DRAFT REPORT

THE ENDANGERED HUMPBACK CHUB *(GILA CYPHA)* IN ARIZONA

A REVIEW OF PAST STUDIES

AND

SUGGESTIONS FOR FUTURE RESEARCH

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INTRODUCTION

Study Purpose

Much of the available information on the endangered humpback chub *(Gila cypha)* population in the Grand Canyon region of Arizona lies in the confines of fisheries biologists field notes or government agency and contract reports. This body of "grey literature" is difficult to access for even the most persistent investigator, and it has seldom been subjected to critical evaluation as part of the "peer review process" involved in publishing in scientific journals. During the course of the ongoing Section 7 Consultation on the Operation of Glen Canyon Dam (2-21-87-F-23), a decision was made to gather together the available data and literature on humpback chub in Grand Canyon, including data gathered by the Arizona Game and Fish Department (Department) during 1987-1989. The objectives of this effort were threefold:

(1) to review the literature, both published and unpublished, on the ecology of the species in the study area;

(2) to compile in a computerized relational database the existing data and, where necessary, analyze (or reanalyze) and interpret these data, and;

(3) to determine what areas of our knowledge are lacking and needful of further research to help ensure the sustained presence of *Gila cypha* in the Colorado River and its tributaries below Glen Canyon Dam.

Although this report is limited in scope to consideration of the endangered humpback chub, this limitation does not indicate a lack of concern by the Department for other threatened and endangered species of wildlife in the Colorado River and its tributaries below Glen Canyon Dam. Department concerns for these species in Grand Canyon are being addressed through provisions of the Fish and Wildlife Coordination Act and the National Environmental Policy Act as they pertain to compliance with the October 27, 1989, directive by the Secretary of Interior to evaluate the effects of the operation of Glen Canyon Dam.

Glen Canyon Dam and *Gila cypha*

Construction of Glen Canyon Dam was officially completed in April of 1963, although hydroelectric production did not begin until the following year. Evaluation of the project's impacts on fisheries resources by the Fish and Wildlife Service (Service) was limited to the potential for sport fisheries development in the reservoir and tailwater. Native suckers and the Colorado squawfish were mentioned only in passing (Service 1958). The humpback chub was officially designated as an endangered species on March 11, 1967 (Federal Register Volume 34, page 4001). Endangered status was assigned because of a restricted, fragmented distribution, small population size, and threats to the species' habitat accrued from hypolimnial release dams, with their associated reservoirs and cold tailwaters, and other types of water development (Service 1988). In 1977, the Bureau of Reclamation (Reclamation) formally requested Section 7 Consultation from the Service concerning the effects of Glen Canyon Dam on endangered species. The following year the Service rendered a jeopardy opinion for humpback chub and also indicated to Reclamation that dam operations were limiting the potential for recovery of Colorado squawfish (Nelson 1978).

In 1979 Reclamation held public meetings on proposed peaking power modifications to operations at Glen Canyon Dam. This proposal met with considerable public opposition and was dropped, but an accompanying proposal for uprating and rewind of the dam's generators was continued. Reclamation delivered a Finding of No Significant Impact (FONSI) for the uprating and rewind in 1982. The Commissioner of Reclamation concurred with the FONSI, but directed that public concern over the impacts of current operations was sufficient to warrant study of these impacts. Thus, in December of 1982 the Commissioner directed that the Glen Canyon Environmental Studies (GCES) should begin.

During the course of the GCES, Reclamation again requested formal consultation with the Service on the operation of Glen Canyon Dam. That consultation, which is presently continuing, has led to an agreement between Reclamation and the Service to develop Conservation Measures for the endangered humpback chub in lieu of Reasonable and Prudent Alternatives under the existing jeopardy opinion.

METHODOLOGY

Information Gathering

In order to gather information used in this report, requests were mailed to government agency offices, to known collectors of fishes in the Grand Canyon region, and to authors of reports and journal articles dealing with these fishes. Early contact was made with Dr. Wayne Starnes of the U.S. National Museum, who is charged with developing the protocol for taxonomic studies on Colorado River endangered fishes (Starnes 1989). Known collectors were requested to provide records on location, date and time of capture, gear used, effort expended, length, weight, and sex, and other species of fish collected with humpback chub. The solicitations acknowledged that collection records might exist in various forms, from field notes to computerized data, and that all information would be centralized into one or more computerized databases available for future access upon request to the Department.

Further attempts to gather the existing literature were accomplished through the DIALOG network of computerized databases, including BIOSIS, NTIS, and ASFA. Keywords included various combinations of endangered fishes, humpback chub, Colorado River, hydroelectric dams, and impacts.

Computerization and Analysis of Data

All data received on fishes collected from the Grand Canyon region, other than those gathered by Department personnel, were in hard copy form. These data were entered into flat (ASCII text) files through the Department's Honeywell Data Entry Facility with subsequent verification to ensure quality control. The data were then transmitted to a COMPAQ 386/25 microcomputer using the KERMIT file transfer facility and XMODEM error checking protocol. Initial data editing was accomplished using WordPerfect Version 5.0 as a text editor. Once the data were considered "clean", they were entered into dBASE III PLUS databases. This database manager was chosen because of its relational capabilities and because it is widely used by other government agencies, universities, and consulting firms involved in research on threatened and endangered fishes of the Colorado River Basin. As warranted by improvements in software, the Department may upgrade the database manager used to store information on humpback chub and other fishes in Grand Canyon. The Department will, however, consider compatibility issues and ease of transfer to other researchers in any decision to change the database manager.

Only four relatively large databases containing information on humpback chub and other fishes collected from the Grand Canyon region are presently held by the Department. These data were collected during the studies of Carothers et al. (1981), Kaeding and Zimmerman (1982, 1983), and Maddux et al. (1987), and during the Department's humpback chub monitoring program in 1987-1989 (unpublished) Limited data are also available from Department monitoring efforts conducted prior to the initiation of the GCES program (J. Brooks, written communication). No attempt has been made to index or standardize file formats and variable designations in these databases pending the decision to incorporate all data into a Geographic Information System database as part of the GCES program. Formats for the respective files in these databases as presently held are provided in Appendix I. Additional information gathered during this study largely is limited to museum accession records and Grand Canyon National Park permit reports (see Table 4).

Statistical analyses were conducted on the microcomputer using SPSS/PC+ Version 3.0. The rigor with which statistical tests could be applied to the various data sets was limited by incomparability of different gear types within and among data sets given acknowledged biases of these gear, missing information on gear types and effort expended, temporal incompatibilities, i.e. lack of collections from the same seasons among years, spatial incompatibilities, i.e. lack of collections from the same areas over time, and insufficient numbers of samples taken at a given time and location to ensure that sample estimates were representative of existing numbers, sizes, habitats utilized, species composition, etc. With respect to humpback chub, certain analytical problems arise simply as a function of the rarity of the species, i.e. regardless of the number of samples, most samples do not contain individuals and the resulting distributions do not lend themselves well to commonly applied statistical techniques.

Lack of humpback chub in many samples provides particular problems for the analysis of differences in catch rates and the use of this parameter as an index of changes in abundance. The preponderance of zero catches and resulting skewness, i.e. non-normal distribution, is problematic for both parametric and nonparametric statistical tests. Parametric tests are limited by a distribution that cannot be normalized by transformations, and analogous nonparametric tests are limited by measures of central tendency being at zero and by an inordinate number of ties (zeroes). Unfortunately, this type of distribution occurs with regularity in fisheries data, and it will, by definition, be observed often wherever rare species are involved. In this report we limit the use of statistical tests of catch rates to those datasets having more intensive and structured collecting regimes. Frequency distributions of catch rate data are presented and both parametric and nonparametric tests are utilized.

Standardization of Results

All mainstream locations in this report are given as river miles (RM) above and below Lee's Ferry (Compact Point). Equivalent metric distisik—s in kilometers (RKM) are also provided. The latter is used as the primary measure for all distances between mainstream locations, but the convention of using river mile as a primary measure of location is observed because of its use in the GCES program and in currently used river guides. Distances upstream in tributaries, where applicable, are in kilometers above the mouth.

Reach categories were designated for the mainstream between Lee's Ferry and Separation Rapids by Carothers et al. (1981) and between Glen Canyon Dam and Diamond Creek by Maddux et al. (1987). Kaeding and Zimmerman divided the 32 km reach of the Colorado River above and below the Little Colorado River (LCR) into six strata and the tributary was stratified into four reaches. One additional stratum contained the confluence zone. Other mainstream divisions were used by Anderson et al. (1986) and Schmidt and Graf (1988). In this report, mainstream segregation into reaches, where employed, follows that of Maddux et al. where the Colorado River was divided as follows: Reach 10 (Glen Canyon Dam to Lee's Ferry); Reach 20 (Lee's Ferry to LCR); Reach 30 (LCR to Bright Angel Creek); Reach 40 (Bright Angel Creek to National Canyon), and; Reach 50 (National Canyon to Diamond Creek). This categorization is used herein largely for convenience as the ecological relevance of these reaches is yet to be determined.

Many of the data in this report were aggregated on a seasonal basis for analysis with months assigned to seasons as follows: Spring (March-May); Summer (June-August); Autumn (September-November), and; Winter (December-February). Seasonal categories were used previously by Carothers et al. (1981) and Maddux et al. (1987) to allow analysis of temporal patterns where collections were not made in all months. Other groupings could be applied, but we believe this categorization best captures environmental changes and biological responses of humpback chub in the Grand Canyon region, while sacrificing the least information.

Collections of fishes in Grand Canyon have been made with a variety of gear types, including trammel nets, gill nets, larval and bag seines, hoop nets, fyke nets, minnow traps, and electrofishing. Degree of attention paid to recording gear types and, particularly, effort has varied considerably among investigators. Reports and collection records written prior to 1980 were very sporadic in this respect, and meaningful calculation of catch rates was impossible for these collections.

All catch rates were standardized by gear type: electrofishing catch rates to fish/100 min; seine catch rates to fish/100 m, and; larval seine or dip net catch rates to fish/10 m^2. Trammel net catch rates have not been standardized to a common net size because of variation in the way in which nets were deployed (parallel with or perpendicular to current), but they were standardized to a 12 hour period. For all gear types, original units are indicated whenever conversions were applied.

THE STUDY AREA

General Description

The primary area covered by this report is the Colorado River and its tributaries between Glen Canyon Dam and the headwaters of Lake Mead, a distance of nearly 485 km (300 mi) (Figure 1). Numerous tributaries enter this reach, but all save approximately a dozen flow intermittently or are ephemeral. Many are first or second order streams that differ markedly from the major river into which they flow.

The mainstream passes successively through Glen, Marble, and Grand canyons before entering Lake Mead. In this report the reach will be referred to collectively as the Colorado River in the Grand Canyon region. Both the mainstream and its tributaries are bordered by high, vertical or V-shaped cliffs formed of limestone or gneiss and schist in much of their traverse across the landscape. These escarpments culminate in the plateau country through which the river cuts its course. Only in two limited reaches, termed Furnace Flats and Lower Canyon by Schmidt and Graf (1988), do the canyon walls retreat appreciably.

Channel geometry of the Colorado River in the Grand Canyon region has been described by Leopold (1969). In its traverse through the canyons, the river passes downward from an elevation of approximately 945 m to 265 m (3100 ft to 870 ft) at an average gradient of 0.49 **m/km** (7.7 ft/mile). The river's fall is not constant, however, but stepped, giving rise to an alternating series of low gradient pools and steeper riffles and rapids. Depths in the pools reach 15-30 m (50-100 ft) and river widths of 90 to 120 m (300 to 400 ft) are common.

The general pattern of rapids and pools is complicated by constrictions of the river's channel formed by debris flows carried to the mainstream by tributary floods or, in some instances, by landslides. Downstream from such constrictions, eddies form recirculation zones which deposit alluvial sediments and create backwaters (Schmidt and Graf 1988).

These backwaters, although typically small in size relative to the mainstream area, are very important nursery habitats for both native and introduced fish species in the Grand Canyon region (Maddux et al. 1987) and in other reaches (Valdez and Wick 1983, Holden et al. 1986, Valdez 1990).

The river's riparian vegetation is constrained to two relatively narrow zones founded on alluvial deposits or the lower extremes of talus slopes. The upper zone, or Old High Water Zone, is a pre-dam community dominated by western honey mesquite and catclaw acacia, whose position largely reflects the scouring line of floods that coursed through Grand Canyon prior to regulation of the river (Carothers et al. 1979, Turner and Karpiscak 1980). The post-dam riparian community, which is dominated by combinations of tamarisk, coyote willow, seep-willow, arrowweed, and desert broom, is formed in the New High Water Zone. With the exception of modifications brought about by floods during 1983-1985, position of this community relative to the river is thought to be controlled largely by the levels of fluctuating flows produced during hydro-electric power generation from Glen Canyon Dam.

The riparian plant communities of both the Old and New High Water Zones are known to be important as habitat and food resources for many forms of wildlife along the river corridor (U.S. Department of Interior 1988). Little attention has been paid to the role of these plants in affecting the river's productivity, however, either as they contribute organic matter through pollen production, leaf-fall and deadwood or as they contribute to the mineralization and solubilization of nutrients necessary for aquatic primary production.

Hydrology

Colorado River

The Colorado River has a drainage basin of 635,000 km^2 (245,000 mi^2) of which 204,000 km^2 (109,500 mi^2) lies above the division between the Upper and Lower basins at Lee's Ferry (Thomas et al. 1963). Recorded annual runoff to the Lower Basin has varied from less than 3 maf (million acre-feet) to over 20 maf. Periodicity of this inflow within the annual cycle prior to impoundment of Lake Powell reflects the importance of the contribution from snowmelt runoff in the high ranges of Colorado, Wyoming, and Utah (Figure 2). The hythograph of mean monthly discharges at Lee's Ferry was unimodal with a maximum during June. The period of increased inflow typically began in late April or early May, and the declining limb of the hydrograph was evidenced in July. Occasional years were marked by the appearance of summer floods, but the average of this contribution was minor when compared to that from snowmelt. During the remaining fall and winter months, flows were generally in the range of 3,000 cfs to 10,000 cfs.

Subsequent to the regulation of the Colorado River by Glen Canyon Dam in 1963, annual flow volume past Lee's Ferry has varied from 2.4 maf to 20.5 maf (U.S.

Department of Interior 1988). This range, which complements that of the pre-dam era, belies the extreme changes in hydrology that have occurred since the impoundment of Lake Powell.

During the first 20 years following impoundment of Lake Powell, the pattern of the hydrograph of mean monthly discharge displayed considerably reduced seasonal variation relative to that of the pre-dam era (Figure 3). The spread between minimum and monthly discharges increased considerably, however, particularly during months previously at or near base flow. Flows below Glen Canyon Dam were dictated by legal mandates for water deliveries to the Lower Basin and the need to fill Lake Powell, conflicting demands which were aggravated during years of low runoff.

The filling of Lake Powell in 1980 received little public recognition, yet this event set the stage for a marked change in the annual hydrograph of flows past Lee's Ferry beginning in 1983 and continuing through much of 1986 (Figure 4). High runoff in the Upper Basin during those years, coupled with lack of storage in the reservoir, forced the release of water from Glen Canyon Dam into an "unregulated mode" and produced a unimodal hydrograph reminiscent of the pre-dam era complete with flood releases reaching over 92,000 cfs.

In 1987 the Secretary of Interior and the seven Colorado River Basin states reached an agreement to modify the management of Lake Powell in order to reduce the frequency of downstream flooding. Ironically, this year also marked the beginning of the current "drought" cycle during which inflow to the reservoir has been less than 80% of the long-term average (R. Peterson, Bureau of Reclamation, personal communication). In response to diminished inflow, monthly water releases reverted to a bimodal pattern similar to that of the pre-flood period (Figure 5). It appears, however, that during the post-flood period of 1987-1989 winter mean monthly maxima more closely approach those of summer maxima and that the latter have been displaced from May to July.

The effects of Glen Canyon Dam operations on the hydrology of the downstream reach are not confined to the monthly pattern of flow volume. Nested within the monthly patterns are regulated daily fluctuations which can vary from less than 1,000 cfs to 31,500 cfs instantaneous release and produce stage changes of up to 13 vertical feet (Turner and Karpiscak 1980). This range of discharges is considerably greater than that indicated by Reclamation during the planning stages for the dam (8,300-27,800 cfs) (Service 1958). With the exception of rare flood surges, daily fluctuations of these magnitudes did not occur in the pre-dam Colorado River.

During the high runoff and full reservoir years of 1983-1986, releases from Glen Canyon Dam were predominantly high and steady (Figure 6). Fifty percent of the days in that period had a mean daily discharge of 25,000 cfs or greater, whereas the coefficient of variation for a like number of days was less than 5%. In subsequent years, low runoff has resulted in a change in dam operations resulting in the median of mean daily

discharge being lowered to approximately 12,000 cfs, while the median coefficient of variation has increased to 40%.

Tributaries

Based largely on their geomorphology, tributaries to the Colorado River in the Grand Canyon region may be divided into two broad categories (Hamblin and Rigby 1968). The first group, which includes the Paria River, LCR, and Kanab Creek, have relatively large watersheds, and they traverse a variety of geological formations while passing through extensive, deeply entrenched meanders before reaching the mainstream. Substrates in these streams have a high percentage of fine particles, a reflection of both the geology of their drainages and their relatively low gradients. All three of these tributaries carry large amounts of suspended sediments to the Colorado River even during minor floods.

The second broad category of tributaries includes the majority of streams that enter the Colorado River in the Grand Canyon region. These streams arise from karst springs in the water-bearing limestone and dolomite formations, mainly the Redwall and Muav limestones, which form much of the high plateaus bordering the river (Huntoon 1974). Notable examples are Bright Angel Creek, Tapeats Creek, Deer Creek, and Havasu Creek. Distance from source to mouth in these tributaries is typically 10 miles or less and their watersheds are consequently much smaller than those of the first category. In their short

run to the mainstream, these tributaries traverse relatively high gradients and course over coarse gravel to rubble substrates. Their waters run clear except during limited periods of high spates.

When the hydrology of the two categories of tributaries is considered, increased divergence is encountered and the first category becomes more diversified. All three tributaries of the first category are intermittent in portions of their drainage, and they vary seasonally from dry beds to extreme floods. The LCR is intermittent to ephemeral in the middle portion of its drainage, but receives perennial input from a series of springs, named Blue Springs, arising from 4.8 to 21 km (3 to 13 mi) upstream of the mouth. These springs provide a perennial base flow of approximately 225 cfs to the lower reach of this tributary (Johnson and Sanderson 1968, Cooley et al. 1969, Brian 1989). Both the Paria River and Kanab Creek also receive spring input, but these inflows are typically insufficient to produce surface flow at their mouths during extended periods lacking surface runoff.

The annual hydrograph of mean maximum and minimum monthly discharges for the Little Colorado River atEt2ameron, some 65 km (40 mi) above the mouth, is bimodal with peaks occurring during spring and late summer-early autumn (Figure 7, see also Hereford 1984). These peaks result, respectively, from snowmelt runoff from the high mountains of eastern Arizona and western New Mexico, and from summer thunderstorms occurring both in these ranges and in lower desert regions (Johnson 1976). This feature serves to contrast the seasonal pattern of flows in the tributary and mainstream, both with

peaks in runoff and the period of maximum flows. As indicated
flows in the hydrograph, the character of these runoff events differs
pring peak is characterized by relatively sustained flow, whereas
en of high magnitude and frequency, but relatively short in duration
periods of no flow.

drograph of median monthly discharges for the same gaging station
dditional information to that derived from a consideration of means.
most months are considerably less than the *means* and particularly
g runoff from other than snowmelt. This fact indicates that the
s of daily discharges typically are positively skewed with most values
Inspection of daily discharges for the period of record (1947-1989)
le months of May-July more than 50% of the days have no recorded
ave been periods of no flow during every month of the year.

ond category of Grand Canyon tributaries, only Bright Angel Creek
od of recorded fi s (U.S. Geological Survey 1924-1969). However,
are probably indicative of flow events in most spring-fed tributaries
st system in the Kaibab Plateau (Huntoon 1974). The annual
Angel Creek is unimodal, reminiscent of the mainstream pre-dam
flows occurring in May rather than June (Figure 9). It is significant

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Thermal Regime--Pre-dam water temperatures of the Colorado River in the Grand Canyon region (measured at Lee's Ferry) displayed a unimodal seasonal pattern similar to, but temporally displaced from, that of flows. High temperatures of 25 C to 29 C were reached on the descending limb of the hydrograph during July and August (Paulson and Baker 1983). Winter lows of near freezing were reached in December or January, but some warming typically was observed during February.

Deep hypolimnetic releases from Glen Canyon Dam, drawn at a depth of approximately 70 m at full stage, are perennially cold. Water temperatures at Lee's Ferry exhibit a very limited range of about 7-12 C. Downstream warming in the mainchannel is retarded by the large mass of water, continuous movement, high evaporation rates, and shading from high canyon walls, so that water temperatures some 250 miles below the dam seldom exceed 16 C (Kubly and Cole 1979, Carothers et al. 1981, Maddux et al. 1987).

Although much of the main mass of water in the Colorado River moves continuously through Grand Canyon, that portion impounded in backwaters or in the mouths of tributaries has a considerably greater capacity for warming. This condition is realized much more appreciably under steady flows than during fluctuating flows. Maddux et al. (1987) found that in summer months during periods of steady flows some backwaters had maximum daytime temperatures above 25 C, while mainchannel waters remained near 10 C. Similar conditions were observed in the mouths of tributaries, notably the LCR, where warm inflowing waters were impounded by high, steady flows in the cold mainstream.

When mainstream water levels fluctuate dramatically, as they do during periods of "load-following demand" (peaking power) dam operations, many backwaters are drained and filled on a daily basis. During such periods, as have been prevalent since the impoundment of Lake Powell, capacity for warming is much diminished in backwater and tributary mouth habitats. Backwater temperatures deviate little from those of the mainstream, but their diel fluctuations appear somewhat out of phase with those in the mainchannel (Figure 10).

Inorganic Chemistry--The first study of water chemistry of the Colorado River in the study area was completed nearly 40 years prior to the impoundment of Lake Powell (Collins and Howard 1927). In the free-flowing river, both the chemical composition and dissolved solids concentration of the Colorado River in the study area were correlated with river discharge (Iorns et al. 1965). High discharges yielried comparatively dilute waters and dissolved solids content increased with lowered flows. The effect of dammg the river has been to diminish the seasonal variation in dissolved solids content, but to increase the mean annual concentration of salts by approximately 50 mg 1' to about 600 mg l^{-1}.

Data for individual major ions suggest greater differences have occurred as a result of impoundment. Sommerfeld et al. (1975) compared their concentrations for calcium, magnesium, and sodium with those reported at the same time of year by Collins and Howard (1927). They found calcium concentrations had increased by 30%, and the latter two cations had doubled in their contributions to dissolved solids. Kubly and Cole (1979) found the ionic composition of the river during 1975-1976 to be

$$\mathrm{Ca}^{++} > \mathrm{Na}^{+} > \mathrm{Mg}^{++} > \mathrm{K}^{+} \text{ and CO,} > \mathrm{SO}_{-} >$$

with sodium occasionally surpassing calcium. They noted that these proportions changed little from month to month or with distance from Glen Canyon Dam. An increase in dissolved solids and the proportions of sodium and chloride was observed below the LCR, but these changes largely were removed downstream due to inputs from dilute, spring-fed tributaries. These same ionic relationships were reported by Maddux et al. (1987) for collections taken a decade later.

Investigations of nutrients in the Colorado River between Glen Canyon Dam and Lake Mead largely have been restricted to measurements of concentrations with little attention paid to loading rates. Paulson and Baker (1983) suggested that phosphorus is probably limiting to primary productivity in reservoirs of the Lower Colorado River, including Lake Powell, and found this reservoir to be an effective trap for both sediments and phosphorus. Watts and Lamarra (1983) also reported that additions of phosphorus stimulated primary productivity in Lake Powell waters under experimental conditions.

Maddux et al. (1987) found both low concentrations of dissolved phosphorus and high molar nitrogen/phosphorus ratios (> 15) in the reach of the Colorado River between Glen Canyon Dam and the LCR. They felt that this combination of factors produced at least the potential for limitations on primary productivity in the upper reaches of the tailwater. Below the LCR, phosphorus concentrations increased sufficiently to bring N/P ratios to below 15, but suspended sediments from flooding in that tributary often produced light-limiting conditions in the mainstream.

Productivity--The **only known estimates of primary productivity in the Colorado River in Grand Canyon were made by Cole and Kubly (1977) from daily changes in dissolved oxygen and pH during a river trip in August 1976. Their admittedly rough estimates indicated hourly values of 51 and 158 mg** C/m **gross production, respectively, for the two methods. No direct measurements of secondary production have been made in the Colorado River or its tributaries within the study area.**

Standing crops of both benthic algae and aquatic macroinvertebrates decline with distance from Glen Canyon Dam and markedly so below the LCR (Carotht,., et al. 1981, Hofknecht 1981, Leibfried and Blinn 1987, Usher et al. 1987). Ponar samples taken from backwaters during humpback chub monitoring in 1988-89 produced 17 taxa of benthic invertebrates (Table 2). Densities varied dramatically, from 2 ind/0.1 m **to nearly 19,000 ind/0.1 m^2 (Figure 11). Samples from backwaters above the LCR had a mean density of 3,592** ind/0.1 m**, whereas samples from below the LCR contained a mean density of 208**

ind/0.1 m^2. These means are an order of magnitude higher than those reported by Leibfried and Blinn (1987), but they did not indicate which mainstream habitats were sampled. Carothers et al. (1981) noted that ponar samples from "side eddies" yielded high numbers of oligochaetes, midges, and amphipods (several thousand ind/m), whereas mainchannel densities were considerably lower.

