, Jones 1969, Trojnar 1973). Stocked rainbow trout fingerlings dispersed throughout the Lee's Ferry area with few moving downstream. Stocking during the study took place during periods of steady flows, and environmental conditions inhibited the ability to fully examine the affects of fluctuating flows on stocked rainbow trout. If flows had been fluctuating, more downstream displacement may have been observed.

8. FISH FOOD RESOURCES

8.1 METHODS

A general idea of food resources available to Colorado River fishes and their utilization was gained by plankton tows, benthic dredges, drift net samples, and analysis of gut contents. Further information is provided in Haury (1986) and Leibfried and Blinn (1986), respectively.

Plankton tows were collected during the course of three river trips: December 1984-January 1985; October 1985; and November 1985 (See Haury 1981, 1986 for collections from other seasons). Samples were taken with tow nets having diameters of 13 cm or 30 cm and mesh sizes of 80 um, 243 um, or 363 um. Quantitative estimates of number of individuals/m^3 were made for samples in which a flow meter was available to determine the volume filtered. Collections were taken from both nearshore and mainchannel locations.

Fishes were collected according to methods described in Chapter 4. Larval fishes and adult guts were preserved in 5% and 10% formalin, respectively. Gut analyses were accomplished for larvae or fry of three species: rainbow trout, bluehead sucker, and flannelmouth sucker. Emphasis for adult fish gut contents was placed on rainbow trout.

Food items in the guts of fishes were identified under a dissecting microscope to various taxonomic levels utilizing keys by Usinger (1956), Edmondson (1959), Pennak (1978), and Merritt and Cummins (1978). Larval fish food items were counted and are presented as numerical proportions. Gut contents of adult fishes were separated into appropriate groups and added to volumetric cylinders so they could be reported as proportions by volume.

Comparisons of adult rainbow trout gut contents were made among reaches with tributaries combined and among seasons. Collections were made from all mainstream reaches and four tributaries (LCR, Tapeats, Deer, and Kanab Creeks). Effort expended in the inspection of gut contents was unequal both spatially and temporally (Appendix 8.1). Seasonal comparisons were restricted to combined mainstream reaches; tributary samples were numerically insufficient for seasonal analysis. Both the frequency of occurrence of food groups and their mean percent volume were analyzed in reach comparisons. All comparisons were made utilizing only fish having guts with some food contents.

8.2 RESULTS

Plankton Tows

A total of 24 taxa were identified from plankton tows taken during the course of this study (Table 8.1). Of these, there were 18: nine cladocerans, eight copepods, and the amphipod *Gammarus lacustris*. Only 12 taxa are members of the true limnoplankton; the remainder are benthic or substrate dependent forms carried by current as part of the invertebrate drift. All planktonic forms inhabit Lake Powell, and their populations in the Colorado River appear to be derived largely from individuals passing from the reservoir through Glen Canyon Dam (Haury 1986).

The two most commonly occurring taxa, the cyclopoid copepod, *Diacyclops bicuspidatus thomasi*, and the calanoid copepod, *Aglodiaptoms ashlandi*, were both present in 30 (88%) of the 34 plankton tows taken from the Colorado River. As a group, copepods occurred more frequently than cladocerans. Among the latter group, only *Bosmina longirostris* occurred in >50% of the samples. Rotifers were observed in only nine samples, but their representation was undoubtedly underestimated by nets with mesh sizes >80 um. No taxonomic determinations were made of rotifers.

Benthic and substrate dependent organisms were often present in plankton tows. Four taxa, the coelenterate *Hydra*, insect larvae, tardigrades, and harpacticoid copepods, occurred in 50% or more of the samples. Even the relatively large amphipod, *Gammarus lacustris*, was observed in four samples.

Inconsistency in mesh size and the sporadic presence of a flow meter prevent all but gross generalizations concerning densities of the taxa in plankton tows. Mean relative abundances were calculated independently for the three trips, but even they are not strictly comparable because all taxonomic groups were not counted consistently (Figure 8.1). As a group, copepods outnumbered the other tallied taxa during all three river trips. Diaptomid naupliar and copepodid densities exceeded those of all other groups on two trips, but they were outnumbered by cyclopoid adults (mainly *Diacyclops bicuspidatus thomasi*), diaptomid adults (mainly *Diaptomus ashlandi*), and insect larvae during November 1985. Although more cladoceran than copepod taxa were observed in plankton tows, the former group always occurred in relatively low densities.

Table 8.1. Taxonomic list of organisms identified from plankton tows in the Colorado River from Glen Canyon Dam to Diamond Creek during 1984-85.

Coelenterata

Hydra

Rotifera

Undetermined species

Tardigrada

Undetermined species

Copepoda

Aglaodiaptomus clavipes
Aglaodiaptomus forbesi
Leptodiaptomus ashlandi
Leptodiaptomus sicilis (?)
Skistodiaptomus pallidus
Diacyclops bicuspidatus thomasi
Mesocyclops edax
Paracyclops fimbriatus poppei
Undetermined harpacticoid species

Cladocera

Daphnia galeata mendotae
Daphnia pulex
Diaphanosoma birgei
Bosmina longirostris
Chydorus sphaericus
Alona guttata
Alona affinis
Leydigia quadrangularis
Pleuroxis denticulata

Amphipoda

Gammarus lacustris

Insecta

Undetermined larvae

Mollusca

Undetermined species

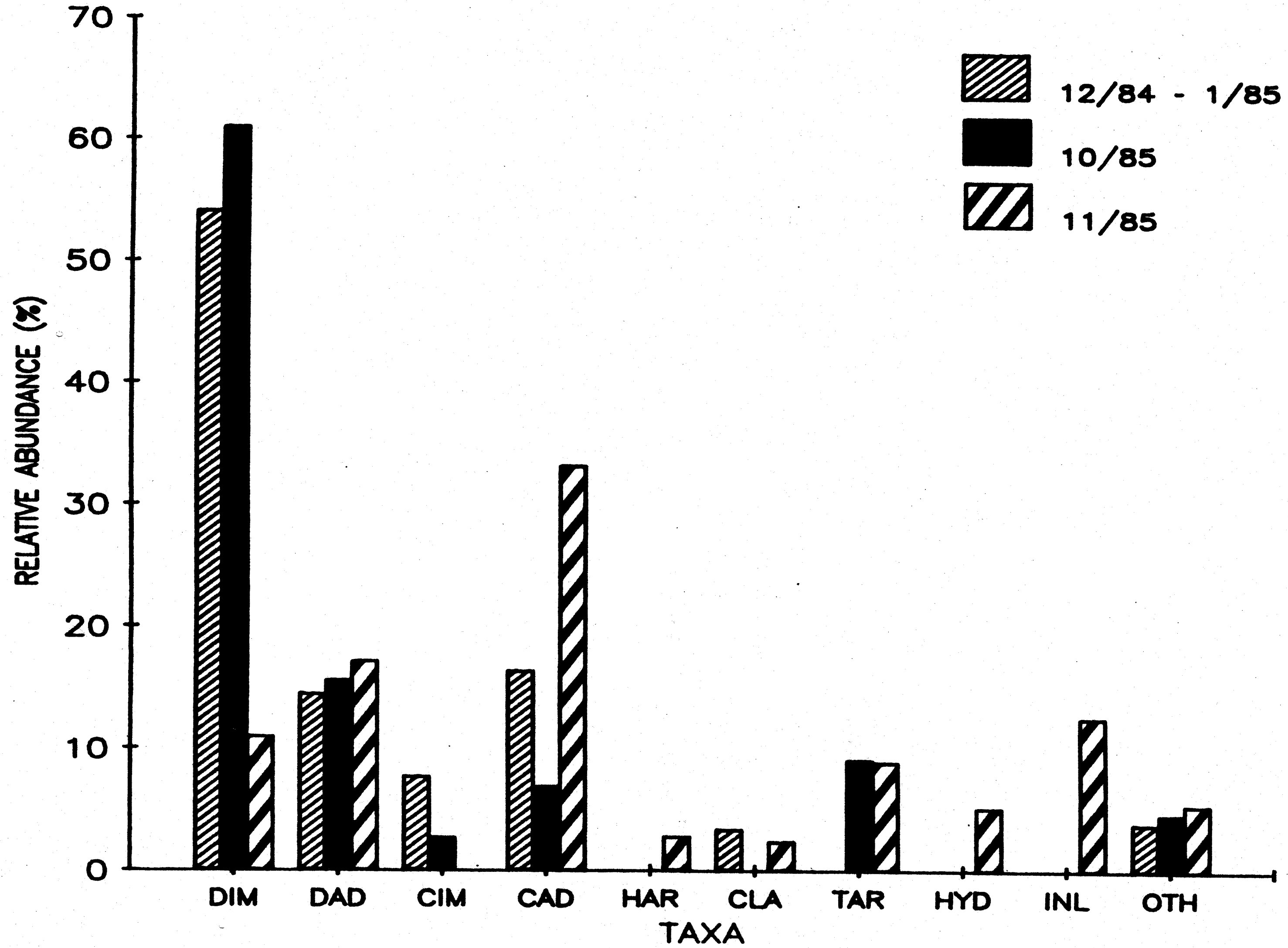


Figure 8.1. Relative abundance of taxa in plankton tows collected from the Colorado River in Glen and Grand Canyons during three sampling trips. DIM = diaptomid copepod immatures; DAD = diaptomid adults; CIM = cyclopoid copepod immatures; CAD = cyclopoid adults; HAR = harpacticoid copepods; CLA = cladocerans; TAR = tardigrades; HYD = *Hydra*; INL = insect larvae; OTH = others.

Substrate dwelling taxa were present in nearly all plankton tows, but their relative abundances were generally low when compared to planktonic forms. In November 1985, however, this group, including insect larvae, tardigrades, Hydra, harpacticoid copepods, and the chydorid cladoceran Alona affinis, comprised more than 30% of all organisms.

Densities of organisms in plankton tows were highly variable, both temporally and spatially. They ranged from 758 individuals/m^3 below Glen Canyon Dam in December 1984, to only five individuals/m^3 at River Mile 77 (Hance Rapids) in November 1985. Samples were taken through nearly the entire study reach only during December 1984 through January 1985. This series exhibited a general downstream decline in total density (Figure 8.2), a condition not unexpected in rivers forming outflows from lakes and reservoirs (See, however, Haury 1981, 1986).

Stomach Contents

Native Suckers - Eighteen flannelmouth and 43 bluehead sucker larvae ranging in length from 10 mm to 23 mm were examined for gut contents. Individuals were collected from both mainstream and tributaries; no attempt was made to separate by habitat. Chironomids were most prevalent numerically in the guts of both species (Figure 8.3) and also were present in more guts than any other group (83% and 49%, respectively). Planktonic Cladocera and Copepoda were second highest in numerical representation in flannelmouth sucker, but this position was held by blackflies in bluehead. Four bluehead sucker contained only detritus in their guts. This category was not included in the numerical proportions of gut contents.

Rainbow Trout - Rainbow trout fry were collected from both the mainstream (130) and tributaries (33). Individual lengths varied from 17 mm to 57 mm ($\bar{x}$=30, SD=6). Seventeen of 33 having empty guts were from tributaries; most of these were yolk fry which had not commenced feeding.

Diversity of food items was considerably greater in rainbow trout fry than in larval suckers, but this may reflect no more than the greater sample size and more protracted period over which the former group was collected. Immature chironomids, primarily larvae, comprised the greatest proportion of food items in both mainstream and tributary rainbow trout (Figure 8.4). Other immature aquatic insects were second highest in tributary

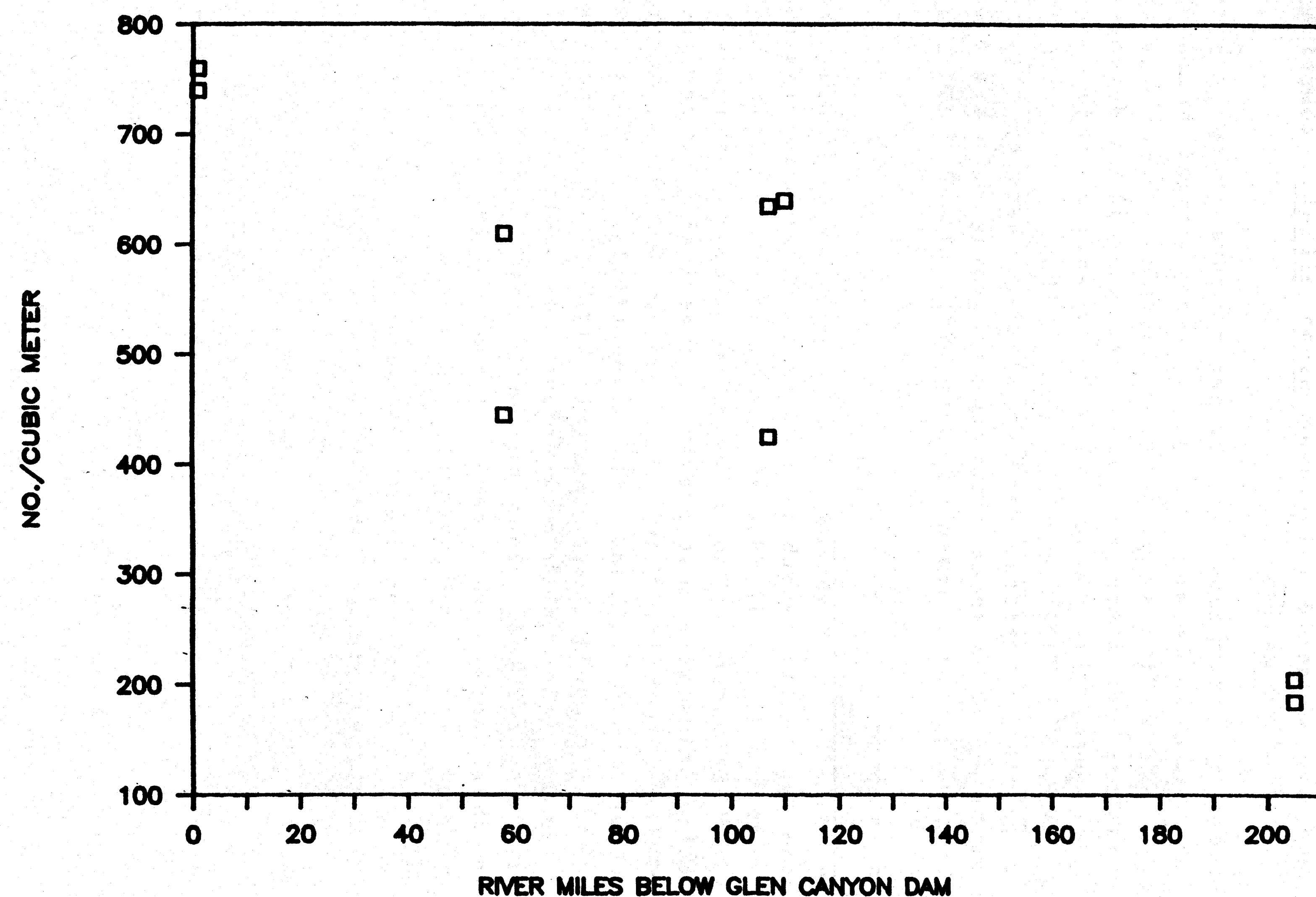


Figure 8.2. Numeric density of organisms (all taxa) collected from plankton tows from the Colorado River in Glen and Grand canyons during December 1984 to January 1985.

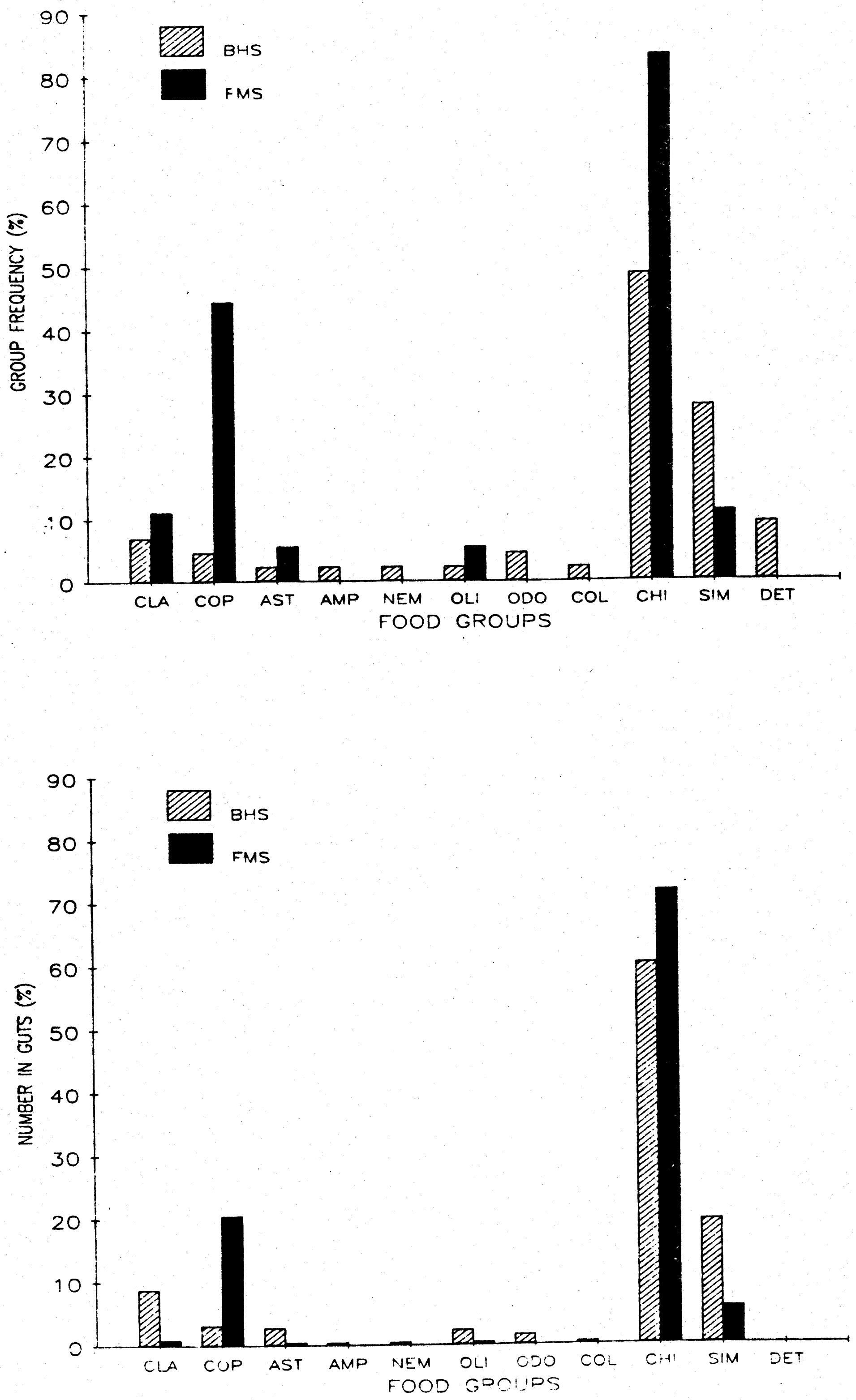
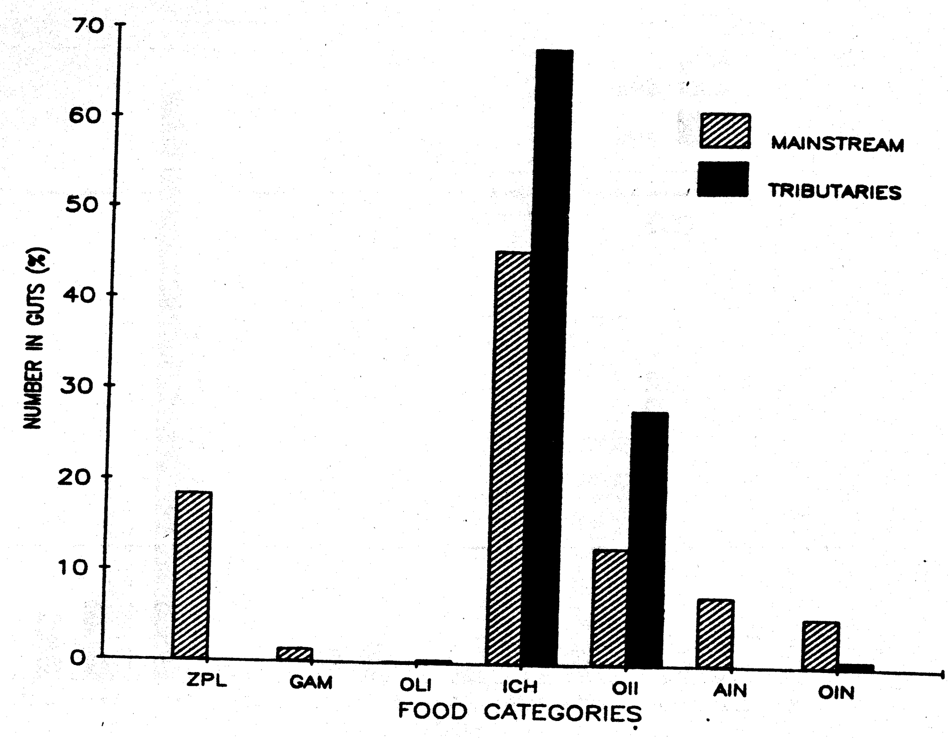


Figure 8.3. (Top) Frequency of occurence of food groups from guts of larval suckers (BHS=bluehead; FMS=flannelmouth) collected from the Colorado River and tributaries in Grand Canyon. (Bottom) Relative abundance of food group items found in guts of larval suckers. Food Groups: CLA=Cladocera; COP=Copepoda; OST=Ostracoda; AMP=Amphipoda; NEM=Nematoda; OLI=Oligochaeta; ODO=Odonata; COL=Coleoptera; CHI=Chironomidae; SIM=Simuliidae; DET=detritus.



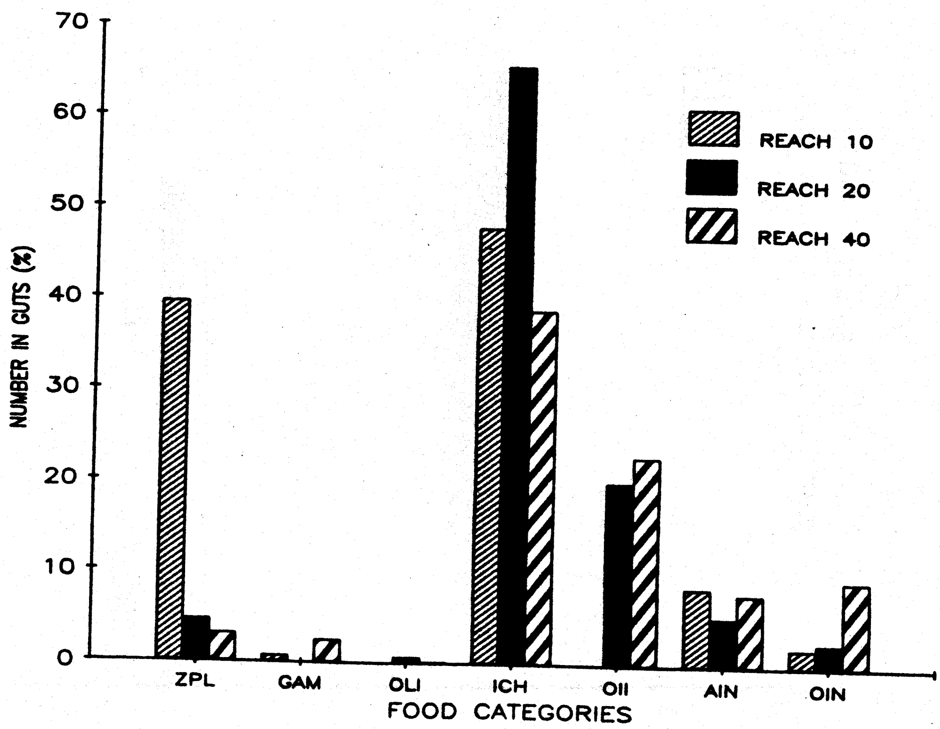


Figure 8.4. Relative abundance of food category items from guts of rainbow trout fry of: TOP-the Colorado River and tributaries in the Grand Canyon; BOTTOM-Reaches 10, 20, and 40 of the Colorado River. Food Categories: ZPL=zooplankton; GAM=Gammarus; OLI=Oligochaetes; ICH=immature chironomids; OII=other immature insects; AIN=adult insects; OIN=other invertebrates.

individuals, but this group was surpassed numerically by zooplankton in mainstream trout. Zooplankton was represented by diaptomid copepods, cyclopoid copepods, Daphnia, and Bosmina in order of decreasing numerical representation.

Sufficient numbers of mainstream rainbow trout fry were available to provide a downstream comparison of food groups in reaches 10, 20, and 40. Nearly 40% of gut items were zooplankton in Reach 10, whereas reaches 20 and 40 larvae contained only 5% and 3%, respectively, of this group. Diaptomid copepods formed the greatest proportion of this group in Reach 10, but the two downstream reaches contained greater numbers of cyclopoid copepods. Immature chironomids exceeded 35% of gut items in all three reaches and comprised more than 65% in Reach 20.

Of 730 adult rainbow trout guts examined, 44 (6%) were empty. Thirty-five of the 44 (80%) were collected during the period December-February, whereas only 35% of the total guts taken during the study were from this period.

Four food groups: chironomid midges, the alga Cladophora, the amphipod Gammarus lacustris, and detritus-occurred in >50% of guts examined from the mainstream and combined tributaries (Appendix 8.2). Presence of the cold stenotherm, G lacustris, in rainbow trout taken from tributaries was somewhat unexpected and may represent winter movements of the amphipod into these streams or fish that fed in the mainstream prior to capture. Molluscs were restricted to guts taken from reaches 10 and 20, whereas other fish occurred only in rainbow from reach 10, 30, 50 and tributaries. Fish occurred in only a small percentage of guts (ca. 1%).

Volumetric proportions of some food groups exhibited strong downstream trends in the mainstream (Figure 8.5, Appendix 8.3). Cladophora proportions decreased consistently downstream, whereas immature insects exhibited the opposite relationship. Increase in the proportion of immature insects was largely attributable to contributions from chironomids and simuliids. The latter group was particularly important in Reach 50, forming 66% of the mean food contents volume. The percentage of detritus increased from reaches 10 through 40, but then fell dramatically in Reach 50. Gammarus proportions were less than 10% of food volume in all reaches except 40, where the amphipod formed the greatest amount of gut contents.

