# Life History And Ecology of the Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona

**EXECUTIVE SUMMARY**

***DRAFT FINAL REPORT***

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# EXECUTIVE SUMMARY

## INTRODUCTION

The life history and ecology of the humpback chub (Gila cypha) in the Colorado River in Grand Canyon was studied from October 1990 through November 1993, as part of the Glen Canyon Environmental Studies (GCES). The purpose of the investigation was to describe the ecological requirements of some life stages of the species and evaluate the effects of Glen Canyon Dam operations. The objectives of the study were to describe and identify limiting factors to distribution, abundance, survivorship, movement, habitat, food habits, and reproductive Capacity. Important biotic interactions and the life history schedule for the species were also described and management option and recommendations for core research and monitoring were discussed with respect to dam operations. This investigation was designed to integrate with other companion studies to provide a comprehensive scientific treatise.

## THE COLORADO RIVER

Preceding the summary of the life history of the humpback chub is a characterization of the changes to the Colorado River following Glen Canyon Dam, as a perspective of the physical and chemical changes to the aquatic ecosystem in Grand Canyon. The physical, chemical, and biological nature of the Colorado River in Grand Canyon was changed dramatically after it was impounded by Glen Canyon Dam in March of 1963. Since impoundment, water has been released through the dam under six operational scenarios, each with unique characteristics but all with common features. The dam eliminated spring floods and increased low base flows in late summer, fall, and winter. Daily fluctuations for hydropower generation became a normal feature of the hydrograph (Fig. 1), and flows of over 31,500 cfs and below 3,000 cfs were eliminated, while daily flows varied by nearly 30,000 cfs. Interim flows implemented in August 1991 decreased high flows to 20,000 cfs and increased lows to 8,000 cfs, with reduced daily fluctuations.

**Fig. 1. Mean discharge (WY 1922-93) and mean daily predam (WY 1922-62) and postdam (WY 1965-92) flow of the Colorado River at Lees Ferry, AZ.**

The physical and chemical nature of the river were also substantially altered by the dam, primarily from retention of sediments in Lake Powell and cold hypolimnetic releases. The predam temperature range at Lees Ferry of 2 to 26°C was modified to a range of 7 to 12°C, resulting in colder spring, summer, and fall temperatures, and warmer winter temperatures. This temperature pattern did not become fully evident until about 1970, when Lake

Powell reached sufficient depth to stratify. Maximum longitudinal warming now occurs in late summer at a rate of about 1°C/51 km.

Sediment load of the river was reduced by about 90% from retention in Lake Powell, and removal of sediments through Grand Canyon has been substantial as a result of clear water releases. Sediment replacement is now primarily from the Paria River and the Little Colorado River (LCR). This has greatly reduced allochthonous material in the Colorado River in Grand Canyon and modified availability of aquatic food supplies, while converting the system from heterotrophic to autotrophic. Clear, cold releases have eliminated many of the invertebrates native to the river, leaving only nearctic species. Also, the degree and frequency of turbidity has been reduced. Daily fluctuations maintain turbidity in the mainstem and a regular supply of food in the system. Water clarity is substantially increased when flows are low and constant (Fig. 2).

**Fig. 2. Relationship of flow to water clarity during a transition of high fluctuating releases (7,000-25,000 cfs) to constant 5,000 cfs, May 10-23, 1991.**

## DISTRIBUTION

The present distribution of humpback chub in Grand Canyon is related to locations of warm tributaries and springs, occurrence of suitable adult habitat, and food availability. Humpback chub were found in 308 km of the mainstem Colorado River, from Shinumo Wash (RM 29) to Granite Springs Canyon (RM 220), as nine persistent aggregations in which 94% of 6,294 chubs were captured (Fig. 3). Four of these aggregations were associated with warm tributaries (LCR, Bright Angel Creek, Shinumo Creek, Havasu Creek), and two with warm springs (Fence Fault Springs, Pumpkin Spring), indicating the fish were attracted to thermal areas in response to cold dam releases that varied from 7°C to 11°C. Four aggregations, including the two largest, were associated with unique geomorphic reaches (LCR, Lava to Hance, Stephan Aisle, Middle Granite Gorge), characterized by a high frequency of debris fans and associated recirculating eddies.

**Fig. 3. Locations (percentage of total numbers) of nine aggregations of humpback chub in the Colorado River in Grand Canyon.**

Longitudinal warming in summer of 1°C/51 km increases mainstem temperature from an average of 8°C at the dam to 16°C at Diamond Creek. Despite the warming, the numbers of humpback chub--and other warmwater species--did not increase in a downstream direction. Suitable habitat was largely unoccupied in the lower reaches of Grand Canyon, apparently because of low food availability and competition from warmwater non-native fishes. These alien species dominated fish biomass and thus energy flow through the aquatic ecosystem (Fig. 4).

**Fig. 4. Number of species, species diversity, and biomass of native and non-native fish species by geomorphic reach from Lees Ferry to Diamond Creek.**

The largest aggregation of humpback chub, and the major reproducing population in Grand Canyon, was located in the lower 14.6 km of the LCR and adjacent 13.5 km of the mainstem Colorado River (6.9 km upstream and 6.6 km downstream of the LCR inflow). This area supports the only self-sustaining population in the canyon and provides a profile for life history requirements for the species in Grand Canyon. The LCR is a warm tributary sufficiently large for spawning, nursing of young, and maintenance of subadults and adults. It provides a constant supply of food for fish in the LCR as well as in the mainstem. This food supply is supplemented by high volumes of terrestrial insects and allochthonous material during floods. The LCR provides suspended sediment to the mainstem that helps maintain fish habitat (i.e., sand deposits) and increases the frequency and duration of turbidity. Humpback chub appear to use turbidity as a cover element during feeding and for protection from aquatic and avian predators.

The adjoining reach of the mainstem is equally important to this population in that it provides suitable subadult and adult habitat, greater living space than the LCR, and regular supplies of food produced locally and transported from upstream. The channel in this reach has one of the highest frequencies of debris fans and associated recirculating eddies, a habitat type selected by adults; 88% of adults captured and 74% of radio contacts were from these eddy complexes. Adults occupy low-velocity vortices in these eddies in which food is entrained, and where adults use a soaring behavior that enables them to feed and rest with relatively little energy expenditure.

The present distribution of humpback chub in Grand Canyon is believed to be a remnant of a more expansive historic distribution that probably extended about 455 km, from the Paria River (RM 0) to Grand Wash (RM 283). As in other canyon regions (e.g., Desolation/Gray Canyon, Cataract Canyon, Westwater Canyon), humpback chub in Grand Canyon probably spawned in the mainstem, and were probably found in higher concentrations in areas of more suitable habitat or greater food sources. The LCR tributaries and tributary inflows were likely also used for spawning, and young remained close to hatching sites. Humpback chub were also believed to be in canyon regions upstream of Grand Canyon, including 80 km in Narrow and Cataract canyons. Hence, historic distribution in this part of the basin probably extended about 535 km from the confluence of the Colorado and Green rivers, UT to Grand Wash, AZ, and included all canyon regions except for Glen Canyon, which was a gentle alluvial reach uncharacteristic of suitable humpback chub habitat.

Fish populations of the Colorado River were affected in unknown ways by land use practices, water diversion, and non-native fishes starting in the late 1800's (Miller 1965). By the time Glen Canyon Dam was completed in 1963, the lower 70 km of Grand Canyon had been inundated and sedimented by Lake Mead, as a result of construction of Hoover Dam in 1935. Lake Powell eventually inundated 52 km of potential habitat in Narrow Canyon and lower Cataract Canyon. The operation of Glen Canyon Dam further reduced habitat by an additional 77 km (Paria River to Shinumo Wash plus Granite Springs Canyon to Separation Canyon). The combined effects of Lake Mead (13%), Lake Powell (10%), and Glen Canyon Dam operations (14%) reduced 535 km of potential historic habitat by 199 km or 37%.

## ABUNDANCE

The largest of nine aggregations in the Colorado River in Grand Canyon was the mainstem component of the LCR population, with 3,000-3,500 adults ( ≥200 mm TL). The second largest aggregation was in Middle Granite Gorge with an estimated 98 adults. The other aggregations and numbers of adults (N) included the Shinumo Creek inflow (N=57), 30-Mile (N=52), Havasu Creek inflow (N=13), and Pumpkin Spring (N=5). The combined estimates for the nine mainstem aggregations were about 3,200-3,750 adults. Since 94% of all humpback chub captured were in these nine aggregations, it is assumed that the total numbers of adults in the mainstem were about 3,400-4,000.

Numbers of subadult humpback chub (<200 mm TL) in the mainstem varied dramatically as young descended from the LCR annually in late summer. Lowest densities of <1 fish/100 $m^2$ were usually found in late winter and early spring, and highest densities of 3 fish/100 $m^2$ (1991 and 1992), and up to 13 fish/100 $m^2$ (1993) were found in mid to late summer, as young descended concurrent with floods from the LCR. Greatest numbers of subadults were usually found between the LCR inflow (RM 61.3) and Hance Rapid (RM 76.6), with dramatically fewer numbers downstream as shoreline habitat was limited and numbers of predaceous brown trout increased. Approximations of subadults in this 24.6 km subreach ranged from 246,000 (1/100 $m^2$) to 738,000 (3/100 $m^2$) individuals in years of lowest observed densities (1991 and 1992), and up to 3,198,000 (13/100 $m^2$) in a year of highest observed density (1993). Subadults upstream of the LCR were rare, and densities downstream of Hance Rapid were much lower than in the subreach immediately below the LCR. Since 92% of all subadults captured were found in this 24.6-km subreach, the numbers of subadults in the mainstem during 1991 and 1992 may have been roughly 250,000-800,000 and numbers in 1993 were perhaps as high as 3,500,000 subadults.

## SURVIVORSHIP

Survival of humpback chub in the mainstem is probably limited by cold temperatures, suitable habitat, food availability, and predation. Parasites are not believed to be a significant factor to survival in the mainstem. Cold mainstem temperatures likely induce thermal shock in many young fish descending from the LCR, causing death or aberrant behavior that can solicit predator response. Cold temperatures also significantly reduce swimming performance of young fish (Bulkley et al. 1991), restricting suitable habitat to low-velocity areas, and limiting escape potential from cold-water predators. Subadult shoreline habitat is destabilized by fluctuating releases from Glen Canyon Dam, causing greater exposure of subadults to predation. Predation on subadult humpback chub in the mainstem could be substantial, and may be a primary factor limiting survival and recruitment of young.

Estimated annual survival of adult humpback chub was 0.755, but the 95% confidence intervals place this estimate as high as 0.896. Subadults in the mainstem, up to 3 years of age, had an estimated annual survival of about 0.100, and over 3 years only 1 in 1,000 fish survive to recruit as adults. Although the various sources of mortality were not quantified, marking studies indicate that movement to reaches downstream of the LCRI aggregation probably resulted in a permanent loss of individuals to the aggregation. Low estimated numbers of subadults surviving to adults in the mainstem suggest that recruitment may not be enough to offset mortality of adults. A smaller than expected number of younger adults (based on length-frequencies of adults captured) indicates that most of the recruitment of larger adults may be from the LCR and not from recruitment of younger chubs from the mainstem.

It is estimated that brown trout, rainbow trout, and channel catfish potentially consume about 250,000 subadult humpback chub annually in the 24.6-km subreach between the LCR and Bright Angel Creek. Surviving fish that are transported into the Inner Gorge probably also have low survival because of limited shoreline habitat and high predator densities.

## MOVEMENT

Adult humpback chub in Grand Canyon exhibited strong spatial fidelity for specific river sites, similar to behavior observed in other populations. Average net displacement (distance from first to last radio contact or capture site) for radio-tagged and PIT-tagged adults in Grand Canyon was only 1.49 km and 0.99 km, respectively, which was similar to 0.8 km and 1.67 km, respectively for adults in Black Rocks (Valdez and Clemmer 1982). Adults in Grand Canyon however, demonstrated greater gross displacement (sum of distances between radio contact sites) of 5.13 km compared to 1.64 km in Black Rocks, primarily as a result of spawning migrations from various mainstem locations into the LCR. Maximum round-trip distance traveled by an adult from the mainstem into the LCR for spawning was 40 km, although the only mainstem adults that migrated to the LCR were from within a 13.5-km subreach (RM 57 - RM 65.4). The majority of these fish returned to locations within 2 km of their premigration sites (Fig. 5).

**Fig. 5. Fidelity of 60 PIT-tagged humpback chub in the mainstem Colorado River following presumed spawning in the LCR, October 1990-November 1993.**

The home range of the adult portion of the LCR Inflow (LCRI) aggregation was 28.1 km, including 13.5 km in the mainstem and 14.6 km in the LCR. Adults moved very little between aggregations, indicating that most adults throughout the canyon were associated with groups of fish at specific river locales. Of 1,524 adults captured in the LCRI aggregation (280 recaptured), only two were recaptured outside of the 13.5-km mainstem area and in other downstream aggregations. Also, four subadults (>175 mm TL) were recaptured downstream of the LCRI aggregation and in the adjacent aggregation.