Oligochaetes comprised more than 95% of the mean number of benthic organisms in 1988-1989, and chironomid larvae/pupae made up 2-3% of the remainder. Again, these proportions are at disparity with those of Leibfried and Blinn (1987) who reported chironomids dominant both above and below the LCR. Chironomid larvae/pupae were relatively more important in samples above the LCR, where they formed 39% and 14% of the mean total organisms in 1988 and 1989, respectively.

Haury (1976) found that, in contrast to most tailwaters, neither total zooplankton or constituent group densities decreased significantly in the Colorado River with distance from Glen Canyon Dam. Zooplankton samples taken from the mainchannel an backwaters during the summers of 1987-1989 appear to confirm that finding (Table 3, Figure 12), although there is sufficient variation in densities to make difficult any strong conclusion. Haury also concluded that Lake Powell is the source of most zooplankton in the tailwater, and the taxonomic list which he provided contains a high degree of overlap with the recent study of that community by Sollberger et al. (1989). Haury was unable to make direct comparisons of mainchannel densities and those of potential refugia or sources of supply, e.g. backwaters and impounded mouths of tributaries. In this respect, zooplankton samples taken during 1987-1989 provide more conclusive evidence on the importance of these habitats to zooplankton productivity. Sampled backwaters had a mean density of 1,363 i d/m , whereas mainchannel samples had a comparable value of 341 i d/m . Furthermore, there were definite differences in relative proportions of important constituent groups (Figure 13). Most exemplary among those differences was the decided increase in the relative density of cladocerans in backwater samples. This increase has potential significance because this group is often one of the first to decline in tailwaters (Ward 1975), and because cladocerans form an important dietary component for many young fishes (Carlander 1969).

Tributaries

Thermal Regime--Tributaries to the Colorado River in the Grand Canyon region exhibit both diel and seasonal changes in water temperature (Cole and Kubly 1976, Carothers et al. 1981, Maddux et al. 1987). Diel cycles reflect both the small volume of water carried by most tributaries and the large degree of daily heating and cooling in these desert environs. Seasonally, tributary water temperatures vary from highs approaching, or in some cases exceeding, 30 C to lows near or below freezing. Both the seasonal degree of warming and cooling are a function of flow volume and distance from the source.

Mainstream flow regimes affect water temperatures in confluence zones of tributaries when stage is high enough to impound the inflowing waters. No known measurements have been made of water temperature stratification in confluence zones under high steady flows, and degree of mixing probably varies seasonally as a function of temperature and density differences in the two water sources. Measurements made at three sites in the LCR during May 1988 indicate both the differences in temperature and daily fluctuation in temperature among warm tributary, intermediate confluence, and cold mainchannel sites (Figure 14). Timing of temperature changes in the confluence zone undoubtedly reflect stage changes in the cold mainstream for they are offset somewhat from those in the tributary, but, unfortunately, no corresponding measures of mainstream stage were made.

Inorganic Chemistry--Kubly and Cole (1979) classified the tributaries to the Colorado River in the Grand Canyon region according to their major ion proportions and total dissolved solids content. Five different categories--dilute dolomitic waters, impure dolomitic waters, sodium bicarbonate waters, sulfate waters, and saline sodium chloride waters—were recognized. The first three of these groups have total dissolved solids contents less than or approaching that of the mainstream. Of the remaining more saline streams, only the LCR, containing predominantly sodium and chloride, has any appreciable effect on mainstream chemistry. At base flow, when fed entirely by the Blue Springs series, this tributary contains more than 5X the dissolved solids of the mainstream. Cole and Kubly (1976) showed experimentally that effects of the tributary at base flow (223 cfs) on mainstream salinity were insignificant when the Colorado River exceeded 10,000 cfs, but that the mainstream's dissolved solids content could be expected to increase appreciably at flows below 5,000 cfs.

Although the major ions of the lower LCR are dominated by sodium and chloride, this stream at base flow also contains large amounts of calcium, magnesium, bicarbonate, and sulfate ions in solution. Waters emanating from Blue Springs are highly charged with free carbon dioxide and oversaturated with respect to calcite (calcium carbonate) (Cole 1975). The combination of high salinity and free carbon dioxide provides an environment inhospitable to many life forms, and Blue Springs has been implicated as a barrier affecting the distribution of native speckled dace *(Rhinichthys osculus)* in the LCR (Carothers and Aitchison 1972).

As Blue Springs waters pass downstream to the Colorado River, carbon dioxide evolves to the atmosphere and calcite precipitates. Precipitating calcite forms the numerous travertine dams common to the lower LCR and covers the stream bottom with a layer of uncemented calcite particles. It also increases the turbidity of stream waters, and imparts to them a milky blue color.

Chemistries of most tributaries to the Colorado River in Grand Canyon exhibit considerable dilution effects during periods of high discharge (Foust and Hoppe 1985), and this is particularly true of the more saline members. In three tributaries--Paria River, LCR, and Kanab Creek--decreases in dissolved constituents are accompanied by tremendous increases in suspended sediment loads. These suspended sediments, primarily silts and clays, have at least two effects of considerable importance on the mainstream, diminution of light penetration and importation of phosphorus adsorbed to sediment particles. Concentrations of total phosphate phosphorus in these tributaries when in flood have been measured at from 3X-70X that of the mainstream at Lee's Ferry (Maddux et al. 1987). Although the benefits of these inputs to aquatic primary production in the mainstream are greatly diminished during the period of flooding by concomitant light limitation, that fraction which settles during transport may be of considerable importance to production following clearing of mainstream waters.

Productivity—Productivity estimates for tributaries to the Colorado River in Grand Canyon are also lacking. Carothers et al. (1981) and Hofknect (1981) found standing crops of benthic invertebrates to range from 0-1,214 mg/m (dry weight) and 0-138,666 ind/m. Both biomass and densities were generally lower in low gradient, sediment-carrying tributaries (Paria River, LCR, and Kanab Creek) than in high gradient stream-fed tributaries. In 45 of 60 cases, upstream portions of tributaries contained higher densities and biomass than the confluence zones. Spring and summer samples yielded lower biomasses and densities than other seasons. This observation was attributed to the scouring effects of spring runoff and floods from summer thunderstorms.

Other studies providing information on aquatic invertebrates in tributaries include Cole and Kubly (1976) and Minckley (1978). Neither study provides densities or biomasses for comparisons with those cited above, although the latter gives information on relative densities of major groups for tributaries in the vicinity of Phantom Ranch (RM 87.5, RKM 141).

DISTRIBUTION AND ABUNDANCE OF *G. CYPHA*

Mainstream Collections

Records of humpback chub collected from the study area prior to the construction of Glen Canyon Dam (Table 4) are limited to three individuals (two complete bodies, one partial) used by Miller (1946) to describe the species and bones taken from archaeological site near the present site of Hoover Dam (Miller 1955). Lack of fish is not necessarily indicative of low humpback chub abundances in this reach, but rather a lack of collections from a remote section of a deeply entrenched river difficult both to access and travel upon. Pre-impoundment investigations which provided information on the flora and fauna of the Colorado River and its tributaries were limited to the reach in and above Glen Canyon (Woodbury 1959, McDonald and Dotson 1960). Failure to consider the dam's impacts on downstream native flora and fauna was, unfortunately, exemplary and indicative of the general lack of biological information collected prior to impoundment of Lake Powell (Perkins 1975, see also White 1972).

Post-impoundment collections of humpback chub in the Colorado River between Lake Powell and Lake Mead have been recorded from just below Glen Canyon Dam (Stone and Rathbun 1967, 1968, 1969, Holden and Stalnaker 1975) to 373 km (232 mi) downstream of that structure (Department, unpublished data). The nearest extant upstream population occurs in Cataract Canyon above Lake Powell (Valdez 1989), and collections from the inflow area to the reservoir have produced humpback chub (Service 1988).

Following the impoundment of Lake Powell, the species was reported as rare to common in the 26 km (16 mi) reach below the dam (Stone and Rathbun 1967, 1968, 1969, Holden and Stalnaker 1975), but in recent investigations (1984-1989) conducted as part of the GCES *G. cypha* has not been collected in that same reach (Maddux et al. 1987, Department unpublished data). There is little doubt that lack of collection represents absence of the species for more than 68 hours of electrofishing and 360 days of creel census were expended in the reach during that period.

Suttkus et al. (1976) contenci-:, based on the distribution of their *G. cypha* collections, that the Little Colorado River and the reach of the Colorado River from that tributary to Shinumo **Creek (RM** 108, RKM 174) constituted critical habitat for the species. Subsequent studies have provided more quantitative information on catch rates and relative abundances of humpback chub, so that the distribution and abundance of the species can be more formally evaluated. Even with these datasets, however, statistical

comparisons among time periods (seasons) and reaches of the river largely are precluded by uneven sampling and a preponderance of zero catches (see Appendices II and III).

Trammel Nets

Carothers et al. (1981) reported trammel net catch rates of from 0.5 to 2.0 fish/12 hr (91.5 m X 2.4 m net, no mesh sizes given) in the Colorado River during 1977-1979. Their data show that 24 humpback chub were taken between RM 20 (RKM 32) and RM 132 (RKM 212), with most individuals collected above the LCR (Figure 15). Effort data from their study were not available, and we were unable to determine variances associated with their catch rates.

Kaeding and Zimmerman (1983) reported similar catch rates for trammel nets (0-3 fish/12 hr with 45.7 m X 1.8 m nets, 2.5 cm inner mesh and 25.4 cm outer mesh) and found that catch rate distribution formed a bell-shaped curve with a maximum in the area of the confluence of the Colorado and Little Colorado rivers. Their study, however, included only a 32 km reach of mainstream centered at the mouth of the LCR.

Maddux et al. (1987) utilized trammel nets in the mainstream on only three river trips during 1984 and took only six humpback chub (Appendix II). They used two sizes of trammel nets: 30.5 m X 2.4 m and 7.6 m X 2.4 m with 2.5 cm or 5.1 cm inner mesh and 25.4 cm outer mesh. Catch rates were standardized to a net of the larger size and

reported as fish/12 hr. Trammel nets were generally set in late afternoon and pulled during evening or in early morning hours. Their mean catch rates ranged from 0.00-0.95 fish/12 hr. No humpback chub were taken above the Little Colorado River by this gear. Trammel nets have not been used in the mainstream subsequent to the study of Maddux et al. 1987 .

Seines

Maddux et al. 1987 used bag seines in nearshore habitats during all seasons and reaches of the mainstream Appendix II . Effort expended was, however, disproportional among seasons with most samples being taken during a controlled flow period and subsequent river trip in September-October 1985. Nevertheless, 28 bag seine hauls involving over 1,400 m of effort produced no humpback chub in the mainstream reach above the LCR. Complementary larval seine and dip net samples, 324 in number, taken during all seasons also produced no humpback chub above the LCR. Mean seasonal bag seine catch rates for reaches below the LCR 393 total humpback chub varied between 0.00 fish/100 m^2 and 21.44 fish/100 m^2, with highest catches occurring in the reach between the LCR and Bright Angel Creek. These values do not include a sample taken from a backwater below the LCR which produced 34 humpback chub and a catch rate of 113.33 fish/100 m. A total of 488 larval seine/dip net samples taken from below the LCR produced only four humpback chub. Maddux et al. 1987 indicated that these humpback chub were juveniles 50 mm TL and did not consider them young-of-the-year fish.

The mainstream portion of the humpback chub monitoring program conducted by Department and other agency personnel during 1987-1989 has concentrated on backwater and other nearshore habitats. Nearly all sampling has been conducted during the month of May, excepting a river trip from Lee's Ferry to Bright Angel Creek in July 1988. Bag seines, larval seines, and dip nets were used as sampling gear, but electrofishing was discontinued.

No humpback chub were collected from mainstream nearshore habitats above the LCR during 1987-1989, and most individuals were again collected from backwaters in the 10-mile reach below the tributary (Figure 15). Both number of individuals and mean catch rates were considerably lower in this reach during May of 1988 (7 fish, 1.90 fish/100 m^2) and 1989 (2 fish, 2.29 fish/100 m^2) than in 1987 (180 fish, 41.72 fish/100 m^2) (Appendix III).

Electrofishing

Neither Carothers et al. (1981) nor Maddux et al. (1987) reported by reach mainstream catch rates of humpback chub taken by electrofishing, which was a primary mode of capture used in their studies. Seasonal means within reaches for this gear type have been analyzed for the latter study and are presented in Appendix II. Most means are between 0.00 fish/100 min and 2.00 fish/100 min. In two instances, during the summer

of 1984 in reaches above and below the LCR, mean catch rates were an order of magnitude higher.

Maddux et al. did indicate that most humpback chub taken by electrofishing were collected in the vicinity of the Little Colorado River, and that 96% of these individuals were taken in the reach between Lee's Ferry and Bright Angel Creek (reaches 20 and 30). Our evaluation of their data set indicates that when all gear types are combined 77.5% of the total humpback chub collected (466) were captured in the 10-mile reach from RM 60 (RKM 96.5) to RM 70 (RKM 113) (Figure 15). This distance includes the reach of mainstream from approximately one and one-half miles above the LCR to eight and one-half miles below the tributary mouth. Furthermore, only 1.3% of captured individuals were taken above that reach, the remainder being collected between RM 70 (RKM 113) and RM 217 (RKM 349).

Tributary Collections

The first reference to humpback chub collected from tributaries in the Grand Canyon region (Table 4) is that of "bony tail" taken for food from the Little Colorado River by the Kolb brothers (Kolb and Kolb 1914). That these fish were indeed humpback chub rather than *G. elegans* was surmised by Suttkus and Clemmer (1977) based on the Kolbs' description of a fish "...with a small flat head somewhat like a pike, the body swells behind it to a large hump." Photographs in the Emery Kolb Collection lend further

credence to this conclusion. Additional collection prior to the construction of Glen Canyon Dam was restricted to eight juveniles (48-57 mm SL) captured by 0. L. Wallis and others in October of 1955 from Spencer Creek at RM 246 (RKM 396).

Subsequent to the impoundment of Lake Powell, humpback chub have been collected from the Little Colorado River, Bright Angel Creek, Shinumo Creek, Kanab Creek, and Havasu Creek (Table 5). Large numbers of individuals have never been collected in other than the Little Colorado River. Other tributaries which have been sampled include the Paria River, Buck Farm Creek, Nankoweap Creek, aear Creek, Pipe Creek, Hermit Creek, Crystal Creek, Elves Chasm, Stone Creek, Tapeats Creek, Deer Creek, Diamond Creek, and Travertine Falls Creek.

Trammel Nets

Of the tributaries in which humpback chub have been collected, only the LCR provides the opportunity for meaningful quantitative comparisons of distribution and abundance. Carothers et al. (1981) reported a seasonal range in trammel net catch rates of from 0.4 fish/12 hr (reported as net nights) in winter to 70.0 fish/12 hr in spring (note that most trammel nets were actually deployed during daytime in the LCR). They did not indicate where in the LCR these nets were deployed, and we assume most, if not all, collections were made at or near the confluence.

Kaeding and Zimmerman (1983) also found that there was a seasonal difference in trammel net catch rates, with substantial increases occurring between February and April-May of 1981. They suggested these increases could be attributed to increased vulnerability of humpback chub during the spawning season or to increased numbers of fish moving from the Colorado River into the tributary to spawn. Their catch rates, which varied between 0 fish/12 hr (reported as fish/hr) and 26 fish/12 hr, were higher during periods of sunset and darkness than during daylight. Kaeding and Zimmerman felt that activity of the fish increased as darkness approached, although they conceded that daytime avoidance of nets could not be discounted as a contributing factor. No consistent relationship was found between catch rate and reach of the LCR.

Maddux et al. (1987) reported a mean trammel net of 33.2 fish/12 hr (net night) in the LCR for the period 1984-1986 and indicated that catch rates were highest in summer, followed by spring, with very low catches in autumn and winter. Their collections, which were confined to the reach just above the mouth, largely were restricted to spring and summer periods (Appendix II). Evaluation of their data shows that there were indeed large differences in catch rates between these two seasons. Spring collections produced mean catch rates of 23-48 fish/12 hr, whereas mean summer catch rates were 693 and 789 fish/12 hr.

Humpback chub monitoring activities in the LCR during May of 1987-1989 have consistently included trammel nets. Nets were deployed at the confluence, 600 m

upstream, and 1,000 m upstream in 1987 and 1988. In 1989 an additional trammel net was emplaced near the mouth of Salt Trail Canyon, some 10 km upstream.

The frequency distribution of LCR trammel net catch rates during 1987-1989 is highly positively skewed and obviously nonnormal with 183 of 430 samples (42%) containing no humpback chub. Log transformation (base 10, x + 1) of the catch rate data for analysis with parametric statistics has the desired effect of reducing the spread of the distribution and producing a more bell-shaped curve of nonzero catch rates, but the predominance of zero catches is not diminished (Figure 16).

Percentage of zero catch samples varied from 20% in 1987 to 52% in 1988, with an intermediate value of 44% in 1989. In order to determine whether the proportion of zero catches was independent of year, we applied the G-test of independence (Sokal and Rohlf 1980, p. 744). The null hypothesis of independence among years was rejected (Chi-square = 25.542, 2 d.f., P < 0.01).

Tests for significant differences among mean and median catch rates were accomplished, respectively, using parametric [one-way analysis of variance, (ANOVA)] and nonparametric (Median) tests. The former was applied to log-transformed distributions at two levels, differences among years and differences among weeks within years. This test would most appropriately be applied as a single nested analysis of variance except that the lower level (weeks) could not be randomly allocated as required (Sokal and Rohlf 1980,

p. 271). Scheffe's multiple comparison test was used to determine which intervals (years or weeks) were significantly different. The Median test was used instead of the Kruskal-Wallis test because the former is less affected by the large number of ties occurring as a function of multiple zero catches (Conover 1971, p. 256).

Log transformed catch rates for 1987-1989 were 0.491, 0.402, and 0.305, respectively. Results of both tests indicated significant differences among the three years (ANOVA F = 7.188, d.f. 2,427, $P < 0.001$, Median Chi-Square = 11.191, d.f. 2, $P < 0.01$). The multiple range test revealed that only 1987 was significantly higher than either of the other two years ($P < 0.05$), although the means of the log-transformed data were nearly equidistant among years.

The same set of statistical tests was applied to comparisons of mean and median trammel net rates among weeks independently for the three years to see if similar trends occurred during the month of May in all years (Table 6). Both tests indicated no significant differences among weeks during 1987 (week 1 excluded, insufficient samples). In contrast to this finding, 1988 and 1989 mean and median weekly catch rates had significant differences. Mean weekly catch rates generally decreased with time in both years, but significant differences among weeks varied. During 1988, the first and second weeks were significantly higher than the last two weeks, whereas in 1989 only the first and third weekly means (highest and lowest) achieved this status.

Seines

Carothers et al. (1981) reported LCR seine catch rates from 0.71-63.64 fish/m with higher values during summer above the confluence. They indicated that the highest catch rate occurred Big Canyon Creek, a tributary to the LCR entering some 11 km above the mouth. This report is in error, however, and the fish were actually collected in the LCR near the mouth of Big Canyon Creek (C. 0. Minckley, personal communication). Seine hauls were also made at 20.8 km above the mouth of the LCR, but these collections produced only speckled dace.

Maddux et al. (1987) used bag or larval seines during every season of the period 1984-1986, but number of samples was typically low and there is a great deal of variation in their mean catch rates (Appendix II). Humpback chub were collected during all seasons with bag seines, but higher catch rates occurred in summer (June-August) during all three years. Seines also have been used somewhat sporadically in the LCR during the humpback chub monitoring of 1987-1989. The 1989 mean catch rate was considerably higher than the other two years, but it represents the effort from only five samples (Appendix HI).

Hoop and Fyke Nets

Hoop and fyke nets were little used in the Grand Canyon region prior to the initiation of the Department's humpback chub monitoring program in 1987. We have found them to be highly efficient at capturing most fish species in the LCR. They have added advantages over trammel nets in capturing a much wider spectrum of size classes and in having much less deleterious effects on the fish, particularly when nets cannot always be tended at intervals of a few hours.

Annual percentages of zero catches and log-transformed catch rate frequency distributions for hoop and fyke nets displayed a pattern reminiscent of that for trammel nets (Figure 16). The 1987 percentage (19%) was considerably lower than that for both 1988 (36%) and 1989 (36%), and the G-test for independence of zero catch proportions from years was again rejected (Chi-square = 17.848, 2 di., P < 0.01). Statistical tests for differences among annual mean and median hoop/fyke nets also exhibited findings similar to those of trammel nets. Significant differences were found for both measures, and 1987 had a significantly higher mean than the two following years. Apparent differences among means were somewhat different, however, with 1988 and 1989 values quite similar and considerably less than the 1987 value.

The pattern of weekly differences within years for hoop/fyke nets was quite different from that of trammel nets (Table 7). Concurrence between parametric and nonparametric tests was observed for 1987 and 1989 with a significant difference occurring in only the latter year, but a marginally significant ANOVA for 1988 had a decidedly nonsignificant Median test counterpart. The multiple range test for 1988 also indicated no significant differences among weeks. Therefore, whereas 1988 and 1989 weekly means were significantly different for trammel nets, hoop and fyke nets exhibited these differences conclusively only during 1987.

Values of weekly mean hoop and fyke net catch rates for 1987 and 1988 increased during the course of the monthly sampling period, in opposition to the pattern for trammel nets, but the progressions were similar in 1989. The significant difference among weeks observed for the first year produced a multiple comparison result suggesting that the mean catch rate for the last week was greater than the two previous weeks (Table 7).

Population Estimates

Kaeding and Zimmerman (1982) provided an estimate of population size for adult humpback chub (>200 mm TL) in the LCR and adjoining Colorado River during 1980-1981 at 7,000-8,000 individuals. They indicated that inclusion of smaller fish would have increased this estimate by a factor of two or three. Computation of the estimates was accomplished using three multiple census techniques--Schnable, Modified Schnable, and Schumacner/Eschmeyer. Kaeding and Zimmerman admitted that several criteria for use of these estimators were not met by their study, and therefore referred to their estimate as a "ball park" figure.

Minckley (1988, 1989) gave population estimates of humpback chub in the LCR during May of 1987-1989. All estimates were accomplished using the Peterson Method, which typically uses data from a closely spaced mark-recapture episode. Estimates for 1987 and 1988, which used all humpback chub collected in the lower 1.2 km of the LCR, were 5,783 (SE 679) and 7,060 (SE 574), respectively. From 1989 tag-recaptures, Minckley estimated population sizes of 10,120 individuals for the same reach of the LCR and 18,253 for the 15 km reach sampled that year.

We also computed 1987-1989 population estimates for humpback chub in the sampled portions of the LCR, using instead the multiple census Schnabel method employed by Kaeding and Zimmerman (1982). Only fish 140 mm TL and larger, the approximate lower limit of tagging, were used and both marks and recaptures were restricted to individuals tagged in the year for which the estimate was computed. Both number of tags and recaptures were accumulated on a daily basis to produce a trend of changing population size over the period of study. The major purpose of this exercise was to compare population estimates and catch rates during May in the three years to see if there was any relationship. Given the lack of geographic closure in this system and known movement of humpback chub between tributary and mainstream, the precision of the estimates are highly questionable and they may be highly biased.

Maximum estimated population sizes during 1987 and 1988 occurred at the end of the sampling period when approximately 1,800 and 2,900 individuals, respectively, were indicated to be in the lower 1.2 km of the LCR (Figure 17). Mean catch rates, although quite variable, exhibited a trend similar to the population trend in 1987, but appeared to break from this estimate near mid-month. During 1989, when fish from the lower 15 km of stream were included, a maximum population estimate of about 25,000 individuals was realized near the end of the first week of sampling. Estimated population size declined until mid-way into the second week and then remained nearly constant at about 5,500 individuals. Mean daily catch rates rose and fell in a similar manner and were relatively stable during the last half of the sampling period.

Two major assumptions of the above population estimators violated during the study of Kaeding and Zimmerman (1982) are those of demographic and geographic closure (White et al. 1982). Demographic closure assumes that initial population size does not change subject to births, deaths, immigration, or emigration, and geographic closure requires that some physical boundary exists to limit the population. It is obvious that the latter can never be satisfied in the LCR and that relaxation of the former, such as assuming that gains and losses are equal, is of little use when the period of study encompasses more than a generation in the life cycle of the species being studied. For shorter periods, such as the May monitoring period, and especially where size classes of fish is restricted, it may be that estimation of population size is a realistic exercise, at least as a relative index similar to that of catch rate.