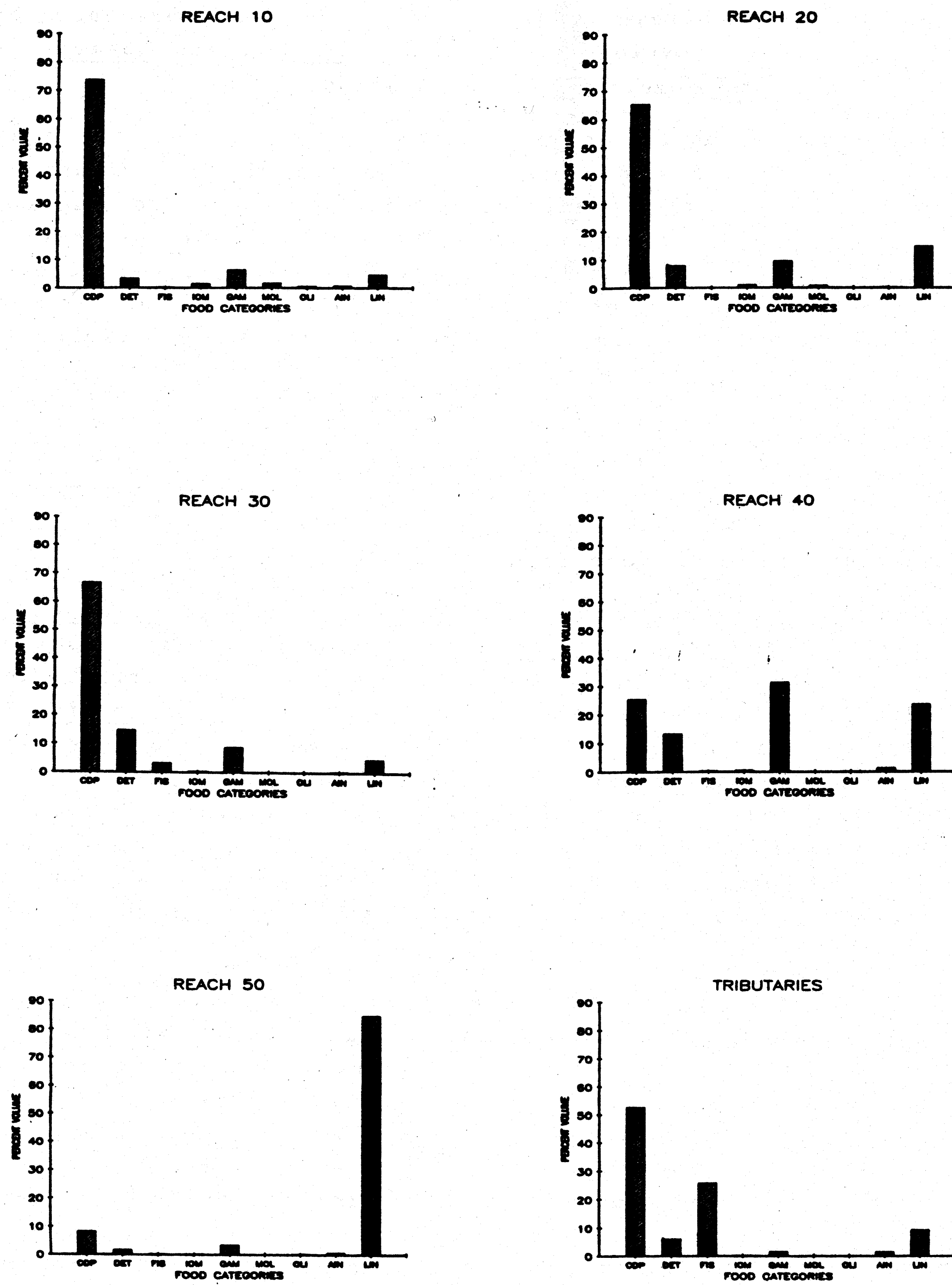


Figure 8.5. Mean percent volume (cc) of food categories from adult rainbow trout guts by reach and combined tributaries. Food Categories: CDP=Cladophora; DET=detritus; FIS=fish and fish eggs; IOM=inorganic matter; GAM=Gammarus; MOL=molluscs; OLI=Oligochaetes; AIN=adult insects; LIN=immature insects.

Combined tributary guts had content volumes dominated by *Cladophora* followed by fish and fish eggs, immature insects and detritus. The volumetric proportion formed by fish and fish eggs exceeded that of any mainstream reach. Immature insect contributions came largely from simuliids and trichopterans.

When all mainstream reaches were combined, *Cladophora* formed the majority (>50%) of adult rainbow trout gut contents in most seasons (Figure 8.6, Appendix 8.4). The proportion of *Cladophora* declined during the two winter seasons (December-February) of the study and markedly so during the fluctuating flow period of 1985-86. Immature insects, particularly chironomids and simuliids, and to a lesser extent *Gammarus*, displayed a contrasting relationship by having their greatest representation during winter months. Remaining food categories seldom made up 10% of gut content volume.

Of nine adult rainbow trout guts collected during the low flow period, 19-21 October 1984, five contained the amphipod *G. lacustris*. Mean percent volumn of the amphipod in these nine guts was 39%, a value more than seven times as great as that from all rainbow trout guts collected during autumn 1984. In the five guts containing the amphipod, the mean percent volumn of this taxon increased dramatically to 70%.

8.3 DISCUSSION

Studies of the food and feeding habits of native fishes in desert streams of the American Southwest are limited (See Deacon and Minckley 1974), and those of early life stages are decidedly lacking in the literature. Food habits of adult fishes in Glen and Grand canyons have been examined by McDonald and Dotson (1960), Stone and Rathbun (1968), Minckley (1978), Carothers et al. (1981), and Kaeding and Zimmermann (1983).

Larval bluehead and flannelmouth sucker in the Colorado River in Grand Canyon consumed a mixture of dipteran larvae, primarily chironomids, and zooplankton with minimal representation of other food groups. Feeding history of these suckers is probably related to that of the white sucker (*Catostomus commersoni*) whose larvae change food habits as the mouth migrates from the anterodorsal position to ventral, as in the adults (Stewart 1926). Early white sucker larvae consume surface and midwater invertebrates and then switch to benthic

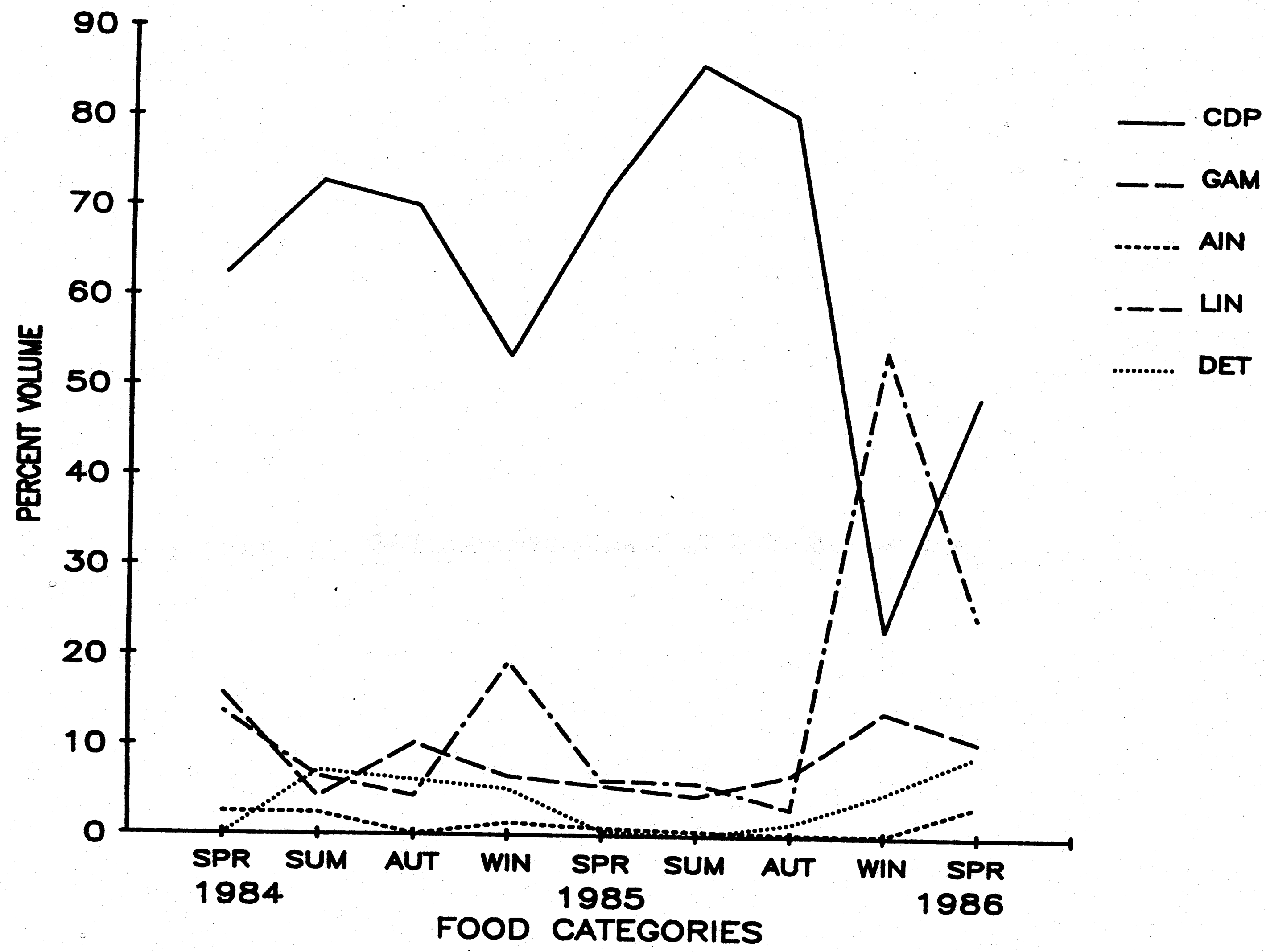


Figure 8.6. Mean seasonal (1984-86) percent volume of selected food categories from guts of adult rainbow trout, Colorado River mainstream. Food Categories: CDP=<u>Cladophora</u>; GAM=<u>Gammarus</u>; AIN=adult insects; LIN=immature insects; DET=detritus.

organisms and detritus as the mouth moves to the ventral position.

The degree to which early stage bluehead and flannelmouth sucker larvae depend on zooplankton cannot be determined from our results. Most individuals were collected from quiet water areas, however, where dipteran larvae probably do not occur in high abundance in the open water. Furthermore, size of prey may be limited to that of zooplankton, as opposed to the larger dipteran larvae, in early stage larvae.

Rainbow trout are opportunistic feeders and eat a wide variety of foods of both plant and animal origin. Early life stages depend primarily on plankton, but adults take larger food items, including aquatic and terrestrial insects, oligochaetes, mollusks, amphipods, fish eggs, fish, and macroscopic algae (McAfee 1966). Proportions of these items vary among bodies of water, season, and size of fish.

Rainbow trout in Grand Canyon follow the general pattern of changing food types with increase in body size. Fry consumed zooplankton, whereas this group was absent in adult fishes. Absence of zooplankton in adult guts contrasts with findings from post impoundment studies in the Glen Canyon tailwater (Stone and Rathbun 1968). This contrast may reflect the relative availability of benthic invertebrates at that time and during our study. There is little doubt that populations of benthic invertebrates, most of which were introduced into the tailwater, are present at considerably higher densities presently than in the years following impoundment of Lake Powell.

Downstream decline in the proportion of *Cladophora* in adult rainbow trout guts reflects the availability of this resource in lower reaches of the Colorado River (Usher et al. 1986). *Cladophora* growth is apparently restricted by suspended sediment loads from the Little Colorado River and consequent decreases in light penetration. Contrasting increases in the proportion of larval insects, primarily filter-feeding simuliids, may indicate a transition in lower reaches to dependence on suspended particulate matter of detrital origin.

Increase in the proportion of *Gammarus* in trout guts during the low flow period of October 1984 indicates the susceptibility of the amphipod to predation under conditions of fluctuating water levels. *Gammarus* appears to enter the drift at a higher rate than other invertebrate groups when discharges fluctuate (Leibfried and Blinn 1986). Amphipod movements are exaggerated in the presence of falling water levels, and these movements result in their aggregation into pools formed by the receding water (H. Maddux, personal observation). These factors appear to greatly increase the amphipod's susceptibility to predation by rainbow trout.

9. AGE AND GROWTH

INTRODUCTION

Age and growth data can provide useful information about a species response to environmental and biological conditions. Changes in growth rates and condition factors frequently can be used to draw inferences about factors that have affected a species or population. However, natural variation in growth rates and condition factors tend to confound and complicate analysis of short term age and growth data. Fish rarely show immediate responses to environmental or biological conditions in growth rates or condition factors. Many of the data presented in this section are provided to serve as baseline data for the years of our study.

This study, although intended to review effects of fluctuating flows on the aquatic ecosystem of the Grand Canyon, was limited to collecting most data during periods of high, steady flow. Therefore, few data were collected that can be used to conclusively show effects of various flow regimes on age and growth characteristics of the fishes in the Canyon.

9.1. METHODS

It was not possible to age fish by conventional scale and otolith methods, probably because the relatively constant water temperature in the river prevented formation of distinct growth annuli. Growth was estimated by examining length frequency distributions and by examining changes in length of marked fish between tagging and recapture.

Condition factor (K) was calculated by the formula:

$$K = W * 10^5/L^3$$

where W is weight in grams and L is total length in mm.

9.2 RESULTS

Rainbow Trout Growth

Rainbow trout were captured in sufficient numbers to use length frequency distributions for estimating growth. Examination of length frequencies by reach revealed several differences in growth rate and size of fish collected in different sections of the river. Rainbow trout collected in the mainstream above the Little Colorado River (LCR) were, in general, larger than fish collected below the LCR. Approximately 30% of rainbow trout collected above the LCR were larger than 400 mm whereas less than 2% collected below the LCR were larger than 400 mm (Figure 9.1). These differences in size distribution may reflect differences in growth rates, age composition, or both factors.

Length frequencies of fish collected during this study were compared with data collected during an earlier study (Carothers et al. 1981). Although maximum size of fish collected by Carothers et al. was larger, we collected a greater percentage of fish larger than 300 mm.

Growth rates were estimated by plotting modes in monthly length frequencies. One cohort, the 1984 year class, was collected in sufficient numbers to allow comparison of growth in all five reaches. Fish in reaches 10 and 20 grew at a similar rate, which was faster than fish in lower reaches (Figure 9.2).

There was great variation in growth estimated from recaptured Floy-tagged rainbow trout. Many fish showed no growth or even negative growth, although period of time at large for many exceeded 60 days. Of 588 rainbow trout recaptured, approximately 40% showed negative growth or no growth. This apparent discrepancy may be due to a variety of factors, including damage to the fish caused by electrofishing equipment, measuring error and data recording error, or no growth.

Many electroshocked fish had bruises or lumps on their backs that were characteristic of fish with broken vertebrae, possibly caused by electrofishing. Condition of backs (bruised and broken) was not routinely recorded on field data sheets. During May, 1986, a careful effort was made to examine fish for evidence of damage, particularly recaptured fish. Twenty three of 86 fish (27%) captured by electrofishing on May 6, 1986 had evidence of damaged backbones. Effects of this damage to fish are unknown, although other workers have reported impaired growth of electroshocked fish (Gatz et al. 1986).

Growth of adult rainbow trout in reaches 10-40 was estimated by regression formulae calculated from change in length of fish between tagging and recapture. The fit of the regression line for rainbow trout in Reach 40 was especially poor (r^2=0.018)

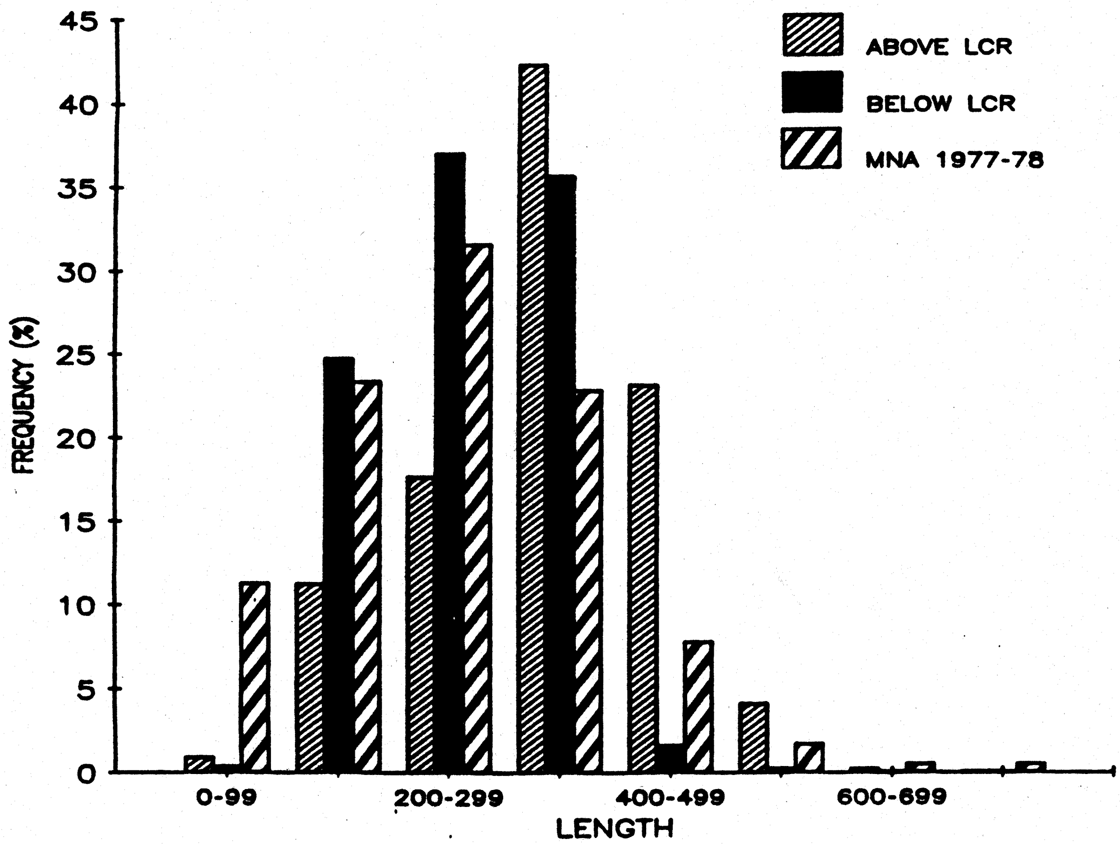


Figure 9.1. Length frequency distribution of rainbow trout collected above and below the Little Colorado River (data from present study and Museum of Northern Arizona-MNA 1977-78).

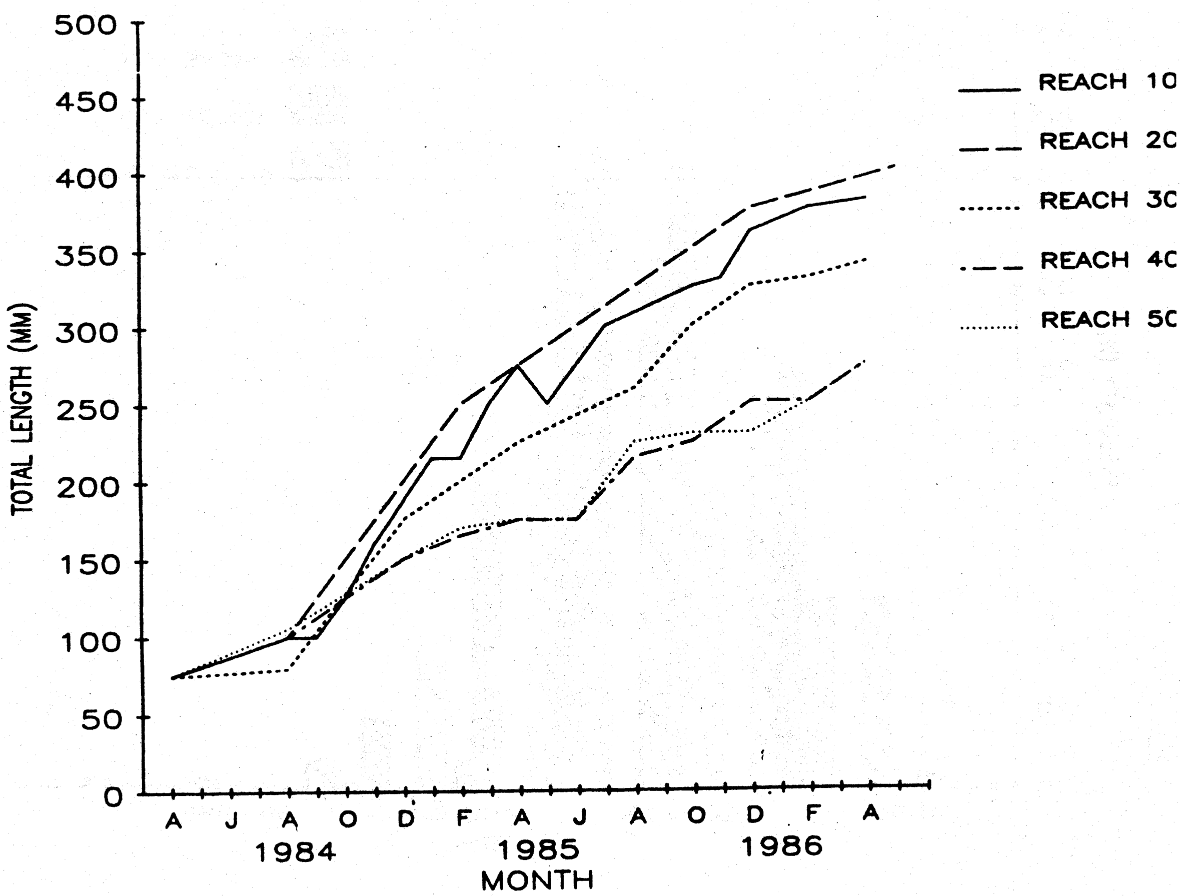


Figure 9.2. Estimated growth of rainbow trout from length frequency modes for reaches 10-50 from 1984-86.

because of small sample size (Figure 9.3). Analysis of covariance indicated that the slopes of regression lines differed significantly among the four reaches (F=16.14; df=3, 161; P<0.01). Calculated growth (B) for adult rainbow was highest in Reach 10 (0.22 mm/day) and lowest in Reach 40 (0.01 mm/day).

Length at recapture was plotted against length at tagging for rainbow trout which had been at large for approximately one year (300-400 days). The points determine a Walford line (Ricker 1975) whose intercept on the diagonal indicates a mean asymptotic size of about 500 mm. Estimated maximum length for fish captured below the LCR was about 469 mm, whereas that for fish captured above the LCR was 569 mm (Figure 9.4). Length frequency analysis also indicated that rainbow trout attained greater length above the LCR than below (Figure 9.1).

Rainbow Trout Year Class Strength

Ages based on monthly length frequencies were assigned to rainbow trout by reach of capture. It was assumed that all fish were "born" on January 1 and had a "birthday" on the same date the following year. Two techniques were used to examine relative year class strengths.

Electrofishing CPUE by year class for ages 0-II was determined to compare year class strength among reaches (Appendices 9.1-9.3). Highest CPUEs of the 1983 and 1984 year classes were in reaches 10 and 40 whereas the 1982 year class appeared strongest in reaches 20 and 40 (Table 9.1, Figure 9.5). Reach 40 had the highest CPUE of the 1985 year class.

There was also great variation in year class strength within reaches. Although CPUE of the 1984 year class was based on catches of fish aged 0, I, and II, only age II fish collected in 1984 could be used to calculate the 1982 year class CPUE. Because CPUEs were calculated for different age groups in different years, the year class strength index developed by Hile (1941) was used to compare year classes within reaches. Based on electrofishing CPUE, the 1984 year class index was higher in reaches 10 and 40 (Table 9.2). In all other reaches the 1985 year class was strongest. The greatest variation in year class strength was in Reach 50 with low year class strengths in 1982 and 1983, and a strong year class in 1985 due to large catches of age I fish in 1986 (Figure 9.5).

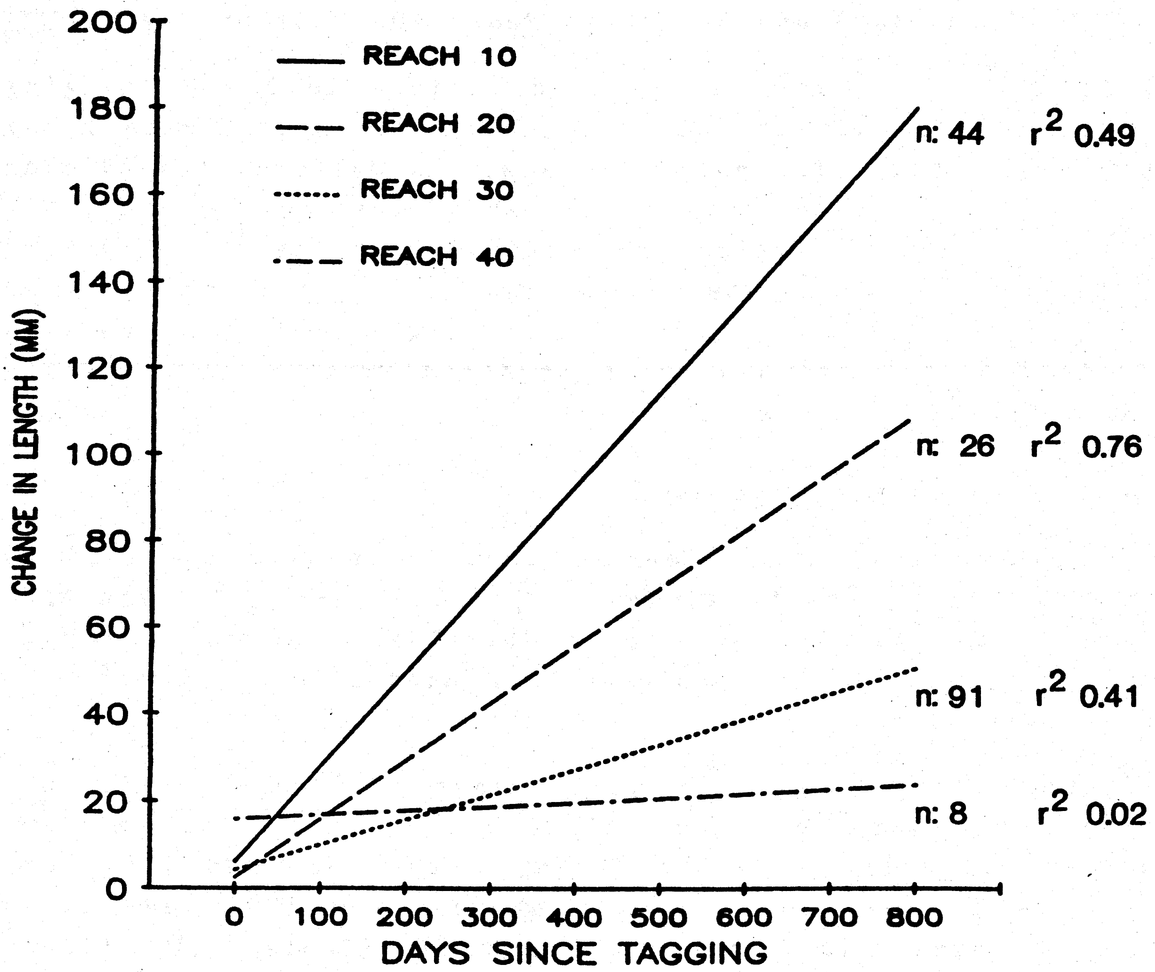


Figure 9.3. Relation between change in length (mm) and days since tagging of recaptured rainbow trout (250-350 mm TL) from reaches 10-40 during 1984-86.