Movement of subadults (<200 mm TL) was attributed primarily to downstream dispersal resulting from unstable shoreline habitats and cold mainstem temperatures. This movement was deduced from reduced densities of subadults between the LCR (RM 61.3) and Hance Rapid (RM 76.6). We believe that this dispersal resulted from a combination of destabilized shoreline habitats (caused by daily flow regulation) and reduced swimming ability of young fish (caused by cold water temperatures); laboratory tests (Bulkley et al. 1991) showed a 98% reduction in fatigue time of juvenile humpback chub in 0.51 mps velocity in 20°C (85 min) compared to 14°C (2 min). It was hypothesized that displacement of subadults from sheltered shorelines exposed these fish to predation, increased their energy expenditure in finding new habitat, and transported young into reaches with little shoreline habitat, such as the Inner Gorge. The combination of cold water releases in spring, summer, and fall, and fluctuating flows from Glen Canyon Dam operations, with increased exposure to predation, were probably the primary causes leading to high mortality of young humpback chub in Grand Canyon.

Long-range movement and local activity were greatest during spawning-related behavior from February through May. Adults moved to large local congregations in disjunct eddy complexes in February, then migrated to stage at the LCR inflow. Adults from upstream and downstream of the LCR moved simultaneously to the LCR inflow, suggesting that external reproductive stimuli, such as photoperiod, cued gonadal maturation and pre-spawning migrations. Remote radiotelemetry indicated an average residence time of about 17 days at the LCR inflow by staging adults suggesting an accumulation of temperature degree days, and contributing to significantly higher catch rates of adults in this area in February or March (Fig. 6). Adults ascended the LCR during decreasing LCR flows, increasing temperatures, and decreasing turbidity, indicating that a different set of cues prompted ascent than those that prompted staging.

**Fig. 6. Monthly geometric mean catch per effort ($GM_{CPE}$) for adult humpback chub captured in nets within RM 60.0-61.9 (LCR Inflow), 1991-93.**

Adults moved very little during non-spawning periods, in summer, fall, and winter (July-January), when local movement was primarily influenced by time of day, turbidity, flow magnitude, and ramping rate. Adult radiotagged humpback chub were more active and in shallower water at night and during the daytime when river turbidity was high (NTU>30). Most adults were in deep water (>4 m) during the day, particularly in clear water conditions.

Catches of subadults indicate that this life stage exhibited similar photosensitivity. Movements during low light conditions were attributed to the use of turbidity as cover from predators and to increased feeding activity from increased loads of suspended and drifting material.

Movement by adults was greater during high magnitude discharges and during highest ramping rates, probably in response to changing river hydraulics or to increased drift food availability, or both. The proportion of times that adults moved was significantly greater when flows were above 10,000 cfs, although the greatest movement occurred during increasing flows or decreasing flows; movement was reduced when flows stabilized at higher magnitudes (Fig. 7). The proportion of times adults moved was also greater when local ramping rates (measured at the nearby LCR USGS stream gage) were greater than 300 cfs/hr during a full range of flow magnitudes, although this movement was significantly greater only at flows above 10,000 cfs. The fish probably moved in response to changing hydraulic characteristics (e.g., water velocity, depth, current direction), as well as to increases in drift food items; densities of macroinvertebrates increased during descending flows and volume of Cladophora glomerata (dominant green algae) increased during ascending flows.

**Fig. 7. Fraction of telemetry observation time blocks with horizonal movement of radio-tagged adult humpback chub in Region 1 during average research and interim flow cycles.**

High relative condition factor of adults indicated that movement during high flows and high ramping rates was not energetically detrimental to the fish. Although this determination was made for flow ranges associated with interim flows, similar effects were expected for higher flows observed under previous peaking power operations. Movement patterns of adults are not likely to change until river flows top the debris fans that form the recirculating eddies used extensively by these fish. These high flows did not occur during this investigation.

Hence, although the presence of Glen Canyon Dam probably did not impede movement of the sedentary humpback chub as it apparently affected the potomodromous Colorado squawfish (Tyus 1984, 1990), and possibly other native fishes, subsequent dam operations have modified movement patterns, frequency of movement, and distance moved. These effects do not seem to be energetically detrimental to adults, but the combination of fluctuating flows, cold temperatures, and large numbers of nonative predators are probably the major factors leading to low survival of subadults.

## HABITAT

Subadult humpback chub (<200 mm TL) used primarily shallow sheltered shorelines, while adults (≥200 mm TL) used primarily large recirculating eddies. The transition from shoreline to offshore habitat use began when the fish were about 1 year old and 100 mm TL, and was largely completed by the time the fish were 3 years old and about 200 mm TL, which is about the size of maturity (Fig. 8).

**Fig. 8. Length-frequency distribution of humpback chub captured in shoreline habitats (with electrofishing, seines, minnow traps) and in offshore habitats (with gill nets, trammel nets) for 1991-93.**

Significantly higher densities of subadults were captured with electrofishing along vegetated banks, talus, and debris fans of the six shoreline types compared. Selected shorelines had a greater degree of cover with more consistent low-velocity interstitial spaces than sand, bedrock, and cobble bars, and provided more stable habitat over the range of flows observed (i.e., 8,000-20,000 cfs). While shoreline velocities were within a suitable range for YOY (0-0.30 mps) and juveniles (0-0.79 mps) from data collected primarily in summer (~16-22°C) (Valdez et al. 1990), the fish in Grand Canyon were constantly exposed to about 8-12°C. Laboratory tests (Bulkley et al. 1991) reported that swimming ability of juveniles was greatly reduced at colder temperatures, and showed a 98% reduction in fatigue time of juveniles in 0.51 mps velocity in 20°C (85 min) compared to 14°C (2 min). Hence, although shoreline habitats of the type selected by subadults appeared to be suitable and abundant in Grand Canyon, we hypothesize that use was reduced by the limited swimming ability of the young fish at cold temperatures, and by the destabilizing effect of fluctuating dam releases.

Nearshore velocities along cobble bars and bedrock exceeded the range of maximum cruising speed of YOY humpback chub (range, 30-100 mm TL) at 14°C (Fig. 9); sand beaches lacked cover and despite low velocities, were not used by YOY during the day or in clear water. Although velocities nearest shore appeared suitable for juveniles (range, 100-200 mm TL), these larger fish are expected to position further offshore where cobble bars and debris fans appeared unsuitable.

**Fig. 9. Average depth (A) and velocity (B) at three distances from shore (0.5, 1.5 and 2.5 m) for six shoreline types in subreach 1 (RM 61.9-65.4) and Subreach 2 (RM 65.4-73.4). The ranges in cruising speed for YOY and juveniles are shaded areas.**

Adult humpback chub selected eddy complexes disproportionate to their composition of surface area; 88% of adults captured and 74% of radio contacts were from eddies which averaged only 21% of surface river area (Fig. 10). This selection for eddy complexes appeared to determine the location of the three largest aggregations of humpback chub in Grand Canyon, which were river reaches with a high frequency of debris fans and channel expansion zones. These complexes were large recirculating zones that entrained and entrapped large volumes of drifting food, and provided low-velocity vortices in which the fish could feed and rest. A fusiform body enabled adults to maintain their position in undulating currents by an energy-efficient strategy of soaring with outspread fins, analogous to raptors soaring on wind currents.

**Fig. 10. Radio contact locations for adult radio-tagged humpback chub in the mainstem Colorado River.**

Adult humpback chub in Grand Canyon selected large recirculating eddies to a greater degree than adults have displayed in other populations (Valdez et al. 1990). Adults in other populations appear to use a wider range of habitats, possibly because more normal warm spring, summer, and fall temperatures enable the fish to occupy relatively higher velocities and utilize local supplies of food. Adults in Cataract Canyon were frequently observed moving to large eddies during runoff or when drift volume was high to feed on entrained flotsom. Adults in postdam Grand Canyon have been largely restricted to recirculating eddies as areas of greatest food supplies with low velocity.

The character of these large recirculating eddies may be changed from predam conditions as a result of nearly 90% sediment retention in Lake Powell, and subsequent scouring of sediments from the river channel downstream of the dam. Because adult humpback chub in Grand Canyon have a demonstrated selection for eddies, the volume of sand in the channel and thus in these eddies is important for shaping fish habitat and hydraulic characteristics, although the relationship and resulting effect to the fish are not understood. Possibly, some expansion zones contain less sand today than predam and are more effective at entraining drifting material, hence attracting greater use by humpback chub.

## FOOD HABITS

Adult humpback chub in the Colorado River in Grand Canyon ate primarily simuliids, freshwater amphipods (Gammarus lacustris), chironomids, other aquatic invertebrates (i.e., beetles) and terrestrial insects (i.e., primarily ants). The algae, Cladophora glomerata also made up a significant portion of gut volume, but it was not determined if this item was consumed incidentally or selected by the fish and of nutritional value. The major food items (excluding Cladophora) of the LCRI aggregation were amphipods (44.8% by volume) and simuliids (40.3%), and the major items of the Middle Granite Gorge aggregation were simuliids (49.1%) and terrestrial invertebrates (29.6%, primarily ants and beetles) (Fig. 11). Johnson's electivity indices indicate that simuliids, chironomids, and amphipods were consumed in approximately the same proportions as available in the drift in both areas, while terrestrial invertebrates were low in numbers in drift samples and high in numbers in guts, indicating selection in the Middle Granite Gorge aggregation. Although Cladophora composed the greatest volume in drift, with increasingly greater amounts in a downstream direction, this algae was absent from guts of Middle Granite Gorge fish, but composed 24% of gut volume of LCRI fish.

Seasonal diet of humpback chub was distinct. The diet in spring was primarily amphipods (51.2%), simuliids (24.3%), and terrestrial invertebrates (22.7%); summer diet was simuliids (47%), amphipods (30%), terrestrial invertebrates (14%), and chironomids (7%); and fall diet was amphipods (43.9%) and simuliids (43.7%). The relative abundance of amphipods and chironomids in gut contents were approximately the same as respective seasonal abundances in drift, but electivity indices indicated selection for terrestrials and other aquatic invertebrates in all seasons. Terrestrial invertebrates were difficult to monitor in drift samples because their abundance varied with floods or behavioral patterns of local invertebrate populations.

**Fig. 11. Volumetric composition of invertebrates found in gut contents of humpback chub from the Little Colorado River aggregations and the Middle Granite Gorge aggregation during 1992-93.**

The proportion of terrestrial insects in the diet increased downstream of Havasu Creek, suggesting a decreased abundance of aquatic invertebrates and greater dependence on terrestrials. The numbers of organisms in drift above the LCR (248/100 $m^3$), from the LCR to Hance Rapid (190/100 $m^3$), and from Hance Rapid to Diamond Creek (96/100 $m^3$) showed decreased drift food availability from eastern to western Grand Canyon and was consistent with the pattern of benthic invertebrates (Blinn et al. 1994). Numbers of drifting organisms and total volume of Cladophora were significantly different among rising (up ramp), falling (down ramp), and steady flows associated with daily release cycles from Glen Canyon Dam. Average volume of Cladophora was highest during rising flows, while densities of drifting organisms were significantly greater during falling flows (380/100 $m^3$) than during rising flows (177/100 $m^3$), indicating that Cladophora was dislodged with rising flows, but invertebrates drifted primarily during descending flows.

Cold releases from Glen Canyon Dam have interfered with life cycles of organisms and greatly affected aquatic invertebrates and hence fish food diversity and availability. Humpback chub are opportunist insectivores, and have apparently adjusted to substantial changes in the invertebrate fauna; e.g., the amphipod Gammarus lacustris is a non-native introduced crustacean that composed nearly 50% of the diet of chubs. Although the effect of reduced abundance and variety of macroinvertebrates on longitudinal abundance of humpback chub has not been fully evaluated, reduced densities of aquatic invertebrates in drift and the lower benthic productivity found by Blinn et al. (1994) suggests a food shortage in downstream reaches.

## AGE AND GROWTH

Average lengths of subadult humpback chub at the first three scale annuli formations were 96, 144, and 186 mm TL. A transition check on the scale also showed that the majority of young fish moved from the warm LCR to the cold mainstem at 74 mm TL (range, 52-132 mm TL), indicating that most of the first year of growth occurred in the LCR.

Average monthly growth rate of age 0 chubs in the LCR was 10.30 mm, which was similar to laboratory results of 10.63 mm at 20°C (Lupher and Clarkson 1994). Average monthly growth rates for age I and II fish were 4.00 mm and 3.50 mm, which was higher than laboratory results of 2.30 mm at 10°C; the difference was attributed to wild fish finding warmed shorelines and backwaters.