REPRODUCTION AND EARLY DEVELOPMENT

Timing and Duration

Suttkus and Clemmer (1977) concluded that reproduction of *G. cypha* in Grand Canyon probably occurs in June and July. Their conclusion was based on specimens collected during these months (from Lake Powell and the Colorado River below Glen Canyon Dam) possessing reproductive coloration, moderate to extensive tuberculation, fully developed testes in males, and developed eggs in females. Additional evidence was provided by capture from the LCR of three 24.6-247 mm individuals on 22 September, which they felt represented young-of-the-year.

Minckley et al. (1981) suggested that the reproductive period probably spans the period of March through June and possibly July. This contention was based on collection of adult humpback chub from the Little Colorado River in reproductive condition during March and April and smaller fish (30-50 mm TL) in June and July. Maddux et al. (1987) did not report reproductive condition of adult humpback chub, but they indicated that larval to post-larval individuals (10-20 mm TL) were present in June of 1984 and May of 1985. Inspection of their data revealed that humpback chub 12-30 mm TL were also collected in early June of 1986.

Kaeding and Zimmerman (1983) were able to express milt from more than 70% of males greater than 200 mm TL collected from the LCR during April 1981, in contrast to much lower percentages in February (25%) and May (17%) of that year. Female gonadosomatic indices and mean ova diameters indicated rapid gonadal development between December and February/April. Rapid declines in these indices during April and May suggested that spawning had occurred. Significant seasonal differences (no statistical test provided) were found for only the latter measure indicating high variance. Inspection of their published figures for these indices showed that, particularly for mean ova diameter, there was an indication of two groups of females, one of individuals still ripe and the other spent, during the period May-June.

Kaeding and Zimmerman (1983) found larval to post-larval humpback chub (14-18 mm TL) in the confluence area of the LCR during May 1981 and concluded that these fish resulted from spawning 2 or 3 weeks earlier. Humpback chub less than 50 mm TL were not collected from the LCR during May and early June of 1980, but the capture of individuals ca. 20-50 mm TL during late June suggests that reproduction probably was occurring during the previous sampling period.

The onset and duration of reproductive activity in fishes and other organisms is influenced by physiological state as acted on by a suite of environmental variables (Brown et al. 1970). Studies on endangered fishes of the Upper Colorado River Basin have shown that hydrology and temperature are important, but probably not exclusive, environmental factors affecting the timing of reproduction (Tyus and Karp 1989). Available information from both upper and lower basin studies suggests humpback chub spawn during or shortly after peak spring flows when water temperatures are in the range of 12-23 C (Valdez and Clemmer 1982, Kaeding and Zimmerman 1983, Archer et al. 1985, Minckley 1988, 1989, Karp and Tyus 1990, Department unpublished). Unfortunately, little is known of the remaining environmental cues that complement hydrology and temperature as initiators of reproductive activity in this cyprinid.

Fecundity

Very little information is available on the fecundity of humpback chub females. Hamman (1982) estimated that nine LCR females (372-425 mm TL) injected with carp pituitary extract produced a total of 30,000 eggs in the hatchery. In the same study, nine females (355-409 mm TL) from the Black Rocks area of the Colorado River produced from 0-5,445 eggs, an average (assumed mean) of 5,262 eggs/kg body weight.

Spawning Behavior and Habitat Use

No recorded observations of humpback chub spawning were found during this investigation. Actual visual sightings in the Colorado River and its tributaries often are precluded by turbidity of the water. Carothers et al. (1981) suggested that breeding requirements and spawning behavior could probably be inferred from information on congeners, the bonytail and roundtail chub. Several males likely attend one female, and eggs are released and externally fertilized as they fall to a variety of substrates.

Hamman (1982) noted that LCR fish spawned naturally in the hatchery (following injection) on cobble (4-10 cm diameter) over boulder (30-40 cm) substrate and that all eggs adhered to the cobble. In contrast, Black Rocks male and female humpback chub had to be stripped of their gametes to facilitate successful reproduction. Observations of spawning behavior in the hatchery were precluded by high turbidities in the holding waters (R. Hamman, personal communication).

Carothers et al. (1981) were apparently the first investigators to suggest the "...crucial importance of the Little Colorado River as a spawning site the *(sic)* nursery area for this endangered species." Based on the presence of higher densities of small fish in upper reaches, they predicted that most reproduction occurred well above the confluence. They also noted that Suttkus et al. (1976) had collected young-of-the-year chub near the mouth of Shinumo Creek and inferred that this collection provided evidence for occasional reproduction in other tributaries. Carothers et al. (1981) captured young-of-the-year humpback chub almost exclusively in the LCR, whereas most individuals taken in the mainstream were adults. Thus, they concluded that reproduction occurs primarily (but not exclusively) in tributaries during periods when adults returned from mainstream habitats.

Kaeding and Zimmerman (1983) found similar gonadal development and stage in female humpback chubs collected during May in the LCR, Colorado River, ard confluence area. Based on these data, they suggested that some humpback chub may spawn in the mainstream (see also Minckley et al. 1981). No humpback chub less than 145 mm were collected from above the LCR, however, leading these investigators to conclude that successful reproduction did not occur in the mainstream. Cold mainstream water temperatures and daily fluctuations in water levels were implicated as causative factors precluding the production of viable offspring in the Colorado River.

Kaeding and Zimmerman (1983) reported that the smallest humpback chub collected from the Colorado River (38 mm TL) was more than twice the length of the largest known age-0 fish collected during the same period from the LCR (18 mm TL). Since they used this observation as further evidence for lack of successful reproduction in the mainstream, other reports of humpback chub length frequencies in potential rearing habitats of the Colorado River are of interest.

Humpback chub were collected from backwaters and nearshore eddy habitats with seines by Maddux et al. (1987) during 1984-1986 and during the Department's monitoring efforts of 1987-1989. The combination of these two studies provides information on length frequency distributions of the species during three seasons—spring, summer, and autumn. During the May monitoring of the last three years, no humpback chub greater than 177 mm TL have been collected from these habitats (Figure 18). The smallest individual, measured at 15 mm TL, was taken from a backwater at **RM** 166 (RKM 267), more than 100 miles below the confluence of the LCR and mainstream. Six other individuals less than 25 mm TL, and thus presumed larval fish, were collected between **RM** 68 (RKM 109) and **RM** 120 (RKM 193). These fish constitute only 3.2% of the total number taken during the period, but there presence in mainstream backwaters these distances downstream of the LCR suggests the distinct possibility of occasional successful mainstream reproduction. Larval humpback chub taken below RM 100 would have been transported through some of the severest rapids of the Middle Gorge, a reach nearly devoid of nearshore low velocity habitat.

The smallest humpback chub taken by Maddux et al. (1987) during summer months (Figure 18) was 32 mm TL and all individuals collected more than 10 miles below the LCR during that period were greater than 40 mm TL. Juvenile humpback chub of a similar size range to those collected in summer were also taken in autumn. The smallest individual taken during the latter period was 38 mm TL.

Hatching, Survivorship, and Early Development

Time to hatching following fertilization, percentage success of hatching, age to swimup stage, and survivorship of swimup fry are highly temperature dependent in humpback chub (Hamman 1982, Marsh 1985). Under hatchery conditions, Hamman (1982) found that eggs kept at 12-13 C required from 340-475 hrs to hatch with a success rate of only 12%. At 21-22 C, time to hatching decreased to 102-146 hrs and percent hatch increased to 79%. This same relationship was observed in swim-up fry where age and percent survivorship of this life stage ranged from 168-72 hrs and 15%-99% at the same extremes of water temperature. Mortality of egg and fry stages was calculated at 88% and 85%, respectively, at the 12-13 C water temperature.

Marsh (1985) found that embryos cultured in a hatchery suffered complete mortality at 5 C (actual mean 7.3 C), 10 C, and 30 C. Highest percentage hatch occurred at 20 C (60%), with significantly lower hatch just 5 degrees above (2%) and below (0.8%) that water temperature. Time to appearance of swimup fry was 372 hr at 15 C and 166 hr at 20 C, considerably longer than the periods reported by Hamman (1982) at comparable temperatures. Marsh (1985) also recorded a significantly higher incidence of abnormal (stunted or deformed) fry at 15 C than at 20 C or 25 C, which suggests sublethal effects at temperatures below those optimal for hatching.

Bulkley et al. (1982) incubated fertilized humpback chub eggs at 5 temperatures: 5, 10, 14, 20, and 26 C. The source of the fertilized eggs was not indicated. They reported no hatch at 5, 30% after 19 days at 10, 50% after 16 days at 14, 100% after 4 days at 20, and 90-100% after 3 days at 26 C. No further information was provided on the growth or survivorship of these individuals.

THERMAL TOLERANCE AND TEMPERATURE PREFERENDA

Thermal Tolerance

Water temperatures of the Colorado River in Grand Canyon (7-15 C) obviously have a great capacity to limit successful reproduction of the endangered humpback chub. Studies of effects of the post-dam thermal regime on other than hatching success and survivorship of post-hatchling fish have not been completed. In particular, effects of thermal shock on larval to post-larval chub analagous to that done by Berry (1986) on squawfish are lacking.

In an attempt to provide at least qualitative information on acute effects of thermal shock to larval and postlarval humpback chub, field experiments were conducted during the monitoring of 1988 and 1989. Fish were seined from edge habitats of the LCR and placed in screened, flow-through cages, either in the tributary or in the mainstream above the confluence. During these experiments, mainstream water temperature varied between 10.8 C and 12 C, while LCR water ranged from 18 C to 24 C. Total time of the experiments varied from 400 min in 1989 to 1530 min in 1988.

Gila cypha larvae comprised only a small part of the total numbers of larval fishes used in the experiments in both years. The null hypothesis that mortality of humpback chubs was independent of treatment was tested using two-way contingency tables and Yate's small sample size correction (Sokal and Rohlf 1981). The null hypothesis could not be rejected for any trial for *Gila cypha* alone, perhaps a result of small sample size, nor did lengths of humpback chub which died in the experiments differ from those which survived (P>.2, t=1.07, 25 df). Considering the entire community of four species used in the experiment in 1988, however, revealed significant (P<.05) deviations from expected mortality rates. Numbers of survivors in the mainstream were lower, and numbers of mortalities there higher, than would be expected if the treatment had no effect. Therefore, it appears that the temperature shock associated with larval transport from

LCR to colder mainstream water increases short-term mortality rates in mixed species assemblages of native larval fishes (combined runs 1 and 2; 31 *Gila cypha,* 133 *Pantosteus discobolus,* 45 *Rhinichthys osculus,* and 1 *Catostomus latipinnis.*

Although mortality rates in the mainstream were significantly higher than expected for the combined species in 1988, this was not found to be the case in 1989. There may *be* two possible explanations for this result. Firstly, and most likely, sizes of larvae were significantly larger (e.g. for humpback chub **P<** <.05, t=12.15, 43 di) in 1989 (humpback chub X=25.8 mm TL, n=18, s=4.6, range *17* to 34 mm) than in 1988 (humpback chub X=13.1 mm TL, n=27, s=2.4, range 9.4 to 19.9 mm) and tolerance to thermal shock likely increases as fish grow. Additionally, species composition of the community was different and almost surely species vary in tolerances to thermal shock. Only four species, all native, were identified in experimental samples of larvae in both years: *Gila cypha, Pantosteus discobolus, Rhinkhthys osculus,* and *Catostomus latipinnis.* Whereas *Pantosteus discobolus* dominated the fauna used in the experiment in 1988 (63%), that species was far less abundant in samples used in the experiment in 1989 (19%). In 1989 *Rhinkhthys osculus* dominated **the** sample (42%), whereas it comprised 21% of the total experimental animals in 1988. Humpback chub larvae were 15 and 25% of the total animals used in the experiments in 1988 and 1989, respectively.

In an attempt to increase sample size of known humpback chub in the 1989 experiment, an attempt was made to administer carp pituitary and Human Chorionic

Gonadotropin to adults to induce maturation following procedures of Hamman (1982) and Hamman (personal communication). This was done with the intent of fertilizing a sample of eggs and incubating them to hatching in the field, however, attempts to strip gonadal products from fish held after injections were unsuccessful. The experiment was therefore carried out again in 1989 using a relatively small sample of wild-caught larval fishes. Though not successfully implemented in 1989, apparently due to prior spawning of injected individuals, application of hormone injections to provide large numbers of experimental larvae in the filed appears promising, and could be used to conduct large-scale field testing of thermal shock tolerance in humpback chub larvae in the future. This study could, however, be perhaps more easily accomplished in the lab once a brood stock of *Gila cypha* is placed at Dexter National Fish Hatchery or other suitable facility.

Temperature Preferenda

Acute preferendum for experimental water temperatures (measured in the first 3 hours of exposure and affected by prior thermal history) in juvenile humpback chub (size not acclimated at 14,), and 26 C was examined by Bulkley et al. (1982). No analogous studies apparently have been conducted on earlier life stages. Experiments were conducted in a horizontal gradient trough (234 cm x 33 cm) supplied at opposite ends by hot and cold water sources. Juvenile chubs acclimated at the intermediate temperature selected higher mean modal temperatures (24.4 C) than did those at 14 C (21 C), but individuals acclimated at the high temperature responded by selecting a lower mean modal temperature (23.5 C) than those held previously at 20 C. The investigators felt that lack of a relation between acclimation temperature and acute preferenda may have resulted from a negative energy balance (insufficient prior food intake) in the experimental fish.

AGE AND GROWTH

Hamman (1982) reported that total lengths of emergent humpback chub larvae ranged from 6.7-7.4 mm in the hatchery. Mean total length for individuals cultured at 19-20 C was 7.1 mm Marsh (1985) found that newly hatched normal prolarvae were longest at 15 C (63 mm) when compared to individuals cultured at 20 C (5.5 mm) and 25 C (5.7 mm). No tests of statistical significance were conducted on these mean lengths.

Hamman (1982) raised both LCR and Colorado River (Black Rocks) progeny for a period of 56 days post-emergence. During this period the LCR group attained a mean total length of 36.9 mm (range 30.3-44.2 mm), whereas the Colorado River population grew to a mean total length of 47.5 mm (range 43.2-51.1 mm) Both groups were grown under similar, if niit equivalent, conditions, i.e. in raceways at water temperatures varying between 12.8 C and 25.5 C and fed first on zooplankton and then trout starter diet. Reductions in water temperature were brought about by the infusion of cold Colorado River water (12-13 C). This infusion of cold water lowered the rearing water by about 7 degrees Celsius in two hours.

Although 10 individuals were removed weekly from each group in Hamman's (1982) hatchery studies, no attempt was made to determine whether the slopes for the growth curves were statistically significant, and the original data are no longer available (R. Hamman, personal communication). Plots of total length against days past emergence for the two LCR and Colorado River groups shows that divergence in growth rates became appreciable after the second week of culture (Figure 19). Given our present knowledge on the effects of temperature on hatching success and questions concerning the same effects on early growth, it would be most interesting to know whether introductions of cold river water were synchronous in the two groups.

Information on age and growth relationships for humpback chub beyond the first seven weeks of age is restricted to that gained from field studies. Kaeding and Zimmerman (1983) found through analysis of scale annuli that humpback chub in the LCR attained a length of about 100 mm TL in the first year. These fish grew to an estimated 250-300 mm in the first three years of life. Further estimates of growth were not provided. For humpback chub collected in the Colorado River, scales proved to be unreliable for growth estimati..... Mainstream fish judged to be yearlings had total lengths of from 38-100 mm, and the investigators deemed that poor early growth was attributable to he effects of cold water temperatures.

Maddux et al. (1987) estimated first year growth of humpback chub to be approximately 70 mm using modes of length frequency distributions. Many of these fish were collected from mainstream backwaters, so their estimate may also reflect diminished growth in these perennially cold waters. Their estimate for larger fish (> 250 mm TL), which was based on linear regression of lengths of recaptured individuals, was approximately 7 mm/year.

Carothers et al. (1981) examined opercles from 10 humpback chub mortalities (maximum TL 380 mm) collected between 1972 and 1979. They did not stipulate whether these fish were from the Colorado River, LCR, or both. Estimated growth in length at age I for these individuals was from 80.5 mm to 92.2 mm with a mean of 86.0 mm. Subsequent mean growth increments for ages II to IX, the last being that of the oldest fish examined, were estimated at 39.7, 46.4, 38.1, 30.4, 39.7, 27.1, 20.0, and 18.6 mm, respectively.

A fit of mean lengths at age for the Carothers et al. (1981) data, with an added datum of 70 mm at emergence (Hamman 1972) to a von Bertallanfy growth equation of the form

$$= L_{\infty} * (1 - e^{(\text{[illegible]})})$$

was made using the computer program **RAFAIL** (see Rafail 1973) provided in Saila et al. (1988). L = length at known age t, = predicted asymptotic length, e = base of natural logarithms, K = a growth parameter, and t_o = the hypothetical age of the fish at 0 length.

For comparative purposes, a related approximation of the von Bertallanfy growth equation was employed using tag and recaptures lengths. This computation uses the computer program FABGROW (see Fabens 1965) provided by Saila et al. (1988). Forty tag-recapture lengths and the same mean length at emergence used above were included in the data set. The form of the Fabens equation is

$$X = a\,[1 - b * e^{(-kt)}]$$

Here X corresponds to L, a corresponds to L_0., and b is related to t_o in the von Bertallanfy equation above. FABGROW output also includes units of physiological time termed chrons. One chron equals ln 2/K units of ordinary time, therefore time in chrons = ordinary time X (K/ln 2). Under this assumption an organism will gain one-half the length from its present linear size to asymptotic size in one chron, here approximately 7.5 years.

Results of the two equations produced asymptotic total lengths of 443 mm and 435 mm, respectively (Table 8). Whether these estimates, and others produced by the equations, are credible is questionable, but it can be stated that few humpback chub collected from the Colorado or Little Colorado rivers have exceeded 450 mm TL. In

practice, a reasonably good agreement has been found between observed mean maximum length and estimated asymptotic length for fishes less than 500 mm TL (Taylor 1962, Beverton 1963). Given the apparent effects of perennially cold Colorado River waters on growth in humpback chub noted by Kaeding and Zimmerman (1983) and the common intraspecific relationship between size and fecundity in fishes (Murphy 1966, Carlander 1969), it appears that further analysis of growth in humpback chub certainly is warranted.

In order to pursue further the relationship between age and growth of *Gila cypha* in the Grand Canyon region, 49 individuals ranging in total length from 104 mm to 476 mm were sacrificed during the 1989 monitoring. Entire viscera of each was preserved in formalin for future studies of diet, parasites, and fecundity. Otoliths and opercles were extracted from each specimen after skeletonizing, and they are being subjected to continuing age estimates by independent experts.

Preliminary evidence from analysis of otoliths suggests that the range of ages in these humpback chub was from one to 22 years. It has been demonstrated that daily growth increments are clearly visible in a subsample of the otoliths; therefore, daily age estimates should be available for at least some individuals. Daily increments display rapid transitions in growth rate during some years in some otoliths. This condition may reflect movement between cold and warm-water habitats of the Colorado and LCR, respectively.

HABITAT AVAILABILITY AND USE

Early Life Stages

Very little apparently is known of the habitat availability or *use* of different habitats by early life stages of humpback chub in the study area. Habitat Suitability Index curves have been developed for four different length categories of humpback chub in the Upper Colorado River Basin (Valdez et al. 1987). Parallel activities to assessment of physical habitat requirements for fishes included: (1) a water routing model for the basin; (2) a water temperature simulation model for the basin, and; (3) hydraulic simulations at selected river cross sections important to the life history of endangered fishes. Several constraints are urged for the different size categories of humpback chub, which include fish less than 21 mm TL, among them being use of these curves only in Upper Basin streams. No similar exercise has been accomplished for any data set collected in the Lower Basin, however, and some evaluation of the applicability of this approach for existing data sets and planned studies might well be of value.

Maddux et al. (1987) measured depth, current velocity, and water temperature in nearshore habitats of the Colorado River sampled with larval seines. They found that backwater habitats were utilized by young-of-the-year to juvenile humpback chub, but no larval fish were collected. In a corollary study, Anderson et al. (1986) evaluated the frequency of different habitat types in the mainstream from aerial photographs taken at

4,800 cfs and 28,000 cfs. Backwaters, cobble bars, and side channels, all considered potential spawning or rearing sites for humpback chub, increased in frequency at the lower flow.

Valdez (1989) provided interesting qualitative habitat use observations made during May 1989 in the LCR. He found that larval to post-larval humpback chub appeared to occupy deeper nearshore pools (15-122 cm) than co-occurring larval catostomids and speckled dace. Humpback chub also seemed to prefer shaded areas around boulders and those having boulder/silt substrates. Valdez noted that the fish occupied mid-water positions after sunset, and he suspected that they move to these positions at night in order to feed on drift carried through the pools.

Juvenile to Adult Stages

Kaeding and Zimmerman (1982, 1983) measured depth, velocity, substrate, and occurrence of major habitat types along cross-sections of the Little Colorado and Colorado rivers. They reported ranges for some of these variables, but no in-depth analyis of habitat availability for humpback chub was presented. Their analysis of physical habitat use was for combined young-of-the-year and juvenile humpback chub. With the exception of one sampling period, young fish were found to be largely absent from shallow, nearshore areas during daylight hours at times of high water clarity. Catch rates in these same areas increased during darkness and in turbid waters. Young-of-the-year and juvenile fish were collected over much of the range of sampled depths and velocities, and no preference was indicated with respect to these criteria. Seines and minnow trap collections produced young humpback chub most often over substrates most suitable to these gear types. The former was effective over sand-silt substrates, while the latter fished most effectively among boulders and over bedrock.

Maddux et al. (1987) analyzed electrofishing catch rates for subadult to adult humpback chub independently among four habitats, five substrate types, and presence or absence of vegetation. Results varied among reaches, and catch rates generally too low to allow meaningful comparisons.

FISH MOVEMENT

Early Life Stages

With the exception of several largely unproductive attempts during humpback chub monitoring in the LCR, no studies of larval drift have been accomplished in the study area. Drift of larval native fishes, including *Gila* sp., has been measured in the Upper Colorado Basin, and this factor has been shown to be an integral part of the life cycle of these species (Valdez et al. 1985, Tyus et al. 1987, Tyus and Karp 1989). It may be of considerable importance to native fishes in the LCR, including *Gila cypha,* because of the

potential for these fish to be carried from warm tributary waters into the perennially cold mainstream where they may well perish.

Juvenile to Adult Stages

Mark-Recapture Studies

Tagging of humpback chub in the Grand Canyon region was first implemented in July of 1978 (Carothers et al. 1981). By October of 1979, 223 individuals had been marked with fingerling tags, but none were recaptured (Minckley et al. 1981).

Kaeding and Zimmerman (1983) reported recaptures of 17 of 433 (3.9%), 13 of 242 (5.4%), and 2 of 45 (4.4%) Carlin-tagged humpback chub from the LCR, confluence zone, and Colorado River, respectively, during 1980-1981. Time at large varied from one day to 16 months and maximum movement was 17.1 km. Thirteen of the 32 recaptures were collected within 0.3 km of the tagging site, but movement averaged 3.8 km for the remaining 19. Within the latttr group, most fish exhibiting upstream movement in the LCR were tagged and recaptured during the spawning season. Two individuals were recaptured from the Colorado River upstream of the confluence following the spawning season. The periodicity and placement of these movements was interpreted as evidence for two important relationships: (1) that most large-scale movements were associated with spawning, and; (2) these movements might occur between the mainstream and tributary.

Maddux et al. (1987) reported 1,009 humpback chub marked with Floy and Carlin dangler tags between April 1984 and June 1986. Forty-one individuals were recaptured, but 29 of these were marked during previous studies. The remaining 12 fish represent 1.2% of those tagged during 1984-1986. Days at large for 30 fish used for determination of growth (minimum of 30 days out) varied from 32 to 2477 (82.5 months). Thirty-six recaptures were captured less than 0.2 km from the site of tagging, and the greatest distance was 10 km. The mean distance for all recaptures was 0.5 km (SD = 1.8 km).

Maddux et al. (1987) indicated that, as found by Kaeding and Zimmerman (1983), most recaptures of humpback chub occurred during the spawning season (spring to early summer). Their sampling effort and collections of humpback chub occurred predominantly during these seasons, however, and the temporal pattern of recaptures may reflect only these factors (see Appendix II). No recaptures occurred in the mainstream, but six individals recovered in the LCR during the spawning season had been tagged in the Colorado River.

Roy fingerling (sew-on) tags were used to mark humpback chub (> 150 mm TL) during the May 1987-1988 monitoring periods. During 1989 these tags were continued, but approximately 60% of marked individuals instead received implants of Passive Integrated Transponder (PIT) tags into the coelomic cavity just anterior to the pelvic fins (Minckley 1989, Hendrickson and Kubly 1990).

Numbers of humpback chub tagged during the May monitoring of 1987-1989 were 522, 723, and 808, respectively. Concurrent numbers of fish tagged and recaptured in the same year were 87 (16.7%), 120 (16.6%), and 84 (10.4%). A total of 143 additional recaptures were of individuals tagged in years prior to that of recapture. Greatest number of days at large for these individuals was 3254 (108.5 months), and 38 recaptures were of humpback chub tagged more than 1000 days prior.