Change in length		=	a	+	B (days at large)
Reach 10	TL	=	6.2	+	0.22(days)
Reach 20	TL	=	2.5	+	0.13(days)
Reach 30	TL	=	4.2	+	0.06(days)
Reach 40	TL	=	15.9	+	0.02(days)

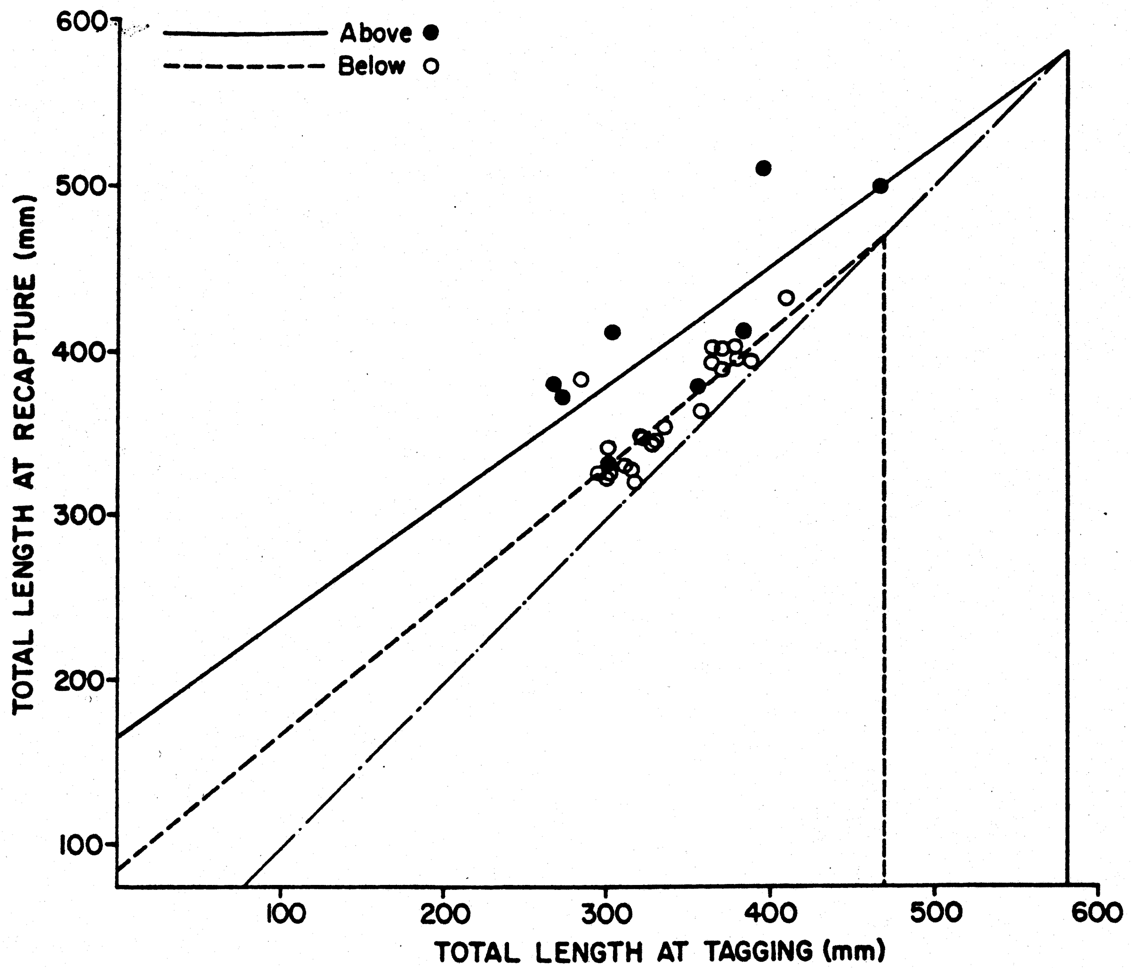


Figure 9.4. Rainbow trout total length at tagging vs recapture (approximately one year later) from above and below the Little Colorado River confluence, 1984-86.

Table 9.1. 1984-86 mean electrofishing catch per unit effort (catch/min) of rainbow trout by year class and reach, mainchannel Colorado River.

Year Class	Reach 10	20	30	40	50	All Combined
1982	0.20	0.29	0.23	0.28	0.05	0.22
1983	0.34	0.29	0.15	0.29	0.04	0.24
1984	0.57	0.34	0.14	0.48	0.11	0.36
1985	0.21	0.35	0.19	0.54	0.27	0.35

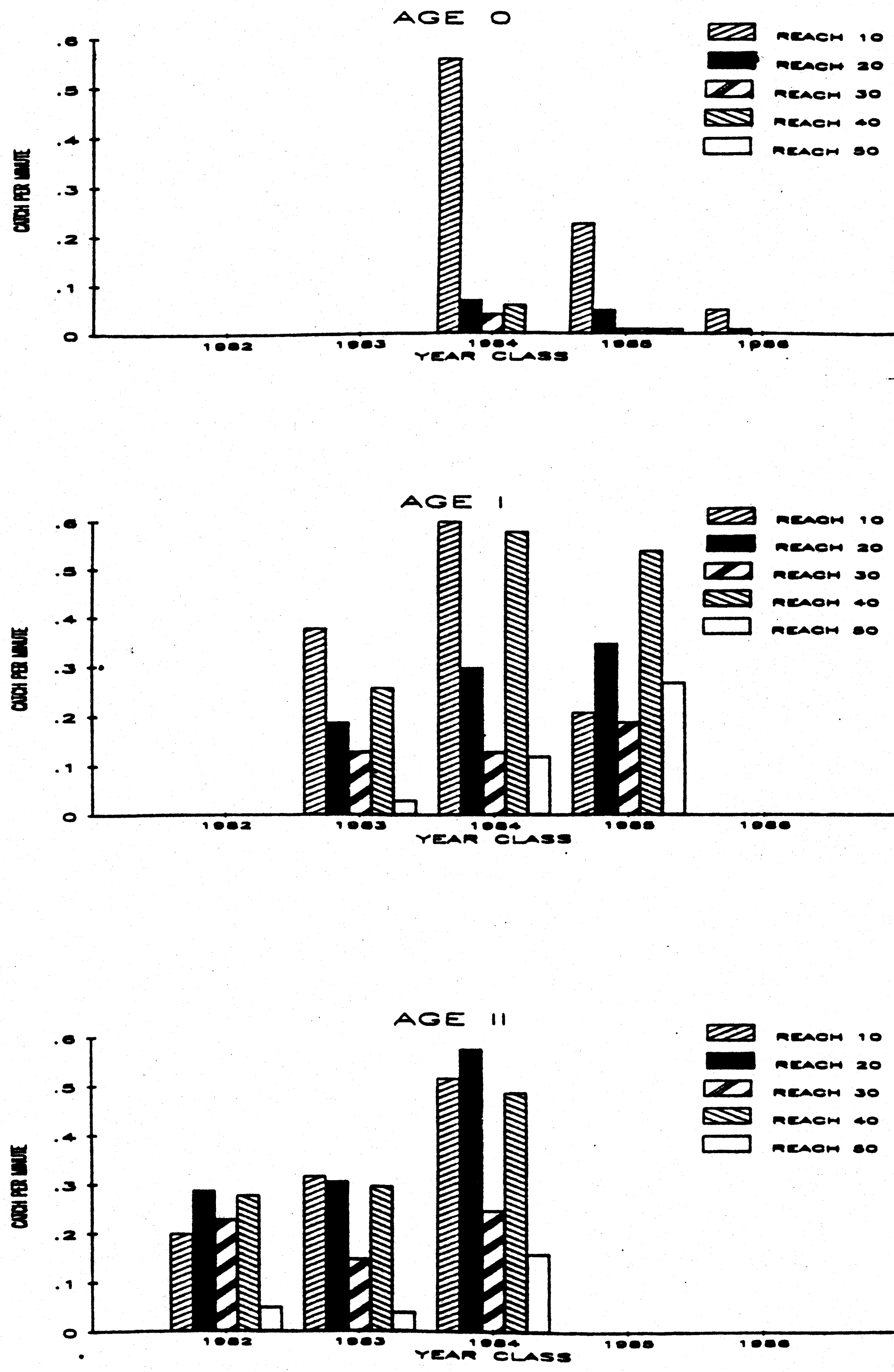


Figure 9.5. Electrofishing catch per unit effort (minute) of rainbow trout by estimated age and assigned year class for reaches 10-50, 1984-86.

Table 9.2. Hile goodness and poorness indices of year class strength of rainbow trout in reaches 10-50, Colorado River.

Year Class	10	20	30	40	50
1982	-33.6	-35.6	7.1	-34.7	-62.6
1983	12.5	-28.9	-35.1	-27.8	-84.8
1984	58.7	26.2	-4.7	34.8	35.2
1985	-37.6	38.3	32.8	27.7	112.1

Table 9.3. Probability (p) values for mean condition factor differences of rainbow trout (200-400 mm) between reaches, mainchannel Colorado River 1984-86. Wilcoxon rank sum test (two tailed) for independent samples. * indicates significance ($P \leq 0.05$).

		Reach			
Reach	Median K	20	30	40	50
10	1.051	0.541	0.021*	0.021*	0.021*
20	1.021		0.014*	0.0142*	0.021*
30	0.962			0.387	0.114
40	0.921				0.481
50	0.864				

Rainbow Trout Condition Factors

Condition factors (K) are used to describe the condition, plumpness, or well-being of a fish. Condition factors can vary with season, sex, sexual maturity, and age of fish.

Because condition factors generally decreased with increase in length of fish, differences in condition factors were examined by 100 mm length classes (Appendices 9.4). There was variation in condition factors between reaches, but in general, condition factors decreased with distance downstream from Glen Canyon Dam for all length classes. Mean condition factors in reaches 10 and 20 were significantly higher ($P<0.05$) than those in reaches below the Little Colorado River (Table 9.3, Appendix 9.5).

There was also variation in seasonal mean condition factors, but no apparent consistent seasonal pattern over the course of the study. In Reach 10, condition factors decreased from 1984 to 1986 for most length classes. In reaches 40 and 50, mean condition factors were highest in 1984, lowest in 1985, and intermediate in 1986.

Humpback Chub Growth

Growth of humpback chub was estimated by examining monthly length frequencies. Modes in length frequencies for young of the year fish in 1985 suggested growth to about 70 mm by the end of their first year (Appendix 9.6). Growth rates could not be determined after first year growth as modes in length frequency distributions were indistinct.

Thirty-one tagged and measured fish were recaptured during this study (Table 9.4). Some were tagged during studies as early as 1978. Most of the recaptured fish were tagged and recaptured in the LCR during the spring spawning period. Humpback chub appear to be slow growing after they reach maturity, and a relatively long lived species (Figure 9.6). Growth of mature fish (>250 mm) based on linear regression of days at large with change in length of recaptured fish averaged about 7 mm per year (length = 4.09 + 0.018473 [days at large], $r^2=0.28$).

Length frequencies of humpback chub collected above, below, and in the LCR were also examined. Most small fish (<80 mm) and large fish (>210 mm) were collected in the LCR, whereas fish 80-210 mm were generally caught below. These data suggest the LCR

Table 9.4. Humpback chub recapture data from the Colorado River and tributaries, 1984-86.

Tag #	Date tagged	Length Tag (mm)	Length Recapture (mm)	Weight Tag (g)	Weight Recapture (g)	Sex	Change in Length	Days out
025077	840518	294	301	218	180	.	7	372
025081	840518	414	415	560	510	.	1	372
025095	840518	335	338	.	300	.	3	373
025148	840518	382	390	524	420	.	8	373
025182	840518	393	395	540	413	.	2	714
0C2004	801106	354	377	550	558	F	23	1289
0C2038	810513	378	400	448	440	.	22	1474
0C2069	811029	262	325	196	286	.	63	932
0C2161	811106	310	341	312	330	.	31	924
0C2171	841221	327	335	297	250	F	8	156
0L0217	810401	350	369	406	.	.	19	1173
0L0218	810401	352	374	424	417	F	22	1887
0L0219	810401	334	363	318	330	.	29	1515
0L0220	810402	318	399	348	546	M	81	1856
0L0230	810401	347	365	370	370	M	18	1515
0L0254	810401	273	328	195	250	.	55	1173
0L0261	810401	318	387	348	523	M	69	1857
0L0263	810402	303	321	256	228	M	18	1888
0L0284	810402	260	317	172	210	.	57	1514
0L0308	810403	348	377	390	430	F	29	1513
0L0312	810403	328	344	328	323	.	16	1141
0L0312	810403	328	343	328	300	.	15	1171
0L0326	810515	276	295	172	304	F	19	1846
312447	860219	377	378	537	468	.	1	71
315223	860502	405	408	505	458	.	3	32
315232	860502	362	364	348	355	.	2	33
FWS132	780813	406	417	688	470	.	11	2477
FWS234	790714	334	342	318	318	.	8	1770
FWS725	800626	333	384	374	621	.	51	1422
FWS747	800625	290	364	180	342	.	74	2170
FWS848	800624	318	353	259	396	.	35	1424

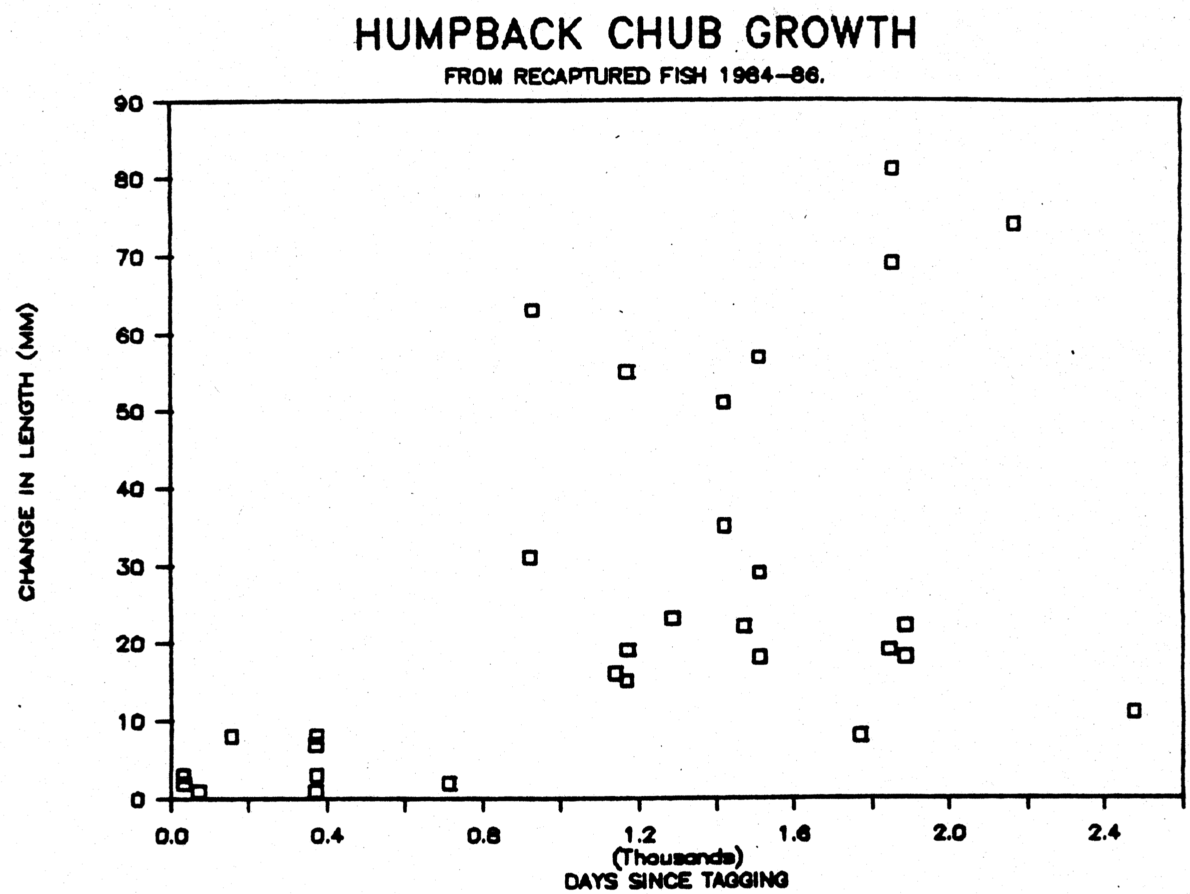


Figure 9.6. Relation between change in length (mm) and days since tagging of recaptured humpback chub, all reaches combined, 1984-86.

serves as a spawning and nursery area for humpback chub with young fish moving downstream in the autumn (Figure 9.7).

Flannelmouth Sucker Growth

Length frequencies of flannelmouth sucker were plotted to estimate first year growth. Modes in monthly length frequencies were not as obvious as for other species, partly because flannelmouth appear to spawn during several months of the year (Chapter 4). Estimated first year growth of flannelmouth ranged from 70 to 100 mm (Appendix 9.7).

Thirty-three tagged and measured flannelmouth sucker were recaptured during this study (Table 9.5). As with other native species, growth of adult fish was slow, and variable.

Length frequency distributions of flannelmouth sucker, in relation to the LCR, were similar to other native species, with large fish present above, adult spawners and small juveniles present in the LCR, and intermediate sized fish caught below the LCR (Figure 9.8).

Bluehead Sucker Growth

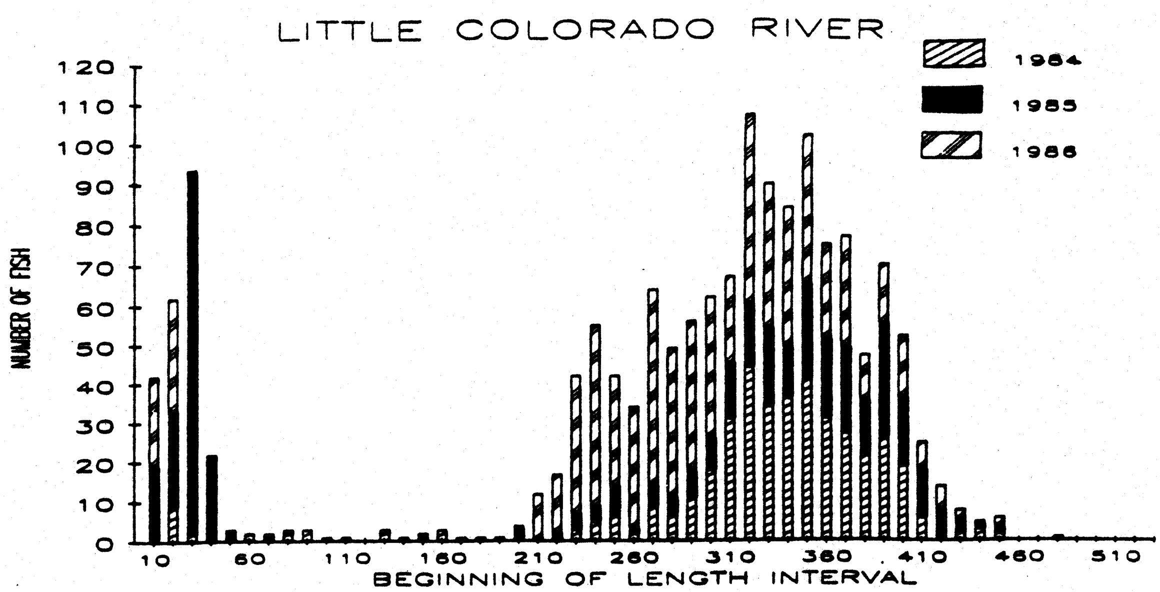
First year growth of bluehead sucker, based on monthly length frequencies, was similar to first year growth of flannelmouth sucker, with individuals attaining 70-100 mm during the first year. Monthly sample sizes were too small to estimate growth of older fish.

Length frequency distributions of bluehead sucker above, below, and in the LCR were similar to other native species, with large fish present above, adult spawners and small juveniles present in the LCR, and intermediate sized fish below the LCR (Figure 9.8, Appendix 9.8).

Not enough bluehead sucker were tagged and recaptured to draw any inferences about growth.

9.3. DISCUSSION

Our study indicates continuous trout growth throughout the year in the Glen Canyon tailwater. Trout growth in tailwaters is variable, frequently comparable to that in reservoirs, and often



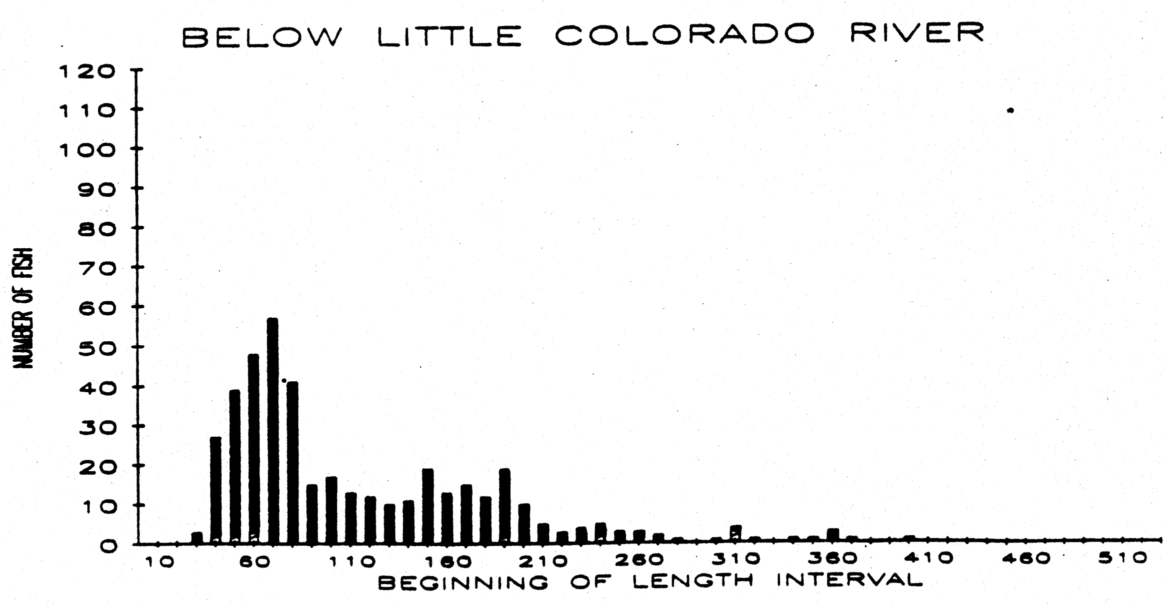


Figure 9.7. Length frequency of humpback chub collected at and below the mouth of the Little Colorado River by year of capture, 1984-86.

Table 9.5. Flannelmouth sucker recapture data from the Colorado River and tributaries, 1984-86.

Tag #	Date tagged	Length: Tag (mm)	Length: Recapture (mm)	Weight: Tag (g)	Weight: Recapture (g)	Sex	Change in Length	Days out
000770	850131	502	513	1360	1234	.	11	452
024264	840414	380	440	500	910	.	60	406
024264	840414	380	441	500	930	.	61	407
024793	840424	220	274	104	214	.	54	473
025291	840518	352	451	358	940	.	99	642
025412	840524	484	490	1150	.	.	6	743
025744	840807	442	443	976	889	F	1	263
025976	850426	406	447	744	875	.	41	299
025981	850425	552	558	1400	1797	F	6	371
026818	850307	539	556	1451	1612	.	17	417
026823	850307	541	545	1806	1780	F	4	342
028062	840922	452	455	950	624	.	3	509
028214	841019	566	570	1800	1306	.	4	483
028256	841218	402	420	720	.	.	18	366
028365	841020	516	517	1350	1360	.	1	111
301143	850526	471	478	840	.	.	7	268
301587	850528	426	427	610	.	M	1	267
305227	850522	503	508	1300	1239	F	5	322
305231	850522	393	405	600	730	M	12	182
305278	850521	506	507	1400	1332	.	1	267
305278	850521	506	508	1400	1395	.	2	323
305352	850521	509	522	1350	1444	F	13	267
305795	850522	512	526	1300	894	F	14	268
306191	850730	494	506	1047	863	.	12	199
306202	850723	455	471	1042	1062	.	16	204
306557	850723	465	467	894	1002	M	2	75
306557	850723	465	466	894	1030	M	1	279
306562	850723	500	516	1247	1349	.	16	204
306566	850723	507	514	1405	1349	.	7	261
306996	850810	370	407	.	704	.	37	273
306997	850810	464	477	.	1090	.	13	193
307084	851006	478	490	944	947	.	12	204
307474	851120	485	488	885	1302	.	3	84

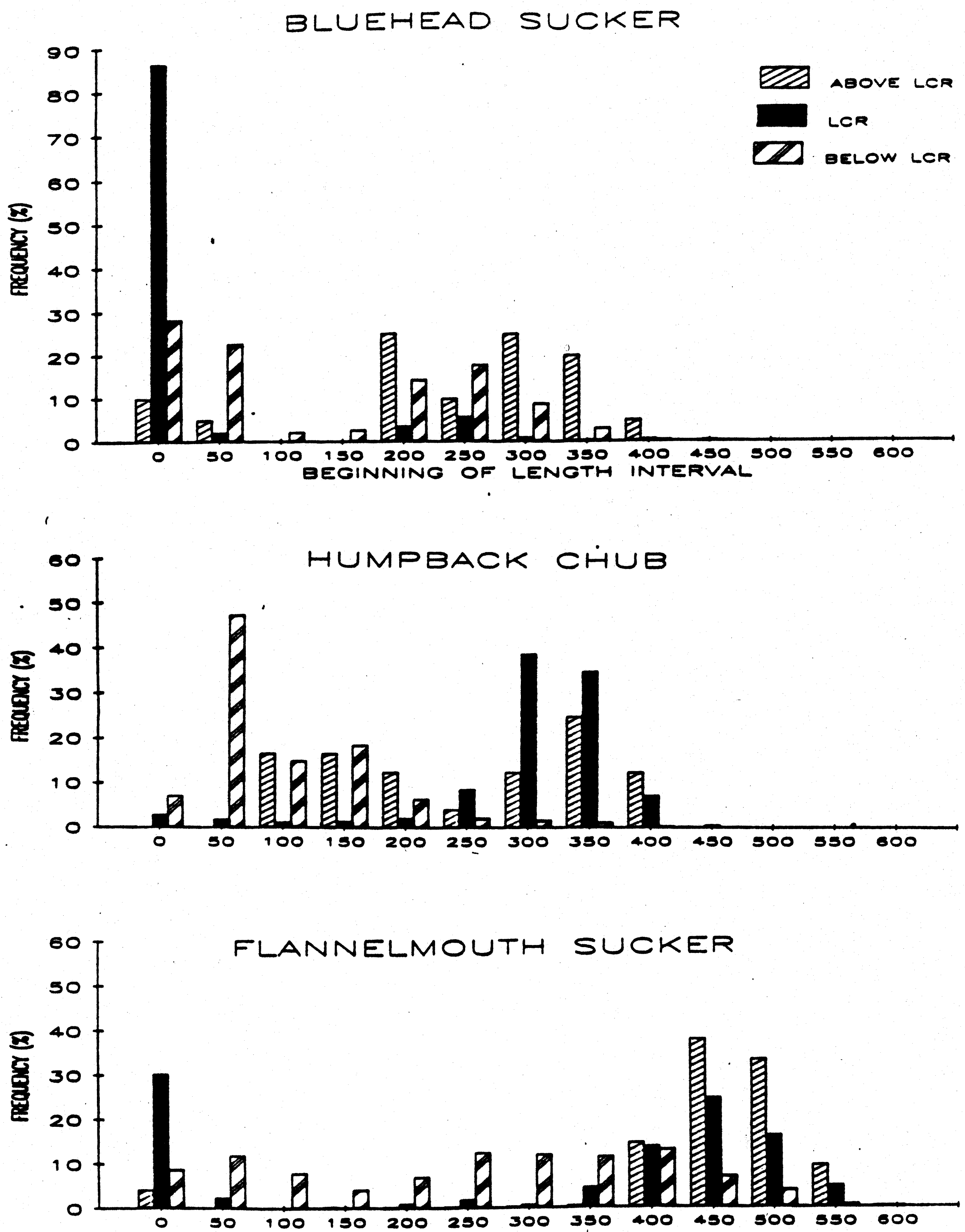


Figure 9.8. Length frequency of bluehead sucker, humpback sucker, and flannelmouth sucker collected at and below the mouth of the Little Colorado River by year of capture, 1984-86.

exceeds that in natural streams (Welch 1961, Trotzky and Gregory 1974). Cold, constant temperatures contribute to year-round growth of rainbow trout in many tailwaters including the Glen Canyon tailwater (Moffett 1942, Parsons 1957, Pfitzer 1962, Olson 1968, Walburg et al. 1981).

During this study rainbow trout fingerling stocked in October 1983 at 100 to 115 mm ranged from 250 to 300 mm total length one year later. Rapid growth of rainbow trout stocked in tailwaters has been reported in many studies. Mullan et al. (1976) reported that stocked fingerlings averaging 191 mm long grew 76 to 102 mm per year in Glen Canyon tailwater; 76 mm fingerlings grew to 254 mm in length in one year in Flaming Gorge tailwater, Utah; and 76 to 127 mm fingerlings grew to 254 to 381 mm in length in Fontenelle tailwater, Wyoming. Rainbow trout fingerlings released at an average length of 83 mm grew 178 mm from July to December in Navajo tailwater, New Mexico (Olson 1965). Stevenson (1975) reported that the average length of rainbow and brown trout below Yellowtail Dam, Montana, increased 152 mm between May and December.