Average monthly growth rate from PIT-tag recapture information was 2.25, 2.79, 2.50, 1.16, 0.79, 0.91, and 0.96 mm for fish in 50-mm length groups of 150-200 mm TL, 200-250 mm TL, 250-300 mm TL, 300-350 mm TL, 350-400 mm TL, 400-450 mm TL, and 450-500 mm TL, respectively (Fig. 12). These adult growth rates were approximately double the growth rates reported from the LCR (Minckley 1992) of 1.4, 1.3, 1.1, 0.4, 0.5, and 0.1 mm for fish less than 200 mm, 200-250 mm TL, 250-300 mm TL, 300-350 mm TL, 350-400 mm TL, and over 400 mm TL, respectively. Average monthly growth of PIT-tagged humpback chub in Westwater Canyon was 1.08 and 1.35 mm for 200-250 mm TL and 250-300 mm TL, respectively (T. Chart, pers. comm., UDWR), which was comparable to the growth rates reported from the LCR, but only about half the growth rate reported by this investigation for mainstem fish.

**Fig. 12. Logarithmic growth curve for humpback chub in the mainstem Colorado River in Grand Canyon. Hatching length of 7 mm from Muth (1990); length at 1-3 years from scale back-calculations; lengths at 50mm increments for 4+ years from PIT tag recaptures.**

Higher growth rates in the mainstem are explained by greater living space, greater consistent food availability, and relatively stable year-around habitat. Hence, despite suboptimal temperatures, adult growth rates in the mainstem Grand Canyon may be higher than growth rates of any other population in the basin. Average total length of mainstem Grand Canyon humpback chub is significantly higher ($P<.05$) than average length of fish from the LCR, and probably higher than lengths of any other population.

Age of adult humpback chub was not determined during this investigation, but Hendrickson (1993) reported a maximum age of 21 years for humpback chub from the LCR that was 461 mm TL. Maximum sizes of fish from the mainstem were 460 mm TL (1,122 g) for males and 480 mm TL (1,165 g) for females, indicating that the fish aged by Hendrickson was close to maximum longevity.

# REPRODUCTIVE CAPACITY AND SUCCESS

The only self-sustaining population of humpback chub in Grand Canyon was found in the lower 14.6 km of the Little Colorado River (LCR) and the adjacent 13.5 km of the mainstem Colorado River (6.9 km upstream and 6.6 km downstream of the inflow). The population consisted of two components--an LCR component and a mainstem Colorado River component, with all known reproduction in the LCR and possibly genetic exchange from spatial and temporal overlap in spawning.

The majority of mainstem adults (≥200 mm TL) of the LCRI aggregation ascended the LCR for presumed spawning from March through May. Adults in other disjunct aggregations reached a peak in spawning readiness in May through June, nearly 2 months later than the LCR population, but consistent with historic mainstem temperatures and timing of spawning by other mainstem populations, such as Black Rocks (Valdez and Clemmer 1982, Kaeding et al. 1990), Cataract Canyon (Valdez 1990), and Yampa Canyon (Karp and Tyus 1990). Thus, mainstem temperatures were sufficient for normal gonadal maturation as reported by Kaeding and Zimmerman (1982), but apparently too cold for survival of eggs and larvae.

The only definitive evidence of mainstem reproduction during this investigation was the discovery of about 100 post-larval humpback chub (14 captured, range, 18-31 mm TL) in a warm spring plume at RM 30.8 on July 12, 1994 (Valdez and Masslich 1995). Water temperature at the source of the spring was relatively constant at 21.5°C, compared to 10°C in the adjacent main channel; the fish were in a plume with a temperature of 15-19°C. These young fish belonged to the 1994 year class, and probably hatched from eggs deposited in the warm spring plume, since mainstem water temperature was too cold for survival of eggs or larvae (Hammon 1982, Marsh 1985). These fish were about 36 days old (hatched about June 8, 1994), based on age to length relationships of larvae and post-larvae (Muth 1990).

Young humpback chub were reported 21.7 km (13.5 mi) downstream of this spring by Arizona Game and Fish Department in 1993 (AGF 1994), i.e., 20 YOY (range, 20-50 mm TL) were captured at RM 44.3. These findings also suggest past spawning attempts by humpback chub, either in springs in the vicinity of Fence Fault (30-Mile area) or in the Paria River. It is unlikely that these young fish originated from the Paria River, since adult humpback chub have not been reported in that tributary, and a large number of young would be necessary to supply a distant backwater with 20 individuals, where fish are expected to become more dispersed with distance downstream.

Although it is unlikely that larval humpback chub could survive the thermal shock of a transition from a spring plume of 20°C to a mainstem temperature of 10°C, sufficient size and temperature of some plumes may persist under various mainstem flows to allow fish to age and acclimate to suboptimal temperatures. If young fish reach sufficient size to survive the thermal transition (i.e., about 50 mm TL), their chances of survival probably remain low because of the large numbers of mainstem predators.

Under interim flows, the existing thermal regime reaches the lower range of suitable spawning temperature for humpback chub of 16°C about 385 km (240 mi) downstream of the dam (i.e., below Diamond Creek) only during the months of July and August. The remainder of the year, the temperature of the Colorado River in this region is too cold for survival of eggs or larvae of humpback chub. Some very localized reproduction may be occurring in the mainstem, most likely at tributary or spring inflows, but the numbers of young fish produced and surviving is probably insignificant to the continued existence of the species in Grand Canyon.

Spawning by humpback chub in the LCR is timed to occur when temperatures of that tributary are within the suitable range of 16 to 22°C, from April through May (Fig. 12). Kaeding and Zimmerman (1983) reported that mean female gonadosomatic indices and ovary diameters of humpback chub in the LCR, mainstem, and LCR inflow were highest between early February and late April 1980, indicating that most spawning probably occurred in March, April, and May.

**Fig. 13. Suitable and optimal temperature range for spawning by humpback chub compared to predam temperature of the Colorado River at Phantom Ranch (A), and the temperature of the LCR and postdam Colorado River at Glen Canyon Dam, LCR, and Diamond Creek (B).**

If humpback chub were spawning in the mainstem prior to Glen Canyon Dam--as they presently do in all other populations in the basin--egg deposition would have had to occur when temperatures were suitable, most likely from late May to early July. One of three explanations accounts for the disparity in timing between predam and present spawning events:

1. Humpback chub in Grand Canyon did not spawn in the mainstem prior to Glen Canyon Dam; an unlikely scenario considering all other populations spawn in similar mainstem conditions.

2. Cold releases forced mainstem spawners to switch to an earlier spawning mode and ascend the LCR to coincide with temperatures of that tributary; a possible scenario considering many fish species are capable of switching spawning times under changed environmental conditions, e.g., temperature, photoperiod.

3. Two population components existed in Grand Canyon--one spawned in the mainstem, and one in the LCR. The mainstem component experienced unsuccessful reproductive efforts following Glen Canyon Dam and few if any individuals remain; this is the most likely scenario and an important consideration for a second population in the mainstem if unique genetic stocks exist.

Some spawning may be occurring in the mainstem downstream of the LCR in lower reaches of warm tributaries, or in warm mainstem springs, as indicated by young humpback chub captured by other investigators. These fish may have been hatched locally, or they may have been hatched in the LCR and survived the thermal transition to the mainstem. Young captured in downstream reaches during 1990-93 could have originated from the LCR and dispersed to any area downstream within days; assuming average transport time of about 6 km/hr (~1.67 m/sec), an object moved by currents could be transported from the LCR (RM 61.3) to Diamond Creek (RM 226) in about 44 hr.

## IMPORTANT BIOTIC INTERACTIONS

Fourteen species of fish were sympatric with humpback chub during this investigation, including 3 native species and 11 non-natives. These interacted with humpback chub as known or potential predators, competitors, and vectors for parasites and diseases. Known predators included brown trout, rainbow trout, and channel catfish. Potential predators included striped bass, green sunfish, brook trout, black bullhead, and walleye, but these occurred in small numbers and probably had an insignificant predator impact. Carp could also be significant predators of incubating eggs in the LCR and warm springs. Small cyprinids, such as fathead minnows and red shiners are known predators of early life stages of native species (Deacon et al. 1991).

It was estimated that brown trout, rainbow trout, and channel catfish in the mainstem potentially consume 250,000 young humpback chub annually (Fig. 14), significantly affecting survival of 1, 2, and 3-year old fish, and reducing recruitment to the adult portion of the population. The most significant predator was the brown trout, with a potential annual consumption of 230,000 chubs. This is the estimated predation occurring between the LCR (RM 61.3) and Bright Angel Creek (RM 87.7), in the area where the species are sympatric and young humpback chub densities are highest. Although the young chubs originate from the LCR, we believe that fluctuating flows and cold dam releases destabilize shoreline habitats and transport the fish downstream into areas with large numbers of brown trout. Brown trout are not presently stocked in the system and are spawned primarily in Bright Angel Creek and the adjacent inflow.

**Fig. 14. Potential daily and annual consumption of humpback chub by adults of three predator fish species in the Colorado River in Grand Canyon. Relationships assume 2.0 chubs consumed daily by 10.4% of adult brown trout, 1.0 chub consumed daily by 1, 5, or 10% of adult rainbow trout; 1.0 chub consumed daily by 1.5% of adult channel catfish.**

Rainbow trout also appear to be important predators of humpback chub and could consume up to 27,375 fish per year. Rainbow trout that are sympatric with humpback chub are primarily progeny of local natural reproduction from tributaries such as Nankoweap Creek, Clear Creek, Bright Angel Creek, Shinumo Creek, Tapeats Creek, Deer Creek, and Havasu Creek. The area of highest predation (i.e., LCR to Bright Angel Creek) was supplied by fish that probably originated primarily from Nankoweap Creek, Clear Creek, and Bright Angel Creek. The rainbow trout that are sympatric with humpback chub downstream of Nankoweap Creek did not appear to originate from the tailwater fishery; only three of approximately 151,000 catchable rainbow trout (marked with coded wire nose tags) released by AGF (1992 - 1993) between the dam and Lees Ferry were recaptured downstream of Lees Ferry, at RM 2.9, RM 3.2, and RM 3.2. Rainbow trout may also compete for food with humpback chub, since favored food items of both species were simuliids, amphipods, and midges. Limited food resources may be limiting fish populations and their numbers in western Grand Canyon.

Channel catfish are apparently primarily mainstem inhabitants that aggregate annually for spawning in warm tributaries, primarily in the LCR, where they have been reported for years (Kaeding and Zimmerman 1983, Gorman et al. 1994). Channel catfish have not been reported in Kanab Creek (AGF 1993, 1994), and were not reported in recent surveys of the Paria River (Weiss 1993), Shinumo Creek, or Bright Angel Creek (Otis 1994).

The effect of striped bass migrating annually from Lake Mead into Grand Canyon has not been fully evaluated. Although the numbers ascending annually from Lake Mead appear small, this species is a voracious predator and even small numbers could account for substantial mortality of native fishes. The numbers of striped bass in the Lake Mead inflow (i.e., downstream of Bridge Canyon) in spring are high (Valdez 1993, 1994, 1995), and suggest that greater numbers of striped bass could ascend the Colorado River into Grand Canyon given more suitable conditions such as warmer temperatures and higher turbidity.

Small non-native forms, such as fathead minnow and plains killifish, are presently low in numbers, but could become numerous with changed conditions, such as warmer mainstem temperatures from a selective withdrawal system. These species are relatively weak swimmers and inhabitants of low-velocity areas; fathead minnows thrive in flood bottomlands and backwaters of their native Mississippi and Missouri rivers, and are often the most resistant species to low oxygen, high temperature, and high turbidity (Pflieger 1975). Plains killifish are typically inhabitants of small to medium streams and prefer low velocity areas. These warmwater species are likely to become transported downstream and stressed with high flows that flood sheltered shoreline habitats such as backwaters. These species are likely to remain in the system, since they inhabit many tributaries from which they can reinvade the mainstem. Red shiners, a known predator and competitor of native stream fishes, are rare upstream of the Lake Mead inflow, but could become numerous if releases are warmed by selective withdrawal.

Removal of adult non-natives from the system may avail more food for native fishes. Biomass estimates indicate that fish biomass in the mainstem is dominated by these alien species. If food is limiting, removing potential predators may also benefit native species by availing greater supplies of food.

Two species of alien parasites presently infect the humpback chub in Grand Canyon, including the parasitic copepod (Lernaea cyprinacea) and the Asian tapeworm (Bothriocephalus acheilognathi). Parasitic copepods were first reported from this population by Carothers et al. (1981), and the Asian tapeworm was first reported in 1989 by D. Hendrickson (Angradi et al. 1992). These warmwater parasites are unable to complete their life cycles in the cold mainstem. Lernaea cyprinacea and B. acheilognathi were in found in 0.13% and 3.6% of humpback chub examined, and were not considered a major threat in the mainstem.

Of four native species captured in the mainstem Colorado River in Grand Canyon, flannelmouth suckers and bluehead suckers showed the weakest age structures, i.e., young fish of these species made up a relatively small proportion of their populations. Of total numbers of humpback chub (6,294), flannelmouth suckers (2,775), speckled dace (1,491), and bluehead suckers (1,040), subadults (YOY and juveniles) composed 72%, 21%, 6%, and 34%, respectively, indicating that reproductive success of other native species was considerably less than that of humpback chub. These species appeared to be reproducing primarily in tributaries, but survival of larvae drifting into the cold mainstem was probably low, and predation on survivors was probably high.