Seven humpback chub recaptured during 1987-1989 provide evidence of movement between the LCR and mainstream. These individuals had been at large for periods of two to 3254 days, and all were recaptured on only a single occasion. Six of the seven were tagged in the mainstream at distances from 4.8 km above to 11.3 km below the confluence. Five were recaptured within 0.1 km of the mouth. The remaining individual, a juvenile 162 mm TL at tagging, was marked in a backwater 11.3 km downstream of the confluence on May 22, 1987 and recaptured in the LCR 0.6 km upstream of the mouth on May 24, 1987. The seventh was tagged in the confluence zone and recovered in the mainstream a short distance upstream.

Movement within the LCR was evaluated independently for recaptures that were tagged during the same month and at large for at least one day. Both parametric and nonparametric statistical tests were used to determine if significant differences were present in the frequency distributions of distance moved. We anticipated that the 1989 distribution would be statistically different from that of the two previous years. In 1987 and 1988 nets were restricted to the lower 1.2 km of the tributary, although in the latter year gill net collections were taken up to 8.8 km upstream. During 1989 two base camps were established, near the mouth and at Salt Trail Canyon, some 10 km upstream, and nets were emplaced to 15 km above the mouth.

The frequency distribution of (minimum) distance moved for humpback chub in the LCR shows a strong grouping of observations within 100 m upstream and downstream of the tagging site (Figure 20). Cumulative frequencies of these observations were 24%, 46%, and 44% of totals in 1987-1989, respectively. Median distances moved were 278 m, 143 m, and 192 in for the same sequence of years. These relationships, with greater clustering of recaptures nearer the site of tagging for the latter two years, was unexpected, since more opportunities existed in those years for large distance recaptures. With respect to measures of central tendency, neither an ANOVA or Median test rejected null hypothes of equality of means and medians among the three years (Table 9).

Mean numbers of days at large for tag-recapture events during May were 4.1, 4.5, and 5.6, respectively, for 1987-1989. Tests for a significant correlation between days at large and distance moved with Pearson's *r* produced a significant relationship only in 1988 ($r = 0.382$, df = 97, $P < 0.001$). This parametric measure may be overly restrictive, however, as it measures the linear relationship of the two variables. A less restrictive nonparametric measure of association, Kendall's tau *b*, requires only that the ranking of the two variables be related (Conover 1971). Application of this test to the relationship between days out and distance moved provided significant results ($P < 0.01$) for all three years.

During 1987-1989 forty humpback chub were recaptured at distances greater than 600 m from the site of tagging. Only 10 of these individuals moved downstream, suggesting that movements of greater distance might have been associated with upstream spawning runs. Only 12 individuals were classified as ripe or spent, however, and differences between upstream and downstream groups were marginal. For example, 23% of upstream movements were by individuals from which milt or eggs could be expressed, whereas 30% of downstream movements were by like individuals.

BIOLOGICAL INTERACTIONS

Parasites and Pathogens

The parasitic copepod, *Lernaea cyprinaceae* (Eucopepoda: Caligoida), was first observed on *Gila cypha in* the LCR by R. Suttkus (Johnson 1976). No further observations of parasitism in humpback chub were made until October 1978, at which time 54% of 65 juveniles (58-189 mm TL) were found infected (Carothers et al. 1981).

Kaeding and Zimmerman (1983) also found *L. cyprinaceae* on humpback chub and reported seasonal differences in infection rates. Incidence of infection was highest in

winter and lowest in spring. Records from the humpback chub monitoring of 1987-1989 complement these observations for only seven individuals have been recorded as infected. Kaeding and Zimmerman also found the parasitic copepod much more common on humpback chub from the LCR than on those collected from the mainstream. Since this parasite cannot complete its life cycle at mainstream temperatures (Bauer 1959), they inferred that infection of mainstream fish provided further evidence for movement between the tributary and Colorado River.

Kaeding and Zimmerman (1983) also reported thirteen species of bacteria, six protozoans, and the fungus *Saprolegnia* to infect humpback chub. Incidence and serious of most infections was considered minor, but many adults collected from the confluence zone and lower LCR during the 1981 spawning season were highly infected with *Aeromonas hydrophila* and displayed resulting poor physical condition.

Potential Interactions With Other Fish Species

Food Habits of G. cypha

***Early Life Stages—Collections* of suspected young-of-the-year humpback chub were first made by Suttkus et al. (1976), but no detailed studies of the food habits of early life stages have been completed for fish collected in the Grand Canyon region. Minckley et al. (1981) reported dipterans (chironomids and dolichopodids) from stomachs of three**

young-of-the-year. They also observed foraging by individuals less than 50 mm TL at bottom, mid-water and surface depths, and assumed these fish were feeding on attached diatoms and small invertebrates. Grabowski and Hiebert (1989) found chironomid larvae and unidentified insect parts, invertebrate eggs, protozoans, and organic matter in stomachs of five larval *Gila* **sp. collected from Green River (Island Park) backwaters near Vernal, Utah. No planktonic organisms were detected.**

Juvenile to Adult Stages—Food **habits of juvenile to adult humpback chub in the study area also have received little attention. Minckley (1973) reported that specimens taken from below Glen Canyon Dam had fed principally on planktonic crustaceans and algae. These individuals must have been subadults to adults, for no earlier life stages have been collected from that stretch of the river, and the finding of these predominant food groups presents an interesting anomaly when compared with subsequent reports.**

Kaeding and Zimmerman (1983, see also Jacobi 1982) examined stomach contents of 44 fish, including 26 from the LCR and 18 from the Colorado River. Immature chironomids and simuliids were numerically predominant, both as the mean percentage of organisms and as the relative frequency of group occurrence, in fish from both rivers. Numerous other taxonomic groups, including other Diptera, Trichoptera, Neuroptera, Coleoptera, Ephemeroptera, Orthoptera, Hymenoptera, Oligochaeta, Nematoda, Amphipoda, and the fathead minnow *(Pimephales promelas),* **were also present. Mean number of organisms per stomach was more than 25X higher in stomachs of fish collected**

from the mainstream than from fish captured in the tributary, and this finding was interpreted as an indication of potentially lower food availability in the LCR.

Stomachs of 17 adult humpback chub (248-495 mm TL) collected from above the confluence zone of the LCR during 1985-1986 have been analyzed by Department personnel, and the diets of a much larger number of larval to adult individuals are presently being examined. Five of the 17 stomachs were devoid of food contents. Absence of food material may be an artifact of sampling, since these individuals were collected by trammel nets and may have digested or regurgitated these materials before collection (see also Kaeding and Zimmerman 1983). Filamentous algae, presumed to be largely *Cladophora glomerata,* formed the greatest mean volumetric percentage (77%) of food materials in the remaining stomachs (Figure 21) and also occurred in highest frequency (11 of 12 stomachs). Presence of such a large percentage of filamentous algae in these stomachs undoubtedly indicates that these fish fed in the mainstream, for little filamentous algae grows in lower reaches of the LCR. A single unidentified fish made up the stomach contents of one individual and provided a second example of piscivory or scavenging by humpback chub. Larval (Chironomidac) and adult (terrestrial Hymenoptera and Homoptera) insects collectively formed a mean relative volume of nearly 10%. Chironomid larvae occurred in 8 stomachs and were present in second highest frequency.

Gila sp. juveniles (21-80 mm TL) from Green River backwaters fed on a variety of food resources, but stomach contents were composed primarily of chironomids and other insects (Grabowski and Hiebert 1989). Algae, other than diatoms, were noticeably absent, although terrestrial plant seeds were present in some stomachs. Piscivory or scavenging of unidentifiable fish and *Notropis lutrensis,* presumably larval stages, was recorded in 7% of juveniles collected from Island Park and Jensen backwaters during 1988.

Food Habits of Other Species—The most commonly referred to biological interaction potentially affecting humpback chub in the study area is predation by channel catfish *ktalurus punctatus.* Recent collections and observations of the highly piscivorous striped bass, *Morone saxitilis,* in Grand Canyon have also led to increased fears for the effects of this predator (Department, unpublished data). Carothers et al. (1981) reported speckled dace, bluehead sucker, and flannelmouth sucker in guts of channel catfish along with a variety of aquatic and terrestrial invertebrates, the filamentous green *alga, Cladophora,* and organic detritus. Kaeding and Zimmerman (1983) did not report predation on humpback chub by channel catfish, but noted crescent-shaped wounds on adult chub which they took to be catfish bite marks. They also remarked that the two sp[illegible] were observed in similar habitats, shaded areas under rock ledges, and felt that this association provided considerable opportunity for predation.

Maddux et al. (1987) did not report any analyses of channel catfish stomachs, but 17 individuals collected during their study subsequently have been analyzed. Twelve of these stomachs were from collections made in the LCR, three from Kanab Creek, and two from the mainstream below National Canyon (RM 167, RKM 269). Four stomachs were empty, and one contained only bait. Of the remainder, three contained fish, which accounted for a mean percent volume of 17%. Greatest mean relative volume was attained by filamentous algae, presumably *Cladophora.* One gut from the LCR held an undetermined species of crayfish.

Channel catfish is also considered to be a potential threat to rare and endangered fish in the Upper Colorado River Basin. Tyus and Nikirk (in review) examined food contents of 575 stomachs from fish collected in the Green and lower Yampa rivers. Piscivory was confirmed for 8.5% of the fish examined, but was limited to larger individuals (mean length 420 mm) Fish species identified from stomachs included conspecifics, suckers, sculpin, *Coilus* sp., and speckled dace. Bones of some consumed fish were large in smaller catfish, leading the investigators that these events must have represented scavenging rather than predation.

Additional information on food habits of Grand Canyon fishes is provided in Minckley (1978), Carothers et al. (1981), and Maddux et al. (1987). The wide variety of food items consumed by humpback chub provides the opportunity for dietary overlap with most other fish species. Whether food is limiting in this system is unknown, but declines in standing crops of both algae and invertebrates in the mainstream below the LCR, where chub are primarily located, suggest at least the potential for competition for food.

Travertine deposition, floods, high sediment loads, and high salinity also may limit production of food resources in the LCR, thereby causing additional concern.

RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for future research into the ecology of humpback chub in Grand Canyon are not yet fully developed. What follows is a list of concerns and areas in which current knowledge is definitely lacking. Further explanation of suggested studies will be forthcoming in the final report; some expansion of this list is also anticipated.

Research into factors affecting reproductive success and survivorship of early life stages

> Quantification of habitat availability **and** suitability in tributaries and mainstream
> Determine susceptibility to and effects of thermal shock on early life stages
> Determine relationship between growth, survivorship, and fecundity at age under different controlled thermal regimes
> Determine relationship of reproductive activity and early survivorship and the magnitude, frequency, and timing of flood events in the LCR
> Determine effects of competitors, predators, and parasites as related to availability of suitable habitat

Proactive management investigations

Modification of mainstream hydrology

Seasonal short-term modification of mainstream temperatures

Augmentation by physical modification of existing habitats

Augmentation by introductions into new or modified habitats

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APPENDICES

Appendix I. File structures for existing humpback chub database held by the Arizona Game and Fish Department.

Database File: MNACATCH.DBF (Carothers et al. Catch File)

Field	Field Name	Type	Width	Decimal	Comment
1	Wacode	Numeric	4		
2	Water	Character	5		
3	Gear	Numeric	1		
4	Date	Numeric	6		
5	Effort	Numeric	5		
6	Station	Character	5		
7	Time	Numeric	4		
8	Species	Character	3		
9	Length	Numeric	5		
10	Weight	Numeric	5		
11	Sex	Character	1		
12	Mat	Numeric	1		
13	Tagno	Numeric	10		
14	Recapno	Numeric	10		

Database File: LKRARE.DBF (Kaeding and Zimmerman Rare File)

Field	Field Name	Type	Width	Decimal	Comment
1	River	Character	2		
2	Stratum	Character	1		
3	Rivermile	Numeric	4	1	
4	Type	Character	1		
5	Date	Character	6		
6	Start	Numeric	4		
7	Stop	Numeric	4		
8	Gear	Character	2		
9	Hab_1	Character	2		
10	Hab_2	Character	2		
11	Depth	Numeric	4	1	
12	Velocity	Numeric	3	1	
13	Substr_1	Character	2		
14	Substr_2	Character	2		
15	Species	Character	2		
16	Sex	Character	1		
17	TL MM	Numeric	5		
18	WT G	Numeric	5	1	
19	Dorsfin	Numeric	2		

Appendix I. Continued.

20	Analfin	Numeric	2		
21	P1 P2	Numeric	3	1	
22	D	Numeric	3	1	
23	Tagno	Character	5		
24	Color	Character	1		
25	Recap	Character	1		
26	Lemaea	Numeric	8		
27	Deposition	Character	2		
28	Ageclass	Character	2		

Database file: LKPHYS.DBF (Kaeding and Zimmerman Physical File)

Field	Field Name	Type	Width	Decimal	Comment
1	River	Character	2		
2	Stratum	Character	1		
3	Rivermile	Numeric	3	1	
4	Date	Numeric	6		
5	Time	Numeric	4		
6	H2OTemp_c	Numeric	3	1	
7	Airtemp_c	Numeric	2		
8	DO_ppm	Numeric	2		
9	Conduct	Numeric	4		
10	Salin	Numeric	2	1	
11	Turb	Numeric	3		
12	pH	Numeric	2	1	
13	Width_1	Numeric	3		
14	Maxd_1	Numeric	3	1	
15	Meand 1	Numeri		1	
16	S2D 1	Numeric	4	1	
17	WidT2	Numeric	3		
18	Maxd_2	Numeric	3	1	
19	Meand 2	Numeric	3	1	
20	S2D 2	Numeric	4	1	
21	Width_3	Numeric	3		
22	Maxd 3	Numeric	3	1	
23	Meand 3	Numeric	3	1	
24	S2D_3	Numeric	4	1	

Appendix I. Continued.

Database file: LKCATCH.DBF (Kaeding and Zimmerman Catch File)

Field	Field Name	Type	Width	Decimal	Comment
1	River	Character	2		
2	Stratum	Numeric	1		
3	Rivermile	Numeric	4	1	
4	Type	Character	1		
5	Date	Numeric	6		
6	Start	Numeric	4		
7	Stop	Numeric	4		
8	Gear	Character	2		
9	Hab 1	Character	2		
10	Hab 2	Character	2		
11	Area	Numeric	4		
12	Depth	Numeric	4	1	
13	Velocity	Numeric	3	1	
14	Substr_1	Character	2		
15	Substr_2	Charater	2		
16	Species	Character	2		
17	YOY	Numeric	4		
18	Juv	Numeric	3		
19	Adult	Numeric	3		

Database File: AGFDLARV.DBF (AGFD Larval Fish File)

Field	Field Name	Type	Width	Decimal	Comment
1	Wacode	Numeric	4		
2	Hab	Character	1		
3	Sub	Character	1		
4	Cover	Character	1		
5	Temp	Numeric	4		
6	Gear	Numeric	1		
7	Month	Numeric	2		
8	Day	Numeric	2		
9	Year	Numeric	2		
10	Effort	Numeric	5		
11	Station	Character	5		
12	Time	Numeric	4		
13	Species	Character	3		

Appendix I. Continued.

14	Length	Numeric	5
15	Weight	Numeric	5
16	Colno	Numeric	3
17	Depth	Numeric	4
18	Velocity	Numeric	4
19	Name	Character	4

Database File: AGFDHAB.DBF (AGFD Habitat File)

Field	Field Name	Type	Width	Decimal	Comment
1	Month	Numeric	2		
2	Day	Numeric	2		
3	Year	Numeric	2		
4	Name	Character	20		
5	RiverMile	Numeric	5		
6	Power	Character	1		
7	Time	Numeric	4		
8	Shore	Character	1		
9	Hab	Character	1		
10	Sub	Character	1		
11	Veg	Character	1		
12	Species	Character	3		
13	Age	Character	1		

Database File: AGFCATCH.DBF (AGFD Catch File)

Field	Field Name	Type	Width	Decimal	Comment
1	Wacode	Numeric	4		
2	Water	Character	5		
3	Gear	Numeric	1		
4	Date	Numeric	6		
5	Effort	Numeric	5		
6	Station	Character	5		
7	Time	Numeric	4		
8	Species	Character	3		
9	Length	Numeric	5		
10	Weight	Numeric	5		
11	Sex	Character	1		

Appendix I. Continued.

12	Mat	Numeric	1
13	Tagno	Numeric	10
14	Recapno	Numeric	10

Appendix **II.** Catch statistics for humpback chub collected from the Colorado River (reaches **10-50**[a]**)** and Little Colorado River in Grand Canyon during the period April 1984-June 1986. Gear codes: EF = electrofishing; TN = trammel net; BS = bag seine; LSDN = larval seine or dip net. Units of effort are minutes for electrofishing, hours for trammel net, and square meters for seines and dip net. Catch rates (CO are in units of individuals per 100 minutes for electrofishing, individuals per net night (12 hours) for trammel nets, individuals per 100 square meters for bag seine, and individuals per 10 square meters for larval seine and dip net. Numbers of samples following slashes (0 represent those samples without recorded efforts.

Gear	EF	EF	EF	EF	EF	EF	EF	EF
Reach	10	10	10	10	10	10	10	10
Season	Spring	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Year	1984	1984	1984-85	1985	1985	1985	1985-86	1986
No. Samples	9	31	9	10/2	9	5/1	5	8
Effort	317	513	281	406	315	256	246	322
No. Caught	0	0	0	0	0	0	0	0
Mean Cf								
SE Cf								
Median Cf								
Mode Cf								

Gear	EF	EF	EF	EF	EF	EF	EF	EF
Reach	20	20	20	20	20	20	20	20
Season	Spring	Summer	Winter	Spring	Summer	Autumn	Winter	Spring
Year	1984	1984	1984-85	1985	1985	1985	1985-86	1986
No. Samples	9	4	16	24	6	7	24	11
Effort	238	97	615	1033	150	327	1000	526
No. Caught	3	2	1	1	1	0	0	0
Mean Cf	1.61	33.33	0.14	0.20	0.50			
SE Cf	1.253	33.334	0.142	0.198	0.505			
Median Cf	0.00	0.00	0.00	0.00	0.00			
Mode Cf	0.00	0.00	0.00	0.00	0.00			

Appendix II. Continued.

Gear	EF	EF	EF	EF	EF	EF	EF	EF
Reach	30	30	30	30	30	30	30	30
Season	Spring	Summer	Winter	Spring	Summer	Autumn	Winter	Spring
Year	1984	1984	1984	1985	1985	1985	1985-86	1986
No. Samples	2	5	8	8	2	1	5	4
Effort	110	82	447	536	67	56	288	176
No. Caught	0	17	2	4	4	2	0	2
Mean Cf		47.67	0.52	0.8	4.88	3.57		1.11
SE Cf		37.351	0.370	0.314	4.879			1.110
Median Cf		10.00	0.00	0.50				0.00
Mode Cf		0.00	0.00	0.00				0.00

Gear	EF	EF	EF	EF	EF	EF	EF	EF
Reach	40	40	40	40	40	40	40	40
Season	Spring	Summer	Winter,	Spring	Summer	Autumn	Winter	Spring
Year	1984	1984	1984-85	1985	1985	1985	1985-86	1986
No. Samples	9	3	20	23	16	3	20	13
Effort	324	115	1148	1166	660	74	956	608
No. Caught	1	1	1	3	3	0	1	0
Mean Cf	0.24	0.56	0.07	0.19	0.32		0.12	
SE Cf	0.242	0.555	0.067	0.112	0.222		0.116	
Median Cf	0.00	0.00	0.00	0.00	0.00		0.00	
Mode Cf	0.00	0.00	0.00	0.00	0.00		0.00	

Appendix II. Continued.

Gear	TN	BS	BS	BS	BS	BS	BS	BS
Reach	50	10	10	20	20	20	20	30
Season	Summer	Summer	Winter	Summer	Autumn	Winter	Spring	Summer
Year	1984	1985	1985-86	1985	1985	1985-86	1986	1985
No. Samples	1	1	1	1	9/1	6	9	1
Effort	4	22	25	20	1020	144	193	30
No. Caught	0	0	0	0	0	0	0	34
Mean Cf								113.33
SE Cf								
Median Cf								
Mode Cf								

Gear	BS	BS	BS	BS	BS	BS	BS	BS
Reach	30	30	30	40	40	40	40	40
Season	Autumn	Winter	Spring	Spring	Spring	Summer	Autumn	Winter
Year	1985	1985	1986	1984	1985	1985	1985	1985
No. Samples	37	6	2	0/1	1	12	25	7
Effort	1768	346	24	--	315	574	1069	927
No. Caught	302	0	0	0	1	5	2	0
Mean Cf	21.44				0.32	1.78	0.16	
SE Cf	7.347					1.370	0.144	
Median Cf	4.00					0.00	0.00	
Mode Cf	0.00					0.00	0.00	

Appendix II. Continued.

Gear	BS	BS	BS	BS	BS	BS	BS	BS
Reach	40	50	50	50	50	50	50	50
Season	Spring	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Year	1986	1984	1984	1984	1984-85	1985	1985	1985
No. Samples	17	1/1	1	3	3	1	33/1	122/1
Effort	205	232	167	135	289	40	1555	7301
No. Caught	0	0	0	2	0	0	27	24
Mean Cf				0.95			2.35	0.32
SE Cf				1.502			1.099	0.104
Median Cf							0.00	0.00
Mode Cf							0.00	0.00

Gear	BS	BS	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN
Reach	50	50	10	10	10	10	10	10
Season	Winter	Spring	Autumn	Winter	Spring	Summer	Winter	Spring
Year	1985	1986	1984	1984	1985	1985	1985	1986
No. Samples	55	14	0/2	10	66/1	3	13	14
Effort	2131	776	--	62	460.3	29	20.5	69.5
No. Caught	0	0	0	0	0	0	0	0
Mean Cf								
SE Cf								
Median Cf								
Mode Cf								

Appendix II. Continued.

Gear	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN
Reach	20	20	20	20	20	20	20	30
Season	Summer	Autumn	Winter	Spring	Summer	Winter	Spring	Winter
Year	1984	1984	1984-85	1985	1985	1985-86	1986	1984-85
No. Samples	0/1	0/5	60/8	59/3	4	44	24/7	13
Effort	--	--	281.4	250	11	226.5	192	26.8
No. Caught	0	0	0	0	0	0	0	0
Mean Cf								
SE Cf								
Median Cf								
Mode Cf								

Gear	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN	LSDN
Reach	30	30	30	40	40	40	40	40
Season	Spring	Winter	Spring	Winter	Spring	Summer	Autumn	Winter
Year	1985	1985	1986	1984	1985	1985	1985	1985
No. Samples	53	6	4	80	83/5	30	2	44
Effort	208.5	28	24	139.5	232	85.5	4	274.8
No. Caught	0	0	0	0	0	0	2	0
Mean Cf							3.33	
SE Cf							3.333	
Median Cf								
Mode Cf								

Appendix **II.** Continued.

Gear	**LSDN**	.;DN	LSDN	LSDN	LSDN
Reach	50	50	50	50	50
Season	Winter	Spring	Summer	Winter	Spring
Year	1984-85	1985	1985	1985-86	1986
No. Samples	48	30/1	21	18	48/2
Effort	145.8	96.5	73.5	156.5	199.6
No. Caught	1	0	1	0	0
Mean Cf	0.42		0.08		
SE Cf	0.417		0.079		
Median Cf	0.00		0.00		
Mode Cf	0.00		0.00		

Gear	TN	TN	TN	TN	TN	TN
Tributary	22	22	22	22	22	22
Season	Spring	Summer	Spring	Winter	Spring	Summer
Year	1984	1984	1985	1985-86	1986	1986
No. Samples	5	2	**10**	4	4	7
Effort	92	0.25	133	51	16	7.5
No. Caught	325	122	255	40	64	501
Mean Cf	43.85	693.00	23.19	9.3	48.00	788.57
SE Cf	20.558	614.999	11.968	4.736	15.636	116.277
Median Cf	37.00		3.50	7.00	39.00	563.00
Mode Cf	0.00		0.00	0.00*	21.00	419.00

Appendix H. Continued.

Gear	BS	BS	BS	BS	BS	BS	BS	BS
Reach	LCR	LCR	LCR	LCR	LCR	LCR	LCR	LCR
Season	Spring	Summer	Autumn	Winter	Spring	Summer	Winter	Summer
Year	1984	1984	1984	1984-85	1985	1985	1985-86	1986
No. Samples	26	3	1	4	1	3	6	1
Effort	1323	234	1625	270	120	273	207	300
No. Caught	17	143	2	1	1	126	2	20
Mean Cf	1.83	2668.70	0.123	0.69	0.83	30.61	1.50	6.67
SE Cf	0.922	2665.684		0.694		24.107	0.957	
Median Cf	0.00	3.00		0.00		10.00	0.00	
Mode Cf	0.00	0.00*		0.00		3.00	0.00	

Gear	LSDN	LSDN	LSDN	LSDN	LSDN
Tributary	LCR	LCR	LCR	LCR	LCR
Season	Spring	Summer	Winter	Spring	Summer
Year	1985	1985	1985-86	1986	1986
No. Samples	2	0/1	4	0/1	4/1
Effort	6		5		5.2
No. Caught	9	2	0	1	53
Mean Cf	15.00				150.25
SE Cf	15.000				111.29
Median Cf					36.00
Mode Cf					0.00*

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*River miles in mainstream reaches: Reach 10 (Glen Canyon Dam to Lee's Ferry) 15.5 miles); Reach 20 (Lee's Ferry to Little Colorado River) 61.5 miles; Reach 30 (Little Colorado River to Bright Angel Creek) 22 miles; Reach 40 (Bright Angel Creek to National Canyon) 79 miles; Reach 50 (National Canyon to Diamond Creek) 58.5 miles.