Rapid growth of trout is associated with the abundance of food organisms coming from a reservoir and the abundant invertebrates produced in the tailwater (Walburg et al. 1981). *Cladophora* beds frequently develop in cold tailwaters and can be an important source of food for trout (Moffett 1942, Mullan et al. 1976, Walburg et al. 1981, Montgomery et al. 1986). Trout feed on this alga and ingest associated diatoms, isopods, amphipods, snails, and other invertebrates associated with the *Cladophora* (Moffett 1942, Parsons 1957, Welch 1961, Mullan et al. 1976, Montgomery et al. 1986). Apparent decreased growth of trout with distance downstream from Glen Canyon Dam is likely associated with decreasing quantity and quality of food resources (Leibfried and Blinn 1986) but may also be due to genetic differences in the trout (Claussen and Philipp 1986).

Fluctuating flows and periodic dewatering may limit production of algae and associated fish food organisms in the Glen Canyon tailwater (Leibfried and Blinn 1986, Uscher et al. 1986). Periodic dewatering of stream margins and current velocity fluctuations over submerged areas of the stream bed due to peaking flow fluctuation have reduced macroinvertebrate standing crops and community complexity in several streams (Radford and Hartland-Rowe 1971, Fisher and LaVoy 1972, Bruvsen et al. 1974, Trotzky and Gregory 1974). Because tailwater trout rely on invertebrates and Cladophora for food, fluctuating flows that impact plants and invertebrates can also affect trout.

Rainbow trout growth decreased in Tennessee's Dale Hollow tailwater, in 1953 and 1954, when the number of fingerlings stocked was increased from 20,000 to 30,000. This indicated high utilization and competition for available food in the tailwater (Walburg et al. 1981). Effect of increased stockings on growth of rainbow trout in the Glen Canyon tailwater are unknown. Other workers have reported decreasing growth rates with increasing density of fish. Such an explanation may account for the lower condition factor in Reach 40 in 1985, when density of fish was high (See Chapter 4).

There are a variety of possible explanations for faster growth of rainbow trout in upstream reaches. Productivity above the LCR is likely higher than below the LCR because of greater light penetration above the mouth of the silty tributary. Food resources may be more abundant; fish may be genetically different; fish may be more effective feeders; and there may be less competition for food resources in upper reaches.

Strong year classes in Reach 10 relative to other reaches may be due, in part, to stocking efforts at Lee's Ferry. The relative weakness of the year 1982 class in Reach 10 (Age II fish collected in 1984) may be due to harvest by anglers. High CPUE of most year classes in Reach 40 may be due to recruitment from several tributary streams that offer good spawning habitat for rainbow trout (See Chapter 5).

The most reliable growth information available for this study is from length frequency distribution analysis. It would be helpful to examine similar data during periods of fluctuating flows. Data available from previous samples (Carothers et al. 1981) were examined, and relative growth rates derived from length frequencies were similar to intermediate growth (Reach 30) determined for our collections. Unfortunately, River Mile locations for fishes collected during 1977-78 were not available, so more specific comparisons are not possible at this time.

10. STRANDING AND REDD DEWATERING

STRANDING

10.1.METHODS

The lack of fluctuating flows during the present study has reduced our ability to examine their effects on the stranding of fish. However, in October 1984 the Bureau of Reclamation lowered the discharge rate to approximately 5,000 cfs for a period of three days. This is the type of flow that often occurs during a holiday period. Arizona Game and Fish Department personnel, with volunteer help from Northern Arizona University, examined stranding during this three day period. Low water inhibited our ability to census the entire river so numbers of stranded fish are underestimated.

Fish were collected from isolated pools (backwaters) using dip nets and seines. Fish collected were identified, measured, and weighed. Live fish were tagged and released. Fish found in stages of decomposition were enumerated. Stranding mortalities were returned to the laboratory and examined for an oxytetracycline dye mark.

An isolated pool at RM 7.5 above Lee's Ferry was seined, and fish were released back into the pool. Water temperature was measured in the pool and mainchannel each day. The pool was examined periodically for dead fish.

Often, when there were changes in flow, pools or backwaters became isolated from the mainchannel. During sampling trips when these isolated waters were encountered, they were sampled for fish and the water temperature was measured.

We also list a few reports of stranding observed by others and reported to our office.

10.2.RESULTS

In excess of 800 trout were observed stranded from October 19-21, 1984. Because many had been partially consumed by predators, physical data were recorded for only 639 fish. The rate of change in discharge during a 30-minute period ranged from 0.4-16.6%; the highest rate occurred when discharge dropped from 7,640-6,370 cubic feet per second (cfs) (Figure 10.1).

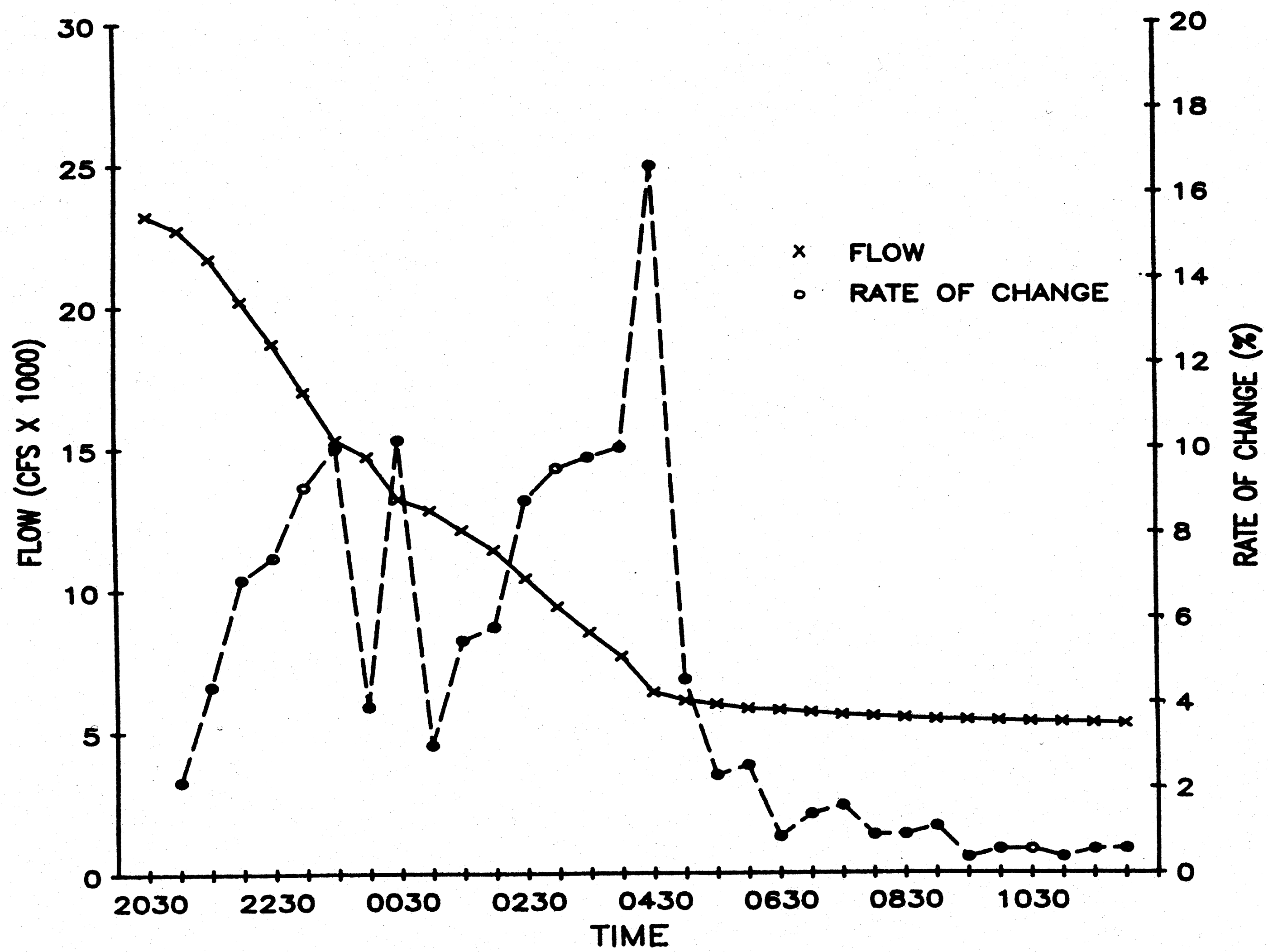


Figure 10.1. Colorado River flow and discharge rate of change from Glen Canyon Dam in 30 minute intervals during October 1984 low flow period.

Of the 639 fish examined, 635 (99.4%) were rainbow trout, three (0.5%) were brook trout, and one (0.2%) was a green sunfish. Eighty-five (13.3%) of the 639 fish were alive when found. Most stranded fish were located on a cobble bar below Lee's Ferry.

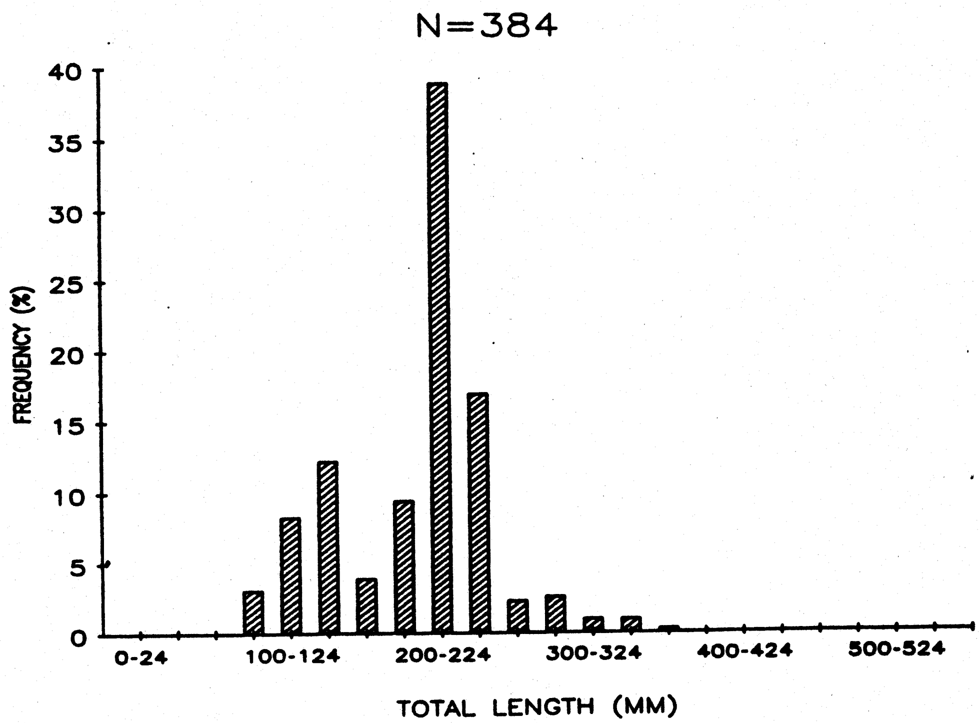
The isolated pool monitored at RM 7.5 contained 13 rainbow trout. Total length for these trout ranged from 102-550 mm ($\bar{x}$=373.0 mm), and weight ranged from 10-1720 g ($\bar{x}$=793.8 g). The pool measured 31.1 x 10.1 m (mean depth 12.0 cm). Water temperature in the mainchannel during this period ranged from 10.5-11.0°C, while temperature in the isolated pool was 11.5°C. The porous gravel substrate probably allowed river water to filter through the pool to maintain water temperatures. In the three day period there were no observed mortalities.

Fish in pools located on a spawning area below Lee's Ferry suffered high mortality (95.2%). Mortality differences may be related to distances of the isolated pools from the mainchannel. At RM 7.5 the pool was $<$20 m from the river, while the pools below Lee's Ferry were $>$100 m.

Fish were captured by electrofishing from a large isolated backwater at RM 12 above Lee's Ferry. No dead fish were found in this backwater. However, there were many anglers fishing the isolated backwater. Fifty-one fish (mean length 364.7 mm, range 140-577 mm; mean weight 804.4 g, range 36-2440 g) were collected in 11 minutes of electrofishing, representing almost 5 fish/min.

Most incidences of stranding reported to our office concerned a bar located immediately downstream from the dam (RM 15). Reports were received following weekend low flows during the winter 1985/86 when water level fluctuated. Stranding was reported to be mostly large adults in reproductive condition. Estimates varied from 20-100 rainbow trout with as many as 40 mortalities. This same pool contained stranded fish during the October 1984 low flow period.

Of the stranded fish examined for an oxytetracycline dye mark, 91.4% displayed a dye mark and 8.6% were nondyed. The greatest percent of dyed fish was from the 200-224 mm size group. Nondyed fish were generally smaller and most were from 75-124 mm (Figure 10.2).



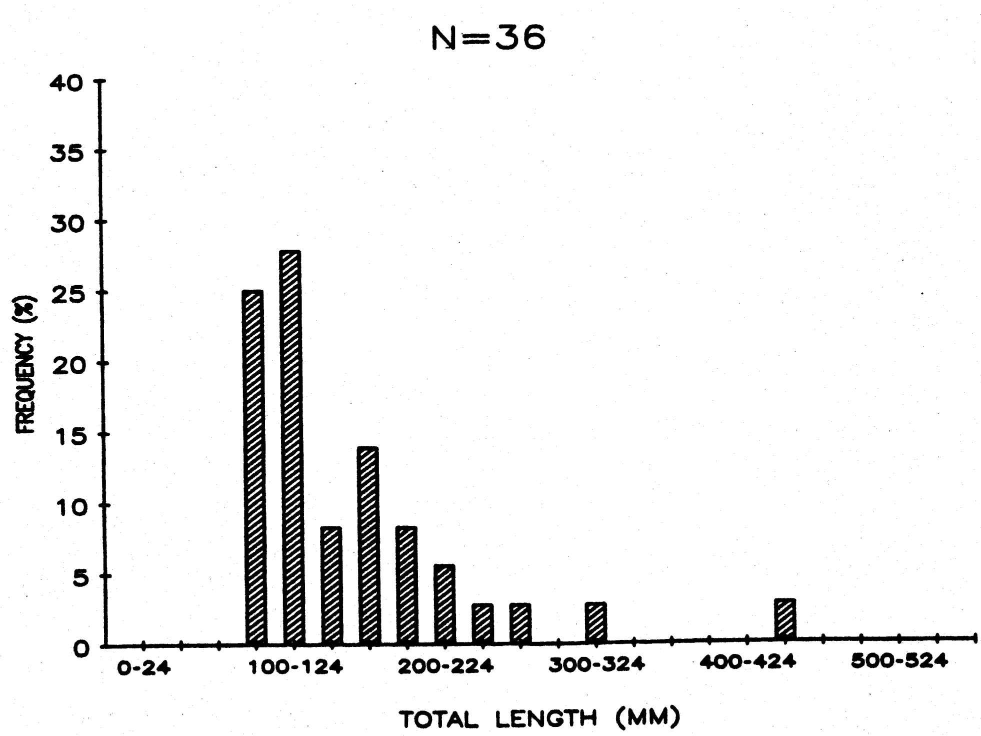


Figure 10.2. Length frequency of rainbow trout stranded in Reach 10 during October 19-21, 1984 low flow period and examined for oxytetracycline dye mark. Top figure represents dyed fish, bottom figure nondyed fish.

The only method used to evaluate stranding in reaches 20-50 was through sampling backwaters that had been isolated from the mainchannel because of changes in flow. Because these isolated backwaters remain for short periods of time only 43 were sampled (Table 10.1). Over half (53.5%) occurred in Reach 50. During video work at 28,000 cfs 30.3% of all isolated backwaters were in Reach 50 (Chapter 4).

Mean length of fish in isolated backwaters was generally small. Except for carp and rainbow trout, the mean length for all species was <55 mm (Figure 10.3).

Isolated backwaters containing few or no fish were often encircled with predatory bird and mammal tracks. This suggests that our estimates of stranding are probably low.

In all, 1,923 fish were found stranded or isolated from the mainchannel. Fathead minnow (61.9%) and rainbow trout (33.3%) accounted for most of the stranding (Table 10.2). Four native species were also found in isolated backwaters: speckled dace (1.9%); bluehead sucker (1.7%); humpback chub (0.2%); and flannelmouth sucker (0.2%).

Catch per unit effort (CPUE) of fishes collected by seining in isolated backwaters from reaches 20-50 ranged from 0.3 fish/100 m^2 for rainbow trout to 287.4 fish/100 m^2 for fathead minnow (Table 10.3).

10.3. DISCUSSION

Documenting fish stranding was done primarily during October 19-21, 1984. This was mainly due to a lack of fluctuating flows (Chapter 3). However, from observations during the three day low flow period in the Lee's Ferry area, and through sampling of isolated backwaters downstream, it appears that fluctuating flows could affect native and sport fishes.

Fish entrapped in pools or backwaters as water levels decline may suffer mortality from several sources. These include: (1) oxygen depletion when fish are concentrated in shallow isolated pools; (2) lethal temperatures during summer months when pools approach ambient temperatures; (3) predation or scavenging by birds and mammals; and (4) desiccation when water within a pool declines leaving fish exposed to the atmosphere (Neel 1963, Becker et al. 1981).

Table 10.1. Number of isolated backwaters sampled in reaches 10-50 from April 1984 - June 1986.

Reach	1985 Spring	1985 Summer	1985 Autumn	1985 Winter	1986 Spring	Totals Number	Totals Percent (%)
10	2	0	0	0	0	2	4.7
20	0	0	0	1	1	2	4.7
30	1	0	3	1	1	6	14.0
40	1	2	3	3	1	10	13.3
50	1	8	6	6	2	23	53.5
Total	5	10	12	11	5	43	

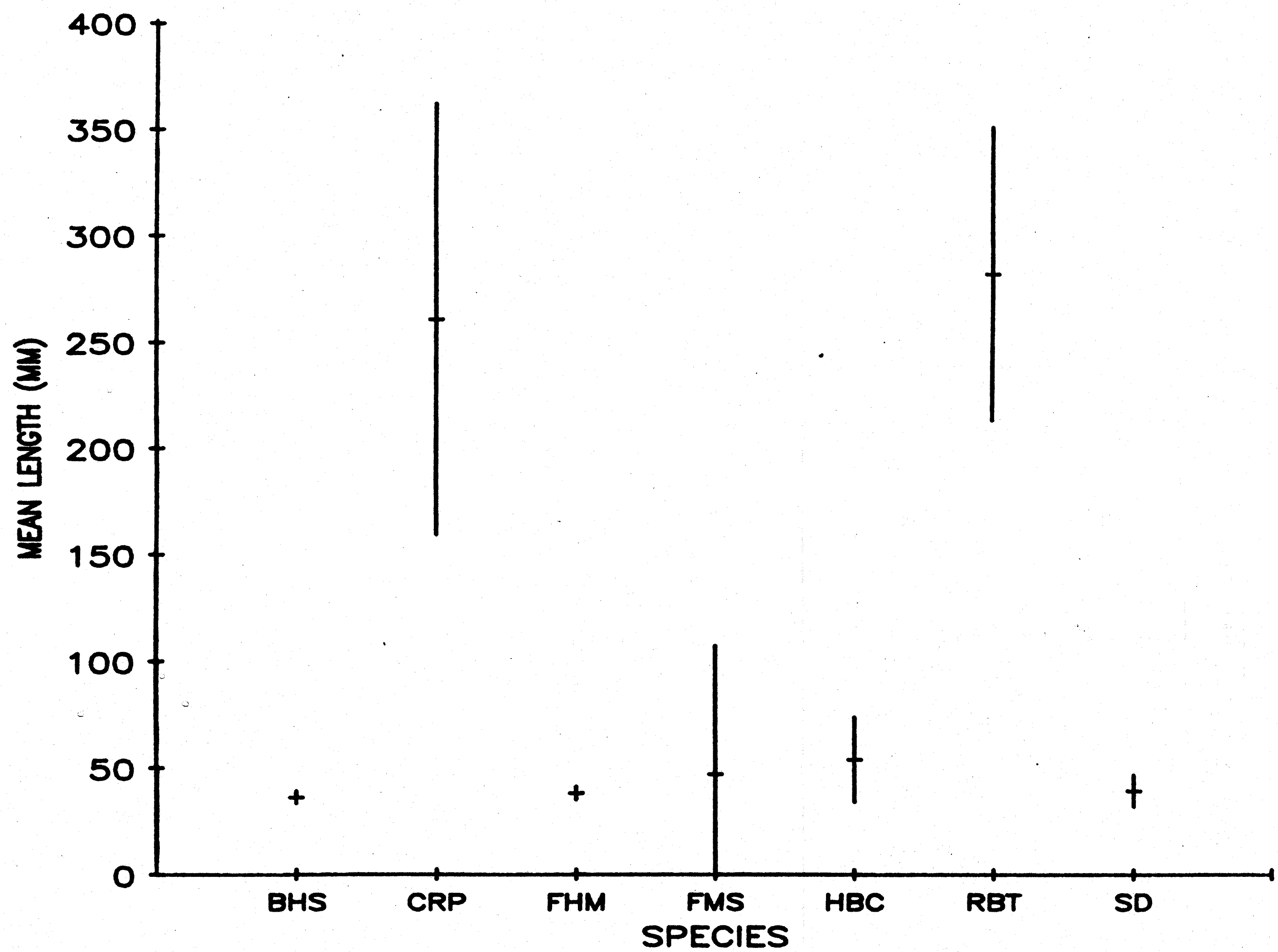


Figure 10.3. Mean length of fish stranded in isolated backwaters of Reach 10 during October 1985.

Table 10.2. Number of each fish species collected from isolated backwaters, all gear types combined, from April 1984 - June 1986.

Species	Reach 10	20	30	40	50	Total
Introduced						
Carp	-	-	-	6	7	13
Fathead minnow	-	-	10	15	1165	1190
Rainbow trout	639	-	-	1	1	641
Brook trout	3	-	-	-	-	3
Green sunfish	1	-	-	-	-	1
	643	0	10	22	1173	1848
Native						
Bluehead sucker	-	-	19	5	8	32
Flannelmouth sucker	-	-	-	1	2	3
Humpback chub	-	-	2	2	-	4
Speckled dace	-	-	12	-	24	36
	0	0	33	8	34	75

Table 10.3. Mean catch per unit effort (fish/100 m^2) by seine for fish collected in isolated backwaters from reaches 20-50, 1984-86.

Species	Mean	SD
Introduced		
Common carp	6.7	44.2
Fathead minnow	287.4	1505.0
Rainbow trout	0.3	1.5
Native		
Bluehead sucker	15.6	63.9
Flannelmouth sucker	0.4	1.6
Humpback chub	0.5	0.6
Speckled dace	25.7	14.3

During the October 1984 low flow, fish suffered mortalities from all these causes except lethal temperatures. Had these flows occurred during summer, thermal stress and oxygen deprivation would have been more prominent. Isolated backwaters sampled during summer ranged from 18.0-31.0°C ($\bar{x}$=25.7°C), which is greater than the upper lethal temperature of 25°C for rainbow trout (Cherry et al. 1977).

Isolated backwaters often contained no fish but were encircled with mammal and bird tracks. Great blue herons (Ardea herodias) and ravens (Corvus corax) were often seen near these backwaters. Becker et al. (1981) examined stranding in the Columbia River and found isolated pools devoid of fishes, which one day earlier had contained an estimated 1,000 fish. They found numerous animal tracks and concluded that attempts to estimate stranding would be grossly underestimated because of the vulnerability of stranded fish to predation. Corning (1970) reached a similar conclusion for fish concentrated into pools. Becker et al. (1981) found that deep backwaters such as the one occurring at RM 12, however, offered protection from predation as well as from other causes of stranding mortality. They failed to mention increased vulnerability and mortality to anglers.

During dropping water levels in October, rainbow trout fry had not yet emerged. Newly emergent fry prefer shallow, nearshore habitats. Gosse and Gosse (1985) found rainbow trout <12 cm in length at mean depths of 2.7 cm and 3.3 cm during stationary and random swimming, respectively. Fish associated with littoral areas of the river are most susceptible to changes in flow (Becker et al. 1981). Persons et al. (1985) showed that suitable rainbow trout fry habitat shifted from one location to another during changes in flow.

Fish stranding on bars was more prevalent than on any other habitat type. Bauersfeld (1978) reported high stranding rates of salmonids on bars. He reported stranding to be selective, usually affecting newly emergent fry between 25-50 mm. Because low flows occurred prior to spawning, very few fry were present.

Rainbow trout could suffer some stranding on a daily basis during fluctuating flows. Reports of stranding at Lee's Ferry were received weekly from anglers during periods of fluctuating flows. Winter periods, when adult fish are in shallow spawning areas and post-emergent fry are in shallow nearshore habitats, may be critical.

The loss of older and larger fish due to stranding could directly and indirectly affect catch and harvest rates of fish in the tailwater fishery. Corning (1970) found that fluctuating flows in small streams eventually reduced trout population levels. Reductions in winter water levels, common since the closing of Glen Canyon Dam (Chapter 3), could reduce the rivers' carrying capacity for both primary and secondary producers (Neel 1963, Corning 1970).

Species tolerant of high temperatures often reproduced in large isolated backwaters where depth was adequate during periods of lowest flow. Therefore, species such as fathead minnow dominated the catch in isolated backwaters. Except for speckled dace, native fishes stranded in backwaters were generally larvae and juveniles, incapable of reproducing.

With the available data, it is difficult to determine the extent of stranding below the Lee's Ferry area where native fishes are more abundant. These areas of the river would have to be examined during periods when life stages of these species are abundant in nearshore habitats.

Not only are minimum water levels important to fishes, but the rate at which the water drops is also important (Bauersfeld 1978, Becker et al. 1981, Cushman 1985, Persons et al. 1985). Rates established on the Cowlitz River, Washington, represent a 10% reduction in flow per 30-minute period (Bauersfeld, 1978). However, after examining stranding this rate was determined to be excessive. It was felt that the rate of change became more critical as volume of water decreased. The rate at which discharge from Glen Canyon Dam changed during October 1984 exceeded 16%. This occurred after discharge was already reduced to less than 8,000 cfs, a level where Persons et al. (1985) felt that bars began to be exposed. An attempt should be made to establish rates of change in discharge that would minimize stranding.

REDD DEWATERING

10.1.METHODS

To evaluate the effects of fluctuating flows on emergence of rainbow trout from redds, an experiment was developed at Glen Canyon Dam. Cement drainage canals, which collect seepage from inside the dam and route water to the river, were used as raceways. Water temperature in raceways was ca. 1°C higher than the river.

Egg baskets were built to conform to the cement raceways. They were 61.0 cm wide on the bottom and 76.2 cm wide on top, 30.5 cm deep, and 61.0 cm long. Frames were built with 12.7 mm square steel tubing and lined with 6.4 mm mesh expanded steel. Baskets were sprayed with rust resistant primer and finish paints.

All water was routed down one raceway with velocity and depth controlled by weirs. A 10.2 cm Flygt submergible pump was placed in this raceway below the egg baskets. The pump was electronically controlled by a sprinkler timer that turned water on and off at specified times. Water was pumped through 10.2 cm diameter schedule 40 PVC pipe to the raceway containing the egg baskets to be dewatered. Subsurface water was controlled by weirs and fluctuation level was controlled by the pump.

Prior to placing gravel in the baskets, gravel measurements were taken with soil sieves from two redds and one bar without redds in the tailwater area. Gravel for the baskets was obtained from a nearby bed being excavated by a sand and gravel company. Proportions of gravel sizes used in the baskets duplicated those from redds observed in the study area.