## LIFE HISTORY SCHEDULE

The life history schedule of the LCRI aggregation is depicted in Fig. 15, based on observations during 1990-93. Adults between RM 57 and RM 65.4 were typically found in or near large eddy complexes from about July through January. In February and March, adults congregated locally in a few large eddy complexes before moving to stage at the LCR inflow. Adults staged primarily in March, April, and May, with individuals remaining an average of 17 days and ascending primarily when flows in the LCR were decreasing, clearing, and warming. Staging and ascent into the LCR, and presumed spawning, occurred over a period of about 3 months (i.e., April, May, June). Adults remained in the LCR from March through June, returning during and after this period to mainstem eddy complexes, often within 2 km from their original location before the spawning movement. Eggs deposited in the LCR at about 22°C probably incubated about 5 days before hatching (Hamman 1982).

**Fig. 15. Life history schedule for the LCRI aggregation of humpback chub in the mainstem Colorado River in Grand Canyon.**

Large numbers of young were seen in the mainstem, primarily downstream of the LCR inflow, during and immediately after heavy summer rainstorms in the LCR drainage. The timing of these "monsoon rains" determined the appearance of these young chubs in the mainstem, indicating that dispersal was concurrent with LCR floods; floods occurred in September 1991, May 1992, and July 1993. Large numbers of subadult humpback chub descended from the LCR into the mainstem in September 1991 and May 1992, concurrent with LCR floods, but in 1993 large numbers of young began to descend to the mainstem in July, during low and clear flow in the LCR. The 1993 cohort was large and movement to the mainstem during low flows in July 1993 suggested that dispersal was density-dependent, and the result of food shortage or habitat limitation in the LCR.

## RECOMMENDATIONS

1. Integrate LCR and Mainstem Data: Reclamation is advised to assimilate and integrate all research conducted under GCES in order to provide a scientific synthesis of the aquatic ecology of Grand Canyon.

2. Develop a Population Model: A population model is currently being developed by Ryel and Valdez (1995) as a means of determining the status and trend of the humpback chub population in Grand Canyon, by integrating empirical data collected by the GCES investigations.

3. Integrate Geomorphology with Fish Habitat: The relationships of channel geomorphology and fish habitat identified by this investigation need to be described and used to help evaluate the likelihood of second spawning population of humpback chub, as well as the effects of high spring releases, and steady summer flows.

4. Develop a Non-Native Fish Management Plan: Predation may be a major source of mortality for subadult humpback chub in Grand Canyon. Major predators need to be identified, their impact quantified, and control options discussed. Sensitive areas need to be identified, such as the blue ribbon tailwater trout fishery and the rainbow trout at Nankoweap Canyon used by migrating bald eagles.

5. Develop a Genetics Management Plan: The last recognizable mainstem stock of humpback chub in Grand Canyon may be represented by 40-60 adults near RM 30, some of which are spawning in the warm springs of Fence Fault. Management strategies need to be identified for taking fish to a refugia or enhancing mainstem spawning and survival.

6. Evaluate EIS Elements: Risk assessments are recommended for evaluating selective withdrawal, high spring releases, and steady summer flows.

7. Conduct Swimming Performance Experiments: Hypotheses need to be tested that subadult humpback chub are being transported downstream and limited to low velocity habitat by reduced swimming performance at cold temperatures. We recommend laboratory swimming performance tests for YOY

(50-100 mm TL) and juveniles (range, 100-200 mm TL) at 10°C, 12°C, 15°C, and 20°C following acclimation to 20°C; these conditions simulate young fish moving from the LCR to the mainstem.

8. Develop Depth and Velocity Isopleths of River Channel: Additional mapping of the river bottom and velocity characteristics is recommended with SuperHydro technology.

9. Determine Relationship of Drift and Benthos: Concurrent sampling of drift and benthos is recommended to characterize macroinvertebrate communities by season, time of day, flow magnitude, and ramping rates.

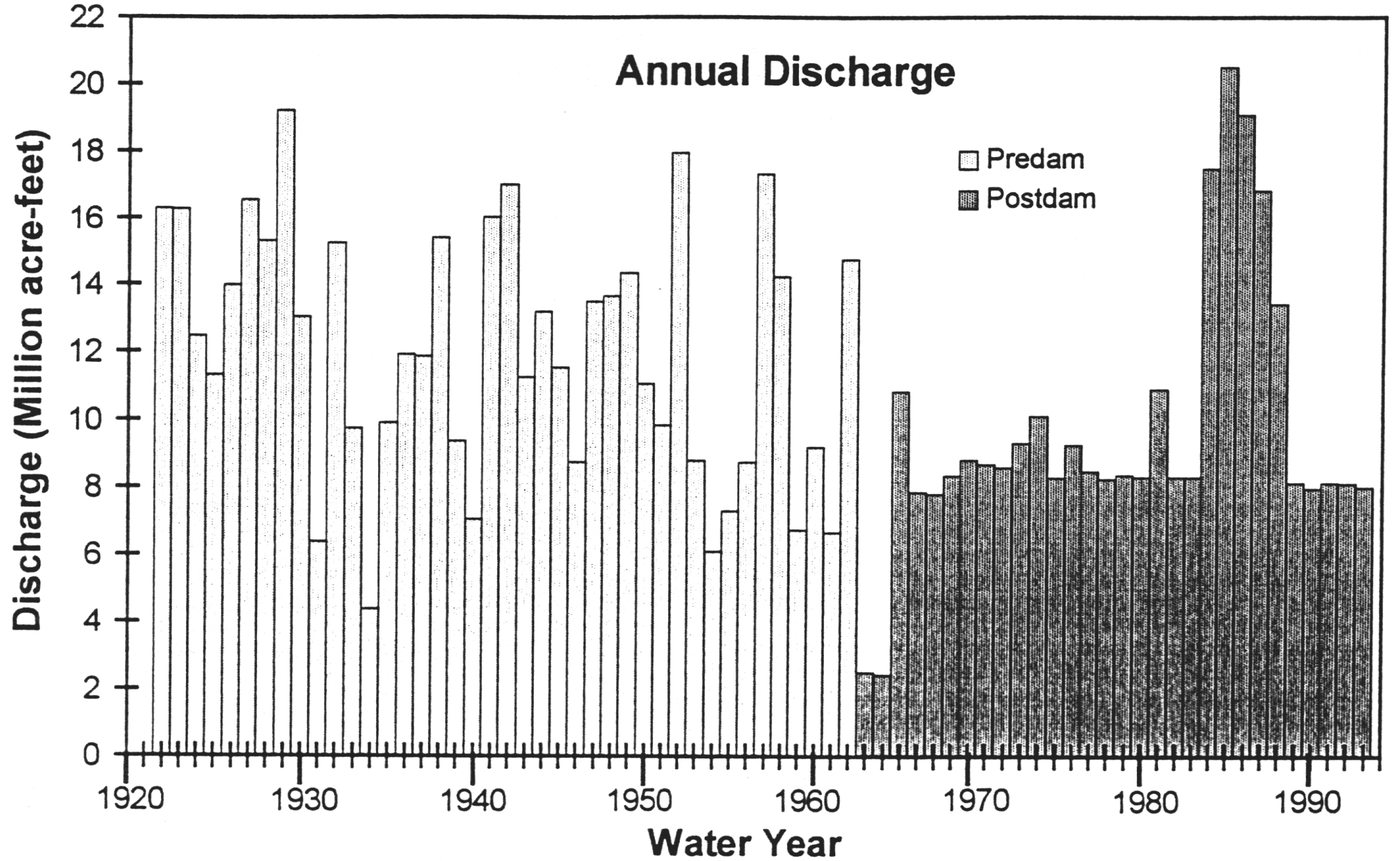
10. Identify Sources of Primary and Secondary Production: The hypothesis should be tested that food supplies for subadults are limiting in western Grand Canyon in order to determine if production can be enhanced in this area as a way to establish a second spawning population of humpback chub.

11. Develop and Implement a Long-Term Monitoring Program: We concur with recommendations in the Glen Canyon Dam Final EIS to develop an implement a long-term monitoring program. We urge Reclamation to insure scientific input from present investigators in development and implementation.

12. Develop a Temperature Model: Longitudinal temperature characteristics of the Colorado River need to be described by season, flow magnitude, and ramping in order to understand the effects of selective withdrawal, high spring releases, and steady summer flows on temperature and thus on fish assemblages.

13. Extend Critical Habitat Designation: We recommend extending critical habitat of the humpback chub in Grand Canyon by 10 mi from Nautaloid Canyon (RM 34) upstream to RM 24. This area of extension includes the Fence Fault springs currently being occupied by the 30-Mile aggregation (40-60 adults) of humpback chub. Post-larval chub were captured in a warm spring in July 1994 indicating successful reproduction.

14. Identify Mainstem Flow Needs for 30-Mile Aggregation: The elevation of spring sources and adjacent crevice cover may be critical to successful spawning by humpback chub near RM 30. The relationship of these elevations and mainstem flow need to be described, as well as flows at which the thermal plume is largest and most stable for the fish.



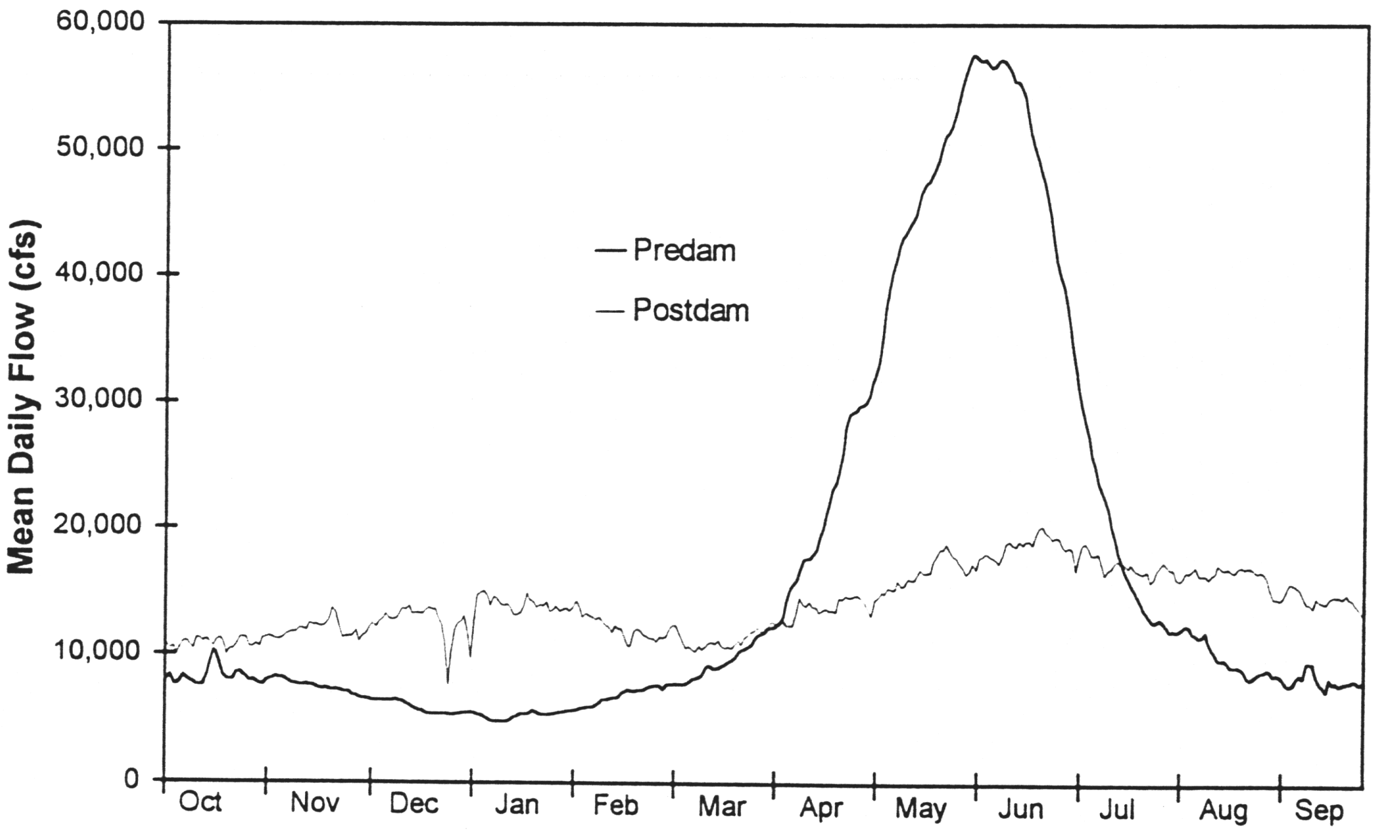




Fig. 1. Mean discharge (WY 1922-93) and mean daily predam (WY 1922-62) and postdam (WY 1965-92) flow of the Colorado River at Lees Ferry, AZ.