Appendix **II.** Continued.

Gear	BS	BS	BS	BS	BS	BS	BS	BS
Reach	LCR	LCR	LCR	LCR	LCR	LCR	LCR	LCR
Season	Spring	Summer	Autumn	Winter	Spring	Summer	Winter	Summer
Year	1984	1984	1984	1984-85	1985	1985	1985-86	1986
No. Samples	26	3	1	4	1	3	6	**1**
Effort	1323	234	1625	270	120	273	207	300
No. Caught	17	143	2	1	1	126	2	20
Mean Cf	1.83	2668.70	0.123	0.69	0.83	30.61	1.50	6.67
SE Cf	0.922	:665.684		0.694		24.107	0.957	
Median Cf	0.00	3.00		0.00		10.00	0.00	
Mode Cf	0.00	0.00*		0.00		3.00	0.00	

Gear	LSDN	LSDN	LSDN	LSDN	LSDN
Tributary	LCR	LCR	LCR	LCR	LCR
Season	Spring	Summer	Winter	Spring	Summer
Year	1985	1985	1985-86	1986	1986
No. Samples	2	0/1	4,	0/1	4/1
Effort	6		5		5.2
No. Caught	9	2	0	1	53
Mean Cf	15.00				150.25
SE Cf	15.000				111.29
Median Cf					36.00
Mode Cf					0.00*

'River miles in mainstream reaches: Reach 10 (Glen Canyon Dam to Lee's Ferry) 15.5 miles); Reach 20 (Lee's Ferry to Little Colorado River) 61.5 miles; Reach 30 (Little Colorado River to Bright Angel Creek) 22 miles; Reach 40 (Bright Angel Creek to National Canyon) 79 miles; Reach 50 (National Canyon to Diamond Creek) 58.5 miles.

Appendix III. Catch statistics for humpback chub collected from the Colorado River reaches **10-50**^{a}**)** and Little Colorado River in Grand Canyon during April **1987-September 1989.** Gear codes: **EF = electrofishing;** TN = trammel net; BS = bag seine; **HF** = hoop or **fyke** net; **LSDN** = larval seine or dip net. Units of effort are minutes for **electrofishing,** hours for trammel, hoop and **fyke** nets, and square meters for seines and dip net. Catch rates **(Cf)** are in units of individuals per **100** minutes for **electrofishing,** individuals per net night **(12** hours for trammel nets, individuals per **100** square meters for bag seine, and individuals per **10** square meters for larval seine and dip net. Numbers of samples following slashes **(0** represent those samples without recorded efforts.

Gear	EF	EF	EF	EF	EF	BS	BS	BS
Reach	10	10	10	10	10	20	20	20
Season	Spring	Autumn	Winter	Spring	Autumn	Spring	Summer	Spring
Year	1987	1987	1987-88	1988	1988	1988	1988	1989
No. Samples	2	1	3	25	11	2	1	7/6
Effort	90	30	129	709	481	220	32	298
No. Caught	0	0	0	0	0	0	0	0
Mean **Cf**		--						
SE **Cf**		--			--			
Median **Cf**								
Mode **Cf**								

Gear	BS	BS	BS	BS	BS	BS	BS	BS
Reach	30	30	30	30	30	40	40	50
Season	Spring	Spring	Summer	Spring	Summer	Spring	Spring	Spring
Year	1987	1988	1988	1989	1989	1988	1989	1987
No. Samples	5	11/2	1	3/4	1	6	4/1	18/1
Effort	410	696	42	194	42	126	150	1695
No. Caught	180	7	7	2	0	2	0	16
Mean **Cf**	41.72	1.90	16.67	2.29		4.76		0.85
SE **Cf**	17.047	1.647		1.676		4.762		0.511
Median **Cf**	53.00	0.00		1.00		0.00		0.00
Mode **Cf**	0.00	0.00		0.00		0.00		0.00

Appendix HI. Continued.

Gear	BS	BS	LSDN	LSDN	LSDN
Reach	50	50	30	40	50
Season	Spring	Spring	Spring	Spring	Spring
Year	1988	1989	1989	1989	1989
No. Samples	35/2	18	0/2	2/5	0/4
Effort	1767	1088		105	
No. Caught			1	1	
Mean Cf				1.00	
SE Cf				0.999	
Median Cf				1.00	
Mode Cf				0.00	

Gear	TN	TN	TN	TN	BS	BS	BS	BS
Reach	22	22	22	22	22	22	22	22
Season	Spring	Spring	Spring	Autumn	Spring	Spring	Spring	Summer
Year	1987	1988	1989	1989	1987	1988	1989	1989
No. Samples	85	76/3	163/5	6	34	30	5/3	0/1
Effort	821.9	06	1444.8	19.2	478	1937	284	54
No. Caught	186	181	370	3	15	11	55	
Mean Cf	3.50	1.92	3.29	2.89	3.57	1.45	180.00	
SE Cf	0.606	0.220	0.420	1.924	1.569	0.612	155.492	
Median Cf	2.00	0.00	1.00	0.50	0.00	0.00	16.50	
Mode Cf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

TABLES

Table 1. Available information on discharge from tributaries entering the Colorado River between Lee's Ferry (RM 0) and Pierce Ferry (RM 279).

	River Mile	Mean	Range	
Paria River	0.5	30.1	0	- 16,100
Vasey's Paradise	31.7	4.0	0.2	- 10
Little Colorado River[b]	61.5	205	0	- 24,900
Blue Springs		223	217	232
Clear Creek	84.1	1.6	0	3.0
Bright Angel Creek	87.5	35.4	10	4,400
Shinumo Creek	108.5	9.1	5	15.5
Elves Chasm	116.5	0.5	0.1	0.3
Stone Creek	131.8	0.5	0	- 1.2
Tapeats Creek	133.6	100.1	51.4	- 283
Deer Creek	136.2	7.2	5.4	- 8.2
Kanab Creek	143.5	5.7	0	- 4,360
Havasu Creek	156.7	63.8	59.3	- 74.5
Lava Warm Spring	179.3	11.0	6	15
Diamond Creek	225.8	1.9	1.5	2.2
Travertine Falls Creek	230.5	0.2		
Spencer Creek	246.0	2.7	1.1	4.4

Table 2. Benthic macroinvertebrate taxa collected in backwaters of the Colorado River in Grand Canyon National Park, 1988-1989.

- Nematoda

- Nematomorpha

- Oligochaeta
  - Lumbriculidae
  - Naididae

- Crustacea
  - Amphipoda
    - Gammaridae
      - *Gammarus lacustris*

- Insecta
  - Ephemeroptera
    - Baetidae
      - *Callibaetis* sp.

  - Hemiptera
    - Corixidae
    - Gerridae
      - *Gerris* sp.

  - Coleoptera
    - Dytiscidae
      - *Laccophilus* sp.

  - Diptera
    - Ceratopogonidae
    - Chironomidae
    - Dolichopodidae
    - Muscidae
    - Simuliidae

- Mollusca
  - Gastropoda
    - Physidae
    - Lymnaeidae
  - Pelycopoda
    - Sphaeriidae

Table 3. Invertebrate taxa collected in zooplankton samples taken from the mainstream Colorado River and backwaters during 1987-1989. Asterisks indicate true plankton.

COPEPODA

Calanoids

*Leptodiaptomus ashlandi**

Cyclopoids

*Diacyclops thomasi**
Eucyclops agilis
*Mesocyclops edax**
Paracyclops fimbriatus poppei

Harpacticoids

Mesochra alaskana
Canthocamptus robertcokeri
Biyocamptussp.

CLADOCERA

Alona affinis
*Ceriodaphnia quadrangula**
*Chydorus sphaericus**
*Daphnia pulex**
Leydigia acantholebris
Leydigia quadrangularis
Macrothrix laticornis
Pleuroxus aduncus
Simocephalus vetulus

OSTRACODA

Herpetocypris reptans
Heterocypris incongruens
Ilyocypris bradyii

OTHER INVERTEBRATES

Acari
Ceratopogonidae larvae
Chironomidae larvae
Gastropoda
Hydra
Oligochaeta
Rotifera
Tardigrada

Table 4. Summary table of recorded collections of humpback chub, *Gila cypha,* from the Colorado River and its tributaries in Glen and Grand canyons.

Collector(s)	Collection Date(s)	Localities	Disposition[a,b]	Citation(s)
E. Kolb & E. Kolb	Before 1914	Little Colorado R.	Consumed	Kolb & Kolb (1914)
N. N. Dodge	ca. 1942	Colo. R. nr. B. Angel Ck.	USNM	Miller (1946)
O. L. Wallis et al.	1955	Spencer Ck.	UMMZ	UMMZ records
P. B. Holden et al.	1967	Colo. R., Glen Cyn Dam to Lee's Ferry	UCFU, NERC	Holden and Stalnaker (1975), Suttkus and Clemmer (1977)
Arizona Game and Fish Department personnel	1967-1969	Colo. R., Glen Cyn Dam to Lee's Ferry	ASU, UCFU	Stone and Rathbun (1967-1969)
P. B. Holden et al.	1970	Colo. R., Glen Cyn Dam to Lee's Ferry	UCFU	Holden and Stalnaker (1975)
R. R. Miller et al.	1968	Little Colorado R. Colo. R. RM 32, 64.5	UMMZ UMMZ	UMMZ records UMMZ records
L. Powers	1969	Colo. R. RM 32	UMMZ	UMMZ records
R. Suttkus et al.	1970-1976	Little Colorado R. Shinumo Ck. Colo. R. RM 44-71	TU, NERC	Suttkus et al. (1976) Suttkus and Clemmer (1977)

Table 4.—Continued.

C. O. Minckley et al.[a]	1975	Little Colorado R.	MNA, ASU	Minckley and Blinn (1976)
R. R. Miller et al.	197[illegible]	Colo. R. RM 64.5	Released	Miller (1975)
C. O. Minckley et al.	1977	Little Colorado R.	Released	Minckley (1977)
C. O. Minckley et al.	1977-1978	Little Colorado R. Colo. R. ca. RM 25-132	MNA	Carothers et al. (1981)
C. O. Minckley et al.	1979	Little Colorado R.	Released	Minckley (1979a)
C. O. Minckley et al.	1979	Little Colorado R. Colo. R. RM 61.5	Willow Beach Hatchery	Minckley (1979b)
G. Clemmer et al.	1980	Little Colorado R.	NWFL	Clemmer (1980)
G. Clemmer et al.	1981	Little Colorado R. Colo. R. RM 122.7	Released NWFL	Clemmer (1981)
L. R. Kaeding et al.	1980-1981	Little Colorado R. Colo. R. RM ca.51-71	Various	Kaeding and Zimmerman (1983)

Table 4. Continued.

H. R. Maddux et al.	1984-1986	Little Colorado R. B. Angel Ck. Shinumo Ck. Kanab Ck. Colo. R. RM 32-217	ASU CSU	Maddux et al. (1987)
Arizona Game and Fish Department personnel	1987-1989	Little Colorado R. Kanab Ck. Havasu Ck. Colo. R., RM 65-204	ASU CSU	This report

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ASU = Arizona State University, Tempe, Arizona; CSU = Larval Fishes Laboratory, Colorado State University, Ft. Collins, Colorado; MNA = Museum of Northern Arizona, Flagstaff, Arizona; NERC = U.S. Fish and Wildlife Service National Ecology Research Center, Ft. Collins, Colorado; TU = Tulane University, Belle Chasse, Louisiana; UCFU = Utah Cooperative Fisheries Unit, Utah State University, Logan, Utah, UMMZ = University of Michigan Museum of Zoology, Ann Arbor, Michigan; USNM = United States National Museum, Washington, D.C..

[b] For further information, see Service (????) and Starnes (1989).

Table 5. Humpback chub collected from tributaries to the Colorado River in the Grand Canyon region other than the Little Colorado River after impoundment of Lake Powell.

Tributary	RM	Gear	Month	Day	Year	Length	Weight
Shinumo	108	Trammel	6	22	1984	244	138
Shinumo	108	Trammel	6	22	1984	275	222
Shinumo	108	Trammel	6	2	1986	199	78
Shinumo	108	Trammel	6	2	1986	273	186
Shimumo	108	Trammel	6	2	1986	255	154
Shinumo	108	Trammel	6	2	1986	244	158
Kanab	144	Bag Seine	6	25	1984	84	
Bright Angel	88	Hoop Net	9	8	1984	263	160
Bright Angel	88	Hoop Net	9	8	1984	242	134
Havasu	157	Hoop Net	5	27	1987	295	258
Havasu	157	Angling	5	27	1988	329	
Kanab	144	Hoop Net	5	26	1989	81	5
Kanab	144	Hoop Net	5	26	1989	64	2
Kanab	144	Hoop Net	5	26	1989	57	
Kanab	144	Hoop Net	5	26	1989	57	

Table 6. ANOVA and Median test results for differences among weekly log-transformed means of trammel net catch rates for humpback chub in the Little Colorado River during 1987-1989.

1987

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	Ratio	Prob.
Between Groups	2	.1611	.0805	.6916	.5040
Within Groups	73	8.5022	.1165		
Total	75	8.6633			

Scheffe Procedure
No two groups are significantly different at the .050 level

Median Test

Cases	Median	Chi-Square	D.F.	Significance
76	.4771	1.0975	2	.5777

1988

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	Ratio	Prob.
Between Groups	3	4.3253	1.4418	14.0510	.0000
Within Groups	- 172	17.6487	.1026		
Total	175	21.9740			

Scheffe Procedure
(*) Denotes pairs of groups significantly different at the .050 level

Mean	Group	4	3	1	2
.0974	4				
.1391	3				
.4000	1				
.4760	2				

Table 6. Continued.

Median Test

Cases	Median	Chi-Square	D.F.	Significance
176	.0000	31.9118	3	.0000

1989

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	2.0746	.6915	4.0341	.0085
Within Groups	159	27.2569	.1714		
Total	162	29.3315			

Scheffe Procedure

Mean	Group	3	4	2	1
.1196	3				
.3325	4				
.3566	2				
.4962	1	*			

Median Test

Cases	Median	Chi-Square	D.F.	Significance
163	.368	9.5717	3	.0226

Table 7. ANOVA and Median test results for differences among weekly log-transformed means of hoop and fyke net catch rates for humpback chub in the Little Colorado River during 1987-1989.

1987

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	Ratio	Prob.
Between Groups	2	1.2483	.6242	5.9913	.0032
Within Groups	129	13.4388	.1042		
Total	131	14.6871			

Scheffe Procedure

Mean	Group	2	3	4
.4729	2			
.4876	3			
.7095	4			

Median Test

Cases	Median	Chi-Square	D.F.	Significance
132	.5501	7.9616	2	.0187

1988

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	.8526	.2842	2.6646	.0477
Within Groups	374	39.8894	.1067		
Total	377	40.7420			

Table 7. Continued.

Scheffe Procedure
No two groups are significantly different at the .050 level

Median Test

Cases	Median	Chi-Square	D.F.	Significance
378	.3229	3.6240	3	.3050

1989

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	.3198	.1066	1.0336	.3775
Within Groups	406	41.8655	.1031		
Total	409	42.1853			

Scheffe Procedure
No two groups are significantly different at the .050 level

Median Test

Cases	Median	Chi-Square	D.F.	Significance
410	.3018	.3543	3	.9495

Table 8. Results of humpback length at age and tag-recapture data applied to a von Bertallanfy growth equation.

Length at Age (RAFAIL)	
Number of observations	10
vB parameter t_J	-.008
vB asymptotic length, L	442.7
Standard error of L	53.12
vB growth parameter, K	
by ordinary least squares regression	0.166
by functional regression	0.180
Tag-Recapture (FABGROW)	
Number of observations	41
	0.984
vB parameter, t_J (derived from b)	-0.175
vB asymptotic length	434.9
vB growth parameter, K	0.093
Units of time per chron	7.485
Chrons per unit of time	0.137

Table 9. Statistical tests for differences among years in distributions of distances moved by humpback chub in the Little Colorado River. All individuals tagged and recaptured in the same month and year; same day recaptures excluded.

ANOVA--Log_{10} Distance Moved by Year (1987-1989)

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.1107	.0553	.8721	.4191
Within Groups	305	19.3525	.0635		
Total	307	19.4632			

Median Test--Distance Moved by Year (1987-1989)

Cases	Median	Chi-Square	D.F.	Significance
308	21.500	2.5826	2	.2749

FIGURES

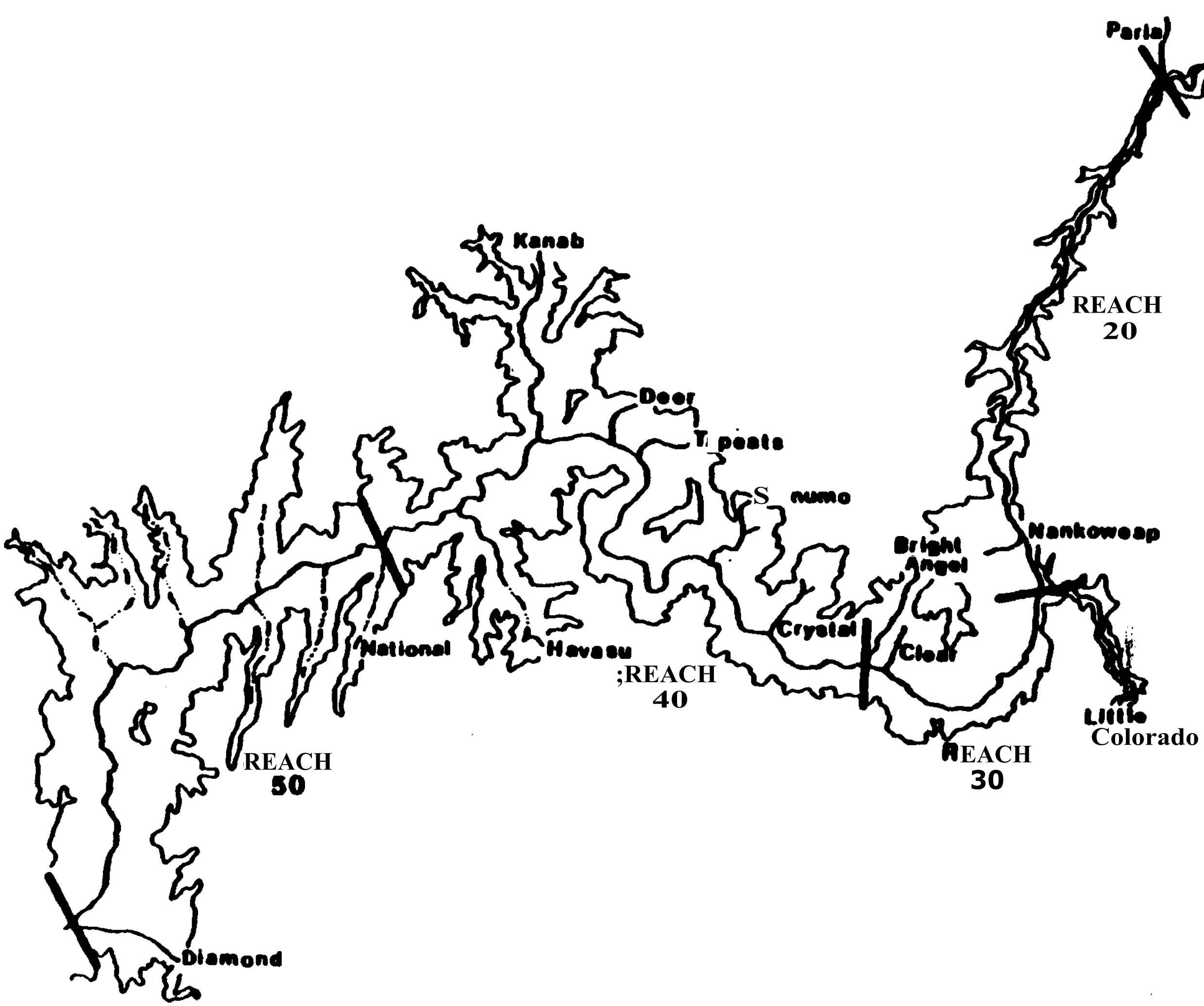


Figure 1. Map of the Colorado River and its tributaries in the study area.

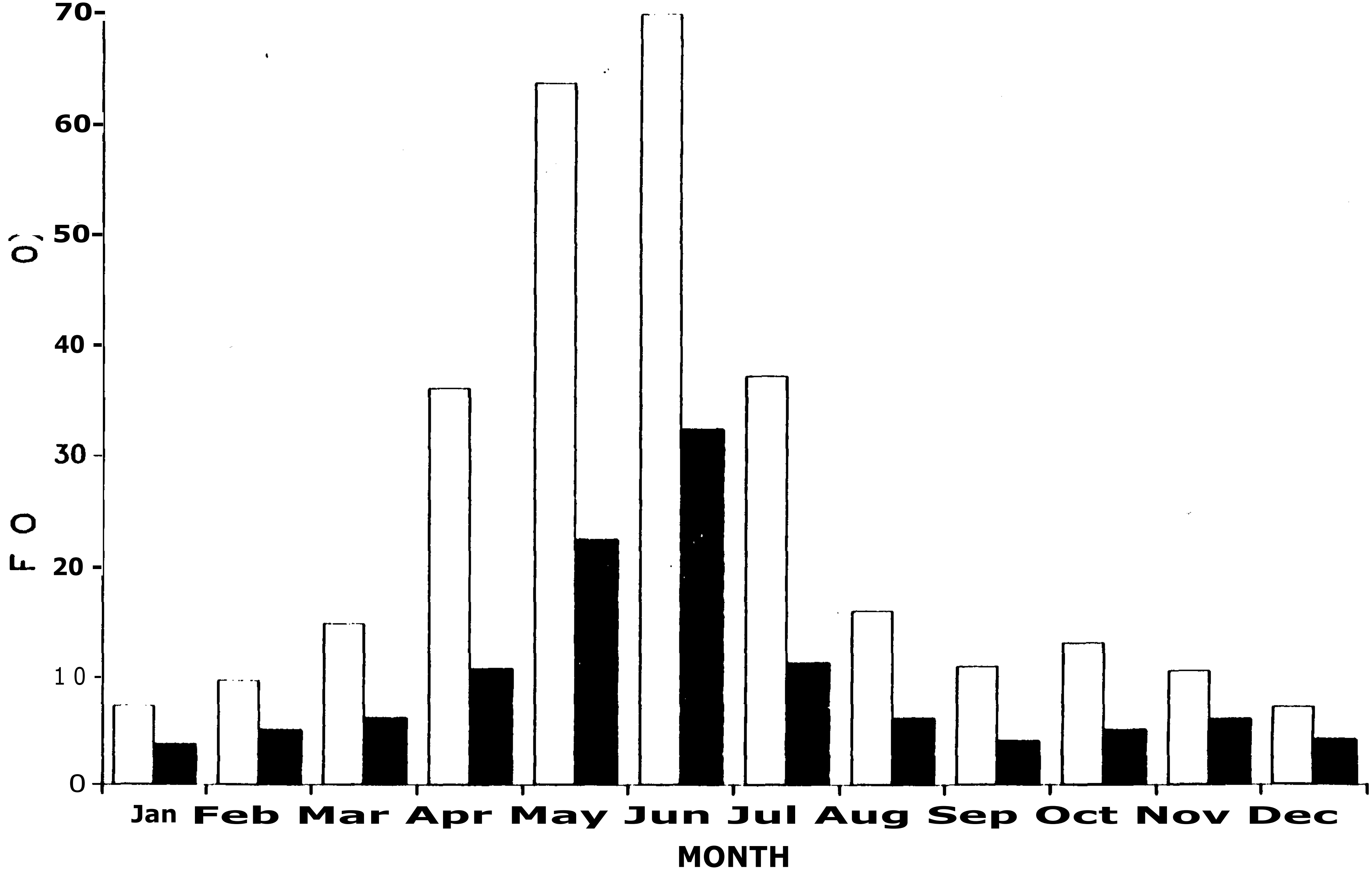


Figure 2. Hydrograph of mean maximum and minimum monthly instantaneous discharges at Lee's Ferry gaging station for the period 1942-1962.