Eyed rainbow trout eggs were purchased from the Plymouth Rock Trout Company. Each artificial redd contained 800 eggs that were counted into porcelain dishes in a dark room. Eggs were placed in baskets using a method similar to that described by Gustafson-Marjanen and Moring (1984). Short pieces of 1.9 cm diameter PVC pipe were placed at six locations in each basket to a depth of 15-20 cm, and the water level was raised to cover the baskets. Eggs were then placed in the pipe and allowed to sink to the bottom. The pipe was removed and the area carefully covered with gravel. This method was repeated until 12 baskets, six on the steady flow side and six on the fluctuating flow side, had been planted with eggs. There were actually eight baskets on each side; the first and eighth baskets did not receive eggs but were used to standardize flow over and through the baskets receiving eggs.

Water level was held steady over all baskets for the initial two days of the experiment. For the remainder of the period the fluctuating side was dewatered daily for 10 h (2000-0600 h).

This duplicated the duration of a single peak fluctuation, common at the dam during winter months, and conditions that exist on the spawning bars during these flows. Though the artificial redds were dewatered, a small amount of water was allowed to flow through the bottom portion of the baskets to simulate bank storage release.

Removable collecting nets were placed on top of each basket on the downstream side. Nets were 73.7 cm wide at the base, 81.3 cm at the top and 15.2 cm high, conforming to channel dimensions. Nets were 20 cm deep and made with 2.5 mm mesh polypropylene.

Each net was checked just prior to the dewatering period each night and collected fish were counted, measured, and recorded. Nets were then cleaned and placed back on the baskets. The experiment was terminated 33 days after eggs were planted.

10.2.RESULTS

Because of the large volume of water being routed through the raceways (1,295 l/min), dissolved oxygen, pH, and water temperature changed very little across the egg baskets (Table 10.4). Water velocity over the egg baskets was similar between the steady flow side ($\bar{x}$=1.28 ft/sec) and the fluctuating side ($\bar{x}$=1.39 ft/sec).

Redd conditions in the baskets simulated natural redds at Lee's Ferry. In gravel samples taken from Glen Canyon Dam tailwater, percent fines (<3.0 mm) was 18.3% by weight in a redd from 4-Mile Bar and 19.1% in a redd from 8-Mile Bar (Table 10.5). All gravel in the two redds passed through a 51.0 mm sieve. At 12 Mile Bar, where no redds were found, percent fines was 24.5%. In addition to a greater amount of fines from 12 Mile Bar, 20.8% by weight of the sample was greater than 51.0 mm. Proportions of gravel used in the baskets approximated that of the two redds; 22.0% by weight was greater than 22.0 mm but less than 51.0 mm, and 19% by weight less than 3.0 mm.

The first emergent fry appeared December 9, 1985, one week after the eggs were planted. In the first week of emergence, 22 fry were collected from dewatered redds, while only three were collected from the steady flow redds. All individuals had large yolk sacs attached during this first week. The rate of emergence

Table 10.4. Dissolved oxygen, pH, and temperature above and below artificial redds taken at 1400 h, December 1986.

Site	Dissolved Oxygen (mg/l)	pH	Temperature (°C)
Steady flow raceway			
Above Redds	10.1	7.70	10.7
Below Redds	10.2	7.70	10.7
Fluctuating flow raceway			
Above Redds	10.3	7.75	10.8
Below Redds	10.6	7.78	10.9

Table 10.5. Gravel samples taken from spawning areas in the Glen Canyon Dam tailwater.

Gravel size (mm)	4-Mile Bar Sample (Redd)			8-Mile Bar Sample (Redd)			12-Mile Bar Sample (Non-redd)		
	Weight (g)	Composition %	Cumulative %	Weight (g)	Composition %	Cumulative %	Weight (g)	Composition %	Cumulative %
51.0	0	0.0	100.0	0	0.0	100.0	6250	20.8	79.2
22.0-51.0	6492	21.4	78.6	7172	27.5	72.5	6510	21.6	57.6
11.0-22.0	7630	25.1	53.5	5928	22.7	49.8	4744	15.8	41.8
6.0-11.0	5079	16.7	36.8	4049	15.5	34.3	2700	9.0	32.8
3.0-6.0	3701	12.2	24.6	2789	10.7	23.6	1689	5.6	27.6
1.7-3.0	1925	6.3	18.3	1167	4.5	19.1	805	2.7	24.5
1.0-1.7	1040	3.4	14.9	651	2.5	16.6	548	1.8	22.7
0.5-1.0	1781	5.9	9.0	1406	5.4	11.2	2020	6.7	16.0
0.25-0.5	1811	6.0	3.0	1562	6.0	5.2	3618	12.0	4.0
0.045-0.25	917	3.0	0.0	1319	5.1	0.1	1135	3.8	0.2
<0.045	11	<0.1	0.0	16	0.1	0.0	53	0.2	0.0

from the steady flow treatment did not show a marked increase until day 20 (after planting) and leveled off around day 30 (Figure 10.4). During this period only 6 fry were collected from the dewatered redds. In all, 579 fry (12.0% of eggs) were collected from steady flow redds and 31 (0.6%) fry from dewatered redds. This represents a 20:1 ratio.

Mean length for the first 22 emergent fry from dewatered redds was 15.3 mm (SD=0.8). The first 22 fry from steady flow redds had a mean length of 22.0 mm (SD=3.2). The few fish emerging later from dewatered redds were similar in mean length to those from steady flow baskets, 25.0 mm (SD=5.2) and 26.1 mm (SD=1.2), respectively.

10.3. DISCUSSION

This experiment was designed to determine the effect of dewatering redds with respect to gravel composition found in Glen Canyon tailwater. Artificial redds were patterned after redds located in the tailwater in an attempt to subject rainbow trout eggs and pre-emergent alevins to natural conditions. Recruitment to the Glen Canyon trout fishery from fish hatched in the river has been shown to be substantial during steady flows (See Chapter 7).

Results from this study suggest that daily fluctuations exposing spawning areas for a maximum 10 h will cause near total mortality.

Hatching success of 12.0% for our watered redds was higher than the 5-7% reported from artificial redds by others (Elson 1957, Meister 1962, Gustafson-Marjanen and Moring 1984). The near total mortality (0.6% survival) of eggs and pre-emergent alevins was similar to those in other dewatering studies (Reiser and White 1983, Neitzel et al. 1985).

Although embryos are known to be tolerant of daily dewatering (Corning 1971, Becker et al. 1982, Reiser and White 1983, Neitzel et al. 1985), pre-emergent salmonid alevins have been shown to suffer almost total mortality. Reiser and White (1983) dewatered rainbow trout and chinook salmon eggs daily for 1-5 weeks. The eggs were then transferred to incubators and hatching success determined. No difference was found between dewatered and control eggs. However, this experiment only tested the effect of dewatering on egg survivability and not pre-emergent alevins.

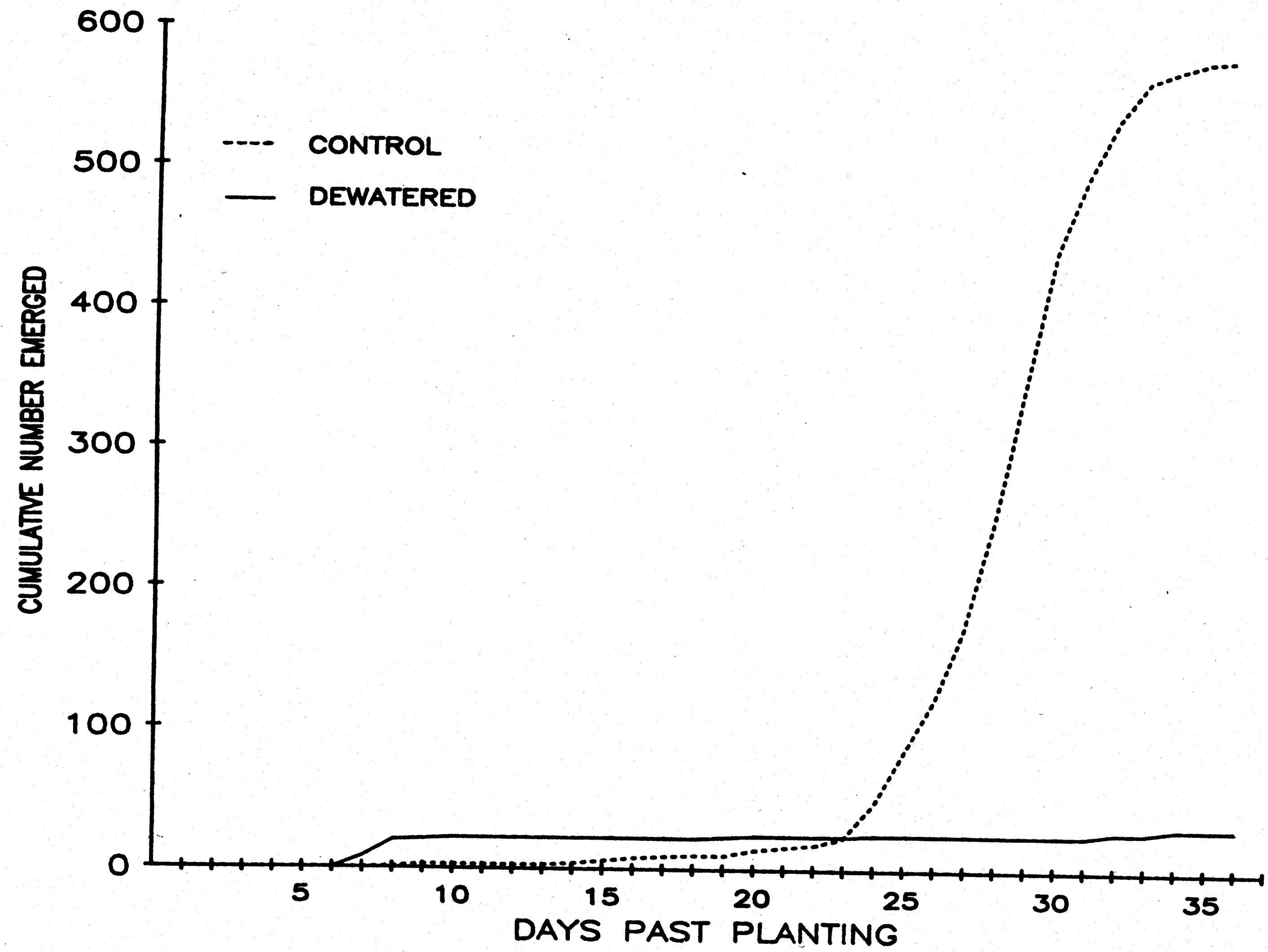


Figure 10.4. Cumulative number of emergent rainbow trout fry from artificial redds during redd dewatering experiment, November-December 1985.

Becker et al. (1981) subjected four salmonid developmental stages to dewatering. Embryos were dewatered using varying combinations of frequency and duration of dewatering. Though embryo survival was good, they concluded that embryos dewatered for one prolonged period did better than those dewatered daily. Pre-emergent alevins were examined during the same season as our experiment, but were dewatered a maximum of eight h daily. Less than 4% survived 1 h daily dewatering and all were killed when the duration exceeded 1 h. They concluded that most were killed during the initial dewaterings.

Neitzel et al. (1985) went one step further and maintained subsurface flow that simulated bank storage. Even then, alevins dewatered for 1-2 h for six consecutive days suffered near total mortality.

It appears that daily fluctuations or periods of low flow that expose trout redds will cause near complete mortality for pre-emergent alevins. Alevins generally remain in the redd for 2-4 weeks after hatching (Breder and Rosen 1966). This increases the period of vulnerability for rainbow trout alevins in the tailwater. Any flow reduction which exposes the spawning bars could reduce year class strength.

Videos taken at 4,800 cfs and compared to 28,000 cfs showed cobble bars increased from 14% to 32% of shoreline substrate samples (Anderson et al. 1986). This suggests that at 4,800 cfs spawning areas are probably exposed. Gosse and Gosse (1985) noted that many redds observed during steady flows in 1984 would have been dewatered by moderate reductions in flow. During 3 days of low flow in October 1984, at the beginning of the trout spawning season, dewatered redds were found on most exposed cobble bars that were examined. The spawning area at RM 7.5, which was re-examined two months later after water levels had returned to more than 20,000 cfs (steady flow), contained more redds than were found at any other location. However, we were unable to evaluate spawning in deep areas of the river. During fluctuating flows in December 1985, redds were found dewatered in the mainchannel near Nankoweap Creek.

It is evident that changes in flow could seriously affect natural recruitment, but our data are inadequate to determine the magnitude of actual losses. Also, the ameliorating effects of bank storage need better clarification. Knowing spawning and hatching periods in the Lee's Ferry tailwater area could aid in minimizing flow effects on pre-emergent rainbow trout.

11. LEE´S FERRY FISHERY

11.1.METHODS

A stratified creel survey, comprised of two weekdays and four weekend days each month, was initiated at Lee´s Ferry in January 1984. A creel clerk was stationed at the boat ramp at Lee´s Ferry where most boat and shore fishermen could be interviewed. Each fisherman or party was interviewed daily, usually at the end of the fishing day.

Catch and demographic data were collected during the interview. Catch information consisted of time fishing began and ended, number of trout caught and number creeled by species. Other information included date, location, boat or shore, complete or incomplete trip, and terminal tackle used. Demographic information included county and state of residence, and number of juvenile, adult, and retired persons in each party.

Fish checked by the creel clerk were identified by species and measured (total length) to the nearest millimeter. Uncleaned fish were weighed to the nearest gram with an Ohaus Model C-3000 Port-O-Gram electronic balance, or to the nearest 10 g with a spring loaded scale.

The National Park Service (NPS) provided monthly estimates of number of anglers at Lee´s Ferry from daily counts of boat trailers and shore fishermen. The 1984 information included number of boats and total fishermen, whereas in 1985 and 1986 only boat and shore angler counts were available. For the latter years, total fishermen per month was calculated by multiplying number of boats by mean annual number of fishermen per boat and adding the number of shore fishermen. Monthly angler hours were calculated multiplying the above estimates by the mean monthly number of hours fished per fisherman. Data pertaining to number of fishermen per boat and number of hours fished were collected from creel surveys. Confidence limits were not calculated for angler pressure and harvest estimates of trout because NPS provided only monthly estimates of the number of anglers.

Catch rates and harvest rates were calculated for all trout species combined because released fish not identified by the creel clerk were of questionable identity. White (1962) has shown that many fishermen are not familiar with the identification of different trout species. Monthly harvest estimates of total trout were calculated by multiplying monthly angler hours by monthly harvest rates. Rainbow and brook trout harvest estimates were then calculated multiplying monthly harvest of total trout by the ratio of these species in the creel.

A one-way analysis of variance (ANOVA) was used to examine temporal differences in catch rate of total trout and mean length and condition factor of harvested rainbow trout. Mean length differences were considered among months and years. When mean length was tested among years, only the first five months were considered due to the limited information collected in 1986. Catch rates and condition factors were tested among seasons. The one-way ANOVA was also used to test for differences in catch rates among the following categories: seasons, daily mean flow, coefficient of variation of daily flow, and discharge categories combining mean and coefficient of variation of daily flow (See Chapter 3). Higher order classifications could not be run because of insufficient data. Significant ANOVAs were followed by the Student-Newman-Keuls (SNK) multiple comparison test. The rejection level for both tests was set at P=0.05.

11.2.RESULTS

Angler Effort and Catch Rates

A total of 168 creel days were expended from January 1984, through May 1986. During this period, 11,542 fishermen were interviewed and data were gathered on 6,266 trout. Of these, 96.4% were rainbow and 3.5% were brook trout. Other creeled fish included five striped bass, eight cutthroat, and two brown trout.

In 1984, NPS estimated 44,878 fishermen at Lee's Ferry (Table 11.1, Appendix 11.1). This number declined to 19,953 in 1985. The grand mean for fishermen/month was 3,740 (SD=1229) in 1984 and 1,663 (SD=437) in 1985. Autumn had the highest angler use for both years followed by spring (Table 11.2).

Only the first five months of 1986 were surveyed. From January through May an estimated 4,866 people fished at Lee's Ferry. Approximately 19,664 and 8,729 anglers used Lee's Ferry during the same period of 1984 and 1985, respectively. The mean number of fishermen/month in 1986 was 973 (SD=173).

The mean catch rate for trout in 1984 was 0.51 fish/h. When months were combined by season, catch rates were highest in

Table 11.1. Summary of Lee's Ferry angler effort and rainbow trout harvest data, 1977-83, from Persons et al. (1985), 1984-86 data from this study.

	Effort			Harvest							
Year	Number of anglers	Hours fished	Hours per hectare	Harvest per hour	Catch per Hour	Mean length (mm)	Mean weight (g)	Number harvested	Number harvested per hectare	Yield (kg)	Yield per hectare
1977	10613	72202	174.0	.24		398	735	17320	41.7	12730	30.7
1978	9990	67932	260.6	.20		445	1015	13586	32.7	13790	33.2
1979	22085	150178	361.9	.15		431	926	22527	54.3	20860	50.3
1980	18986	129105	311.1	.09	.13	465	1153	11619	28.0	13397	32.3
1981	28784	195731	471.6	.14	.22	436	957	27402	66.0	26224	63.2
1982	49000	333200	802.9	.13	.19	449	1042	43316	104.4	45135	108.8
1983	52725	358530	863.9	.15	.27	431	926	53780	129.6	49800	120.0
1984	44878	288504	695.2	.21 SD .41	.51 SD 1.32	383 SD 94	691 SD 540	56887	137.1	39309	94.7
1985	19953	132162	318.5	.22 SD .29	.60 SD .66	370 SD 78	549 SD 348	29497	71.1	16194	39.0
1986[a]	4866	30856	74.4	.10 SD .15	.26 SD .44	418 SD 53	807 SD 313	3053	7.4	2464	5.9

[a] January to May 1986 data only.

Table 11.2. Angler hour estimates by season at Lee's Ferry, January 1984 - May 1986.

Year	Winter	Spring	Summer	Autumn
1984	30995[a]	78781	74232	94577
1985	29581	38794	26010	40303
1986	20893	17336	---	---

[a] January - February 1984 data only.

summer and autumn (Table 11.3). In 1985, the mean catch rate was 0.60 fish/h. Seasonal catch rates were highest in winter and summer. From January-May 1986, the mean catch rate for trout was 0.26 fish/h. Seasonally, catch rates were higher in winter when compared to spring (Table 11.3).

An estimated 56,887 rainbow trout were harvested in 1984, but only 29,497 were harvested in 1985 (Table 11.3). During these years rainbow trout harvest/ha declined and yield/ha. This was mainly due to a decrease in fishing pressure.

For the first five months of 1986 an estimated 3,053 rainbow trout were harvested, whereas in the first five months of 1984 and 1985 an estimated 11,953 and 9,991 rainbow trout, respectively, were harvested.

Length Frequency and Condition Factor

A total of 2,710 rainbow trout were measured at the Lee's Ferry creel station in 1984. These trout ranged in size from 150 mm to 750 mm ($\bar{x}$=383.1) with highest peaks from 300 mm to 375 mm (Figure 11.1). Rainbow trout over 500 mm in total length made up 13% of the total, while those over 600 mm made up 2.1%. Rainbow trout less than 300 mm in length made up 19.6% of the total. Monthly length frequencies show that both rainbow trout over 600 mm and rainbow trout under 300 mm were present in the creel every month in 1984 (Figure 11.2).

A total of 2,786 rainbow trout were creeled in 1985. Mean length for creeled rainbow trout was 370.4 mm (Table 11.3). These trout ranged in size from 150 mm to 700 mm with highest peaks from 300 mm to 400 mm (Figure 11.3). In 1985, 5.5% of the creeled rainbow trout were larger than 500 mm and 0.4% were larger than 600 mm. Rainbow trout less than 300 mm made up 16.8% of the total. In every month during 1985, rainbow trout less than 300 mm in total length were creeled. There were no trout longer than 600 mm creeled in five of twelve months in 1985 (Figure 11.4).

A total of 545 rainbow trout were creeled in the first 5 months of 1986. Mean length for creeled rainbow trout at Lee's Ferry was 417.5 mm (Table 11.1). Rainbow trout creeled in 1986 ranged in size from 225 mm to 600 mm with a peak from 375 mm to 425 mm (Figure 11.5). From January through May, 7.3% were over 500 mm in total length but none were greater than 600 mm (Figure

Table 11.3. Results of ANOVA and SNK multiple range tests for seasonal catch rate (fish/hour) of creeled trout at Lee's Ferry during December 1983 to May 1986. Plus mark (+) indicates significant differences among seasons.

Mean Catch Rate	Season	Spr 1984	Spr 1986	Win 85/86	Spr 1985	Win 83/84	Aut 1985	Sum 1984	Aut 1984	Sum 1985	Win 84/85
0.23	Spr 84										
0.26	Spr 86										
0.39	Win 85/86										
0.43	Spr 85										
0.43	Win 83/84										
0.53	Aut 85	+									
0.56	Sum 84	+	+								
0.57	Aut 84	+	+								
0.74	Sum 85	+	+	+							
0.94	Win 84/85	+	+	+	+	+	+	+	+		

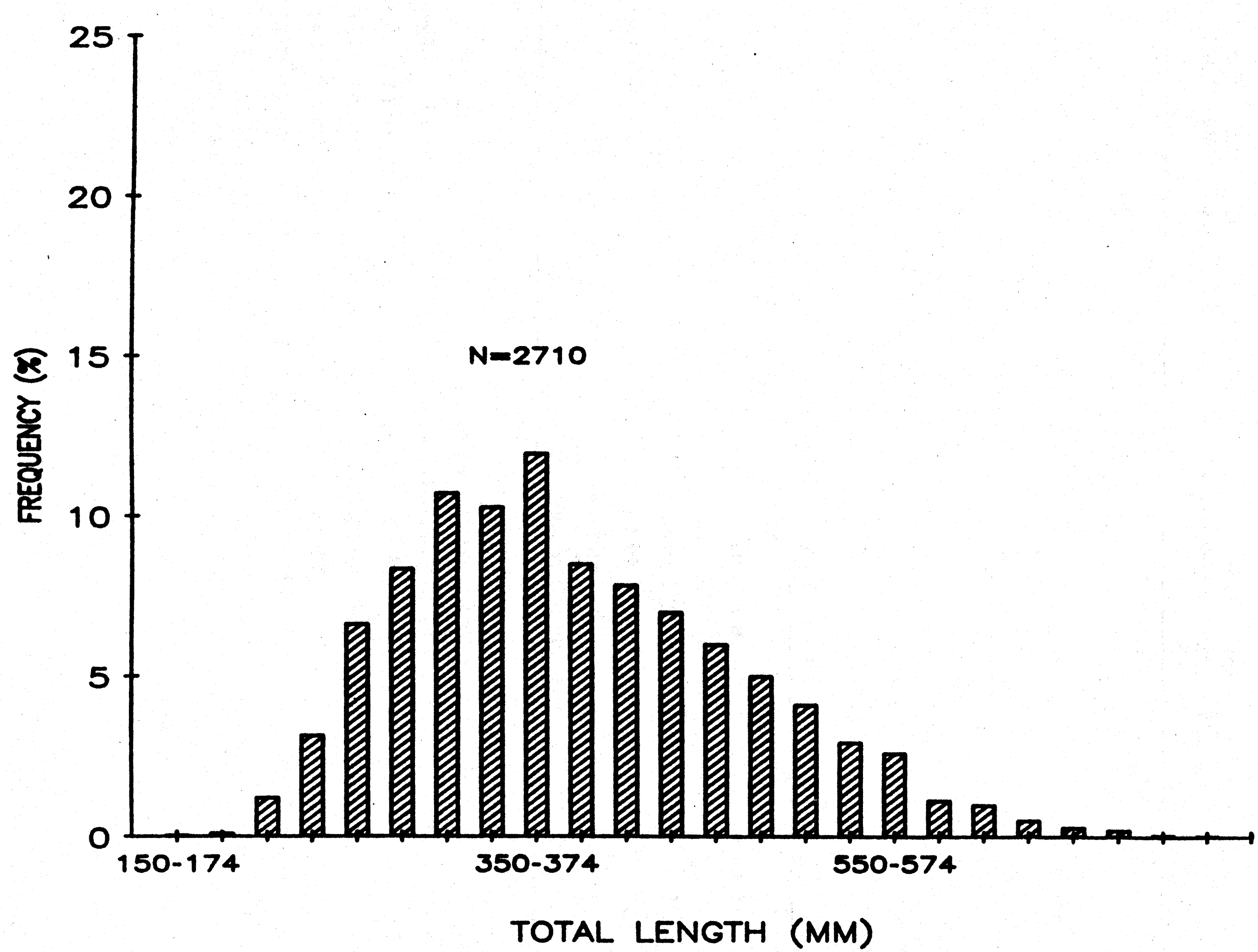


Figure 11.1. Length frequency histogram of rainbow trout measured at the Lee's Ferry creel station, 1984.

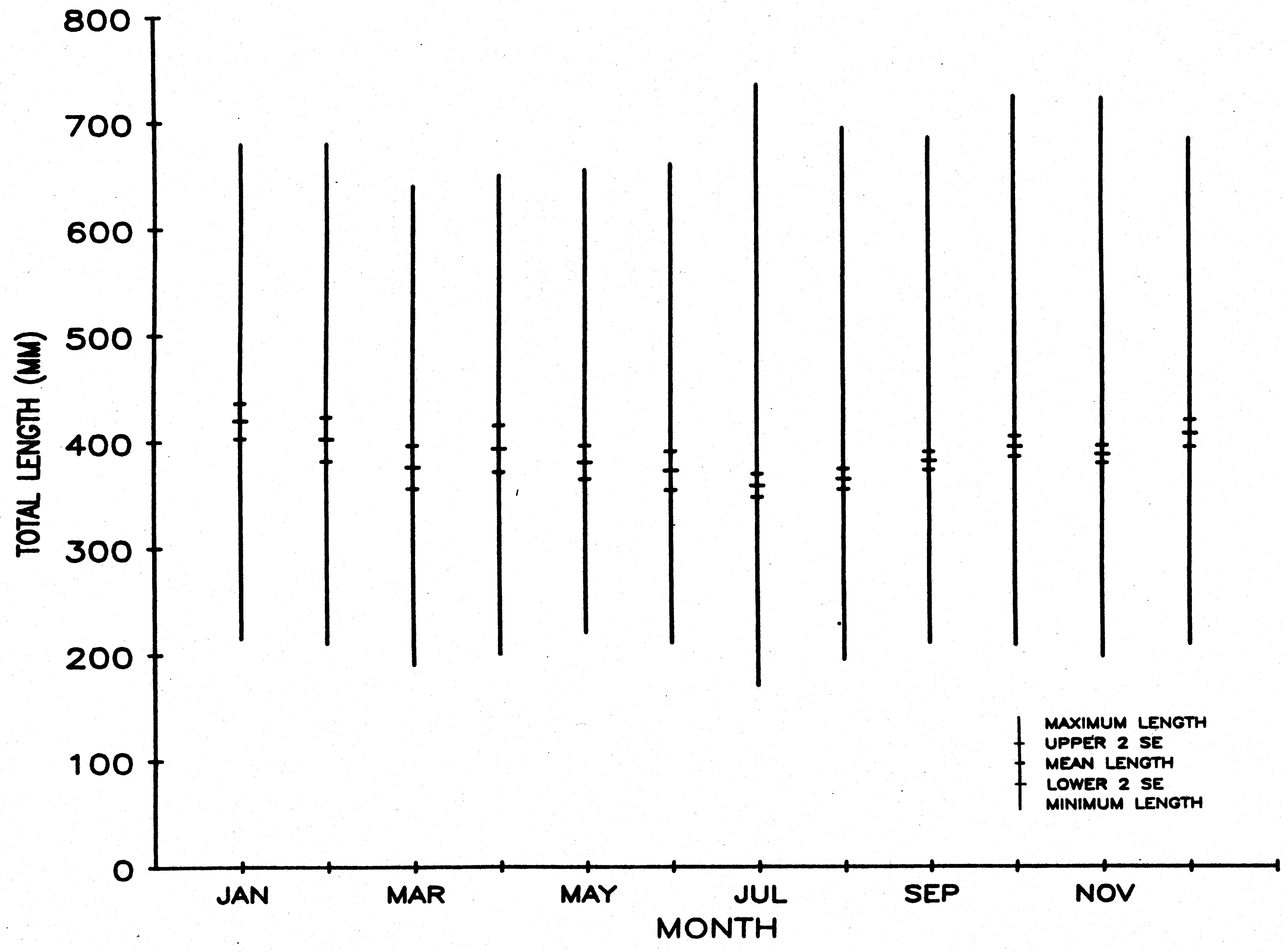


Figure 11.2. Monthly variation of rainbow trout lengths measured at the Lee's Ferry creel station, 1984.