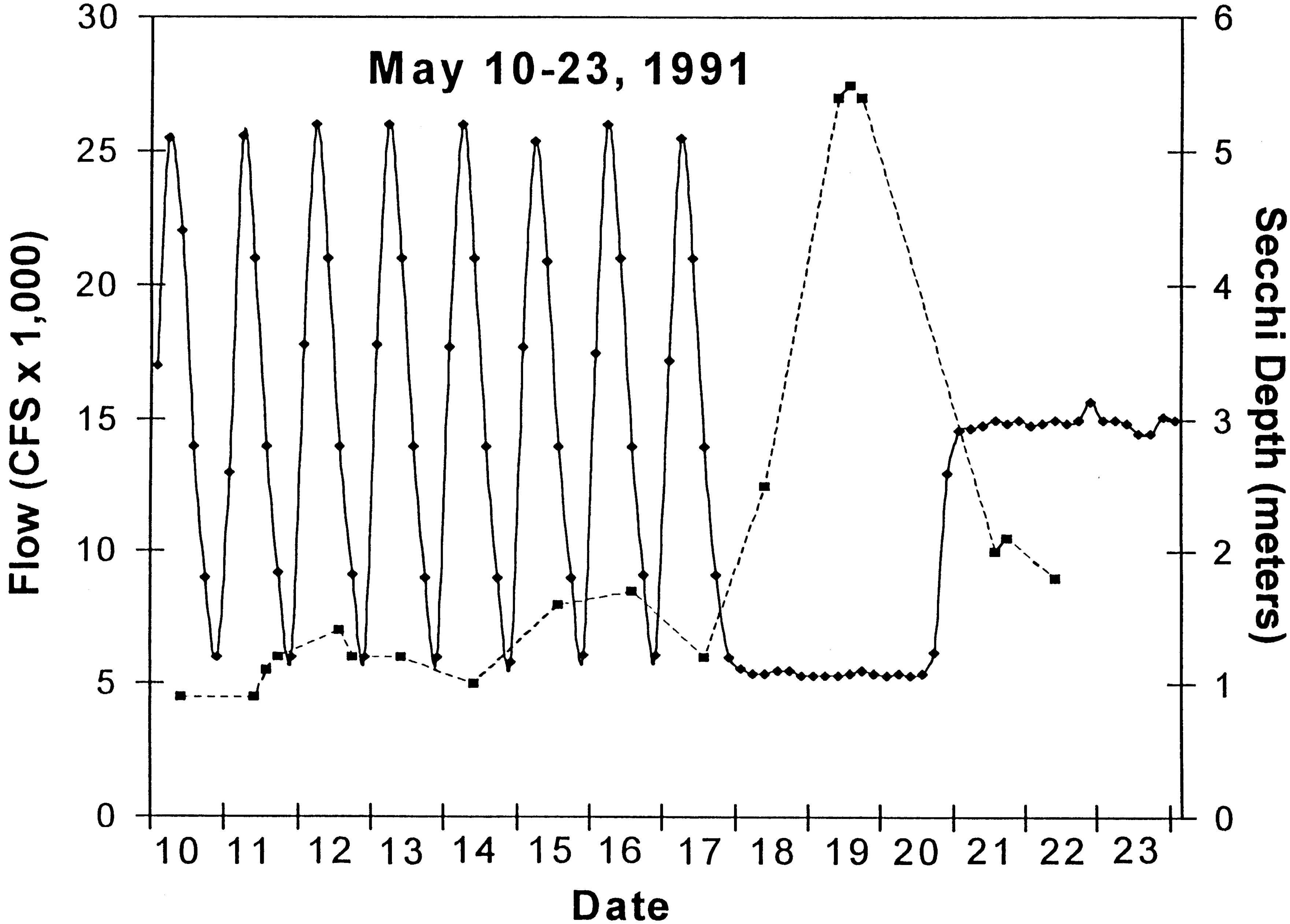



Fig. 2. Relationship of flow to water clarity during a transition of high fluctuating releases (7,000-25,000 cfs) to constant 5,000 cfs, May 10-23, 1991.

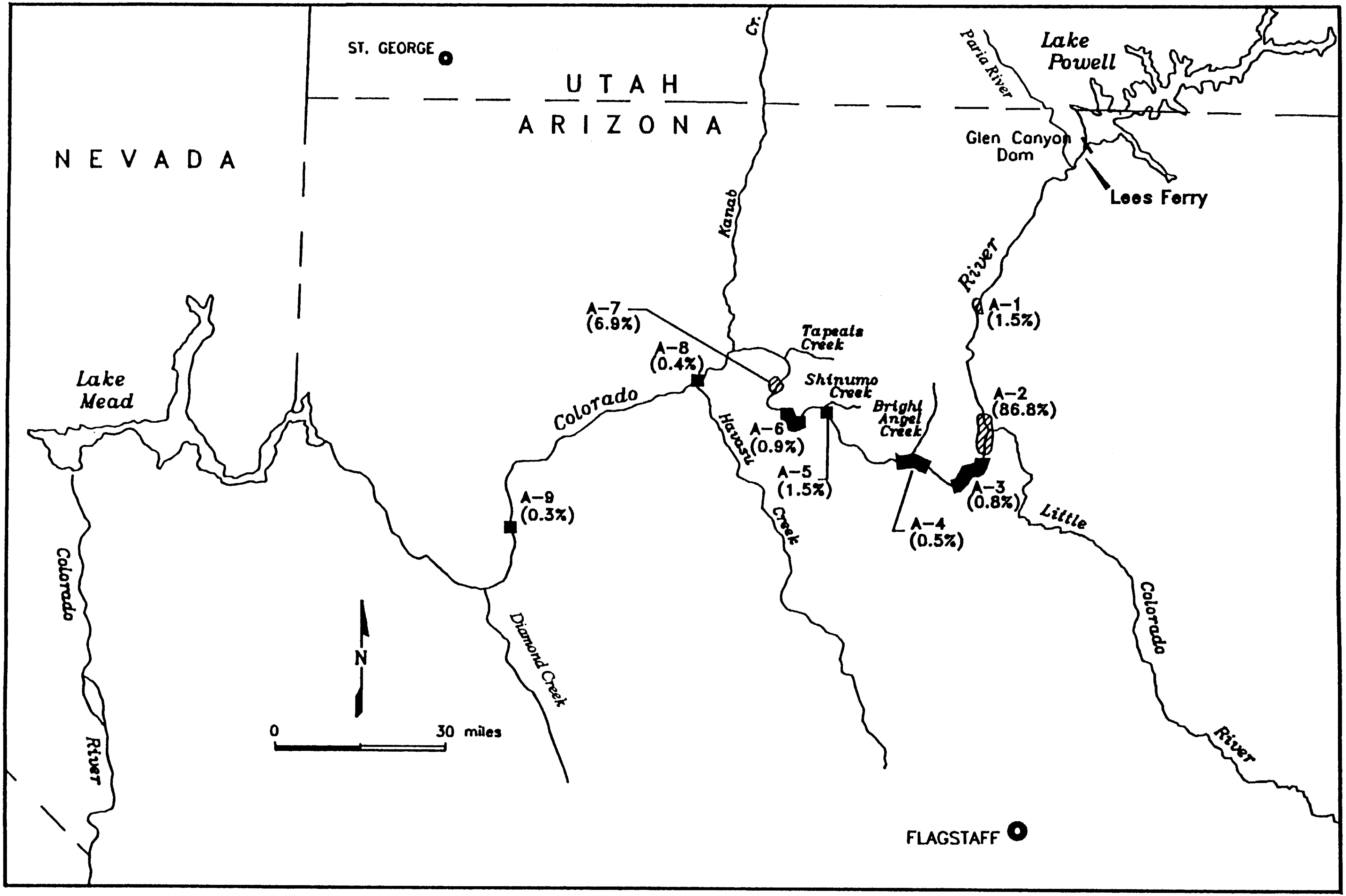



Fig. 3. Locations (percentage of total numbers) of nine aggregations of humpback chub in the Colorado River in Grand Canyon.

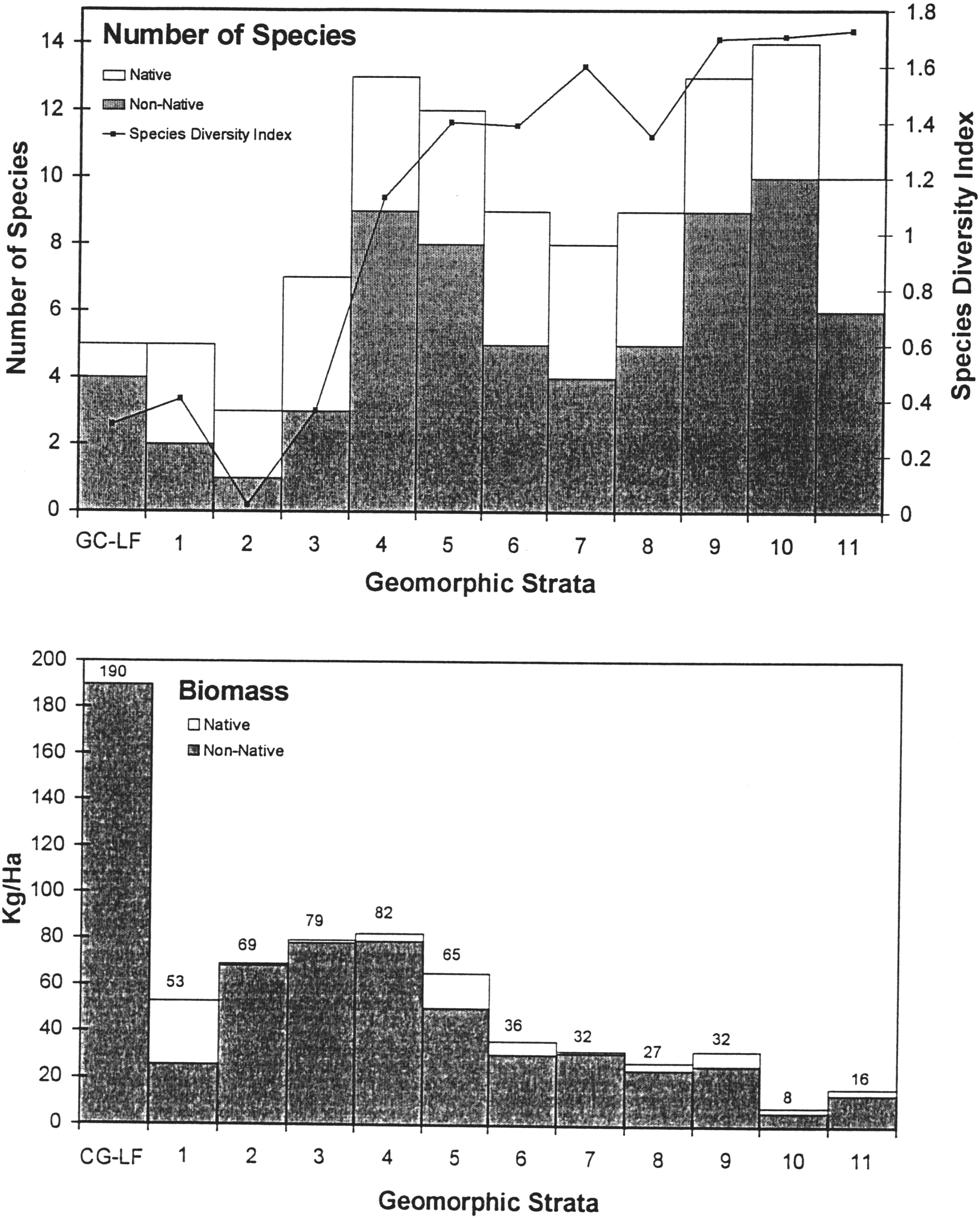



Fig. 4. Number of species, species diversity, and biomass of native and non-native fish species by geomorphic reach from Lees Ferry to Diamond Creek.