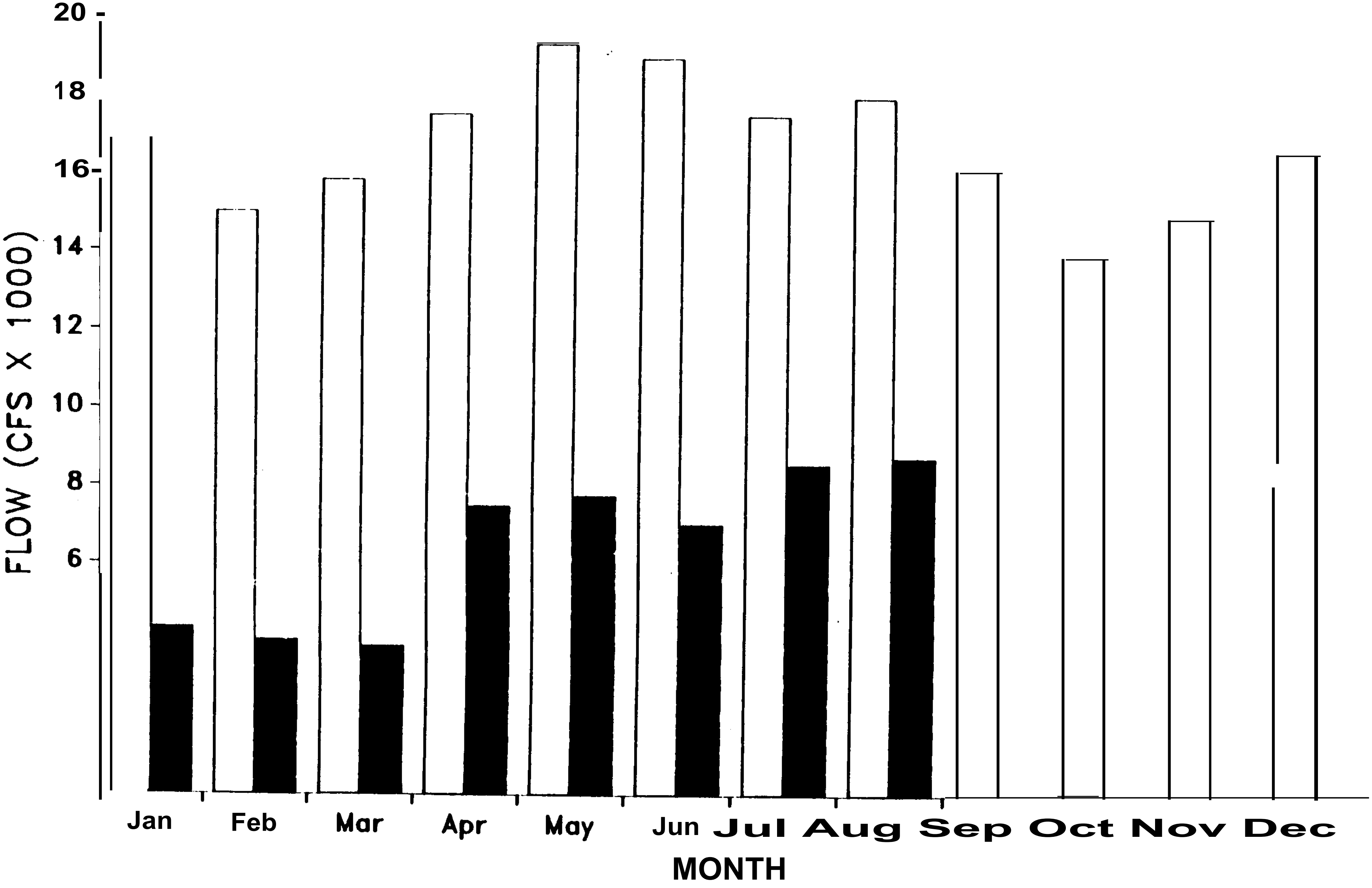


Figure 3. Hydrograph of mean monthly discharges from Glen Canyon Dam for the period 1963-1982.

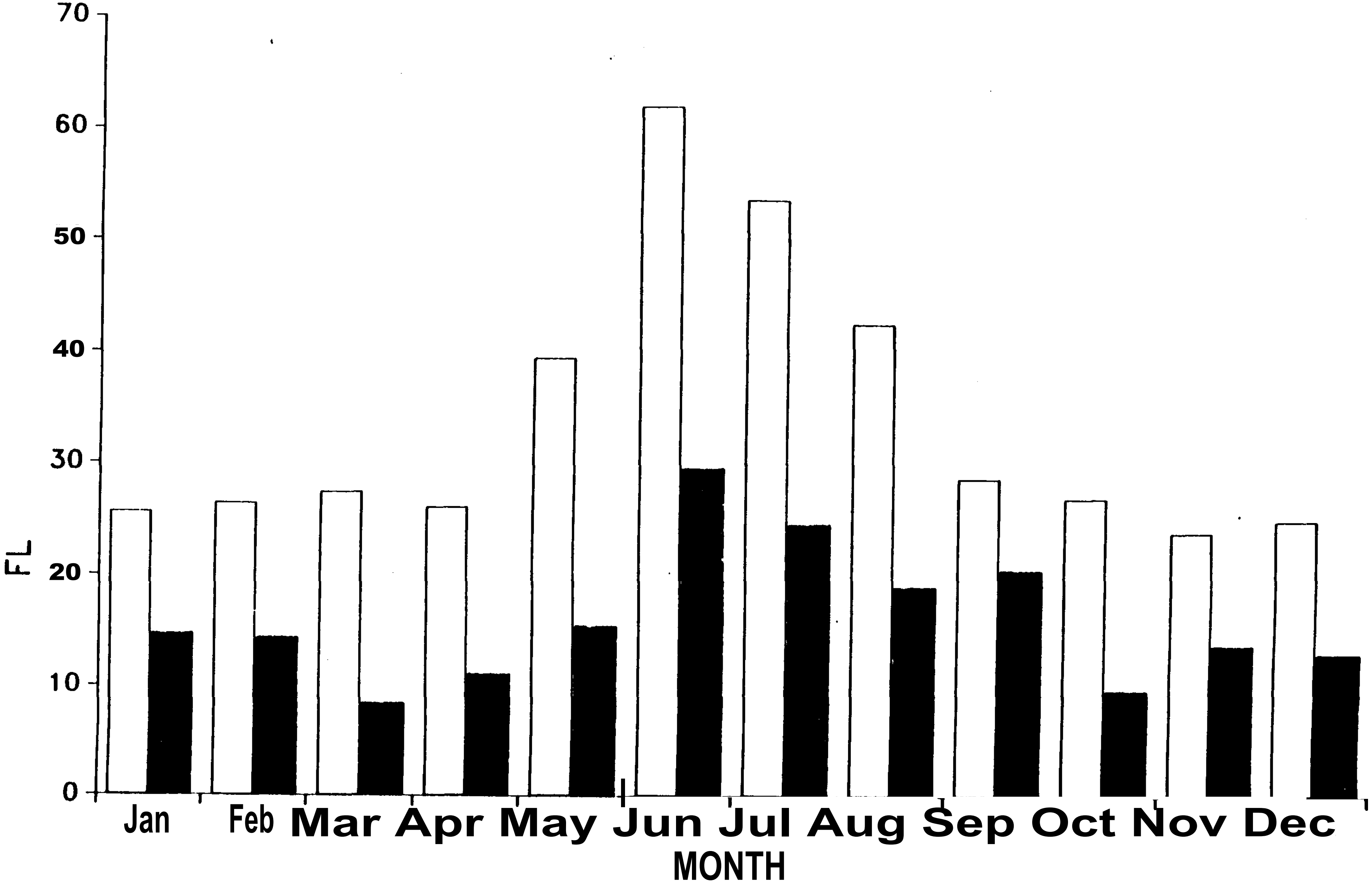


Figure 4. Hydrograph of mean monthly discharges from Glen Canyon Dam during the period 1983-1986.

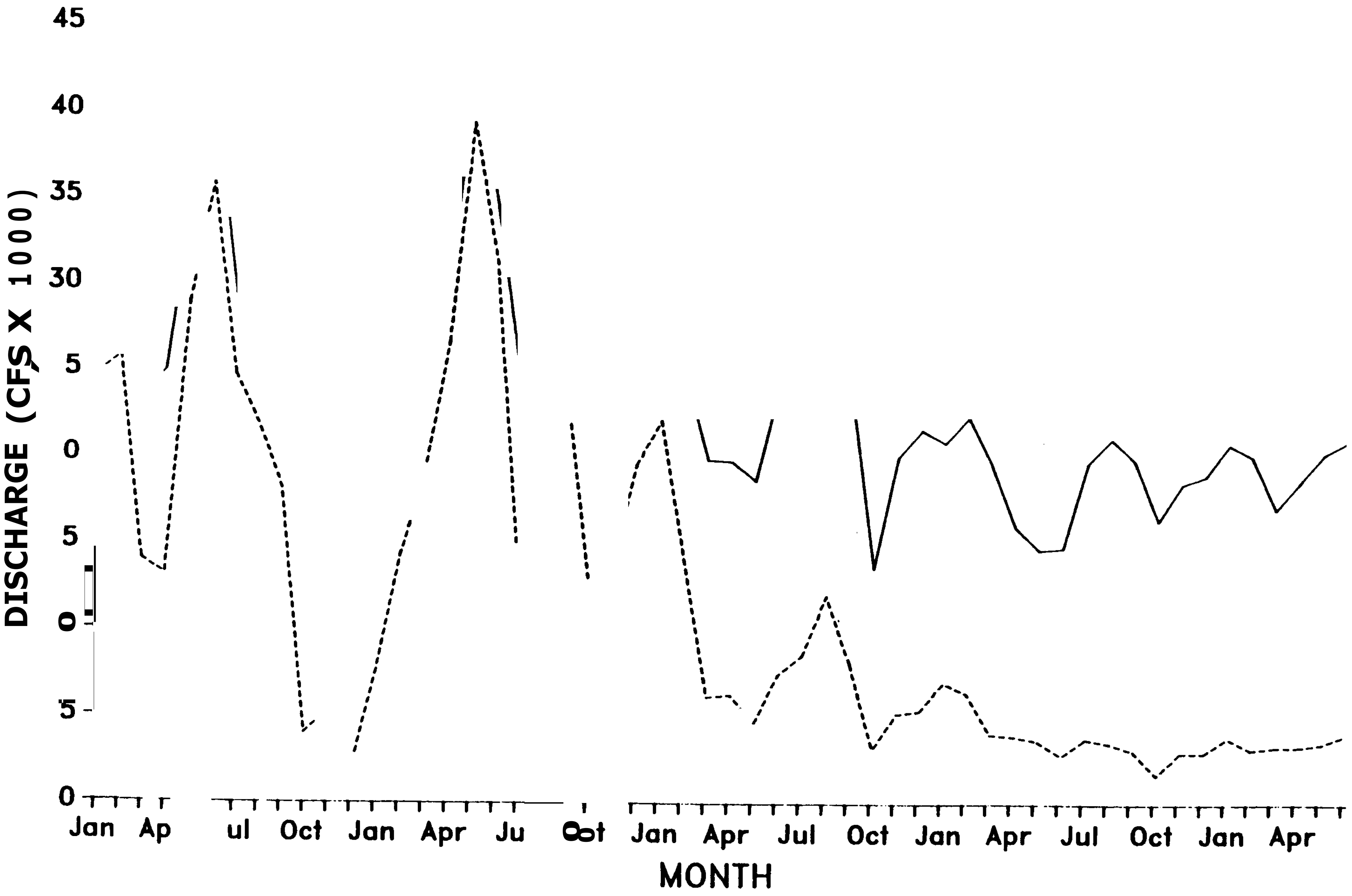
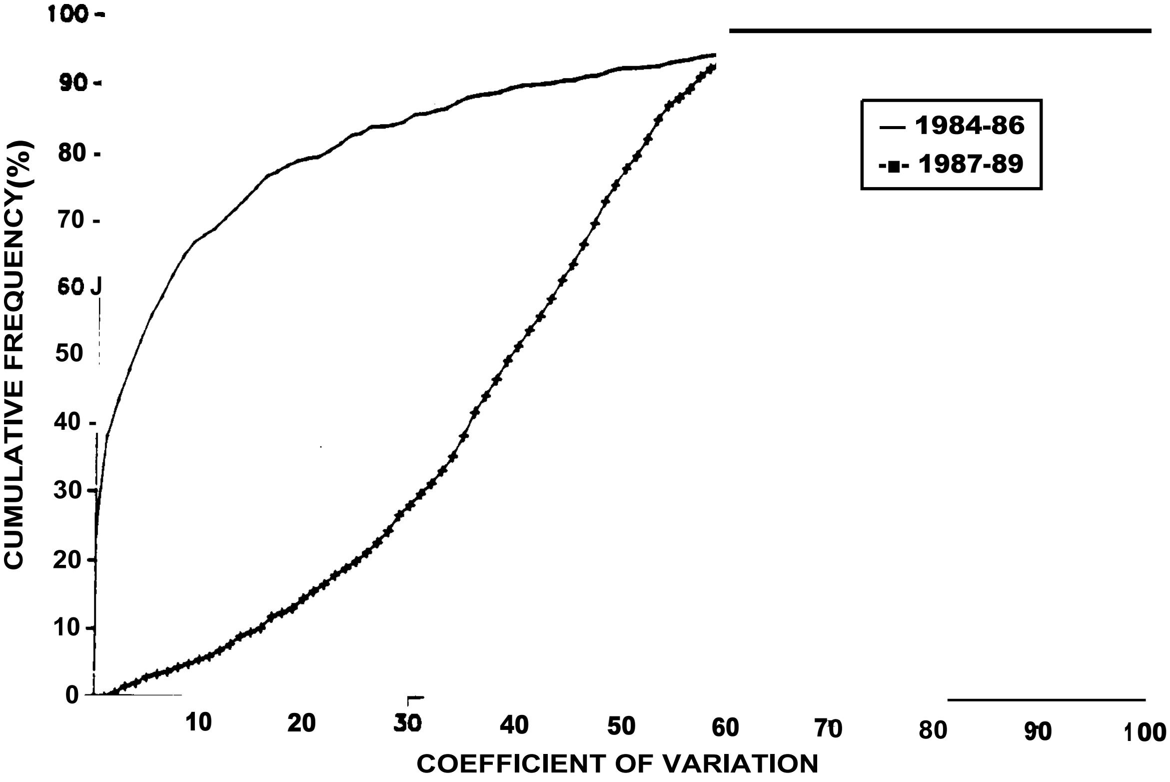


Figure 5. an monthly discharges from



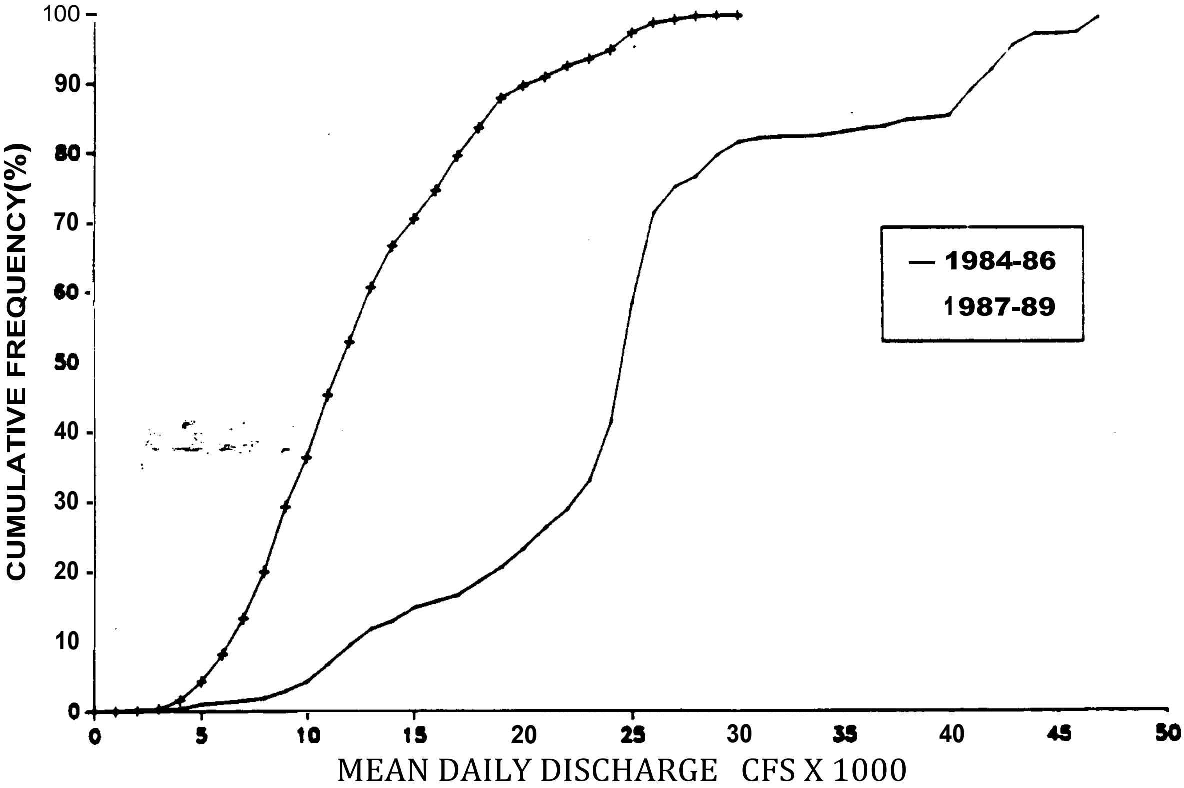


Figure 6. Cumulative frequency distribution of coefficient of variation and mean of daily releases hourly measures from Glen Canyon Dam during the water years 1984-1986 and 1987-1989.

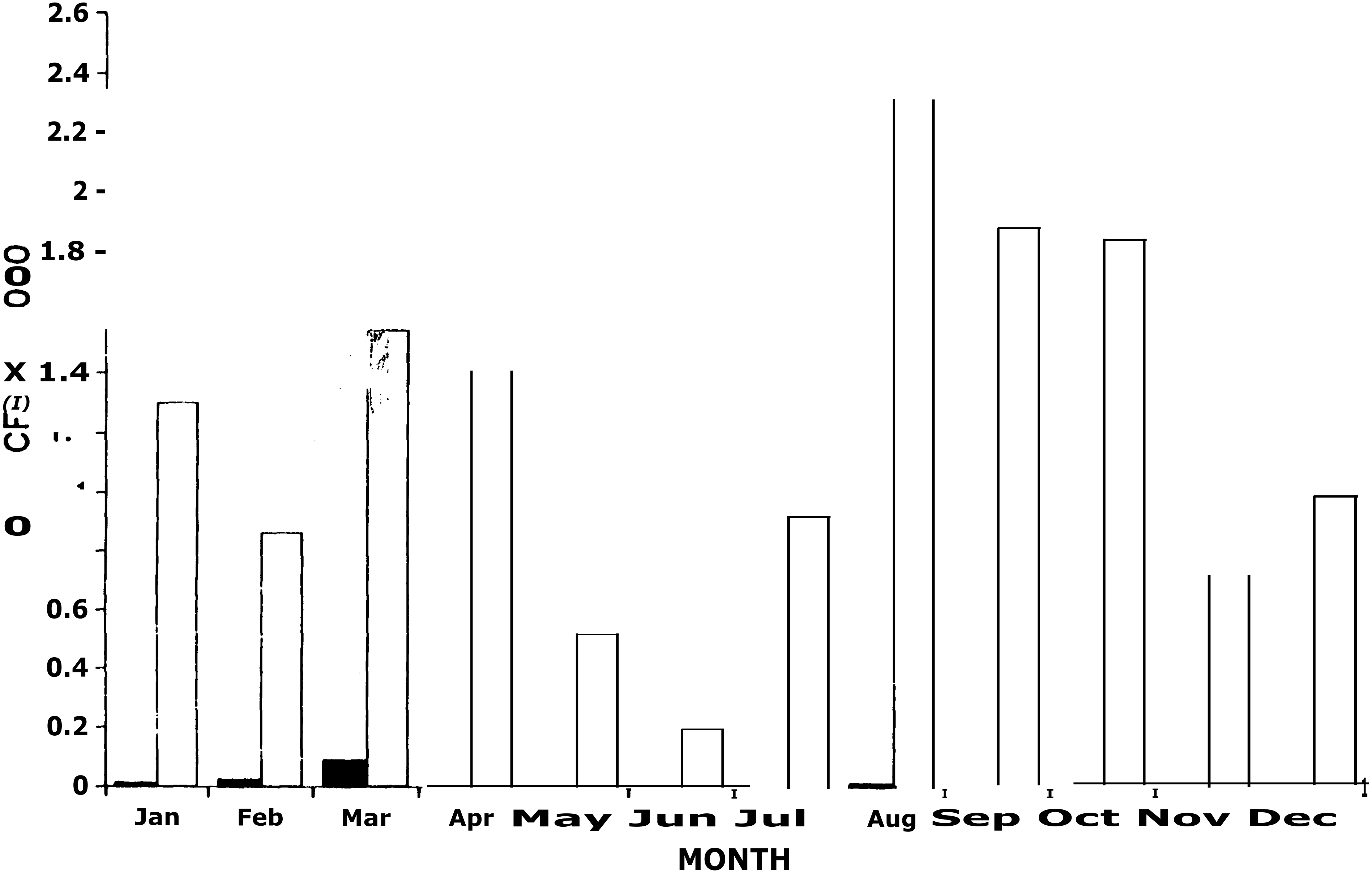


Figure 7. Hydrograph of mean maximum and minimum monthly discharges for the Little Colorado River gaging station near Cameron, Arizona, during the period 1947-1962.

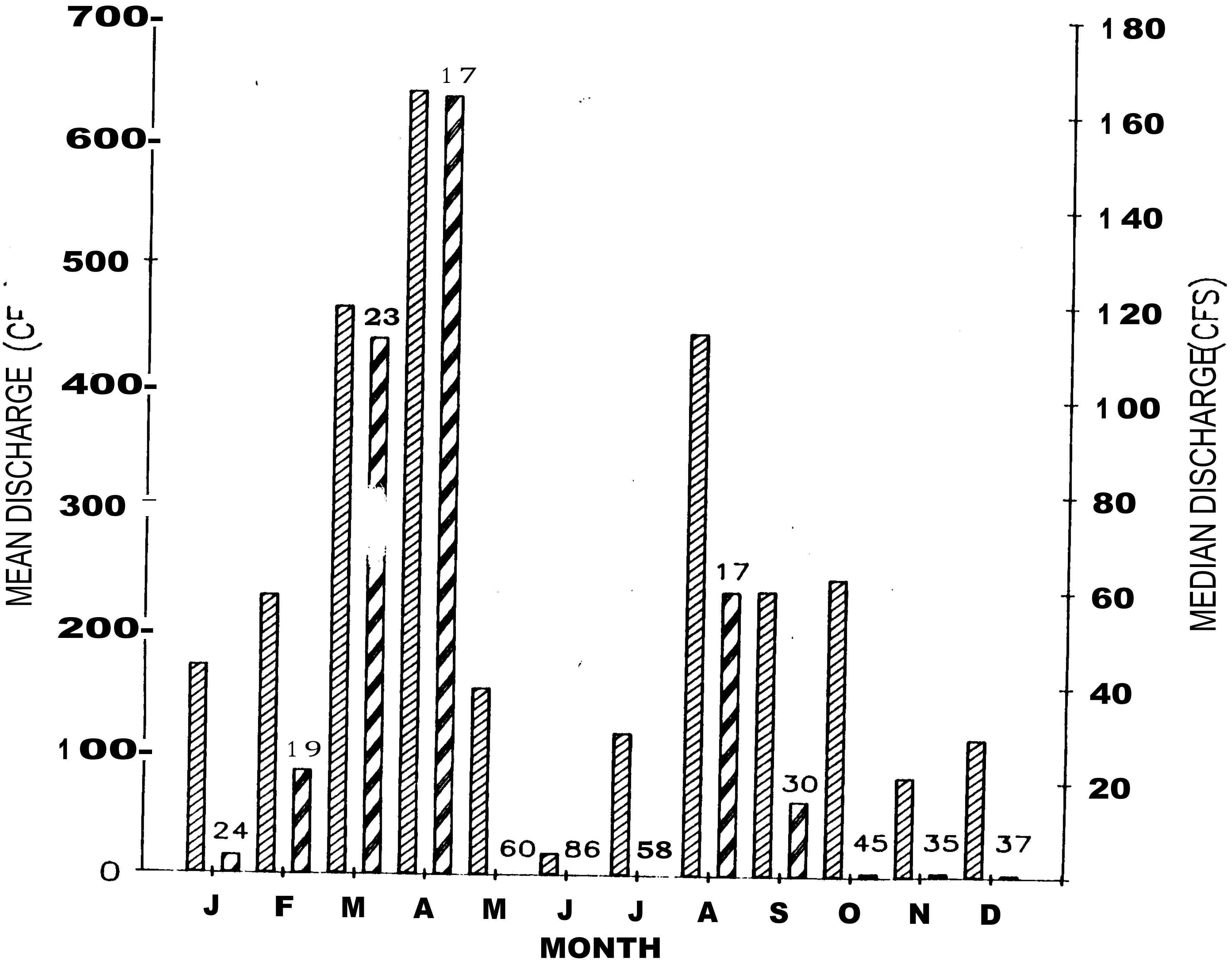


Figure 8. Hydrograph of mean and median monthly discharges for the Little Colorado River gaging station near Cameron, Arizona, during the period 1947-1989 with percentages of days within months on which no flows were recorded.