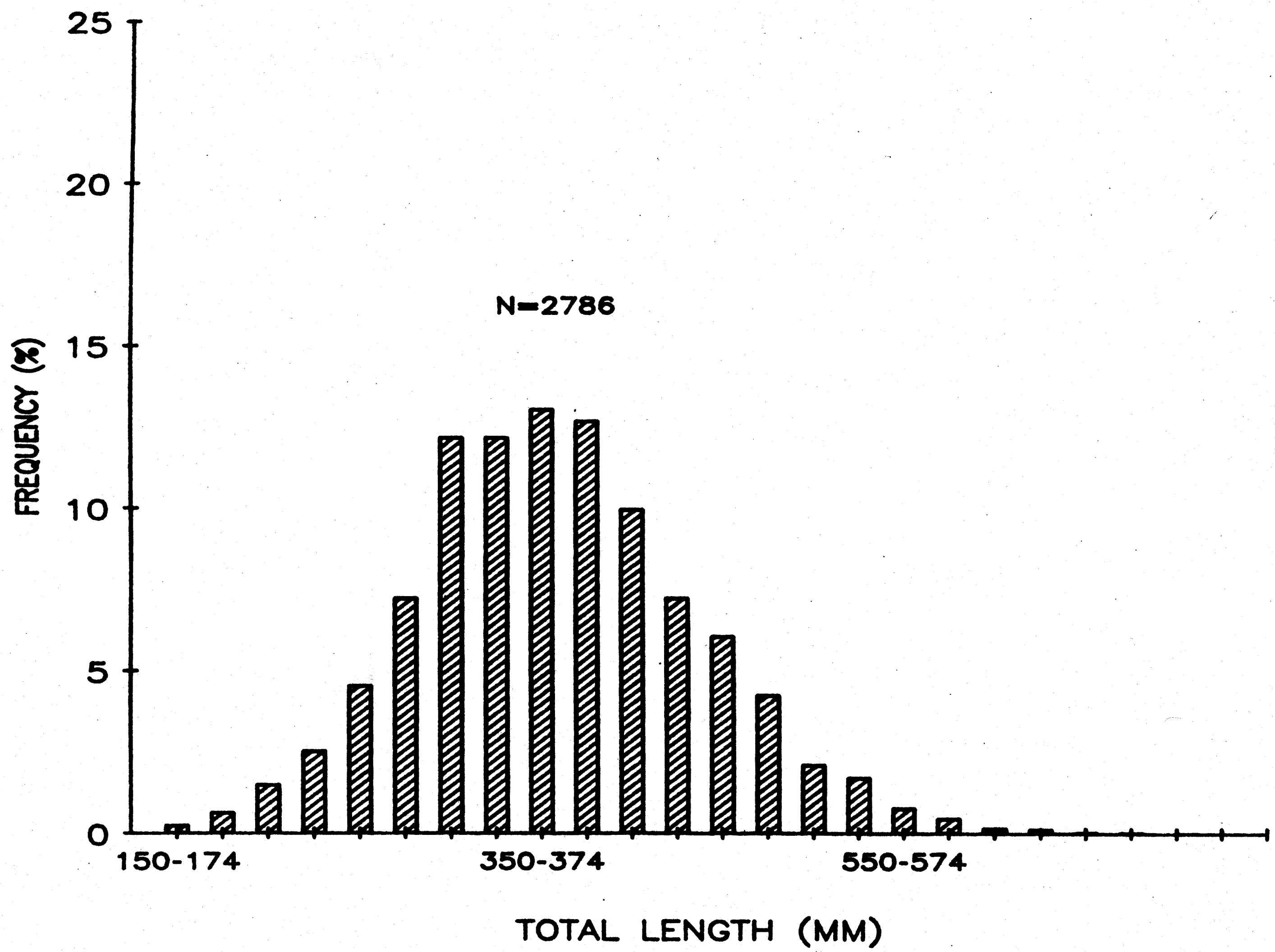


Figure 11.3. Length frequency histogram of rainbow trout measured at the Lee's Ferry creel station, 1985.

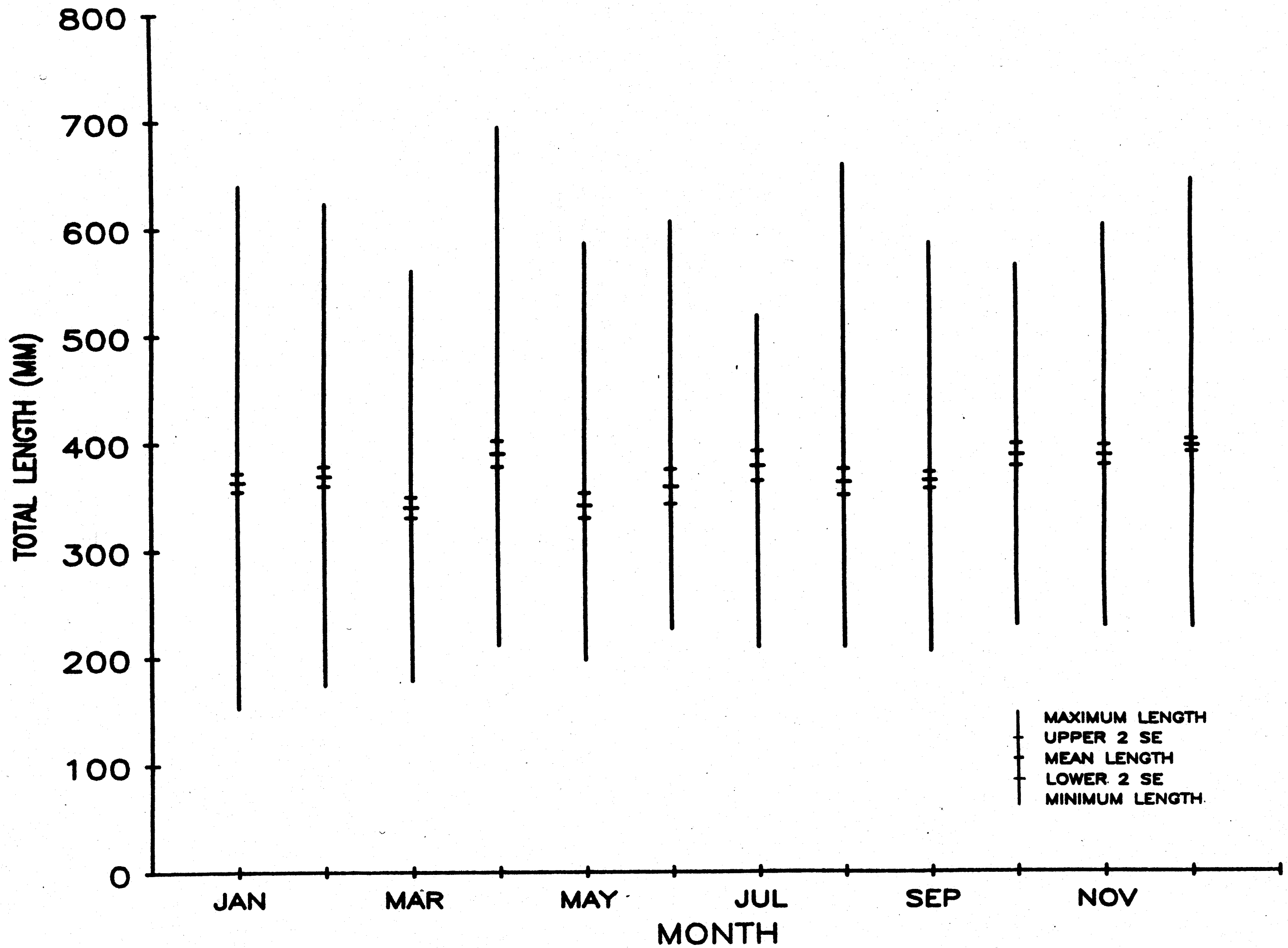


Figure 11.4. Monthly variation of rainbow trout lengths measured at the Lee's Ferry creel station, 1985.

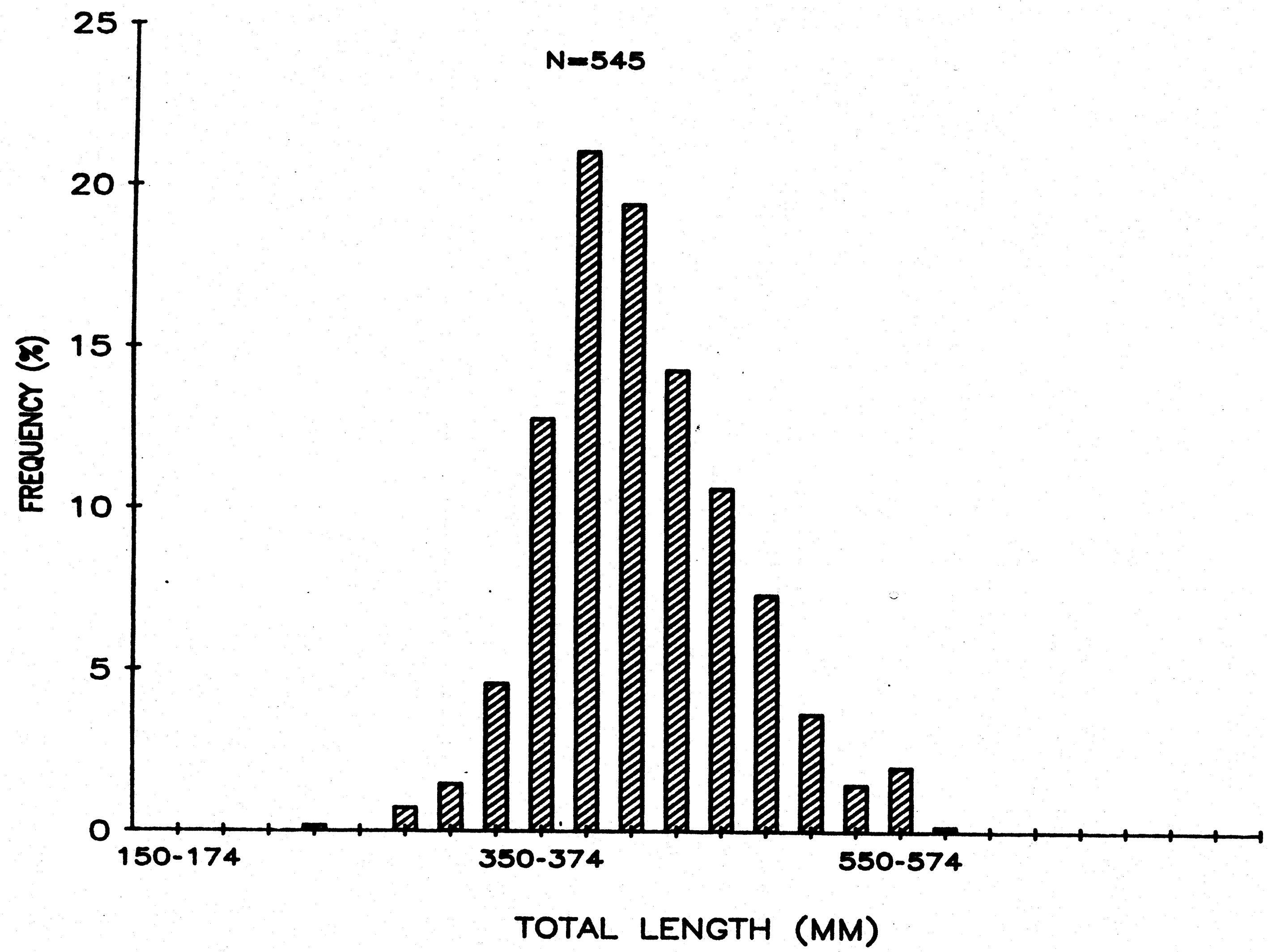


Figure 11.5. Length frequency histogram of rainbow trout measured at the Lee's Ferry creel station, 1986.

11.6). In the first five months of 1984, 17.0% of the rainbow trout harvested were over 500 mm and 4.0% were over 600 mm. In the first five months of 1985, 6.1% and 0.4% of the rainbow trout were over 500 mm and 600 mm, respectively. Only 0.4% of the creeled rainbow trout were less than 300 mm in length in 1986, while 22.9% and 25.7% were less than 300 mm in the first five months of 1984 and 1985, respectively.

The SNK multiple range test showed that mean lengths of creeled rainbow trout were significantly greater in winter than summer in 1984 and 1985 (Table 11.4). In 1984, mean length of rainbow trout creeled in January, February, and December were significantly greater than those creeled in July and August. Rainbow trout creeled in January and February were significantly larger in mean length than those creeled in June. In 1985, mean length of rainbow trout creeled in December, October, November, and April were significantly greater than those creeled in May, June, and August. In 1986, the SNK multiple range test ($P<0.05$) was run on the first five months only. Summer and autumn months were not included. Results showed that rainbow trout creeled in May, April, and February were significantly larger in mean length than those creeled in March. When the one-way ANOVA ($F=93.97$; $df=2, 2606$; $P<0.01$) was considered among years, each year's mean length for rainbow trout was found to be significantly different.

Mean seasonal condition factor for rainbow trout were lowest in winter and highest in summer. Those for rainbow trout in the winters of 1985 and 1986 were 0.97 and 0.98, respectively. Mean condition factors for the summers of 1984 and 1985 were 1.05 and 1.03, respectively. The results of the ANOVA and SNK tests are shown in Table 11.5. The SNK multiple range test ($P<0.05$) showed that these differences were significant. Spring and autumn condition factors were between these extremes.

In 1984, 139 brook trout were creeled, while the next year 73 were creeled. The mean harvest rates for brook trout in 1984 and 1985 were 0.007 and 0.005 brook trout/h, respectively (Table 11.1). Mean length for creeled brook trout was 354.5 mm in 1984 and 357.1 mm in 1985. Only three brook trout were creeled in the first five months of 1986, while 68 and 61 were creeled during the same months in 1984 and 1985, respectively. Mean harvest rate in 1986 was 0.001 brook trout/h. The mean length for creeled brook trout in 1986 was 389.3 mm (SD=34.8).

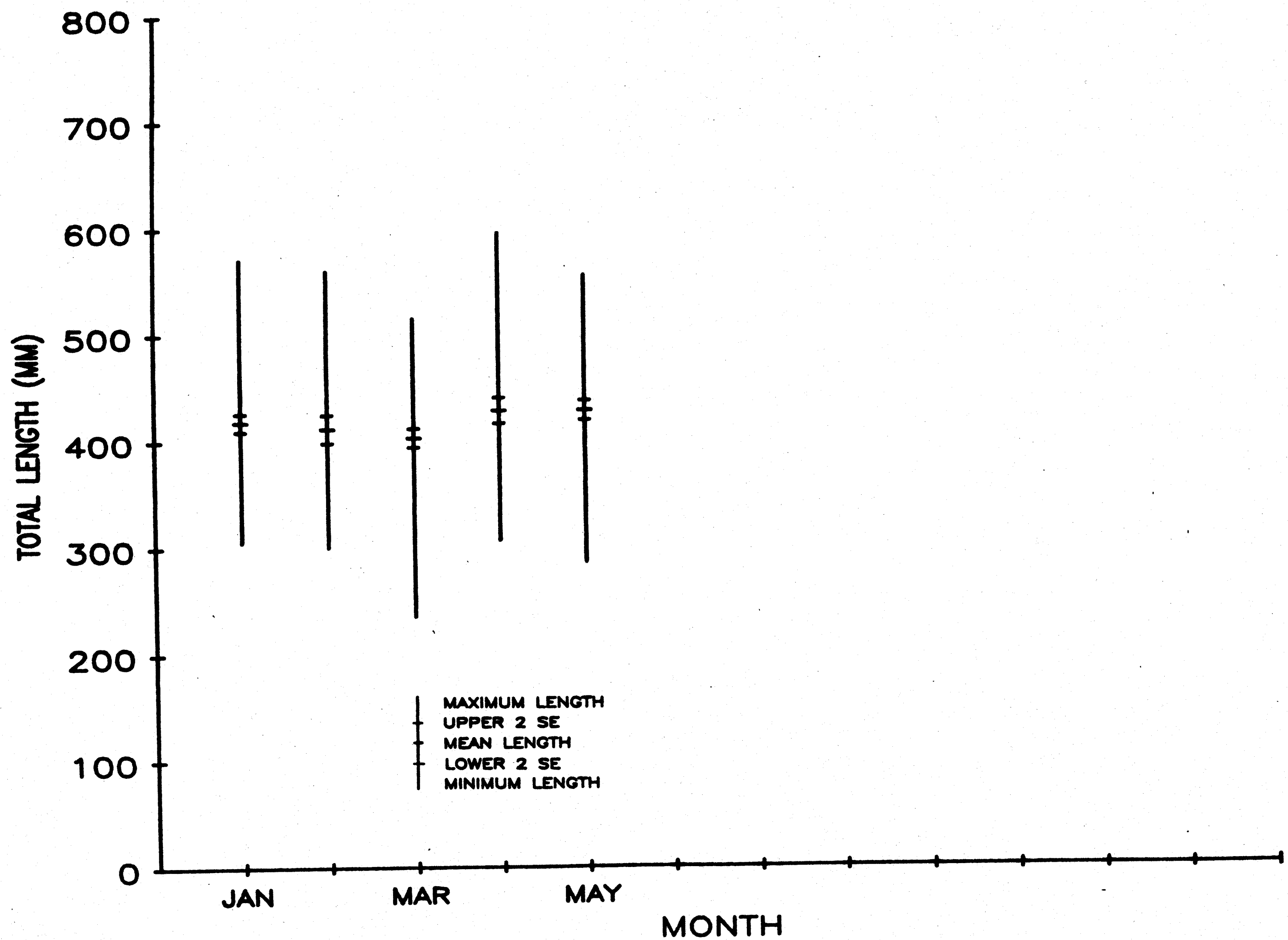


Figure 11.6. Monthly variation of rainbow trout lengths measured at the Lee's Ferry creel station, 1986.

Table 11.4. Results of ANOVA and SNK multiple range test for differences in monthly mean length of creeled rainbow trout at Lee's Ferry, 1984 and 1985. Significant (p <.01) month-by-month comparisons indicated by plus (+) mark.

1984

Mean length (mm)	Month	Jul	Aug	Jun	Mar	May	Sep	Nov	Apr	Oct	Feb	Dec	Jan
357.7	Jul												
363.9	Aug												
371.9	Jun												
375.8	Mar												
380.0	May												
381.4	Sep	+											
387.4	Nov	+	+										
393.1	Apr	+	+										
394.6	Oct	+	+										
402.3	Feb	+	+				+						
407.0	Dec	+	+	+									
419.7	Jan	+	+	+	+	+	+	+		+			

1985

Mean length (mm)	Month	Mar	May	Jun	Aug	Jan	Sep	Feb	Jul	Nov	Oct	Apr	Dec
339.9	Mar												
341.3	May												
358.7	Jun												
363.0	Aug	+	+										
363.7	Jan	+	+										
364.6	Sep	+	+										
369.1	Feb	+	+										
378.0	Jul	+	+										
388.3	Nov	+	+	+	+	+	+	+					
388.5	Oct	+	+	+	+	+	+	+					
389.7	Apr	+	+	+	+	+	+	+					
396.9	Dec	+	+	+	+	+	+	+					

Table 11.5. Results of ANOVA and SNK multiple range test for differences in mean condition factors (K) of creeled rainbow trout among seasons at Lee's Feery, 1984-86. Significant ($p < .01$) season-by-season comparisons indicated by plus (+) mark.

Mean K	Season	Win 1985	Win 1986	Spr 1985	Spr 1986	Aut 1985	Aut 1984	Sum 1985	Spr 1984	Sum 1984
.97	Win 85									
.98	Win 86									
.98	Spr 85									
1.00	Spr 86	+								
1.01	Aut 85	+	+	+						
1.03	Aut 84	+	+	+						
1.03	Sum 85	+	+	+						
1.04	Spr 84	+	+	+						
1.05	Sum 84	+	+	+	+	+				

Effects of Flow

When the effects of discharge on catch rates were tested, we found significant differences (One-way ANOVA F=8.36; df=2, 6224; P<0.01) in party catch rates. Catch rates were highest at 0.76 fish/h when daily mean flows were less than 14,000 cfs. Catch rates were lowest (0.58 fish/h) when daily mean flows were greater than 31,500 cfs. Another one-way ANOVA showed significant differences (F=6.44; df=7, 6211; P<0.01) in catch rate when both daily mean flow and coefficient of variation were tested. The mean catch rates for each flow type are shown in Table 11.6).

11.3.DISCUSSION

From 1977 to 1983 fishing pressure, catch rate, and harvest of trout generally increased at Lee's Ferry. During this time Lee's Ferry had a reputation as a trophy trout fishery with mean length of creeled rainbow trout at 400 mm or greater and many over 600 mm. Fishing pressure rose during these years as increasing numbers of people came to catch large trout. There were small decreases in fishing pressure due to changes in fishing regulations during this time. In 1978 and 1980, the number of fishermen decreased slightly and then increased the following years. In 1978, the daily limit was reduced from 10 to 4 trout. In 1980, a regulation was established whereby any fish retained in the creel had to be killed immediately.

Yearly catch rates increased 300% from 1982 to 1985; at the same time mean lengths of creeled rainbow trout decreased. Catch per unit effort is often proportional to mean stock present during the time of fishing (Ricker 1975). This increase in catch rate was likely due to increased numbers of fish at Lee's Ferry when stocking efforts were resumed after a 28 month period (March 1978 to July 1980) when no fish were planted (Appendix 11.2). A decrease in mean length could have been caused by two factors, the 28-month period with no stocking and the increase in fishing pressure. The period with no stocking potentially reduced two year classes of rainbow trout that would not have been noticed in the creel until they had grown to a size kept by fishermen. An increase in fishing pressure undoubtedly contributed to the decline in mean length. Wiley and Dufek (1980) found this to occur in the Green River below Fontenelle Reservoir. Trout were being harvested before they could grow to a large size. Lee's

Table 11.6. Mean party catch rates (trout/hour) by daily mean flow and coefficient of variation. Daily mean flow (cfs): Low = <14,000; Intermediate = 14,000 - 31,500; High = >31,500. Coefficient of variation: Low = <3; Intermediate = 3 -15; High = >15.

		Mean flow		
		Low	Intermediate	High
	Low	0.63	0.54	0.37
Coefficient of variation	Intermediate	0.38	0.50	0.31
	High	0.57	0.32	-

Ferry was no longer considered a trophy fishery and fewer people were fishing there. The fishing pressure decreased from 1984 to present and catch rate decreased in the first part of 1986.

Since a regulation change in 1986 to lure and fly only, mean length of creeled rainbow trout has increased. This occurred even though few large fish were creeled. Fewer than 1% of the rainbow trout creeled in 1986 were less than 300 mm. This decrease in numbers of small trout creeled may reflect a change in the type of fisherman as a result of the regulation change.

There were seasonal differences in catch rate, mean length, and condition factor for creeled rainbow trout. Catch rate and mean length were generally highest in winter. Seasonal differences were most likely due to winter being the main spawning period at Lee's Ferry. Rainbow trout may be more accessible to fishermen at this time when they are concentrated around areas of good quality spawning gravel. Their aggressiveness when over redds may make them more susceptible to angling. This is in contrast to Mullan et al. (1976) who stated that trout become nonaggressive, feed less actively, and seek deep pools during lower winter temperatures.

Mean condition factor for creeled rainbow trout was lowest in winter. The weight of a fish is affected by stomach contents, time of year and spawning condition (Ricker 1975). Low condition factor in winter could be attributed to weight loss during spawning.

Brook trout made up only a small percent of the total trout creeled at Lee's Ferry during the study period. Brook trout at Lee's Ferry appear to be dependent on stocking. There was a 21-month period with no stocking of brook trout harvested from October 1983 to August 1985 (Appendix 11.2). Numbers of brook trout decreased from 1984 to 1986. Brook trout were collected in such low numbers during the study period that no statistical analysis was run.

The effects of discharge on angling were difficult to determine. Catch rates were highest during winter months when most low mean flows (<14,000 cfs) occurred. Catch rates were lowest during summer when most high mean flows (<31,500 cfs) occurred. Many of the days creeled during fluctuating flows occurred in 1986 after a change in fishing regulations. This change in fishing regulations had an effect on catch rates. It appeared that both daily mean flow and variation of flow had an effect on catch rates, but due to seasonality and changes in fishing regulations it could not be proven conclusively.

Fishery managers have looked at the effects of discharge on angling with different results. Fogle and Shields (1961) surveyed managers of 52 tailwater fisheries in 14 states. They reported that fishing was generally best during periods of moderate flow with little or no fluctuation. When moderate fluctuations occurred, angling was better when flows were increasing. Kelly and Thorne (1986) showed that mean monthly catch was inversely related to mean monthly flow on the San Juan River in New Mexico. Parsons (1957) stated that trout fishing on the tailwater below Dale Hollow Reservoir in Tennessee was best during low discharge when the hydroelectric dam was completely shut down. This created a series of long shallow pools where fishing was good. During steady, high discharges fishing was poor. Corning (1957) stated that as water levels decrease, fish become concentrated into smaller areas. This concentration of fish could improve fishing success. Fogle and Shields (1961) reported that increases in discharge and fluctuations altered resting and hiding places for fish and made angling more difficult.

Persons et al. (1985) tried to correlate mean monthly catch rate with mean monthly flow, mean monthly range in flow, (daily average of maximum minus minimum) and the coefficient of variation of flow at Lee's Ferry from April 1980 to March 1981. They could not find any significant correlations. The only exceptions were periods of low flows that impeded upstream navigation and extreme high flows that made boating unsafe and fishing difficult.

Hanson (1977) reported that fishing was generally best when discharge was highest at Pomme de Terre tailwater, a cool water fishery in Missouri. Hanson showed a positive relationship between the daily mean discharge and daily mean catch rate for all species in four of seven years. When catch rates were compared over a longer period of time (by month, season, or year), significant positive correlations were found consistently. During high discharge, water flowed into shallow quiet backwater areas where fish were concentrated resulting in good angling.

12. CONCLUSIONS

Water Quality

1. Impoundment of the Colorado River by Glen Canyon Dam and release of deep hypolimnial water from Lake Powell has dramatically changed the physicochemical and trophic nature of the river downstream from the dam.

2. Tributaries of the Colorado River in Glen and Grand canyons little affect mainstream temperature and major ion chemistry. The Little Colorado River is an important contributor of suspended sediment and phosphate to the mainstream during periods of flooding. The effect of this tributary on the trophic nature of the mainstream has not been adequately determined, but appears to be very important.

Distribution, Habitat Utilization, and Backwater Examination.

1. The river has changed from one dominated by warmwater species to one dominated by cold water and eurythermal fishes.

2. Adult native fishes are dispersed throughout the river, while larvae and juveniles are concentrated in reaches below the Little Colorado River.

3. Humpback chub were collected most frequently in the vicinity of the Little Colorado River, although they were collected throughout the lower reaches.

4. Recruitment of brown and rainbow trout from tributary streams was reflected in their distribution.

5. Habitat use above and below the Little Colorado River differed for most species.

6. Species diversity appeared to be related to the distribution of backwaters.

7. By October most native fishes have attained a size where they are less affected by fluctuating flows, even though they continue to utilize backwaters.