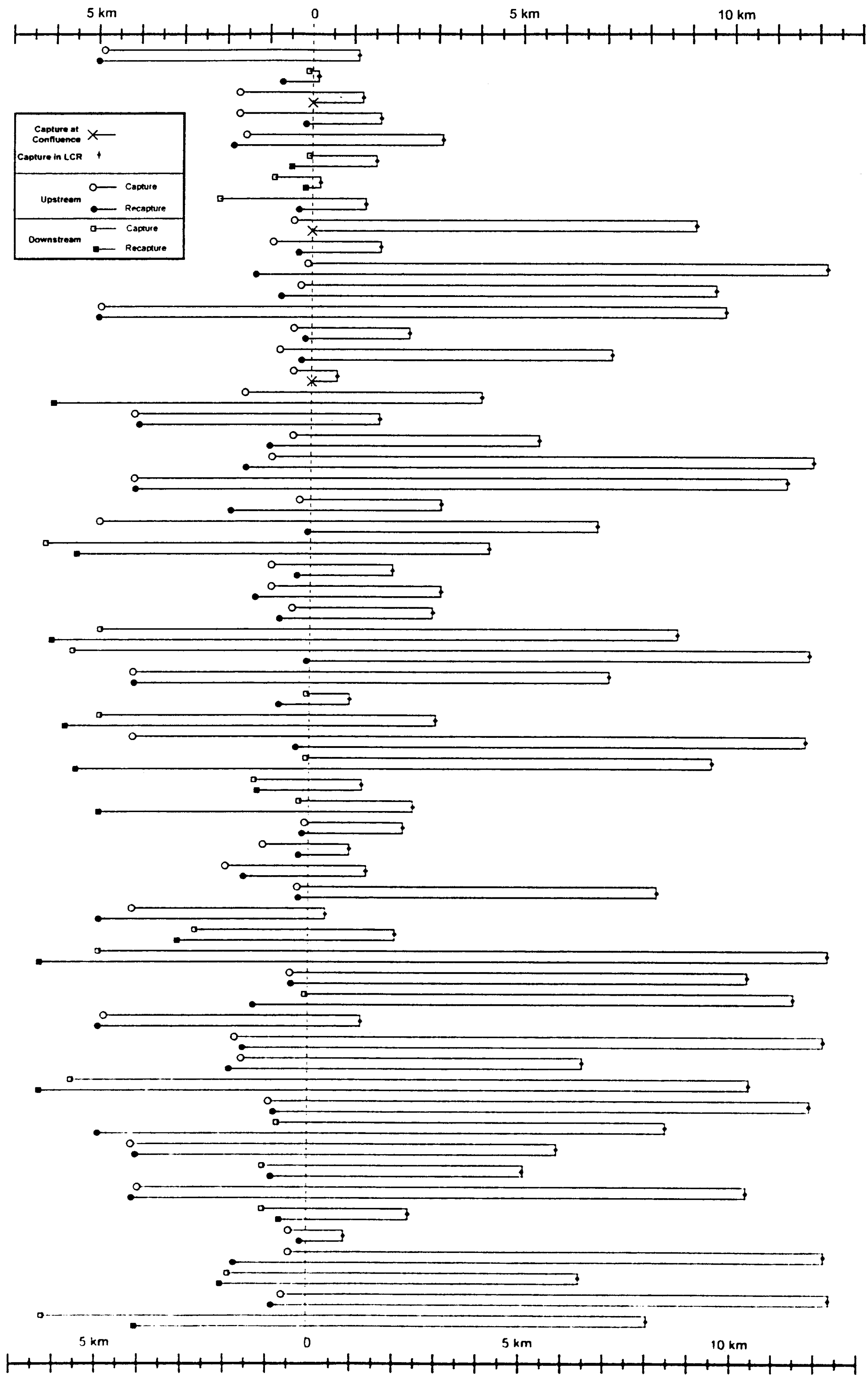



Fig. 5. Fidelity of 60 PIT-tagged humpback chub in the mainstem Colorado River following presumed spawning in the LCR, October 1990-November 1993.

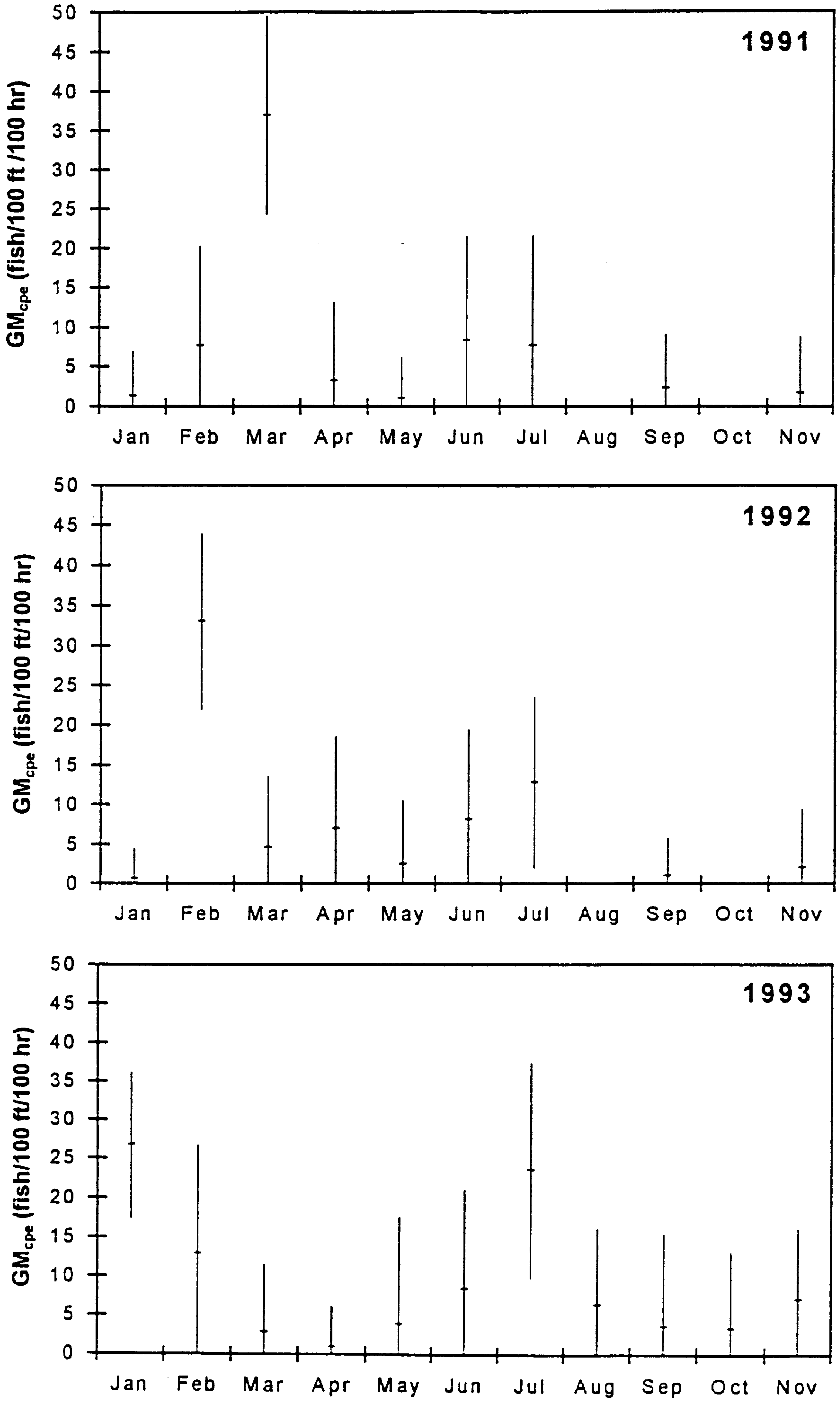



Fig. 6. Monthly geometric mean catch per effort ($GM_{cpe}$) for adult humpback chub captured in nets within RM 60.0-61.9 (LCR Inflow), 1990-91.

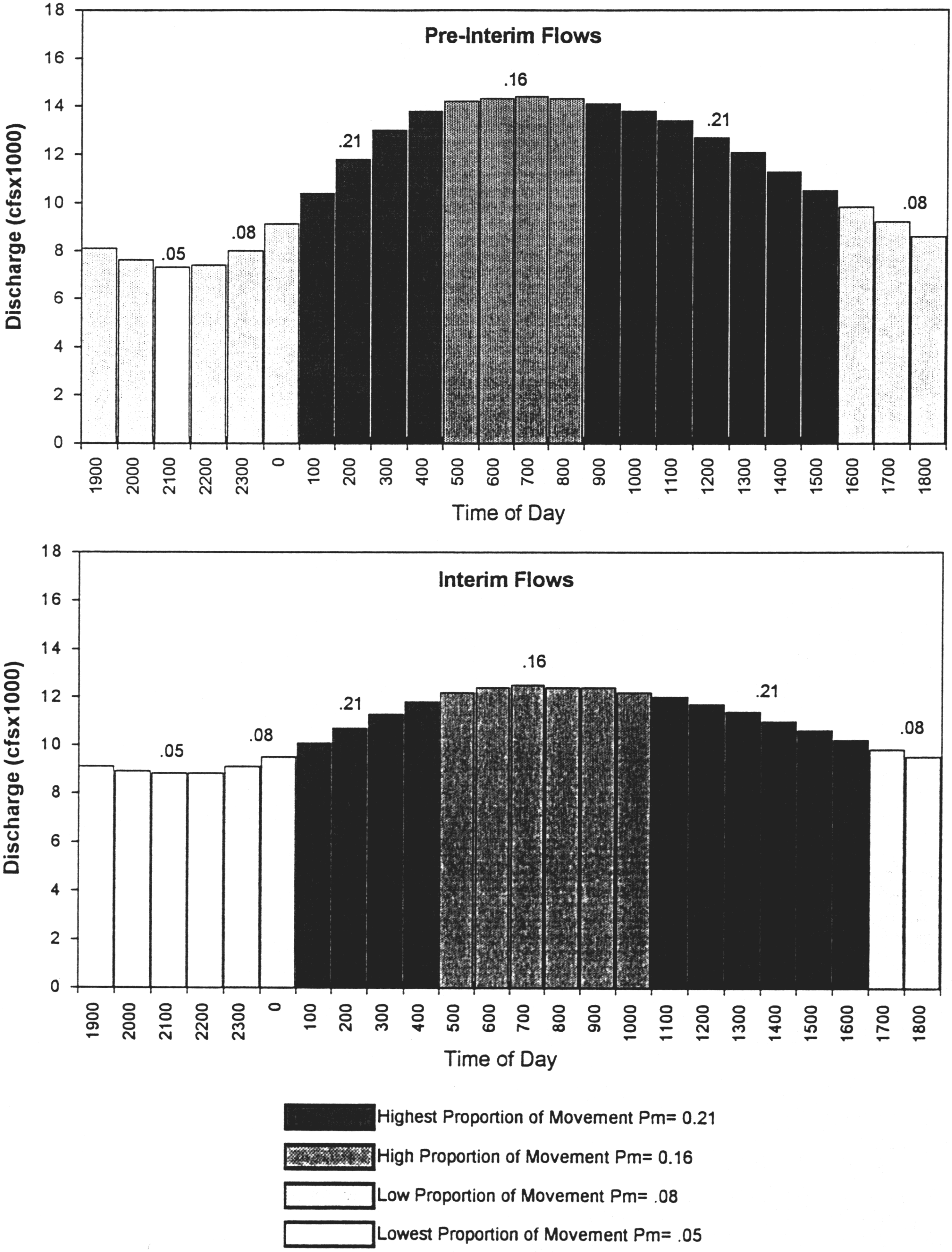



Fig. 7. Fraction of telemetry observation time blocks with horizonal movement of radio-tagged adult humpback chub in Region 1 during average research and interim flow cycles.

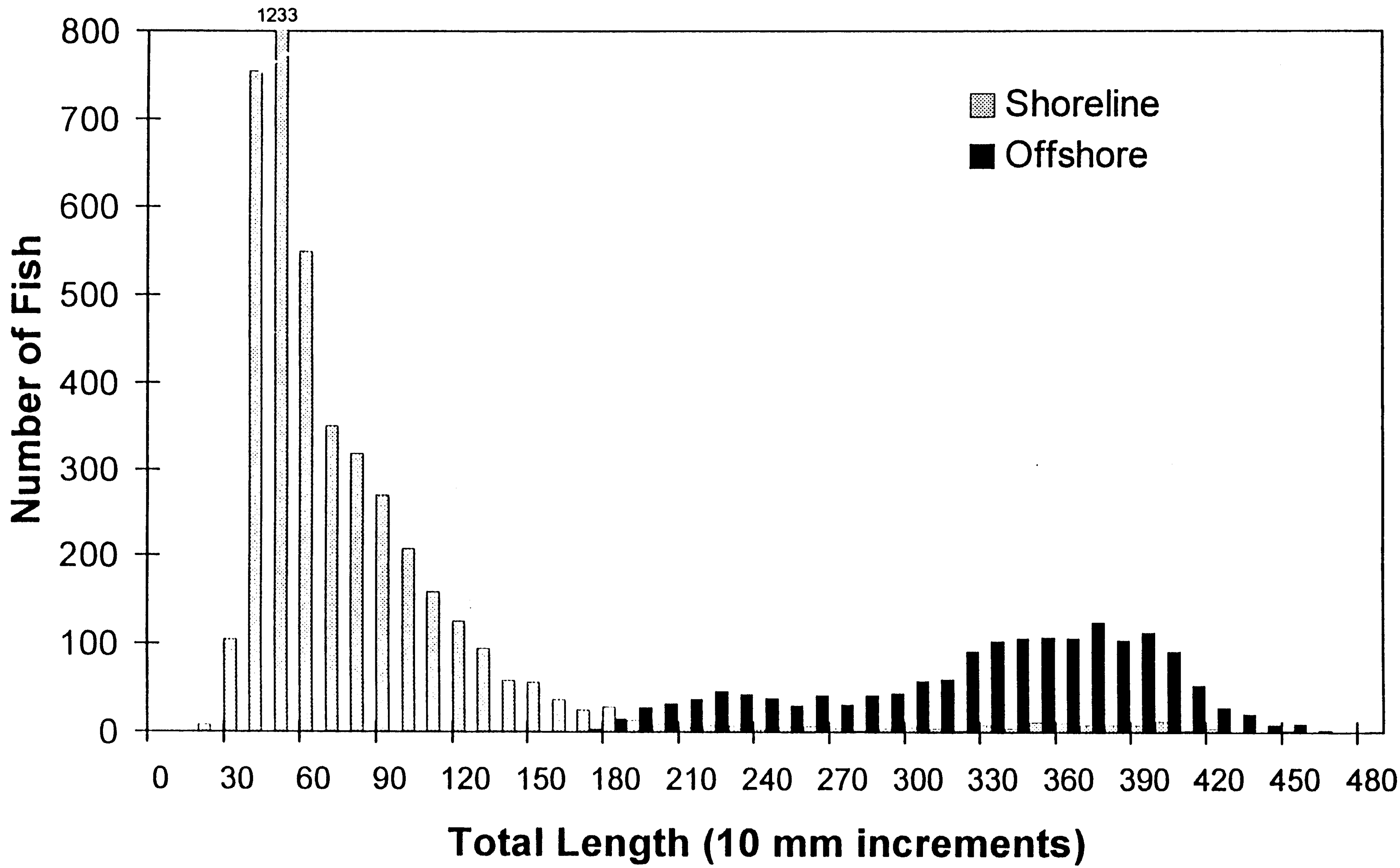



Fig. 8. Length-frequency distribution of humpback chub captured in shoreline habitats (with electrofishing, seines, minnow traps) and in offshore habitats (with gill nets, trammel nets) for 1991-93.