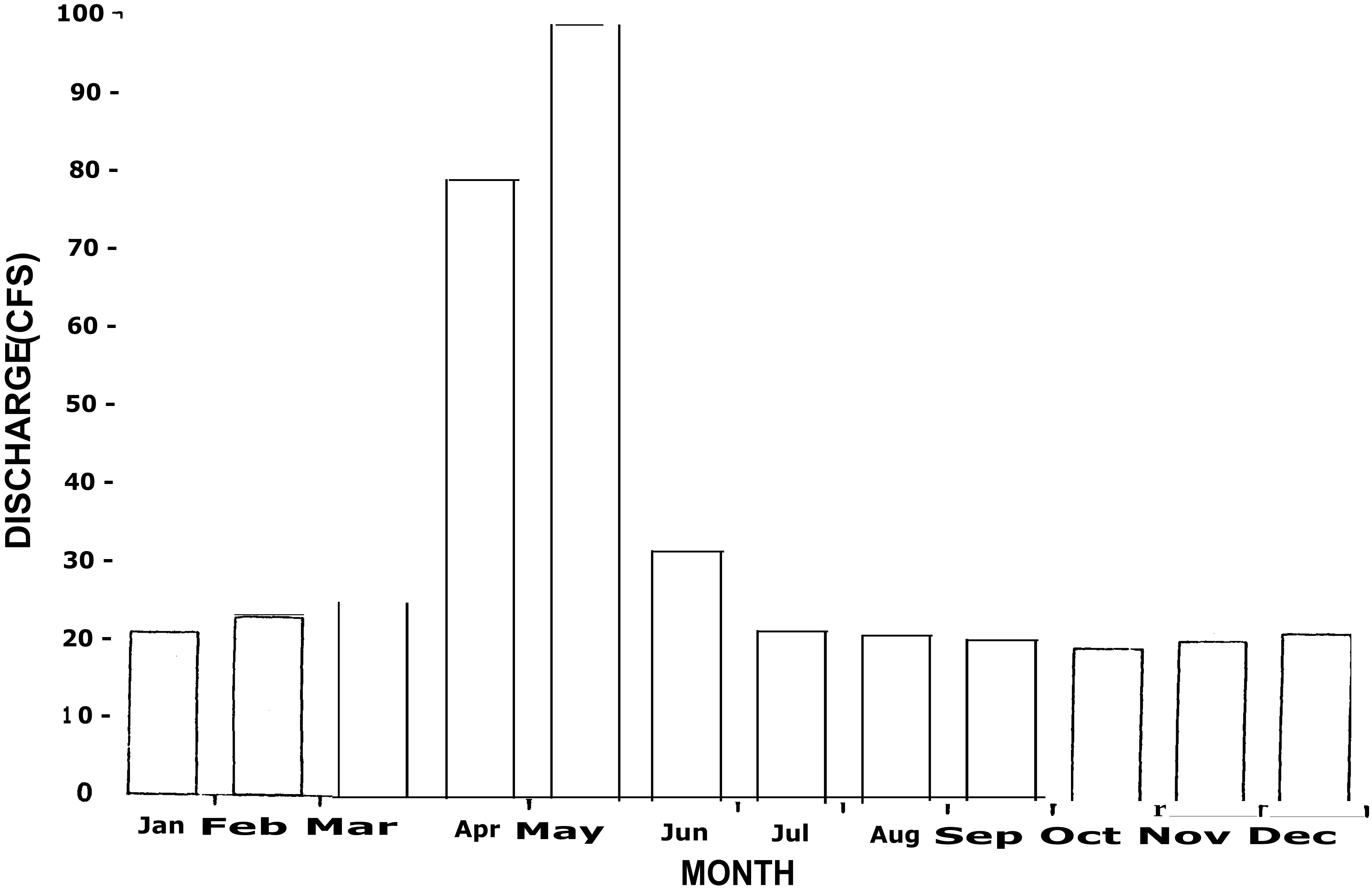


Figure 9. Hydrograph of mean monthly discharges at the Bright Angel Creek gaging station in Grand Canyon.

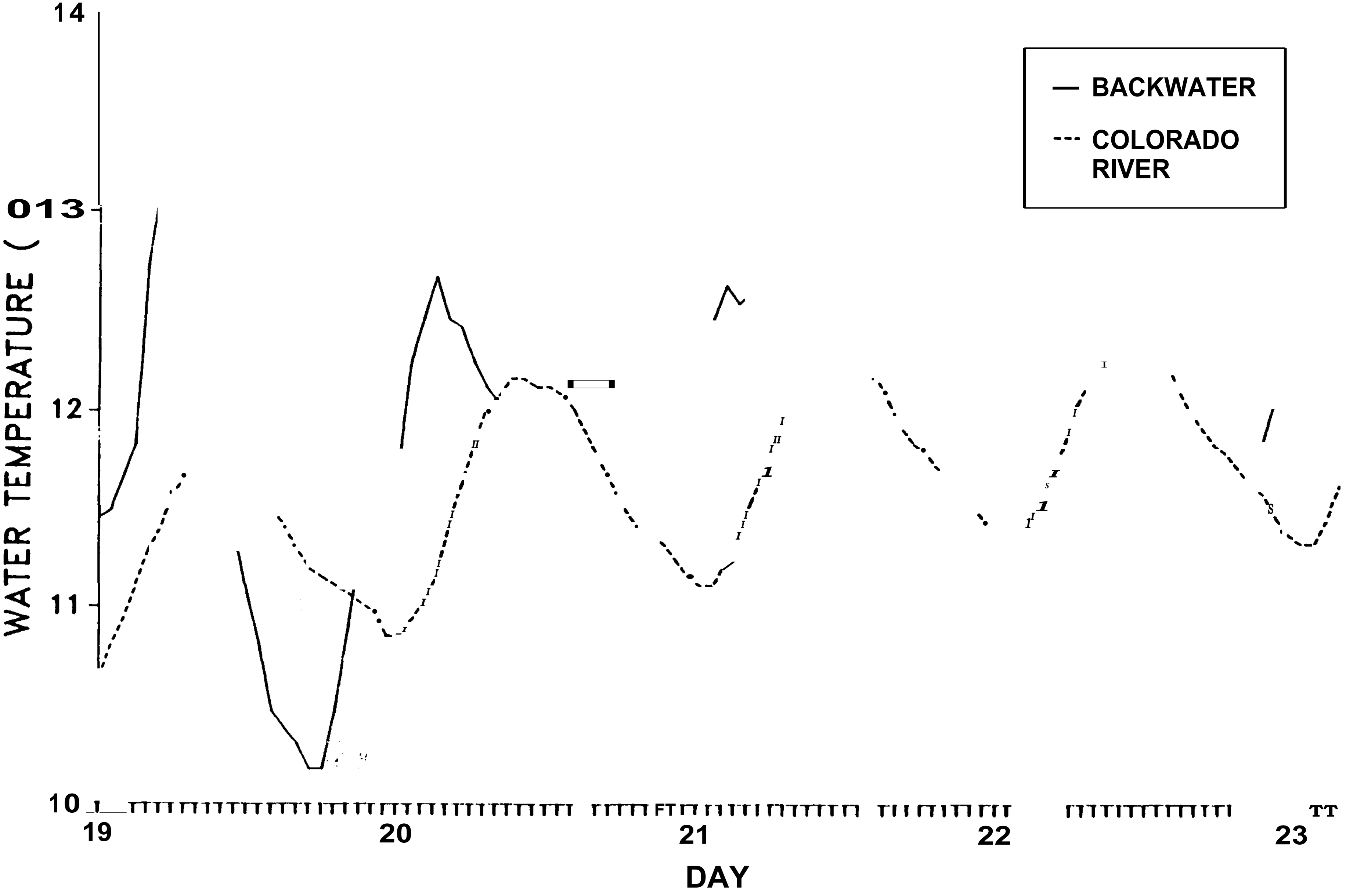


Figure 10. Continuous data recorder water temperature measurements from the Colorado River and an adjacent backwater at RM 60.8 during the period May 19-23, 1988.

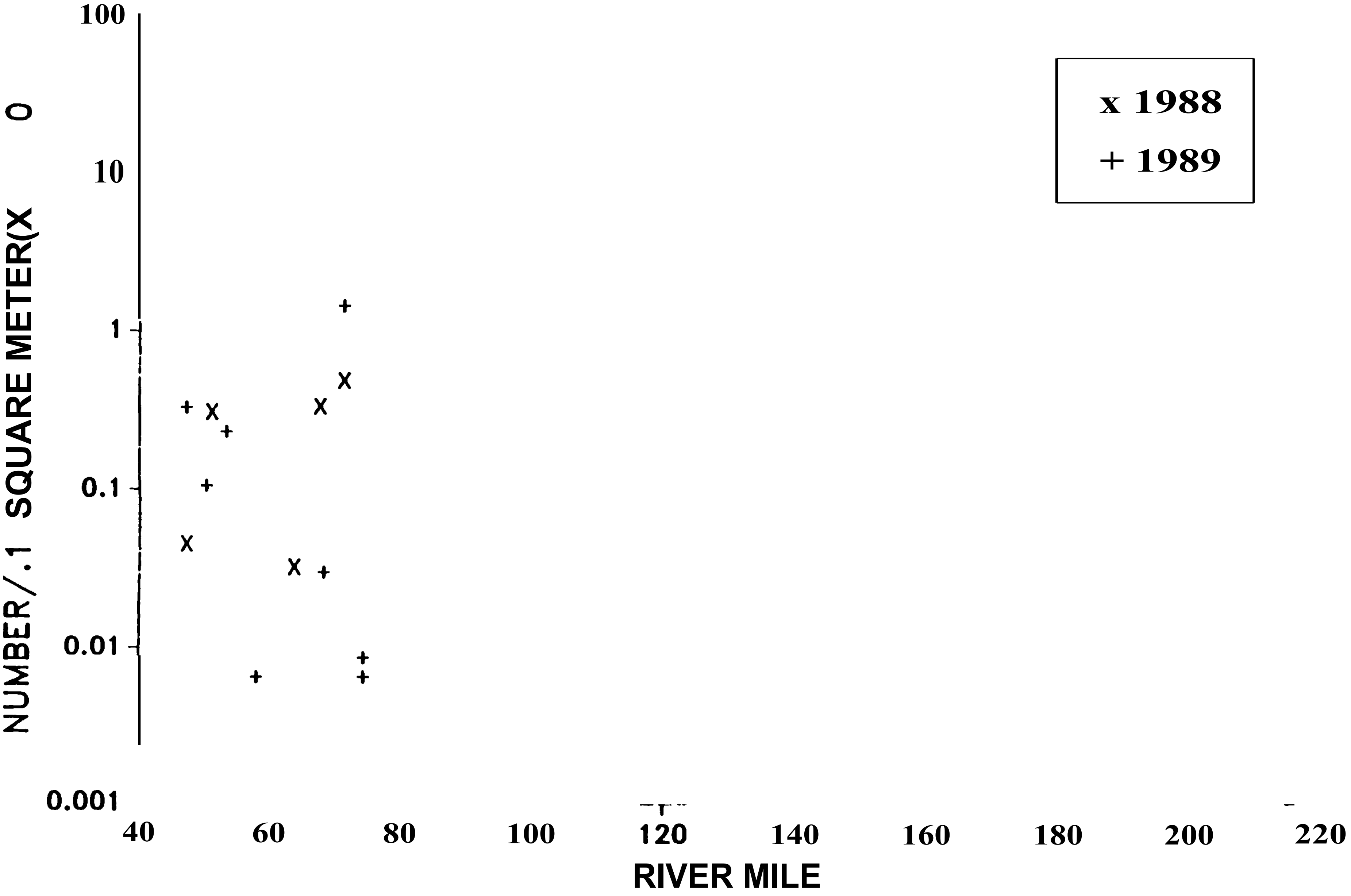


Figure 11. Densities of benthic invertebrates in backwaters of the Colorado River in Grand Canyon during 1988-1989.

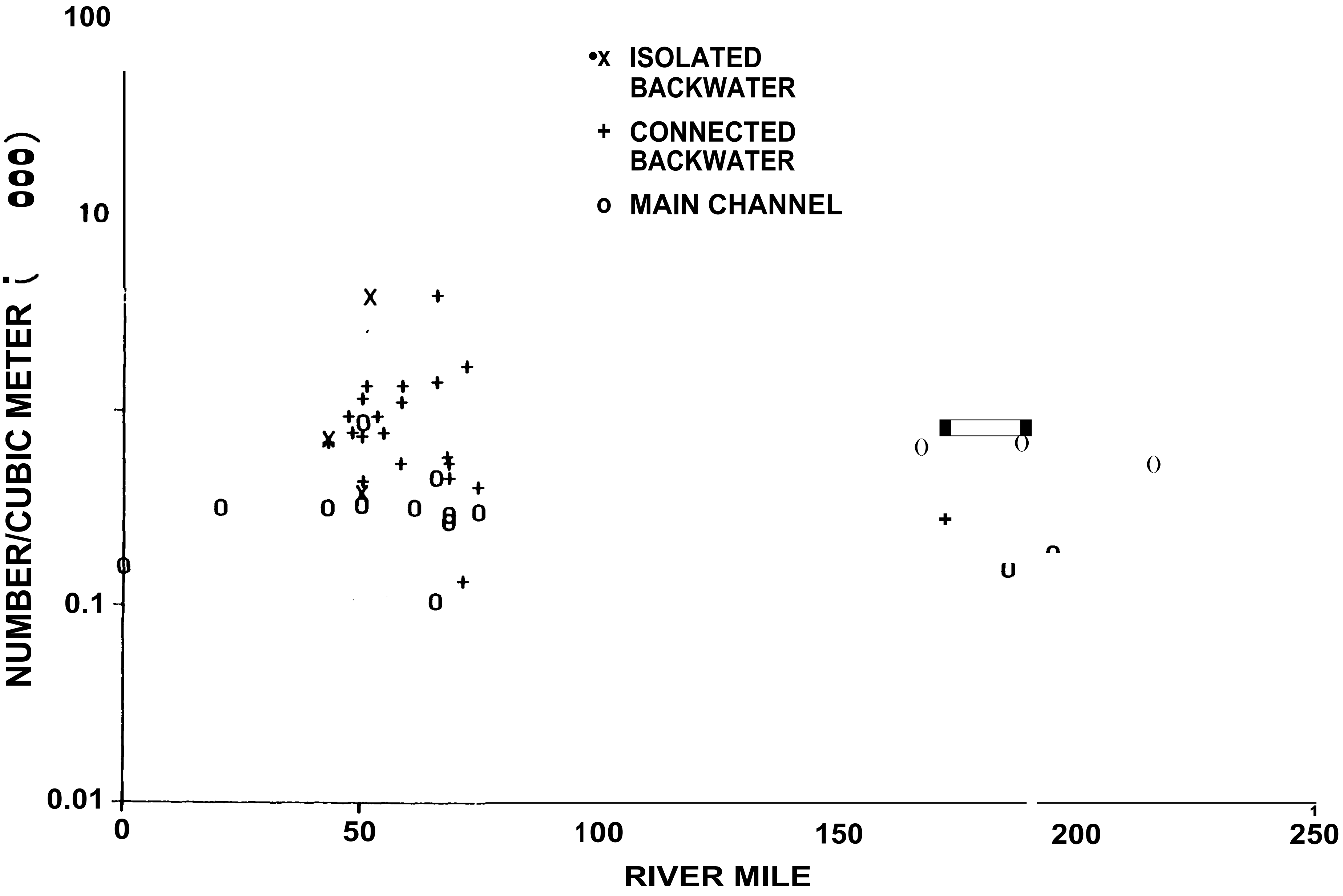


Figure 12. Densities of rotifers and microcrustacean species collected in mainstream and backwater habitats of the Colorado River in Grand Canyon during 1987-1989.

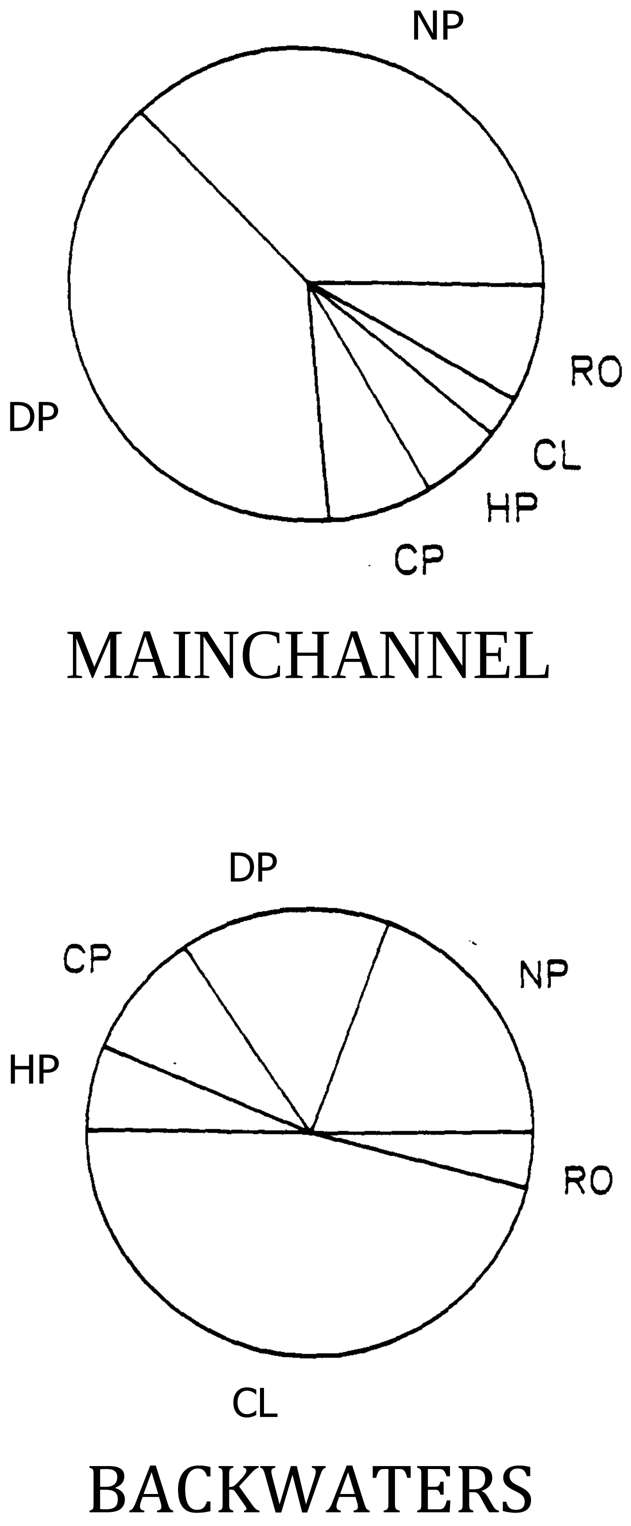


Figure 13. Relative proportions of rotifer, cladoceran, and copepod groups in zooplankton samples taken from mainstream and backwater habitats of the Colorado River in Grand Canyon during 1987-1989. NP = nauplii, RO = rotifers, CL = cladocerans, HP = harpacticoid copepods, CP = cyclopoid copepods, and DP = diaptomid copepods.

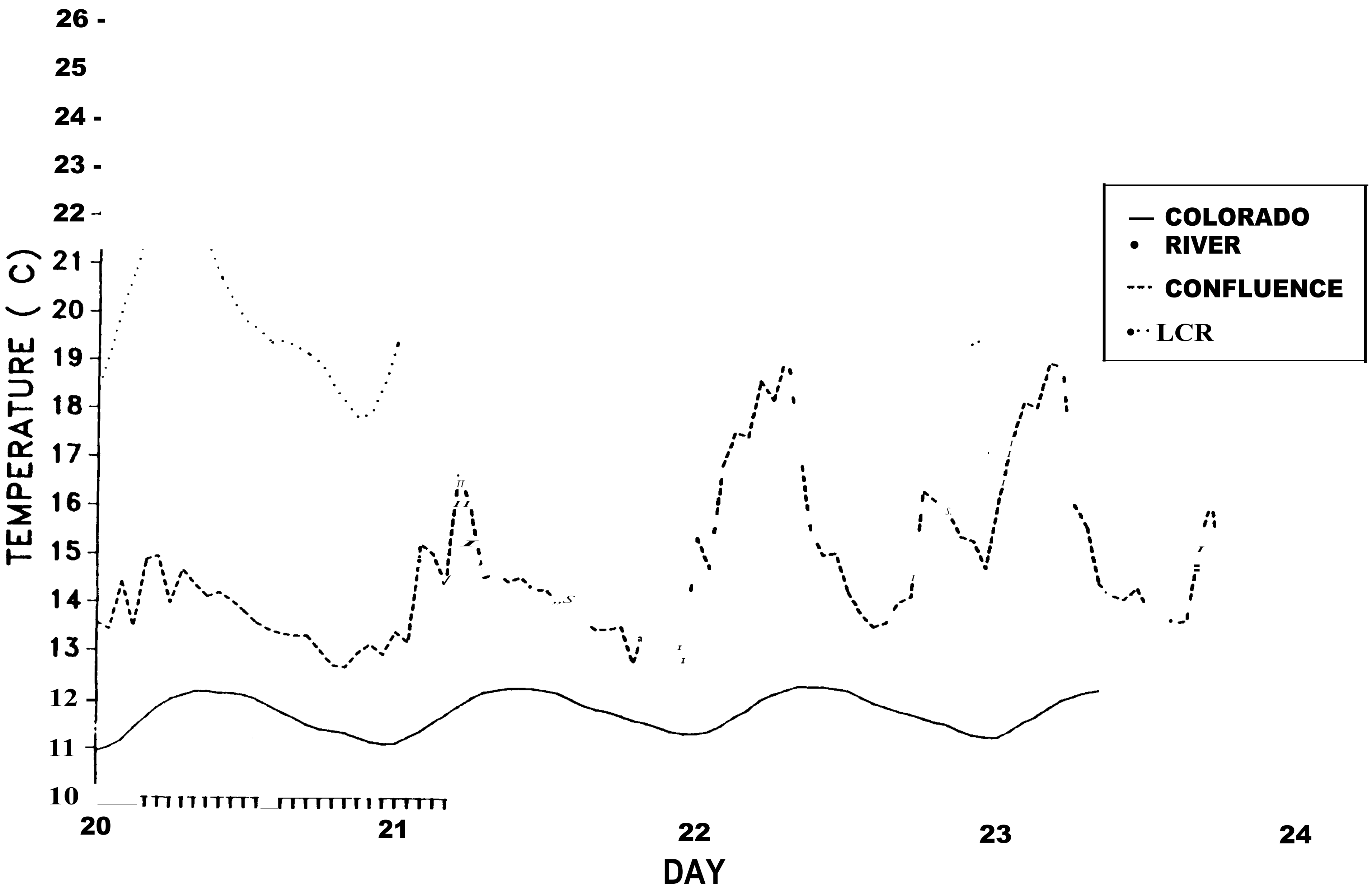


Figure 14. Continuous data recbrder water temperature measurements from the Little Colorado and Colorado rivers during the period May 19-23, 1988. LCR measurements are from approximately 1 km upstream and from the mixing zone in the confluence region. Mainstream measures were made just upstream of the mouth of the tributary.

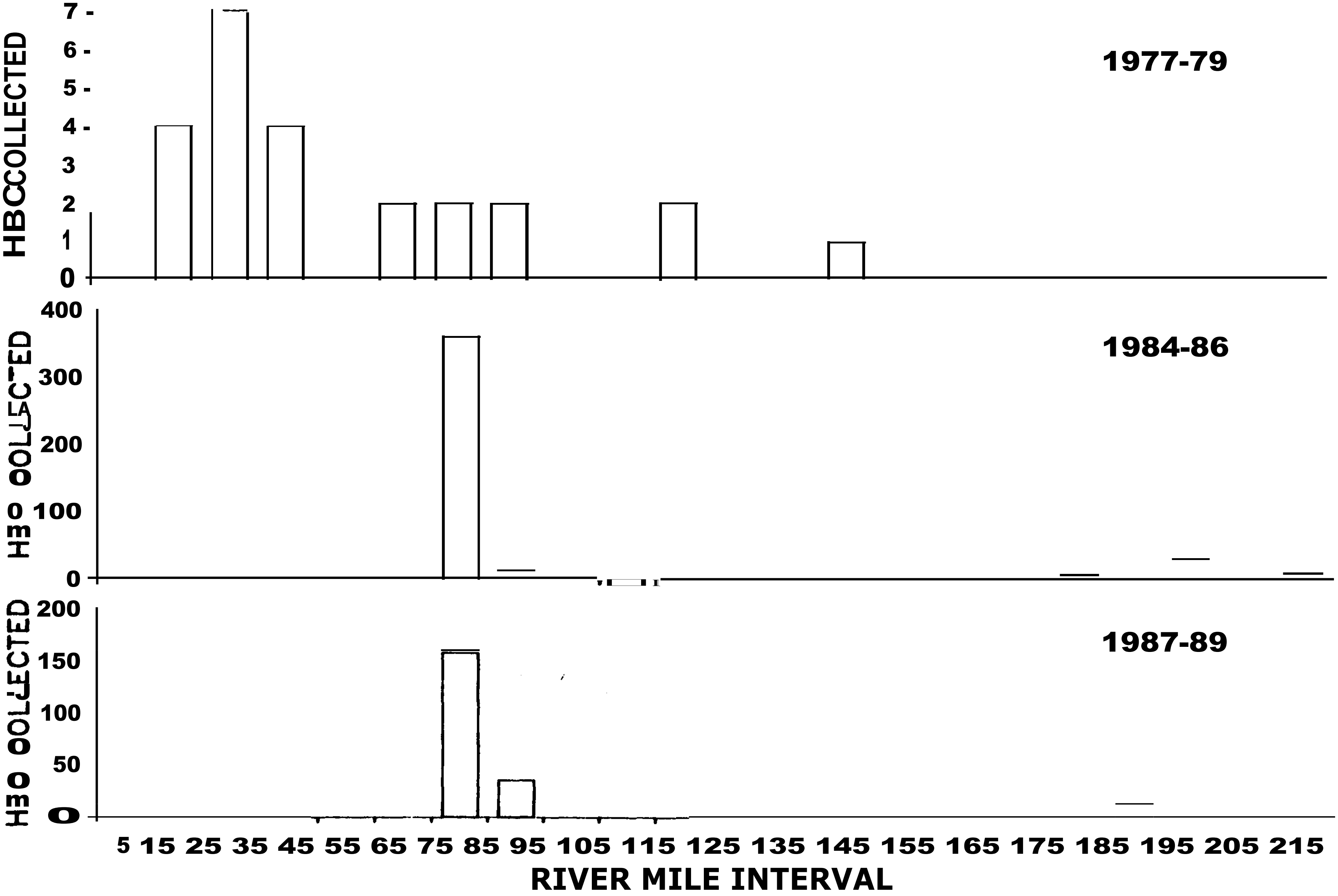


Figure 15. Frequency distribution of humpback chub collections from the Colorado River during 1977-1979 Carothers et al. 1981 , 1984-1986 Maddux et al. 1987 , and 1987-1989 Department unpublished . Intervals are 10-mile reaches beginning at Lee's Ferry.