Tributaries

1. Tributaries are important to maintaining viable populations of native fishes in Grand Canyon. Apparently, low mainchannel water temperatures limit their ability to fully utilize the Colorado River as a spawning area.

2. Highest native fish catch per unit effort in tributaries occurred in the Paria and Little Colorado rivers and Kanab Creek.

3. Salmonids use tributaries in winter to spawn and in early spring as nursery areas.

4. Nankoweap, Clear, Bright Angel, Tapeats, and Deer Creek were areas where catch per unit effort for rainbow trout was relatively high.

5. Seasonal use patterns occur for both native and introduced fishes within the tributaries. Use by native fish is highest in spring and summer with trout use being highest in winter.

6. The Little Colorado River is crucial to the humpback chub as a spawning and nursery area.

7. The peak in rainbow trout spawning occurs in winter (usually December). Peak of native fish spawning is variable and tends to be in late spring and early summer.

8. Fluctuating flows could adversely impact tributary access in at least four tributaries, and thus limit spawning habitat for both native and introduced species.

9. The ponded area formed at the mouth of the Little Colorado River during high flows in the mainstream may provide an important thermal acclimation zone for young-of-the-year native fishes entering the perennially cold Colorado River.

Reproduction-Mainchannel

1. Rainbow trout appear to have reacted to flow conditions during the spawning season, as spawning in 1985-86 was later than that observed the previous year. Once flows returned to a high steady condition in 1986, trout moved onto cobble bars to spawn.

2. Some native fishes spawned in the mainchannel during periods of steady flows. Bluehead suckers that spawn on shallow gravel bars could have been affected by fluctuating flows. No one has studied the effects of dewatering on bluehead ova.

3. Species that use warm backwaters as nursey and spawning areas could be affected by dewatering and desiccation during periods of low flows. Backwaters that become isolated, warm, and then are reconnected to the mainchannel may benefit species that respond quickly to warmer water and reproduce.

4. There was no evidence of mainchannel spawning by humpback chub.

Movement

1. Directional movement appears to be in response to reproduction. Movement related to tributaries during the spawning season was observed for rainbow trout, brown trout, flannelmouth sucker, and humpback chub.

2. Stocked Canyon Creek Hatchery, rainbow trout dispersed throughout Glen Canyon, and more than a quarter of these stocked fish were harvested by anglers in the vicinity of the release.

3. Dye marked rainbow trout represented 61% of the sampled fish in Reach 10. Few marked fish were sampled down river. Natural reproduction did occur in the Lee's Ferry area.

Fish Food Resources

1. The Colorado River through Glen and Grand canyons contains a diverse and abundant zooplankton community. Zooplankton is utilized as a food resource by larval native suckers and rainbow trout fry.

2. Adult rainbow trout consume primarily *Cladophora* and its associated epiphytes, larval insects (mainly chironomids and simuliids), and the amphipod *Gammarus lacustris*. Composition of food in adult rainbow trout guts varies with distance downstream from Glen Canyon Dam and by season.

Age and Growth

1. Rainbow trout growth is greater above the Little Colorado River than below.

2. Harvest by anglers of rainbow trout appears to affect their size distribution in Reach 10.

3. Growth of humpback chub estimated from monthly length frequencies averaged approximately 70 mm during the first year, and growth of adults was also slow. Humpback chub appears to grow slowly after reaching maturity, and it is a relatively long-lived species. Growth of recaptured mature fish averaged less than 10 mm per year, and some individuals were at large for more than five years.

4. Distribution and length frequency data suggested that adult humpback spawned in the Little Colorado River in the spring, and young fish moved downstream in the autumn.

Stranding and Redd Dewatering

1. All size classes of rainbow trout in Reach 10 were stranded during October 1984 when the water level dropped after an extended period of high steady flows.

2. Most rainbow trout stranded during October 1984 were fish that had been stocked by Arizona Game and Fish Department.

3. Pre-emergent rainbow trout in redds dewatered at the dam suffered near total mortality. Trout hatched in redds on cobble bars below the dam may suffer similar mortality during periods of fluctuations and extended low flow during weekends and holidays.

4. Native fishes are stranded in backwaters when river stage lowers.

Lee's Ferry Fishery

1. Rainbow trout in the creel decreased in mean length from 1982 to 1985. This was probably due to a period of low stocking and increased fishing pressure.

2. Rainbow trout mean length increased in 1986, yet few large individuals were checked in the creel. Very few small fish were kept in the creel in 1986, probably due to changes in fishing regulations.

3. Brook trout decreased in numbers in the creel throughout the study period, probably due to lack of stocking and natural reproduction.

4. Catch rates and mean lengths of rainbow trout increased in the creel during rainbow trout spawning periods.

5. Catch rates for trout were highest when daily mean flows were less than 14,000 cfs.

13. RECOMMENDATIONS

A full reservoir and high runoff during the study made it difficult to address completely the questions surrounding fluctuating flows. However, data collected provide insight for answering questions relating to fluctuating flows.

Using data from this and other studies we can make inferences about the effects of flow variation on the aquatic resources. Below are responses to the seven flow alternatives that we were asked to evaluate and criteria that could be used in developing an alternative to better maximize discharges for the aquatic resources. The problem with these alternatives provided by BOR is that they show only averages and ranges within which flows would fall. Information concerning rate of change in discharge and duration of low flows was not provided, and this confounds our ability to completely evaluate these alternatives.

Narrative Description of Alternative Number One
Monthly Base Flow Releases from Glen Canyon Dam

Month	Acre feet	Average monthly flow	Ranges
Oct	608,000	9,900	9,900
Nov	584,000	9,800	9,800
Dec	836,000	13,600	13,600
Jan	899,000	14,600	14,600
Feb	677,000	12,200	12,200
Mar	509,000	8,300	8,300
Apr	611,000	10,300	10,300
May	614,000	10,000	10,000
June	620,000	10,400	10,400
July	784,000	12,750	12,750
Aug	883,000	14,400	14,400
Sept	589,000	10,000	10,000

Discussion of Alternative Number One

Even though flows in alternative number one remain fairly stable with no daily fluctuations, there are periods when these flows could have positive and negative effects on the aquatic resources. Steady flows during winter and spring could benefit rainbow trout spawning and alevin survival and provide stable habitats for newly emergent fry. Flows in May and June, though steady, are lower than historic flows and those observed during the study. The higher water level backs up the mouth of the Little Colorado River potentially creating both additional rearing habitat and a staging area to allow acclimation to temperature differences between the mainchannel and LCR.

Narrative Description of Alternative Number Two
Maximized Power Plant Releases from Glen Canyon Dam

Month	Acre feet	Average monthly flow	Ranges
Oct	568,000	9,200	1,000-31,500
Nov	560,000	9,400	1,000-31,500
Dec	856,000	13,900	1,000-31,500
Jan	889,000	14,500	1,000-31,500
Feb	527,000	9,500	1,000-31,500
Mar	510,000	8,300	1,000-31,500
Apr	578,000	9,700	1,000-31,500
May	551,000	9,000	1,000-31,500
June	585,000	9,800	3,000-31,500
July	1,045,000	17,000	3,000-31,500
Aug	1,012,000	16,500	3,000-31,500
Sept	609,000	10,200	1,000-31,500

Discussion of Alternative Number Two

Alternative number two would have negative impacts on most aquatic resources of the canyons. Cobble bars used by rainbow trout as spawning sites would be dewatered on a daily basis. The result could be stranding of adult spawners and mortality of eggs and alevins in dewatered redds. Successful emergent fry would be stranded or displaced from near shore habitats on a daily basis. Low flows would limit access to some tributaries for spawning.

Native fishes would be similarly impacted. Mainchannel spawning areas would be dewatered daily. Backwaters that provide warm water habitats for larval natives would be dewatered and have temperature profiles altered by fluctuations. If zooplankton are reproducing in the Colorado River, a probable location would be in backwaters, which would be made unsuitable because of daily dewatering. Fluctuating flows may affect the success of humpback spawning. The mouth of the Little Colorado River, which may be used as a staging area, would be lentic during high discharge and change to a lotic environment at low flow, flushing chub larvae into the mainchannel. These chub larvae may suffer high mortality from thermal shock.

Narrative Description of Alternative Number Three
Maximized Power Plant Releases from Glen Canyon Dam

Month	Acre feet	Average monthly flow	Ranges
Oct	568,000	9,200	8,000-25,000
Nov	560,000	9,400	8,000-25,000
Dec	856,000	13,400	8,000-25,000
Jan	889,000	14,500	8,000-25,000
Feb	527,000	9,500	8,000-25,000
Mar	510,000	8,300	8,000-25,000
Apr	578,000	9,700	8,000-25,000
May	551,000	9,000	8,000-25,000
June	585,000	9,800	8,000-25,000
July	1,045,000	17,000	8,000-25,000
Aug	1,012,000	16,500	8,000-25,000
Sept	609,000	10,200	8,000-25,000

Discussion of Alternative Number Three

Alternative number three does not have the minimum flows of alternative number two. Most rainbow trout spawning bars in Reach 10 would not be dewatered. However, emergent trout along the littoral areas could still be displaced daily by fluctuations of 8,000-25,000 cfs. Fluctuating flows may increase drift of *Gammarus lacustris* making them more vulnerable to trout predation. However, *G. lacustris* population levels may be negatively affected if flows fluctuated throughout the year.

Effects on native fishes including humpback chub would be similar to those described in alternative two.

Narrative Description of Alternative Number Four
Maximized Power Plant Releases from Glen Canyon Dam

Month	Acre feet	Average monthly flow	Ranges
Oct	300,000	4,900	1,000-31,500
Nov	300,000	5,000	1,000-31,500
Dec	700,000	11,400	1,000-31,500
Jan	700,000	11,400	1,000-31,500
Feb	300,000	5,400	1,000-31,500
Mar	300,000	4,900	1,000-31,500
Apr	300,000	5,000	1,000-31,500
May	300,000	4,900	1,000-31,500
June	1,487,000	25,000	25,000
July	1,537,000	25,000	25,000
Aug	1,537,000	25,000	25,000
Sept	500,000	8,400	1,000-31,500

Discussion of Alternative Number Four

Winter flows in alternative number four duplicate winter flows in alternative number two. The same effects on rainbow trout discussed in scenario two apply here.

The high steady flows in June may benefit humpback chub spawning and recruitment. If May were similar and did not fluctuate, this alternative would be satisfactory for humpback chub. The steady flows through the summer would provide warm backwaters beneficial to larval and young-of-the-year native fish.

Narrative Description of Alternative Number Five
Maximized Power Plant Releases from Glen Canyon Dam

Month	Acre feet	Average monthly flow	Ranges
Oct	570,000	9,300	1,000-31,500
Nov	530,000	8,900	6,000-10,000
Dec	490,000	8,000	6,000-10,000
Jan	490,000	8,000	6,000-10,000
Feb	444,000	8,000	6,000-10,000
Mar	490,000	8,000	6,000-10,000
Apr	750,000	12,600	1,000-31,500
May	800,000	12,200	1,000-31,500
June	800,000	13,400	3,000-31,500
July	1,045,000	17,000	3,000-31,500
Aug	1,012,000	16,500	3,000-31,500
Sept	800,000	13,400	1,000-31,500

Discussion of Alternative Number Five

This alternative does not provide a minimum flow of 8,000 cfs for inundating spawning bars during the winter. Those portions of the bars where spawning could still occur may be dewatered. However, newly emergent fry would find suitable littoral habitat and fluctuations in the narrow range proposed would not be deleterious.

This alternative would have the same negative impacts on native fishes and humpback chub as alternative two.

Discussion of Alternative Number Six

Scenario six proposes how best to route water downstream if water had to bypassed. In the past, during high runoff, water has been bypassed in the spring. These high spring discharges approach historic flows and seem not to negatively affect humpback chub. They may in fact provide additional spawning and nursery habitat in the mouth of the Little Colorado River. However, the rate at which the water level is increased and decreased may affect native and introduced fishes.

Discussion of Alternative Number Seven

Scenario seven evaluates how to parcel out water during low water years. It is felt that 8.23 MAF set down by law represents drought conditions. To maximize aquatic resources, annual discharge needs to exceed this level. If annual discharge drops below 8.23 MAF, then native and introduced species would both be adversely affected. If this were to occur it may be best to have low water released during the winter and to conserve water for native fish spawning in the spring and early summer. Rainbow trout could be stocked to mitigate loses of natural reproduction. Even though with reduction of habitat; however, it would be unknown what population levels could be supported at such low flows.

Other Alternatives to Present Operation

In proposing alternatives for operation of the dam, it must be remembered that these studies have examined a system at a point in time when what we saw was not only dictated by present flows, but the flows that proceeded the study. An operating alternative that would optimize flows for fishes would include flows for all life stages as well as providing food and habitat.

Flows would need to maintain a minimum of approximately 8,000 cfs to inundate spawning areas during winter for trout. Flows in early spring would need to be steady to provide stable habitat for emergent fry. If food could be made more available to trout by fluctuating the water, then fluctuating flows for some unknown amount of time may be beneficial.

Flows for native fishes, especially humpback chub, would be best high and steady during late spring and early summer, then dropping to a lower level but remaining steady with little or no fluctuation. This would create additional backwaters for rearing of larval natives.

If the determination is made to maximize flows for humpback chub year round, the alternatives for the trout could be examined. This might include considering strains of rainbow trout that spawn during different seasons than what presently occurs. This also holds true if more flexibility in release patterns are desired. Summer spawning trout could be used to maximize flows for both humpback and rainbow trout during the same seasons.

A better understanding of certain areas would provide essential additional information. These areas include zooplankton, invertebrates, backwaters, and humpback chub. Utilization of zooplankton by larval native fishes and rainbow trout fry has been established. Zooplankton may be of critical importance to the early life stages when fishes are too small to consume large prey. The following questions remain.

If the plankton in the river are indeed from the reservoir, then what is the community structure and seasonality at a depth greater than 60 m where the water for release is withdrawn? How can we maximize use of the community by flow releases to the river? Are there zooplankton communities established in low velocity downriver habitats?

G. lacustris and insects provide food for the fish fauna. During most of the study, *G. lacustris* made up from 5-10% of trout gut volume. However, when the discharge pattern was altered in October 1984, *G. lacustris* volume in trout guts increased four-fold. Can the system be managed to provide a variety of discharge patterns to optimize fish utilization of *G. lacustris*. How does *G. lacustris* respond to different discharge patterns and are there seasonal interactions? Backwaters have been shown to be important habitats for larval and young-of-the-year native fishes including humpback chub. Are there factors other than temperature and velocity that contribute to high fish densities? How do backwaters change physically with changes in flow?

Though many data were collected on the population of humpback chub in the Grand Canyon, most were in relationship to the Little Colorado River. We know that during much of the year humpback chub are using the mainchannel, and we collected adult chub throughout the lower reaches of the study area. Most of these fish move to the Little Colorado River in the spring for spawning. Are there, as we believe, other tributaries providing additional spawning areas? And finally, what is the frequency of successful reproduction necessary to maintain current population levels?

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Appendix 3.1. Monthly tabulation of discharge (D), hydrolab (H), nutrient (N), and major ion (I) samples taken from the Colorado River and its tributaries in Glen and Grand canyons during April 1984 - May 1986.

	1984									1985						
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
Reach 10	D	D,H	D	D	D	D,H	D,I	D	D	D	D	D	D,N	D	D	
Paria River	H	H			H	D,H			H				D,H,N	D,H		
Reach 20		H			H	H	N,I		H,I		H		H,N	H		
Nankoweap Creek				H			D,H			D,H,N		D,H		H,N	H	
Little Colorado River		H	H				H	N,I		H		H		H,N	H	
Reach 30		H			H	H			N,I		H		H,N	H		
Clear Creek		H	H						D				D,H	H		
Bright Angel Creek			H	H			D,H			D,H		D		D,H,N	D,H	
Reach 40	H	H,N	H		H	H			H,I	N	H		H,N	H,N		
Crystal Creek		H	H	H			D,H			D		D,H		D,H	D,H	H
Shinumo Creek		H	H	H			D,H					H		D,H	H	
Tapeats Creek		H	H,N	D,H			H			D,H,N,I		D,H			H,N	D,H
Deer Creek			H			H			H,N,I		H			H,N	H	
Kanab Creek	D,H	H,N	D,H			D,H			D,H,I		H			H,N	D,H	
Havasu Creek		H,N	H			H					H,N,I	H		H,N	H	
Reach 50	H	H,N			H	H				H,N,I	H			H,N	H	

Appendix 3.1. continued

	1985 Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	1986 Apr	May	Jun
Reach 10	N,I			H,N,I		N,I		H		N,I		
Paria River		H		H,N,I		H,N,I		D,H		D,H,N,I		
Reach 20	N,I	H		H,N,I		H,N,I		H,N,I		H,N,I	H	
Nankoweap Creek	N,I			H,N,I		D,H,N,I		D,H,N,I		H,N,I		
Little Colorado River	N,I	H		H,N,I		H,N,I		H,N,I			H,N,I	
Reach 30	N,I			H,N,I		H,N,I		H,N,I			H,N,I	
Clear Creek	N,I					D,H		D,H			D,H	
Bright Angel Creek	N,I	H		H,N		D,H,N,I		D,N,I			H,N,I	
Reach 40	N,I	H		H,N,I		H,N,I		H,N,I			H,N,I	
Crystal Creek		H		H		H,N,I		D,H			D,H	
Shinumo Creek		H		H		D,H		D,H			H	
Tapeats Creek	N,I	H		H,N		D,H,N,I		D,H,N,I			D,H,N,I	
Deer Creek	N,I	H		H,N,I		D,H,N,I		D,H,N,I			H,N,I	
Kanab Creek	N,I	H		D,H,N,I		H,N,I		D,H,N,I			D,H,N,I	
Havasu Creek	N,I	H		H		D,H,N,I		D,H,N,I			D,H,N,I	
Reach 50	N,I	H		H,N,I		H,N,I		H,N,I			H,N,I	

Appendix 4.1. Sampling effort expended in collecting fishes from the Colorado River and tributaries in Grand Canyon during the period April 1984 - May 1986.

Electrofishing (minutes)

Mainstream

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
1343	1381	522	3306	3478	1891	760	3310	2018

Tributaries

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
179	111	95	101	65	46	0	166	91

Seining (sq m)

Mainstream

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
2500	6800	4450	498	355	2131	10128	3573	729

Trammel Net (hours)

Mainstream

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
110	33	84	0	0	0	0	0	0

Tributaries

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
152	51	6	0	119	0	0	51	12

Dip Net and Larval Seine (sq m)

Mainstream

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
0	0	0	287	916	278	0	487	578

Tributaries

1984				1985			1986	
SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN	SPR
0	0	0	102	202	1	0	1095	654

Appendix 4.2. Larval seine catch per unit effort (catch/100m^2) by habitat, substrate, and presence or absence of cover.

	Mean	Percent	SD	n[a]
Rainbow trout				
Habitat				
Backwater	5.0	4.6	32.7	193
Eddy	30.6	28.2	118.4	141
Run	72.1	66.4	237.4	117
Side Channel	0.9	0.8	3.3	14
SUBSTRATE				
Boulder	-	0.0	-	19
Rubble	16.6	-	74.5	29
Cobble	65.3	39.0	132.3	12
Gravel	16.5	20.9	91.3	44
Sand	31.6	40.1	149.3	368
COVER				
No Cover	11.7	22.3	57.7	182
Cover	40.8	77.7	170.9	283
Flannelmouth sucker				
HABITAT				
Backwater	4.8	75.7	25.3	193
Eddy	1.6	24.3	10.6	141
Run	-	-	-	117
Side Channel	-	-	-	14
SUBSTRATE				
Boulder	-	-	-	19
Rubble	-	-	-	29
Cobble	-	-	-	12
Gravel	2.9	51.3	9.8	44
Sand	2.7	48.7	19.2	368
COVER				
No Cover	2.1	43.6	11.6	182
Cover	2.7	56.4	20.2	288

Bluehead sucker

Habitat	Mean	Percent	SD	n[a]
Backwater	12.8	66.7	56.0	193
Eddy	1.8	9.5	14.1	141
Run	4.6	23.8	49.3	117
Side Channel	-	-	-	14
SUBSTRATE				
Boulder	-	-	-	19
Rubble	1.7	5.6	9.3	29
Cobble	-	-	-	12
Gravel	13.8	62.8	79.5	44
Sand	6.5	31.7	41.5	368
COVER				
No Cover	0.0	0.0	-	182
Cover	0.8	100.0	11.8	288

Humpback chub

HABITAT				
Backwater	0.1	6.0	1.2	193
Eddy	-	-	-	141
Run	1.7	94.0	18.5	117
Side Channel	-	-	-	14
SUBSTRATE				
Boulder	-	-	-	19
Rubble	-	-	-	29
Cobble	-	-	-	12
Gravel	0.1	13.4	0.6	44
Sand	0.6	86.6	10.4	368
COVER				
No Cover	14.8	34.2	102.1	182
Cover	28.5	65.8	125.2	288

Appendix 4.2. continued.

Speckled dace

Habitat	Mean	Percent	SD	n[a]
Backwater	23.1	14.0	117.4	193
Eddy	15.0	9.2	99.1	141
Run	24.1	14.8	89.3	117
Side Channel	100.0	61.7	331.0	14
SUBSTRATE				
Boulder	-	-	-	19
Rubble	1.3	1.5	4.8	29
Cobble	-	-	-	12
Gravel	34.0	56.7	180.7	44
Sand	25.1	41.9	115.2	368
COVER				
No Cover	14.8	34.2	102.1	182
Cover	28.5	65.8	125.2	288

Fathead minnow

HABITAT				
Backwater	14.2	11.2	81.2	193
Eddy	29.4	23.1	141.1	141
Run	83.7	65.8	366.9	117
Side Channel	-	-	-	14
SUBSTRATE				
Boulder	-	-	-	19
Rubble	1.9	2.8	7.2	29
Cobble	-	-	-	12
Gravel	2.6	5.4	13.3	44
Sand	44.3	91.98	231.4	368
COVER				
No Cover	7.7	12.7	68.6	182
Cover	53.1	87.3	257.2	288

Appendix 5.1. Summary of fish collected for tributaries in 1984 using all gear types (except larval seine).

Species	Paria	Nankoweap	LCR	Clear	Bright Angel	Crystal	Shinumo	Tapeats	Deer	Kanab	Total	Percent
Black bullhead			1								1	0.03
Bluehead sucker			12		3	4	49	4		92	164	4.98
Brook trout				1				1	1	2	5	0.15
Brown trout		18			4		2	1			25	0.76
Channel catfish			6		2					3	11	0.33
Carp			16							18	34	1.03
Fathead minnow			1			4				16	21	0.64
Flannelmouth	5	1	239		2		125	11		212	595	18.05
Golden shiner	1										1	0.03
Humpback chub			609		2		2			1	614	18.63
Rainbow trout		166		101	34	20	5	300	58	14	698	21.18
Plains killifish						1					1	0.03
Speckled dace	150	288	5	108	54	115	33			373	1,126	34.16
TOTAL	156	473	889	210	101	144	216	317	59	731	3,296	
PERCENT	4.73	14.35	26.97	6.37	3.06	4.37	6.55	9.62	1.79	22.18		99.90

Appendix 5.2 Summary of fish collected from tributaries in 1985, using all gear types (except larval seine).

Species	Paria	Nankoweap	LCR	Clear	Bright Angel	Crystal	Shinumo	Tapeats	Deer	Kanab	Havasu	Total	Percent
Black bullhead												0	0
Bluehead sucker	6	2	647		3	1	77		16	177	1	930	36.57
Brook trout												0	0
Brown trout					3		4	1				8	.31
Channel catfish			35									35	1.38
Carp			3				1		1	4		9	.35
Fathead minnow			4			1				41		46	1.81
Flannelmouth	120		228				18		1	35		402	15.81
Golden shiner											0	0	
Humpback chub			409									409	16.08
Rainbow trout	5	44	4	7	19	10	18	20	13	16	32	188	7.39
Plains killifish												0	0
Speckled dace	27	72	7	3	15	52	167			172	1	516	20.29
TOTAL	158	118	1337	10	40	64	285	21	31	445	34	2543	
PERCENT	6.21	4.64	52.58	.39	1.57	2.52	11.21	0.83	1.22	17.49	1.34		100.0

Appendix 5.3. Summary of fish collected in tributaries for 1986, except those caught with the larval seine.

Species	Paria	Nankoweap	LCR	Clear	Bright Angel	Crystal	Shinumo	Tapeats	Deer	Kanab	Havasu	Total	Percent
Black bullhead													
Bluehead sucker			38		1		46		1	2	24	112	6.50
Brook trout												0	0
Brown trout				1	4		1				1	7	.41
Channel catfish			12									12	.70
Carp			4						1			5	.29
Fathead minnow						1						1	.06
Flannelmouth	41		97				15			30	41	224	13.00
Golden shiner												0	
Humpback chub			628				4					632	36.68
Rainbow trout		407	1	3	14	3	2	7	11		3	451	26.18
Rio Grande killifish												0	0
Speckled dace	13	113		2	62	78				11		279	16.19
TOTAL	54	520	780	6	81	82	90	7	12	44	69	1723	
PERCENT	3.13	30.17	45.27	.35	4.70	4.76	3.95	.41	.70	2.55	4.00		999.9

Appendix 7.1. Floy and Carlin dangler tag numbers used during the study, 1984-1986.

000127-000142
000201-001000
024167-025658
025685-025758
025770
025787-025801
025815-025984
026036-026063
026101-026540
026551-026789
026805-027000
028003-028140
028153-028197
028213-028450
028466-028590
028601-029000
034393
0C2171-0C2194[a]
0C2299[a]
0L356-0L0421[a]
300001-300126
300145-301606
301615-301725
301757-302057
302076-302080
302101-302400
302408-302443
302451-302523
302530-303000
305001-305025
305040-306058
306073-306075
306084-306107
306116-306288
306307-306317
306324-306400
306410-306662
306673-306748
306768-306897
306908-306961
306968-306975
306989-307375
307401-307450
307476
307482-307532
307551-307581
307601-307625
307704-307877
307884-307925
307938-308000
309001-309999 [b]
310001-310195
310207-310300
310326-310430
310437-310829
310883-310900
310924-311049
311101-311132
311144-311297
311312-311540
311601-311874
311883-312618
312624-312858
312864-313155
313176-313225
313251-313353
313376-313725
313751-314199
314251-314598
314651-314750
314801-314900
314926-314961
314976-315025
315126-315724
315745
315826-315950
315976-316000

[a] - Carlin dangler tags on humpback chubs
[b] - Canyon Creek Hatchery rainbow trout

Appendix 8.1. Location by stream reach and season of adult rainbow trout guts analyzed from 1984-86.

Season	10	20	30	40	50	22	43	44	45	TOTAL
Spr 84	1				5					6
Sum 84	134			14			7		7	162
Aut 84	77									77
Win 84-85	40	5	4	72	7			9		137
Spr 85	69									69
Sum 85	52			1	10					63
Aut 85	58									58
Win 85-86	29	14	29	29	28	5				134
Spr 86		1	1	8	13					23
Sum 86	1									1
TOTAL	461	20	34	124	63	5	7	9	7	730

Appendix 8.2. Number of adult rainbow trout stomachs containing food items by stream reach and tributaries (combined). Fish with empty guts not included.