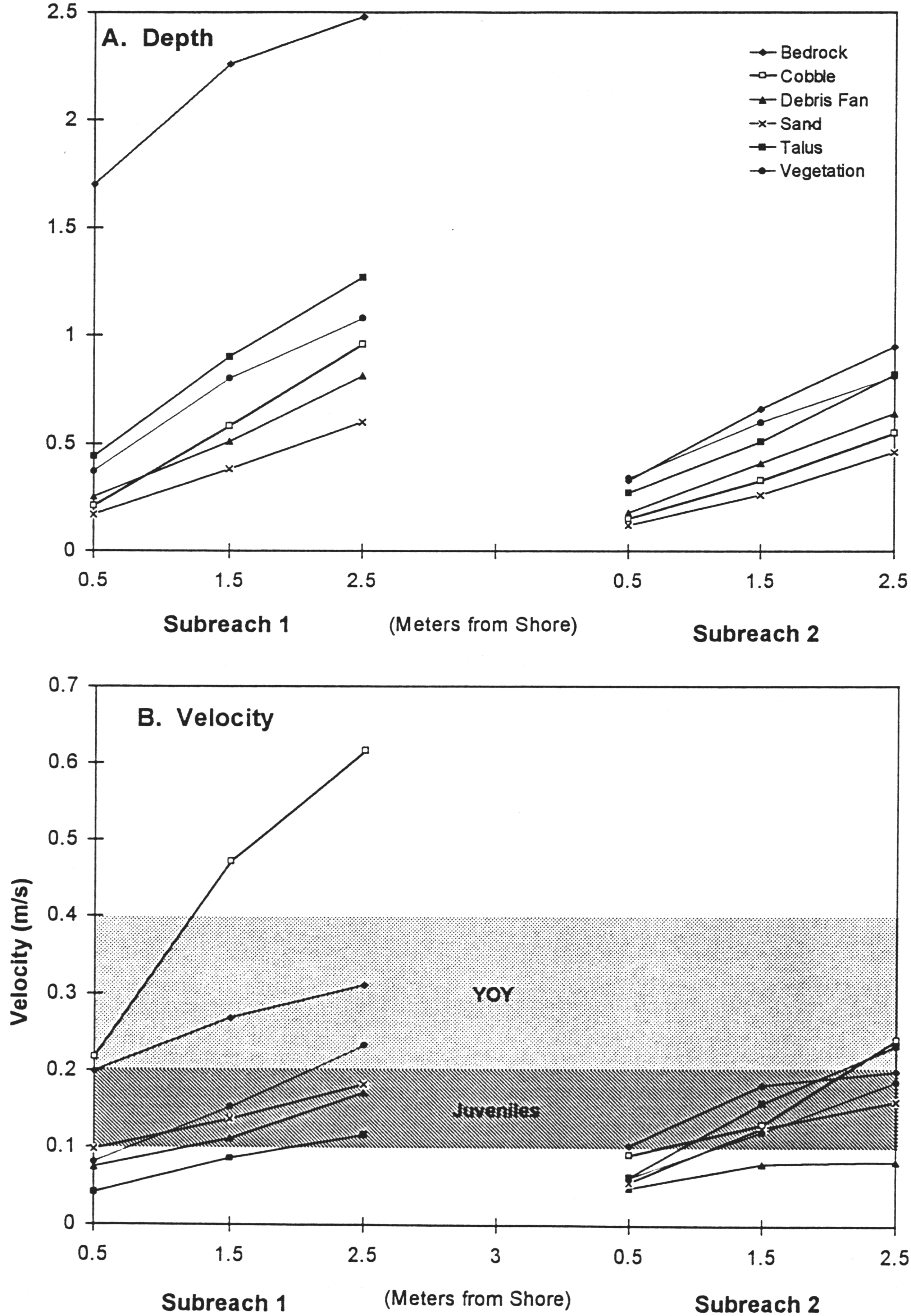



Fig. 9. Average depth (A) and velocity (B) at three distances from shore (0.5, 1.5, and 2.5 m) for six shoreline types in Subreach 1 (RM 61.4-65.4) and Subreach 2 (RM 65.4-73.4). The ranges in cruising speed for YOY and juveniles are shaded areas.

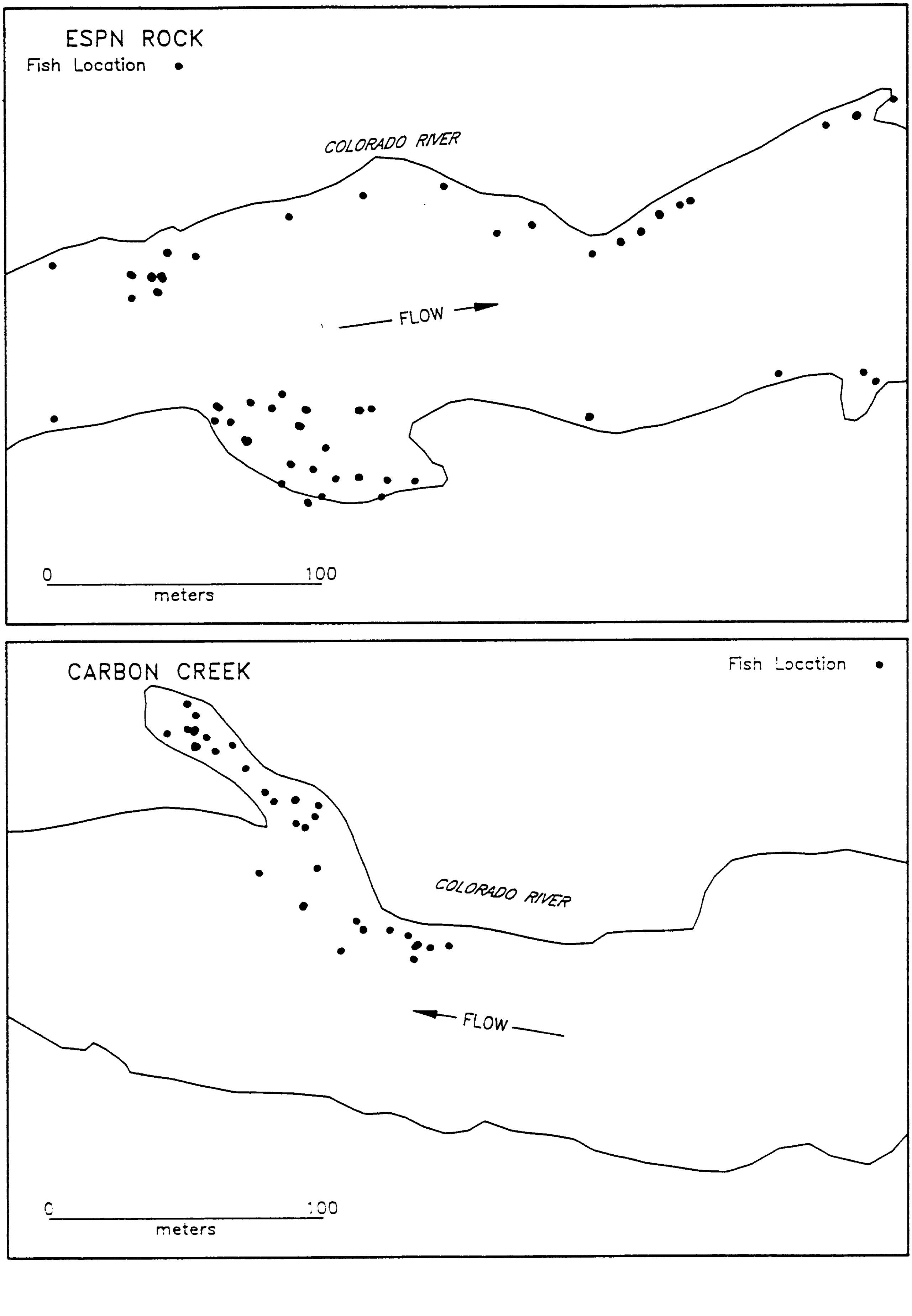
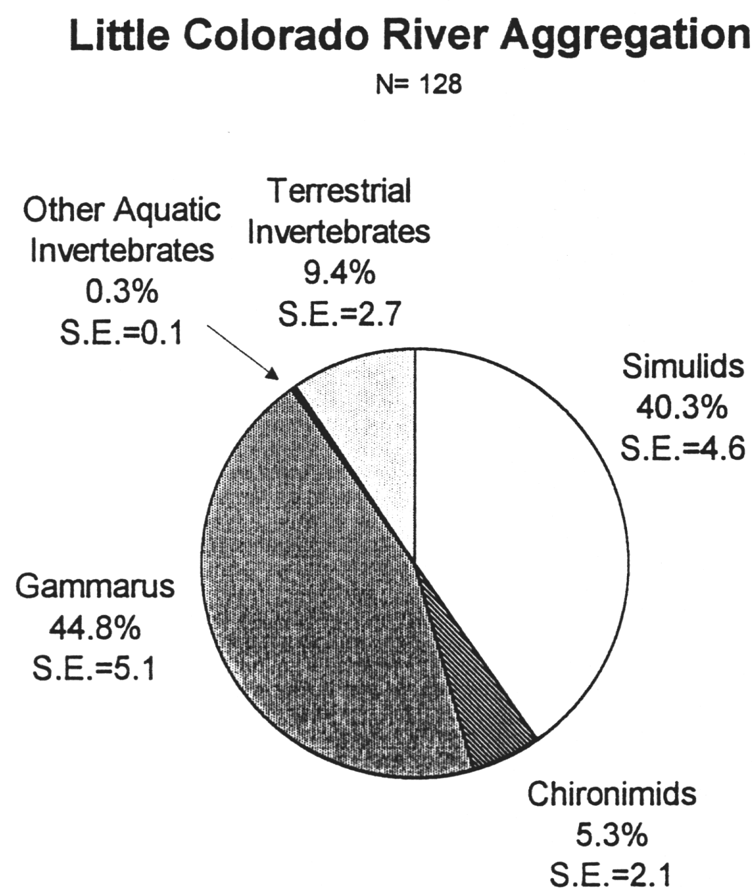



Fig. 10. Radio contact locations for adult radio-tagged humpback chub in the mainstem Colorado River.



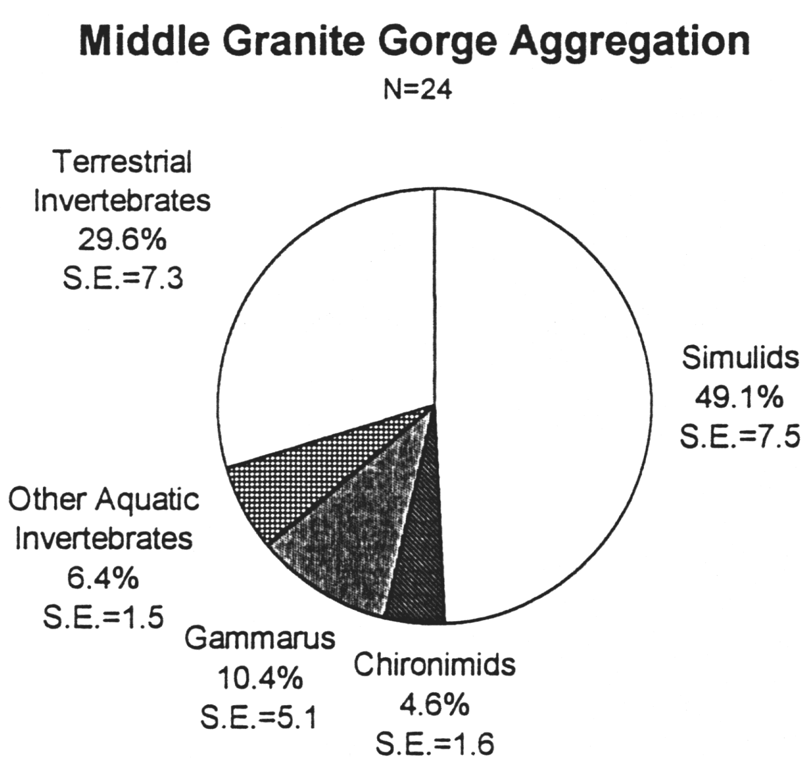




Fig. 11. Volumetric composition of invertebrates found in gut contents of humpback chub from the Little Colorado River aggregations and the Middle Granite Gorge aggregation during 1992-93.