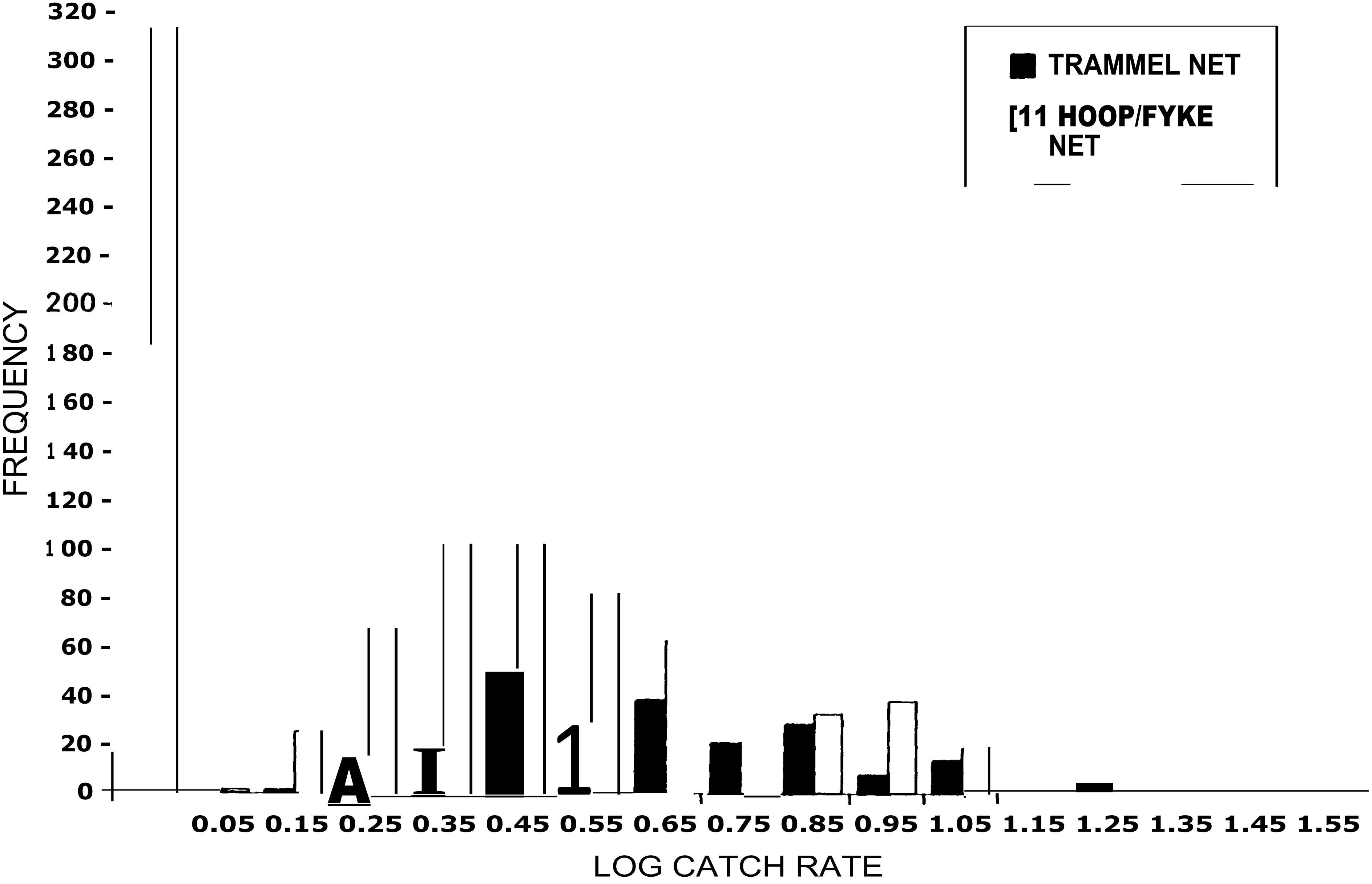


Figure 16. Frequency distribution of log. (x + 1) transformed trammel net and hoop net catch rates for humpback chub in the Little Colorado River during May 1987-1989.

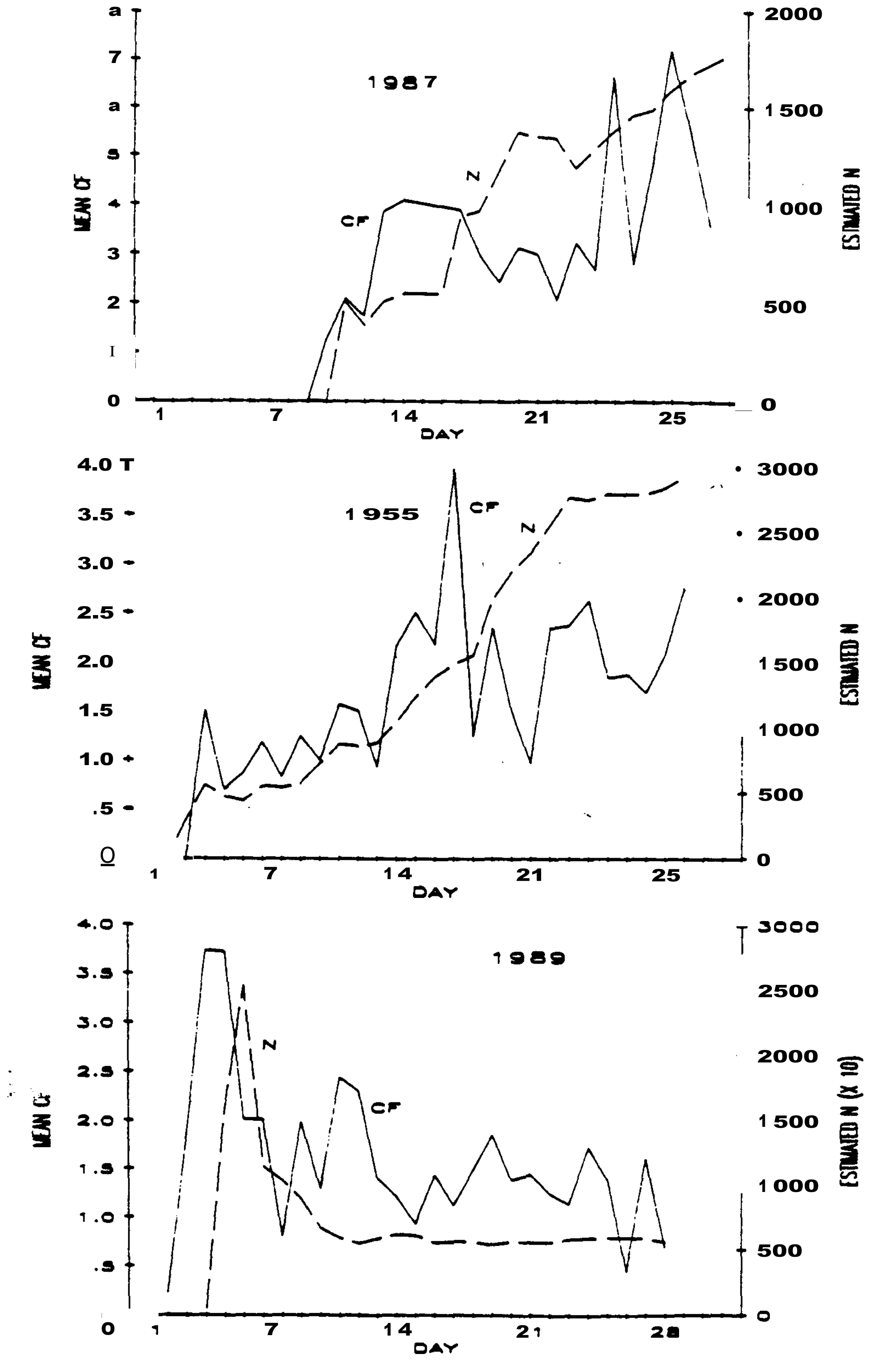


Figure 17. Mean daily hoopgyke net catch rates (CF, individuals/12 hr) and estimated population size for humpback chub (N) in sampled reaches of the LCR during May of 1987-1989.

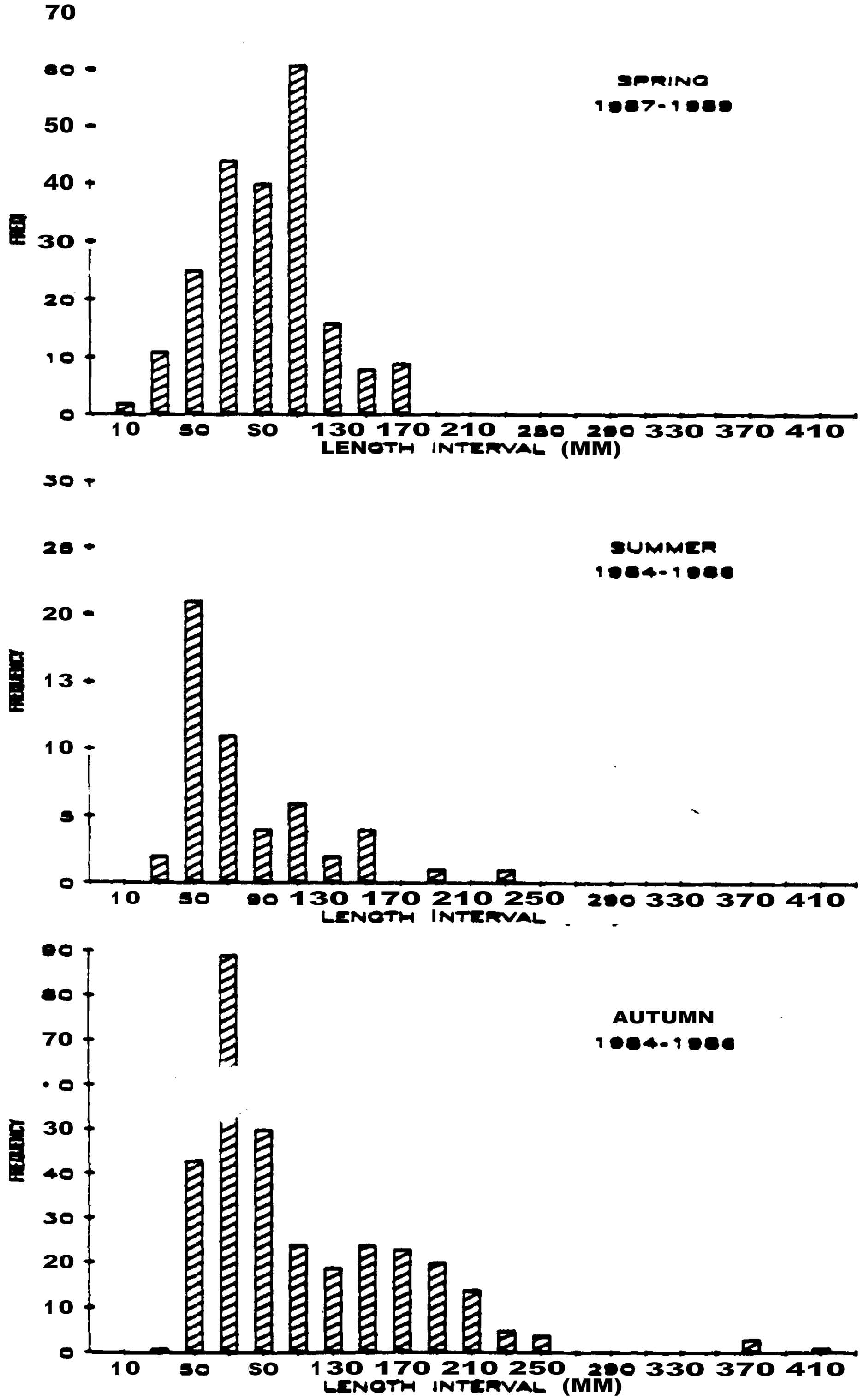


Figure 18. Length frequency distributions of humpback chub collected by seines from backwaters of the Colorado River during spring, summer, and autumn seasons 1984-1989.

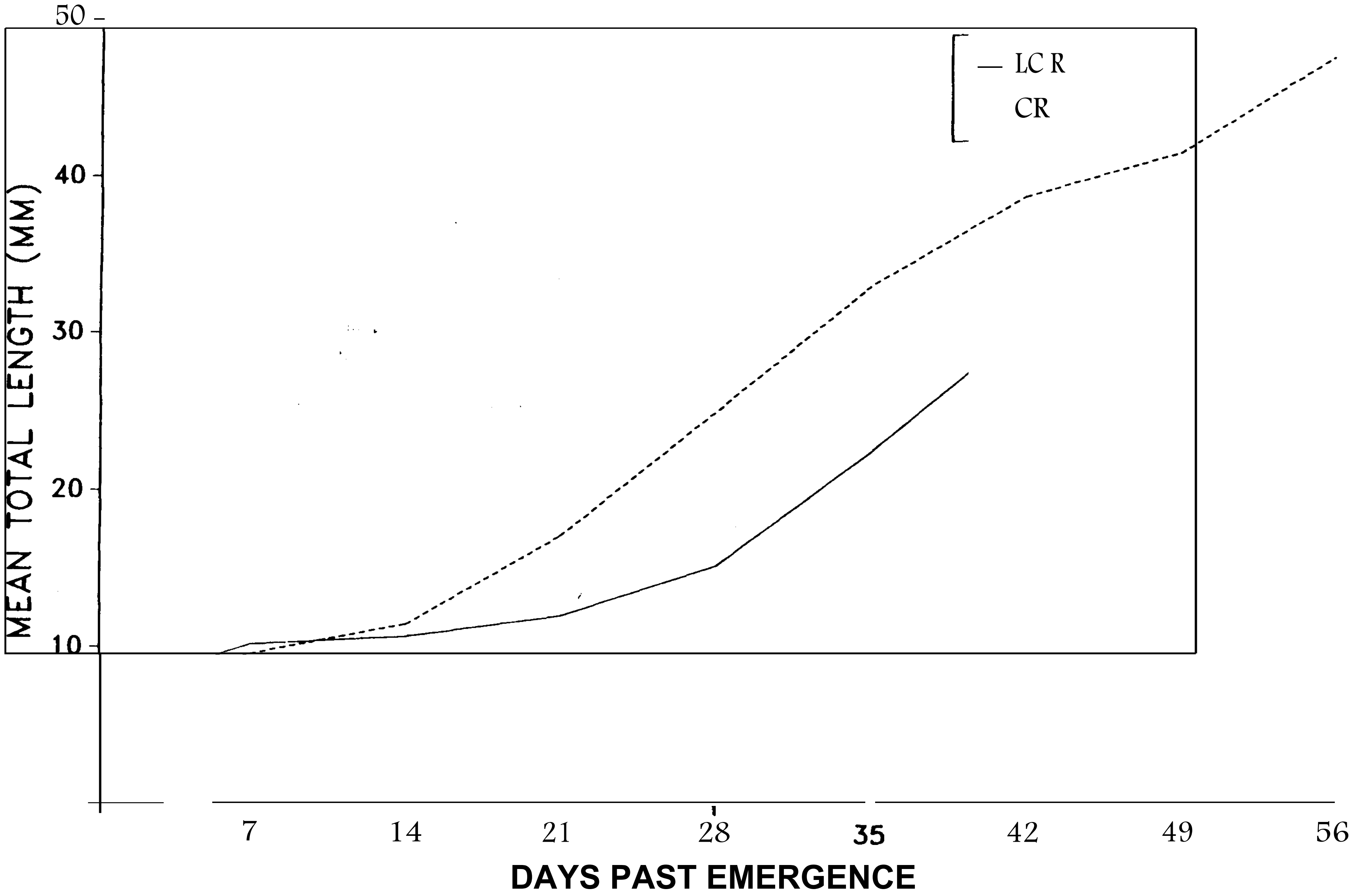


Figure 19. Early growth of hatchery-reared humpback chub from Little Colorado River (LCR) and Black Rocks (CR) populations.

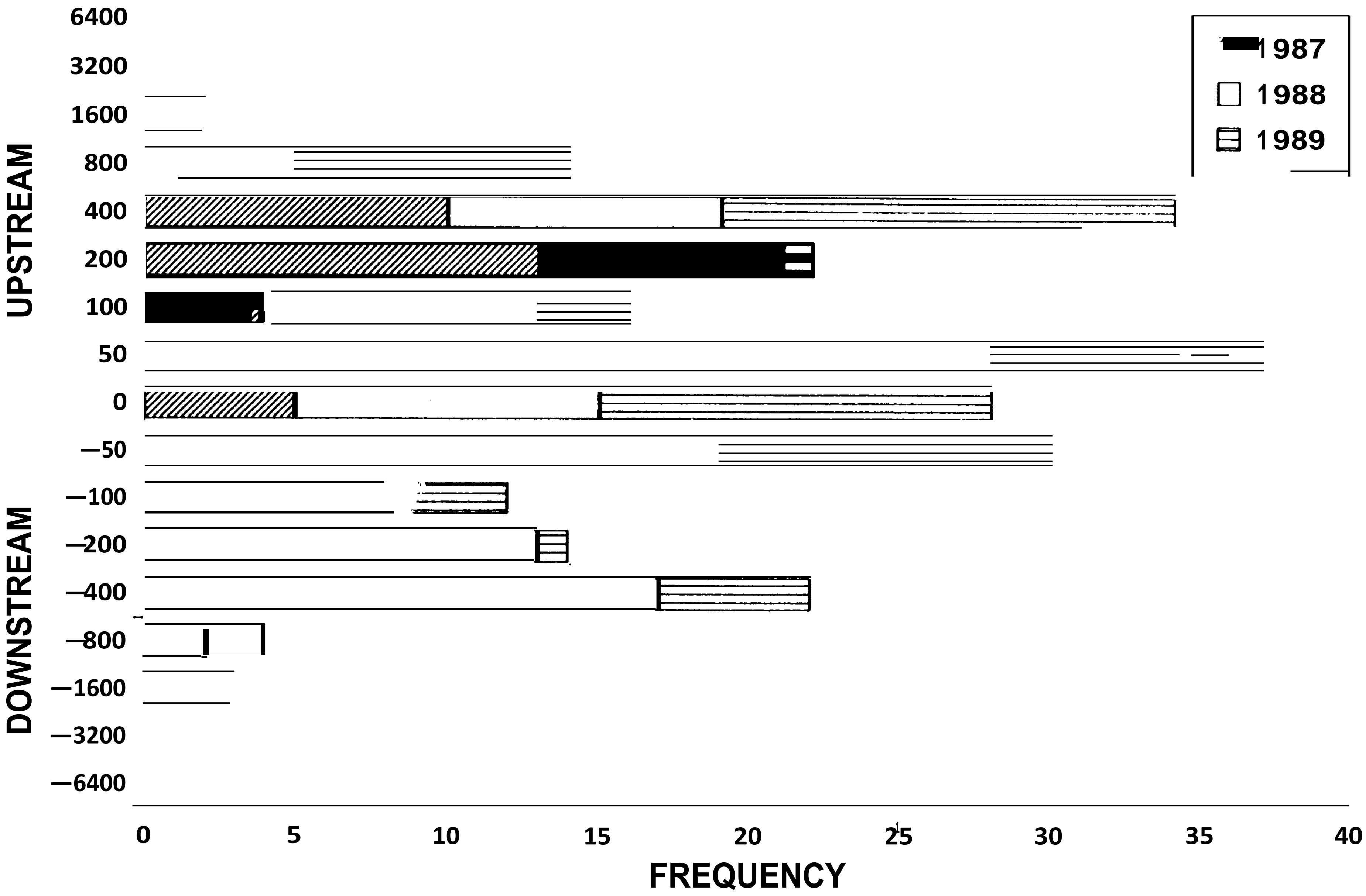
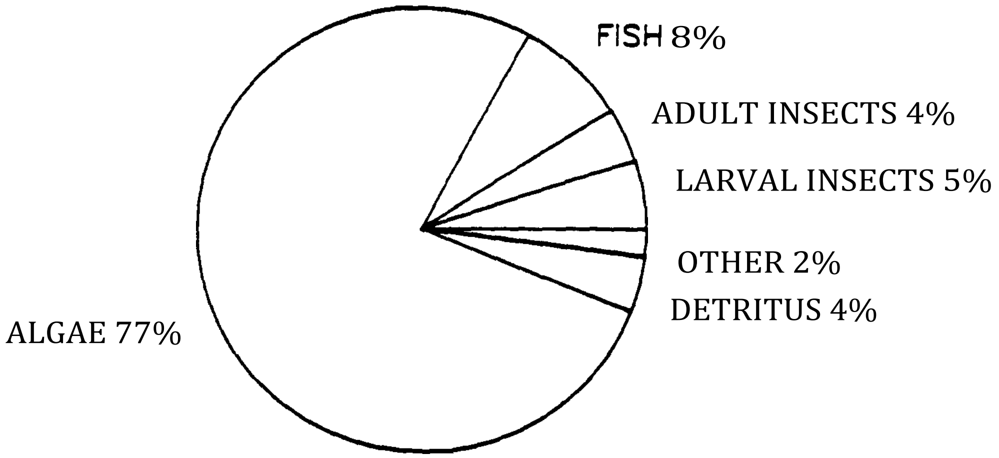
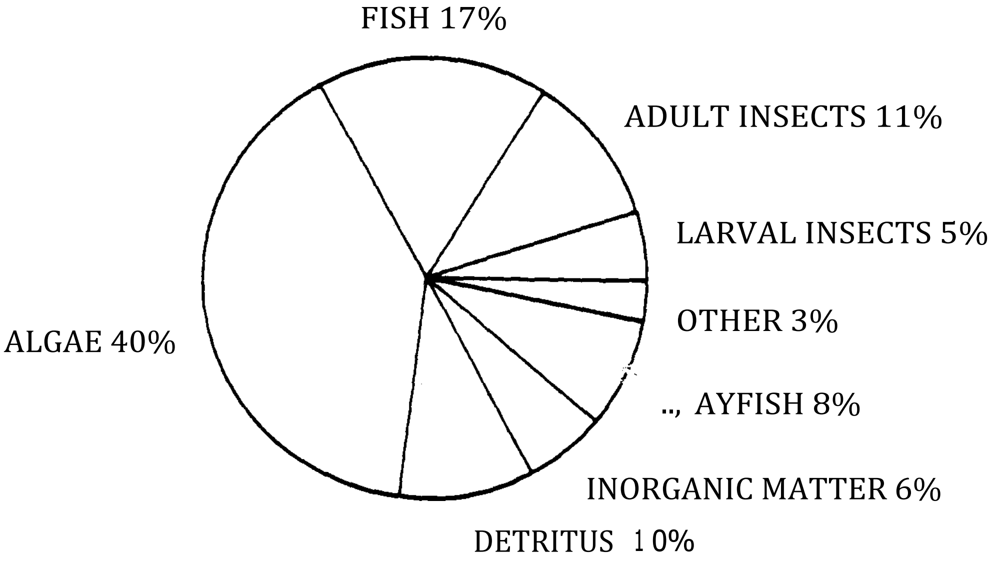


Figure 20. Frequency of upstream and downstream movements (m) by humpback chub in the LCR during May of 1987-1989. Note that ordinate scale is in octaves.



HUMPBACK CHUB



CHANNEL CATFISH

Figure 21. Mean relative volumetric proportions of different food groups found in humpback chub and channel catfish collected from the Colorado River and its tributaries in Grand Canyon.