Food Item	10	20	30	40	50	Tribs
Cladophora	302	19	33	53	28	12
Gammarus	306	17	29	83	38	8
Mollusca	88	1	0	0	0	0
Oligochaeta	17	0	0	0	1	0
Adult Insects						
Aquatic						
Trichoptera	0	1	0	1	0	0
Chironomidae	176	2	0	7	3	1
Simuliidae	1	3	3	16	9	5
Tipulidae	2	0	0	1	4	0
Other Diptera	9	0	0	1	1	1
Terrestrial						
Hymenoptera	26	1	2	9	3	5
Hemiptera-Homoptera	14	0	0	5	5	1
Coleoptera	0	0	0	6	5	2
Other insects	3	0	2	0	2	1
Other invertebrates	8	0	1	1	0	0
Immature insects						
Aquatic						
Trichoptera	1	0	1	3	2	12
Odonata	0	0	0	0	0	1
Plecoptera	0	0	0	0	0	2
Ephemeroptera	0	0	1	1	0	3
Hemiptera-Homoptera	3	0	0	0	1	0
Coleoptera	0	0	0	1	0	0
Chironomidae	381	17	34	81	44	11
Simuliidae	11	17	34	93	44	12
Tabanidae	21	0	4	2	1	0
Tipulidae	6	0	6	3	2	2
Terrestrial						
Coleoptera	1	0	0	0	1	0
Diptera	3	0	0	0	1	0
Other invertebrates	2	0	0	1	0	0
Fish eggs	3	0	0	1	0	7
Fish	2	0	1	0	1	4
Bait	49	0	0	0	0	0
Body parts	134	12	29	74	30	17
Detritus	154	18	33	87	35	16
Inorganic matter	55	9	4	9	4	1
Miscellaneous	32	0	0	0	2	0
Number of stomachs	452	19	34	106	53	28

Appendix 8.3. Mean volumes (cc) of adult rainbow trout gut contents by food item from mainstream Colorado River reaches and tributaries combined. Fish with empty guts not included.

Food Item	10	20	30	40	50	Tribs
Cladophora	3.48	3.52	2.59	0.65	0.77	1.32
Gammarus	0.30	0.51	0.35	0.81	0.32	0.04
Mollusca	0.8	0.04	0	0	0	0
Oligochaeta	0.02	0	0	0	0.01	0
Adult insects						
Aquatic						
Trichoptera	0	<0.01	0	<0.01	0	0
Chironomidae	0.04	<0.01	0	<0.01	<0.01	0.01
Simuliidae	0	0.03	0.01	0.02	0.01	0.04
Tipulidae	<0.01	0	0	<0.01	<0.01	0
Other diptera	<0.01	0	0	<0.01	<0.01	<0.01
Terrestrial						
Hymenoptera	0.01	<0.01	<0.01	0.01	0.01	<0.01
Hemiptera-Homoptera	<0.01	0	0	<0.01	<0.01	0
Coleoptera	0	0	0	<0.01	0.02	<0.01
Other Insects	<0.01	0	0.01	0	0.01	<0.01
Other Invertebrates	<0.01	<0.01	0.01	0	0	0
Immature insects						
Aquatic						
Trichoptera	<0.01	0	<0.01	0.01	<0.01	0.11
Odonata	0	0	0	0	0	0.03
Plecoptera	0	0	0	0	0	0.01
Ephemeroptera	0	0	0	<0.01	0	0.01
Hemiptera-Homoptera	<0.01	0	0	0	<0.01	0
Coleoptera	0	0	0	<0.01	<0.01	<0.01
Chironomidae	0.22	0.09	0.17	0.08	1.69	0.05
Simuliidae	<0.01	0.78	0.93	0.51	6.17	0.14
Tabanidae	<0.01	0	0.03	<0.01	<0.01	0
Tipulidae	<0.01	0	0.01	<0.01	<0.01	<0.01
Terrestrial						
Coleoptera	<0.01	0	0	0	<0.01	0
Diptera	<0.01	0	0	0	<0.01	0
Other invertebrates	<0.01	0	0	0.01	0	0
Fish eggs	<0.01	0	0	0.01	0	0.15
Fish	<0.01	0	0.13	0	0.01	0.65
Bait	0.11	0	0	0	0	0
Body parts	0.09	0.03	0.05	0.10	0.05	0.10
Detritus	0.16	0.42	0.57	0.34	0.16	0.20
Inorganic matter	0.03	0.05	0.01	0.01	0.01	<0.01
Miscellaneous	0.04	0	0	0	0.02	0
Sum	4.63	5.49	4.87	2.56	9.28	2.86
No. of stomachs	452	19	34	106	53	28

Appendix 8.4. Mean seasonal volumetric gut contents (cc) of rainbow trout from mainstream Colorado River. Some taxonomic categories designated terrestrial or aquatic contain small portions having unknown affinities. Fish with empty guts not included.

	1984				1985
Food Item	Spr	Sum	Aut	Win	Spr
Cladophora	2.53	4.03	3.53	0.75	2.32
Gammarus	0.63	0.23	0.51	0.09	0.18
Mollusca	0	0.05	0.24	<0.01	0.03
Oligochaeta	0	0.03	0.01	0.01	0.01
Adult insects					
Aquatic					
Trichoptera	0	<0.01	0	0	0
Chironomidae	0.03	<0.01	0	0	0
Simuliidae	0	<0.01	0	0	<0.01
Tipulidae	0.02	0.01	0	<0.01	0
Other diptera	0.01	0.03	0	<0.01	0
Terrestrial					
Hymenoptera	0	0.09	0.01	0.01	0.02
Coleoptera	0.01	<0.01	0	0.01	0
Hemiptera-Homoptera	0	<0.01	0	<0.01	0
Other insects	0	<0.01	0	0	0.01
Other invertebrates	0.03	<0.01	0	<0.01	0
Immature insects					
Aquatic					
Trichoptera	0.02	0	0	<0.01	0
Ephemeroptera	0	0	0	0	0
Hemiptera-Homoptera	0	0	0	<0.01	0
Coleoptera	0	0	0	0	0
Chironomidae	0.43	0.28	0.22	0.07	0.20
Simuliidae	0.08	0.06	0	0	<0.01
Tabanidae	<0.01	0.01	<0.01	0	0
Tipulidae	0.03	<0.01	0	0	0
Terrestrial					
Coleoptera	0	<0.01	0	0	0
Diptera	0.09	0	0	0	0
Other invertebrates	0	<0.01	0	0	0
Fish eggs	0	0	0	0.01	<0.01
Fish	0	0	0	<0.01	0
Bait	0	0.01	0	0.13	0.04
Body parts	0.08	0.16	0.16	0.02	0.19
Detritus	0	0.40	0.31	0.07	0.02
Inorganic matter	0	0.15	0.10	<0.01	0.01
Miscellaneous	0.16	0	<0.01	0.02	0.21
Sum	4.05	5.54	5.03	1.40	3.23
No. of Stomachs	6	144	75	104	69

Appendix 8.4. Continued.

Food Item	1985 Sum	1985 Aut	1985 Win	1986 Spr
Cladophora	4.88	3.33	1.62	1.79
Gammarus	0.25	0.28	0.98	0.39
Mollusca	0.05	0.02	0.03	0
Oligochaeta	0.08	0	0	0.02
Adult insects				
Aquatic				
Trichoptera	0	0	0	0
Simuliidae	0	<0.01	<0.01	0.03
Tipulidae	0	0	<0.01	0.01
Other diptera	0.01	0	0	0.01
Terrestrial				
Hymenoptera	0.02	<0.01	<0.01	0.03
Hemiptera-Homoptera	0	0	0.01	0.01
Coleoptera	0	0	0.01	0.03
Other insects	0	0	0	0.02
Other invertebrates	0	0	0	0
Larval insects				
Aquatic				
Trichoptera	0	0	<0.01	0.01
Ephemeroptera	0	0	<0.01	0.01
Hemiptera-Homoptera	0	0	<0.01	0
Coleoptera	0.00	0	<0.01	0
Chironomidae	0.31	0.13	0.76	0.12
Simuliidae	0.02	0	3.04	0.76
Tabanidae	0	0	<0.01	0.01
Tipulidae	0	0.00	<0.01	0
Terrestrial				
Coleoptera	<0.01	0	0	0
Diptera	0	0	<0.01	0
Other invertebrates	<0.01	0	<0.01	0
Fish eggs	0	0.00	<0.01	0
Fish	0	0.03	0.03	0
Bait	0.02	0.28	0.10	0
Body parts	0.02	0	0.05	0.06
Detritus	0	0.06	0.34	0.34
Inorganic matter	0	0.00	0.04	0.01
Miscellaneous	0	0.00	0	0
Sum	5.67	4.14	7.02	3.65
No. of Stomachs	63	56	124	22

Appendix 9.1. Number of rainbow trout by age, year, and reach collected by electrofishing, mainchannel Colorado River, 1984-86.

		Reach					
Year	Age	10	20	30	40	50	Total
1984	0	463	41	10	54	2	570
	1	319	102	35	220	14	690
	2	166	157	61	236	23	643
Total		948	300	106	510	39	1903
1985	0	300	133	13	45	18	509
	1	768	778	161	1955	193	3855
	2	410	812	187	1001	66	2476
Total		1478	1723	361	3001	277	6840
1986	0	24	12	0	0	1	37
	1	104	377	66	617	256	1420
	2	262	617	86	568	152	1685
Total		390	1006	152	1185	409	3142

Appendix 9.2 Electrofishing effort (minutes) by year and reach, mainchannel Colorado River, 1984-86.

	Reach					
Year	10	20	30	40	50	Total
1984	829	547	268	834	479	2957
1985	1290	2580	1220	3343	1656	10089
1986	506	1063	340	1150	959	4018
Total	2625	4190	1828	5327	3094	17064

Appendix 9.3 Catch per unit effort (minute) of rainbow trout by age, year, and reach, mainchannel Colorado River, 1984-86.

		Reach					
Year	Age	10	20	30	40	50	Total
1984	0	0.56	0.07	0.04	0.06	0.000	0.19
	1	0.38	0.19	0.13	0.29	0.13	0.23
	2	0.20	0.29	0.23	0.28	0.05	0.22
Total		1.14	0.55	0.40	0.61	0.08	0.64
1985	0	0.23	0.05	0.01	0.01	0.01	0.05
	1	0.60	0.30	0.13	0.58	0.12	0.38
	2	0.32	0.31	0.15	0.30	0.04	0.25
Total		1.15	0.67	0.30	0.90	0.17	0.68
1986	0	0.05	0.01	0.00	0.00	0.000	0.01
	1	0.21	0.35	0.19	0.54	0.27	0.35
	2	0.52	0.58	0.25	0.49	0.16	0.42
Total		0.77	0.95	0.45	1.03	0.43	0.78

Appendix 9.4. Rainbow trout Mean condition factors by length interval and year, 1984-86.

Length Interval (mm)	Reach 10			Reach 20			Reach 30			Reach 40			Reach 50		
	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986
0 - 99	1.33	1.15	1.19	1.01	-	-	1.09	-	-	-	-	-	-	-	-
100 - 199	1.21	1.08	0.97	1.18	1.05	-	0.84	1.05	-	1.01	0.92	1.03	-	0.95	0.97
200 - 299	1.16	1.07	1.00	1.16	0.95	1.11	0.95	0.95	1.11	1.05	0.88	0.96	1.15	0.84	0.94
300 - 399	1.09	1.04	0.97	1.06	0.91	1.02	0.92	0.94	1.02	0.98	0.80	0.91	0.95	0.79	0.88
400 - 499	1.06	1.00	0.94	1.02	0.87	0.94	-	0.87	0.94	0.81	0.73	0.81	-	-	-
500 - 599	0.96	0.95	0.95	0.94	-	-	-	-	0.69	-	-	-	-	-	-
600 - 699	0.89	-	-	0.86	-	-	-	-	-	-	0.69	-	-	-	-
Mean Condition	1.14	1.05	0.96	1.06	1.01	0.99	0.94	0.93	1.04	1.01	0.87	0.95	1.04	0.87	0.93

Appendix 9.5. Seasonal condition factors for rainbow trout (200-400 mm tl) by season and reach, 1984-86.

	Reach					
Season	10	20	30	40	50	Mean
Spring 84	1.13	1.19	0.94	1.10	1.12	1.10
Summer 84	-	1.11	1.00	1.02	0.91	1.01
Fall 84	1.12	0.96	0.96	0.95	-	1.00
Winter 84	1.01	1.06	0.92	0.84	0.83	0.93
Spring 85	1.06	1.04	0.90	0.83	0.78	0.92
Summer 85	1.08	1.02	0.97	0.82	0.85	0.95
Fall 85	1.01	1.00	0.91	0.88	0.82	0.93
Winter 85	0.91	1.00	1.03	0.92	0.88	0.95
Spring 86	1.04	1.00	1.02	1.00	1.01	1.01
Mean 0.98		1.05	1.02	0.96	0.90	0.91
SD 0.06		0.14	0.11	0.11	0.13	0.13
Number	1957	2974	683	4151	740	10505

Appendix 9.6. Monthly length frequencies of humpback chub collected at all locations, Colorado River and tributaries, 1984-1986.

Length Interval (mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1984	1985	1986	TOTAL
10 - 19			1											9														1	9	0	10
20 - 29			9													24												9	24	0	33
30 - 39			2													90	3		1									2	94	0	96
40 - 49					1	1								1		17	9		16									2	43	0	45
50 - 59					1	1											17	1	22									2	40	0	42
60 - 69					3	1			1					1			4	6	34									5	45	0	50
70 - 79	1								1								7	6	43		1							2	57	0	59
80 - 89	2		1														4	3	33		1							3	41	0	44
90 - 99	3																	4	11									3	15	0	18
100 - 109	1																3	2	12									1	17	0	18
110 - 119	1																2		10									1	12	0	13
120 - 129					2														11									2	11	0	13
130 - 139	2				2												2		8									4	10	0	14
140 - 149	1				1						1						3	1	6									2	11	0	13
150 - 159	1				1	1											1	1	16								1	3	18	1	22
160 - 169	2	1									1				1		1	2	7						1			3	12	1	16
170 - 179		1																3	12									1	15	0	16
180 - 189		1			1								1					3	1	8								2	13	0	15
190 - 199					2				1	1				1	1			2	3	8							2	3	16	2	21
200 - 209		1			2									3					2	7							1	3	12	1	16
210 - 219																			1	4							10	0	5	10	15
220 - 229					1								1	1				1		2			2		1		13	1	5	16	22
230 - 239		3												2	2					3			2		1		33	3	7	36	46
240 - 249		5	1			1							3	1						2			1		1		45	7	6	47	60
250 - 259	2	6							1				3	4						2			1				29	9	9	30	48
260 - 269		2				2							1	1	1										1		30	4	3	31	38
270 - 279		9	1											5									2		2		47	10	5	51	66
280 - 289	2	5	1										1	3									2		2		35	8	4	39	51
290 - 299		10	1										1	6									1		1		36	11	7	38	56
300 - 309		17	2											8									2		1		33	19	8	36	63
310 - 319	2	25	5		1	1							3	11	1								1				21	34	15	22	71
320 - 329	1	32	12						1				1	14		1							2		4		41	46	16	47	109

Appendix 9.6. continued.

Length Interval (mm)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1984	1985	1986	TOTAL
330 - 339		31	3										1	19									1		6		29	34	20	36	90
340 - 349		30	6		2								1	13									2		5		28	38	14	35	87
350 - 359	1	29	11										1	24									3		6		28	41	25	37	103
360 - 369	2	24	8		1									19		1			3				5		5		14	35	23	24	82
370 - 379		18	10											22			1						4		7		17	28	23	28	79
380 - 389		20	2			1								13		1									5		7	23	14	12	49
390 - 399		23	3											28									2		6		7	26	28	15	69
400 - 409		17	2											17			1		1				2		6		8	19	19	16	54
410 - 419		5	2											12									1		3		3	7	12	7	26
420 - 429						1								8									3		2		1	1	8	6	15
430 - 439		2												3											1		2	2	3	3	8
440 - 449		2	1											1											1			3	1	1	5
450 - 459		2												1									1				2	2	1	3	6
460 - 469																												0	0	0	0
470 - 479																												0	0	0	0
480 - 489														1														0	1	0	1
490 - 400																												0	0	0	0
TOTAL:	24	321	84	0	21	10	0	0	5	1	2	0	21	252	3	134	64	36	282	0	2	0	40	0	68	0	523	465	797	631	1893

Appendix 9.7. Length frequencies of flannelmouth sucker collected above, below, and in the Little Colorado River, 1984-86.

Length Interval(mm)	Number Collected Above LCR	LCR	Below LCR	Length Interval	Number Collected Above LCR	LCR	Below LCR
10 - 19		59	33	310 - 319		59	33
20 - 29	20	71	3	320 - 329		1	19
30 - 39	21	26	24	330 - 339	1	2	23
40 - 49	1	46	29	340 - 349			22
50 - 59		2	40	350 - 359		1	24
60 - 69		3	23	360 - 369	2	1	14
70 - 79		5	16	370 - 379	1	7	28
80 - 89		2	22	380 - 389	1	11	22
90 - 99		4	21	390 - 399	1	11	29
100 - 109			21	400 - 409	14	11	33
110 - 119			23	410 - 419	18	13	30
120 - 129			7	420 - 429	25	28	20
130 - 139			13	430 - 439	41	13	25
140 - 149			17	440 - 449	46	26	24
150 - 159			13	450 - 459	60	27	13
160 - 169			6	460 - 469	80	34	17
170 - 179			13	470 - 479	93	41	16
180 - 189			4	480 - 489	79	38	11
190 - 199	1		7	490 - 499	60	23	15
200 - 209		1	6	500 - 509	70	31	8
210 - 219			15	510 - 519	78	20	12
220 - 229		1	16	520 - 529	68	19	11
230 - 239	1	1	17	530 - 539	63	18	3
240 - 249		4	18	540 - 549	48	19	6
250 - 259		2	18	550 - 559	34	12	2
260 - 269			18	560 - 569	28	9	3
270 - 279	1	7	37	570 - 579	20	5	1
280 - 289		2	24	580 - 589	10	4	1
290 - 299		2	30	590 - 599	2	3	
300 - 309		2	34	600 - 609	1	1	
				Total	990	669	1024

Appendix 9.8. Length frequencies of bluehead sucker collected above, below, and in the Little Colorado River, 1984-86.

Length interval (mm)	Number Collected Above LCR	LCR	Below LCR
10 - 19		65	98
20 - 29		68	32
30 - 39	2	301	50
40 - 49		264	92
50 - 59	1	17	82
60 - 69			61
70 - 79			36
80 - 89			32
90 - 99			6
100 - 109			10
110 - 119			4
120 - 129			4
130 - 139			3
140 - 149			
150 - 159			2
160 - 169			4
170 - 179			8
180 - 189			6
190 - 199			6
200 - 209			10
210 - 219		3	21
220 - 229		2	17
230 - 239	2	9	43
240 - 249	3	15	46
250 - 259		13	42
260 - 269		9	55
270 - 279	2	10	31
280 - 289		5	23
290 - 299		10	20
300 - 309		3	23
310 - 319		1	25
320 - 329	1	2	13
330 - 339	25	2	12
340 - 349	2		12
350 - 359	1		13
360 - 369	1		3
370 - 379	1	1	11
380 - 389	1		2
390 - 399		1	1
400 - 409		1	2
410 - 419			
420 - 429	1	1	
430 - 439			
440 - 449		2	
450 - 459			
460 - 469		1	
Total	20	806	961

Appendix 11.1. Lee's Ferry monthly estimates of angler hours, catch and harvest rates, and harvests of rainbow and brook trout, January 1984 - May 1986.

1984	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NPS Angler Counts	2781	3662	4186	3820	5215	3194	4193	2941	2268	6133	4617	1868
Angler Hours	13015	17980	19256	23646	35879	26414	28554	19264	17509	42440	34628	9919
Hours/Day	4.7	4.9	4.6	6.2	6.9	8.3	6.8	6.6	7.7	6.9	7.5	5.3
Catch/Hour	.62	.25	.22	.20	.28	.50	.56	.59	.51	.56	.64	1.48
Harvest/Hour	.20	.13	.10	.10	.11	.20	.30	.33	.23	.21	.30	.28
Number RBT	2350	2045	1670	2213	3675	5216	8221	6160	3784	8635	10141	2777
Number BKT	253	292	256	152	272	67	345	197	243	278	247	0
Total	2603	2337	1926	2365	3947	5283	8566	6357	4027	8913	10388	2777
1985												
NPS Angler Counts	1587	1365	2040	2257	1480	1244	1184	1304	2222	2278	1811	1181
Angler Hours	10284	9378	12709	15799	10286	8609	8430	8972	14910	14944	10450	7393
Hours/Day	6.5	6.9	6.2	7.0	7.0	6.9	7.1	6.9	6.7	6.6	5.8	6.3
Catch/Hour	.93	.65	.58	.35	.34	.72	.55	.87	.42	.58	.65	.62
Harvest/Hour	.24	.17	.23	.14	.12	.23	.20	.35	.25	.25	.33	.27
Number RBT	2392	1508	2761	2127	1203	1907	1619	3102	3698	3736	3448	1996
Number BKT	76	86	162	85	31	73	67	38	29	0	0	0
Total	2468	1594	2923	2212	1234	1980	1686	3140	3727	3736	3448	1996
1986												
NPS Angler Counts	1170	921	1029	1038	708							
Angler Hours	7874	5646	6472	6622	4241							
Hours/Day	6.7	6.1	6.3	6.4	6.0							
Catch/Hour	.24	.31	.16	.31	.32							
Harvest/Hour	.08	.11	.09	.11	.12							
Number RBT	626	612	578	728	509							
Number BKT	4	9	5	0	0							
Total	630	621	583	728	509							

Appendix 11.2. Arizona Game and Fish Department stocking records for Lee's Ferry, 1964-1986.

	Date	Number Stocked	Mean Length (mm)	Strain
Rainbow trout	03/64	10,200	140	NA
	05/64	5,000	216	
	06/64	5.000	254	
	07/64	5,000	267	
	10/64	5,000	279	
	11/64	5,000	279	
	01/65	4,366	292	
	03/65	4,464	292	
	06/65	2,000	254	
	07/65	10,000	76	
	09/65	2,000	216	
	10/65	2,000	216	
	01/66	1,500	249	
	04/66	10,000	76	
	04/66	1,500	292	
	09/66	1,500	229	
	03/67	5,000	114	
	03/67	1,600	318	
	05/67	2,500	178-254	
	06/67	1,500	241	
	12/67	10,000	102	
	01/68	2,800	279	
	03/68	1,000	229	
	03/68	20,000	127	
	08/68	4,500	203	
	09/68	10,000	140	
	05/69	945	241	
	05/69	16,000	127	
	05/69	24,000	114	
	06/69	1,500	229	
	06/69	1,225	241	
	07/69	20,000	178	
	08/69	1,225	216	
	04/70	20,000	152	
	05/70	1,050	229	
	06/70	1,050	229	
	07/70	1,225	229	
	08/70	1,050	229	
	05/71	2,450	229	
	07/71	1,400	229	
	08/71	1,260	241	
	05/72	875	254	
	06/72	1,225	267	
	07/72	1,225	267	
	08/72	1,260	241	
	06/73	1,225	216	

	Date	Number Stocked	Mean Length (mm)	Strain
	08/73	1,225	241	
	07/74	3,990	216	
	05/75	30,000	76	
	06/73	4,500	229	
	03/76	50,000	51	
	10/76	50,000	76	
	04/77	95,000	76	
	03/78	50,000	102	
	07/80	846	229	
	08/80	7,522	140	
	09/80	7,581	140	
	02/81	39,506	102	
	03/81	18,298	102	
	08/81	50,000	102	Plymouth
	07/82	50,000	102	Servier
	10/83	39,287	114	Arlee
	06/84	24,952	102	Bellaire
	08/84	25,000	76	Bellaire
	08/84	28,000	76	Shasta
	09/84	50,000	76	
	02/85	4,962	178	Shasta
	03/85	19,841	175	McConaughy
	06/85	15,000	NA	Bellaire
	07/85	60,168	76	Kamloops
	09/85	30,000	76	Bellaire
	09/85	943	381	Servier
	10/85	2190	305	Fish Lake-Desmet
	04/86	53,180	67	Bellaire
	06/86	34,445	Fingerling	Kamloops
Brook trout	06/77	47,880	64	
	08/78	100,000	64	
	11/78	42,700	Fingerling	
	07/80	886	229	
	09/80	40,000	76	
	09/81	50,000	102	
	12/81	10,096	127	
	06/82	50,000	76	OWHI
	10/83	50,000	89	OWHI
	08/85	50,000	76	Soda Lake
	06/86	40,000	Fingerling	OWHI
Cutthroat trout	12/78	60,000	76	
	11/80	857		
Coho salmon	6/71	20,000	76	

Acknowledgments

When we initiated this project, it was not without a great deal of concern. The tasks appeared to be monumental. Not only was the study one of the most complex undertaken by this Department but the logistic problems of working in the Grand Canyon were great. It was not until the first trip downriver that we realized the full implications of the problems faced. Only through a great deal of cooperation and a lot of personal sacrifice would we be successful. Almost three years later, it appears that the majority of the objectives have been addressed and many questions answered. The success that we have achieved is due largely to the following people:

Dave Wegner (BOR) - Dave has been a dynamic force in this project. Somehow he has always been able to come up with the key piece of equipment or the right word of advice when needed. He has also been able to keep a positive attitude towards this project and has been able to affect those of us on the project with the same enthusiasm. The staff in the Glen Canyon Environmental Studies office have also been a great help.

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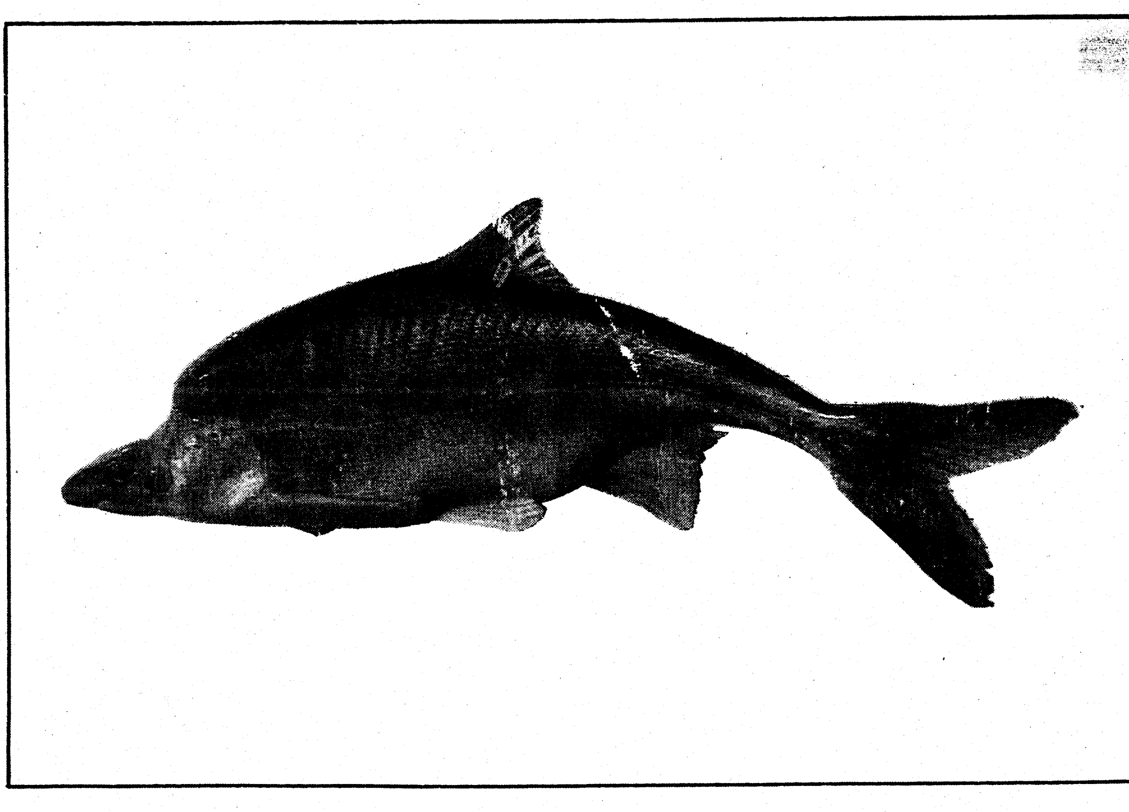
LEE'S FERRY TROPHY TROUT



THE ENDANGERED HUMPBACK CHUB