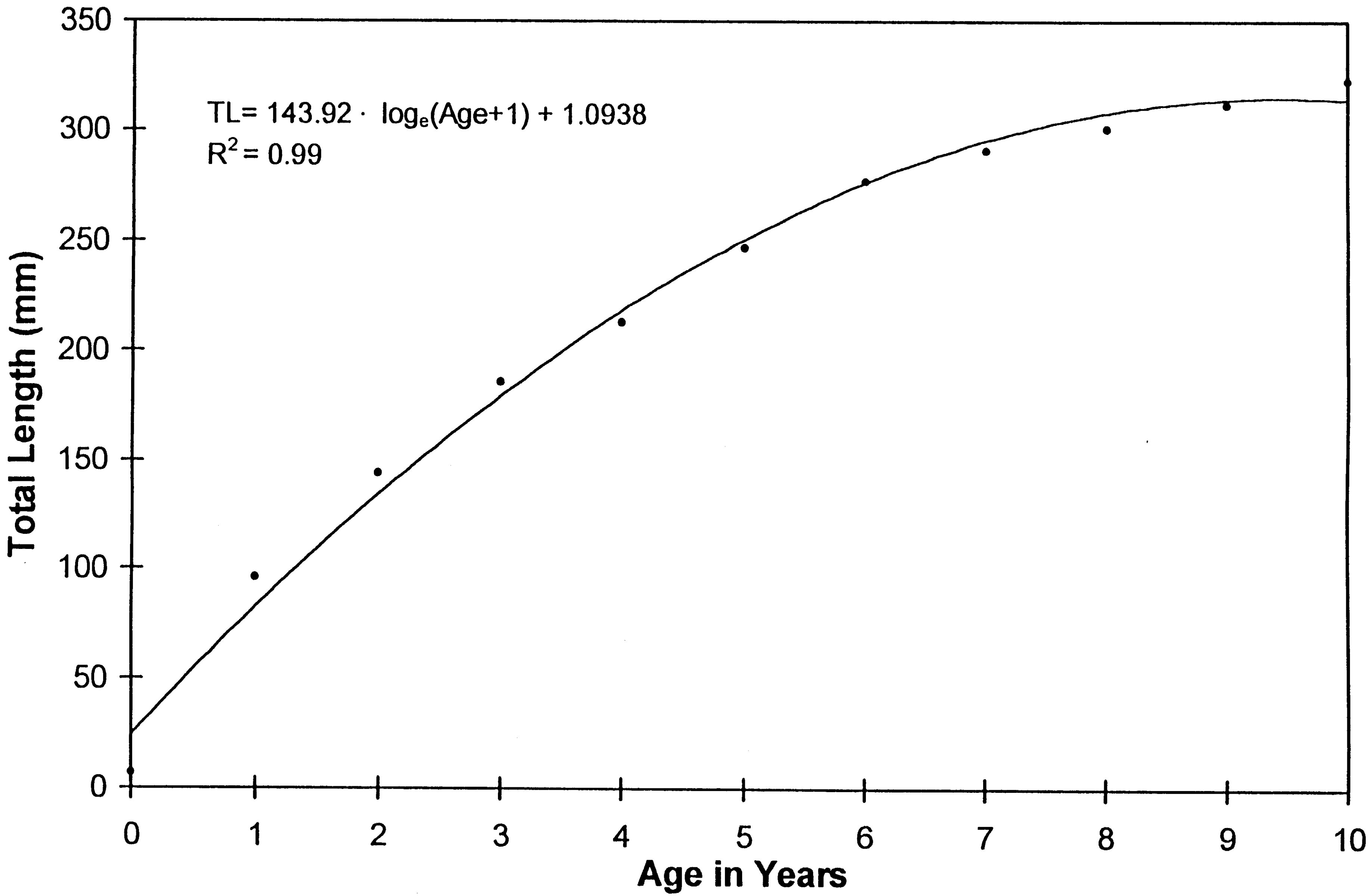



Fig. 12. Logarithmic growth curve for humpback chub in the mainstem Colorado River in Grand Canyon. Hatching length of 7 mm from Muth (1990); length at 1-3 years from scale back-calculations; lengths at 50mm increments for 4+ years from PIT tag recaptures.

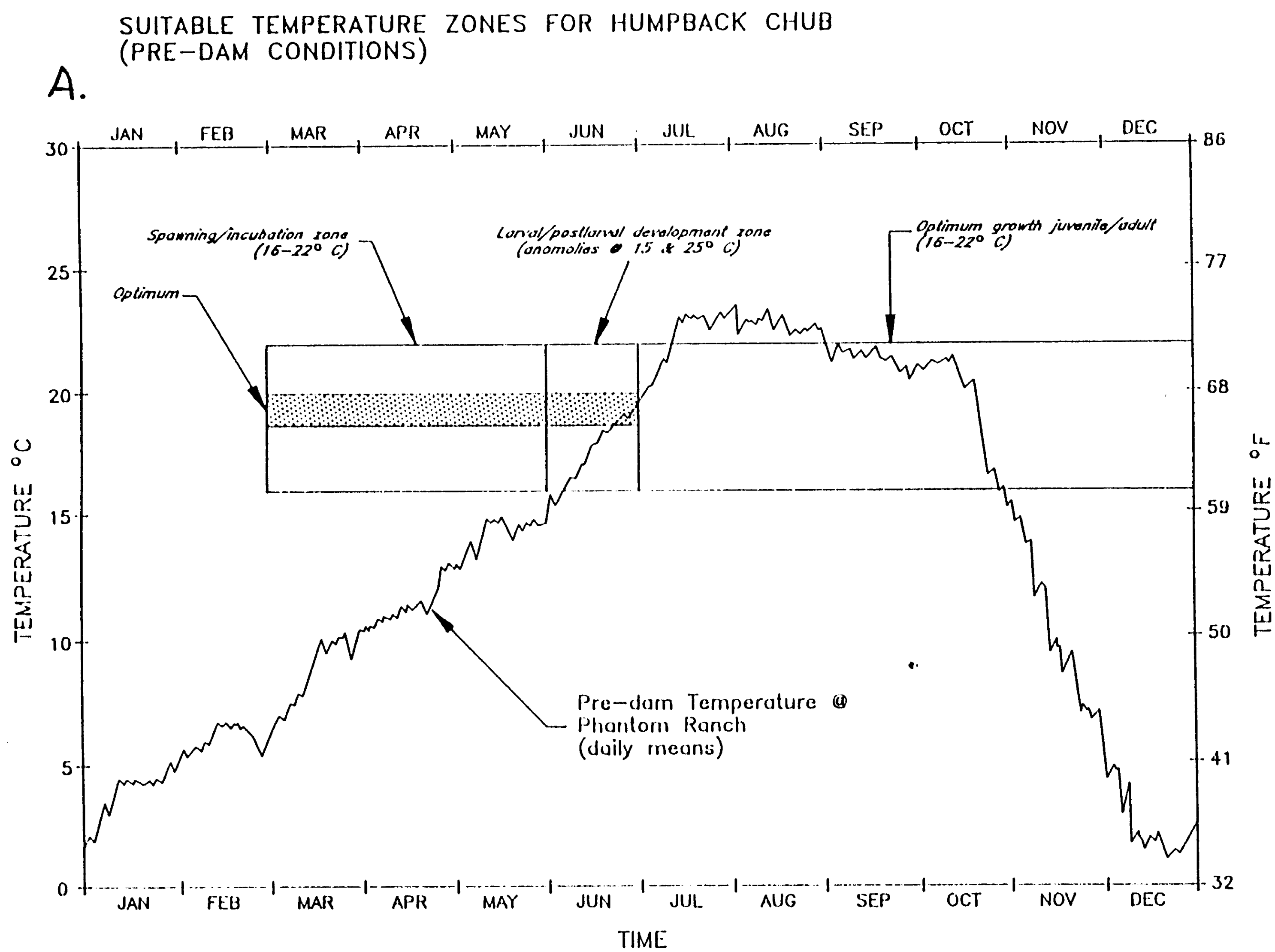



**Fig. 13.** Suitable and optimal temperature range for spawning by humpback chub compared to predam temperature of the Colorado River at Phantom Ranch (A), and the temperature of the LCR and postdam Colorado River at Glen Canyon Dam, LCR, and Diamond Creek (B).

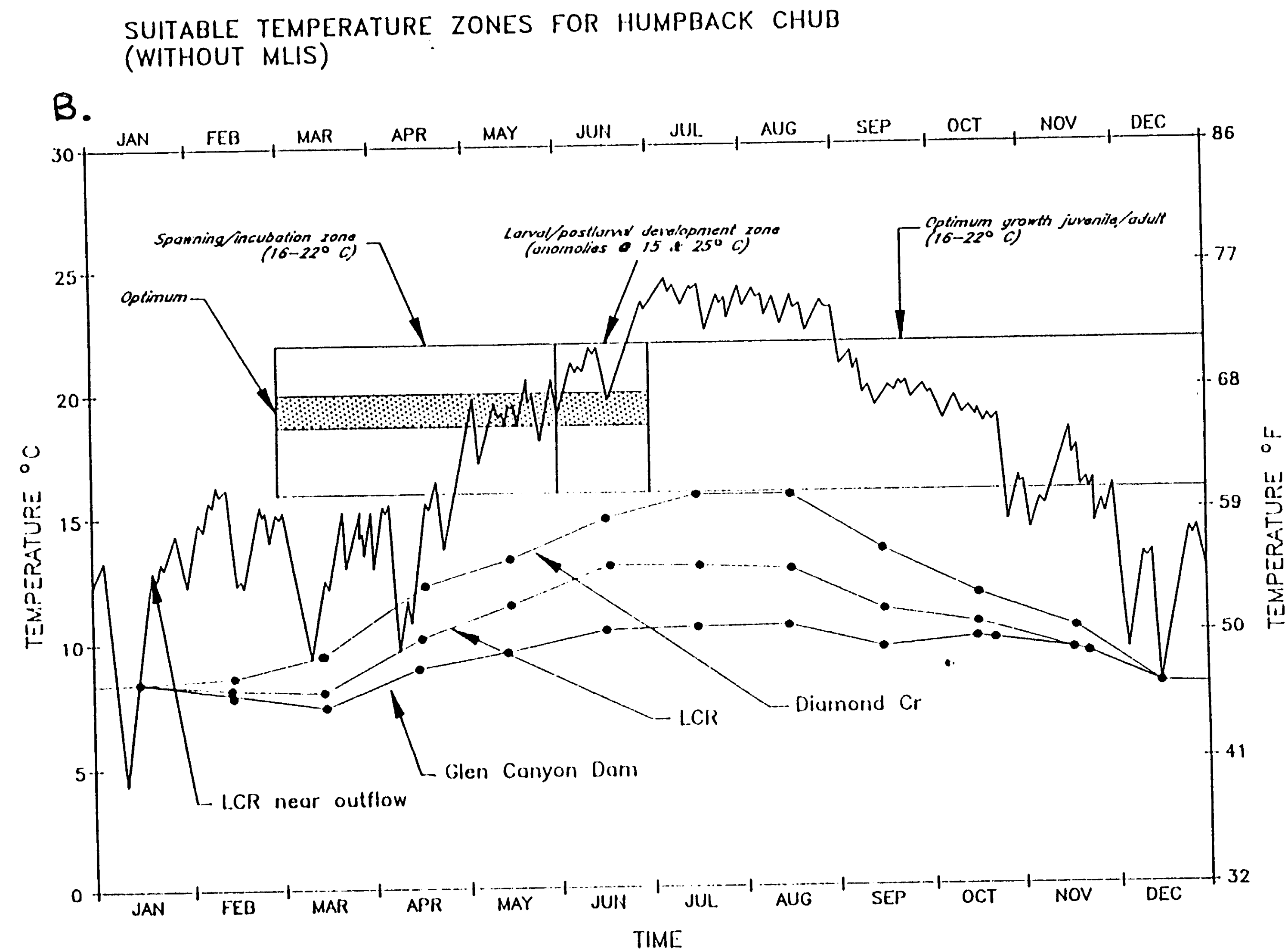



Fig. 13. Continued

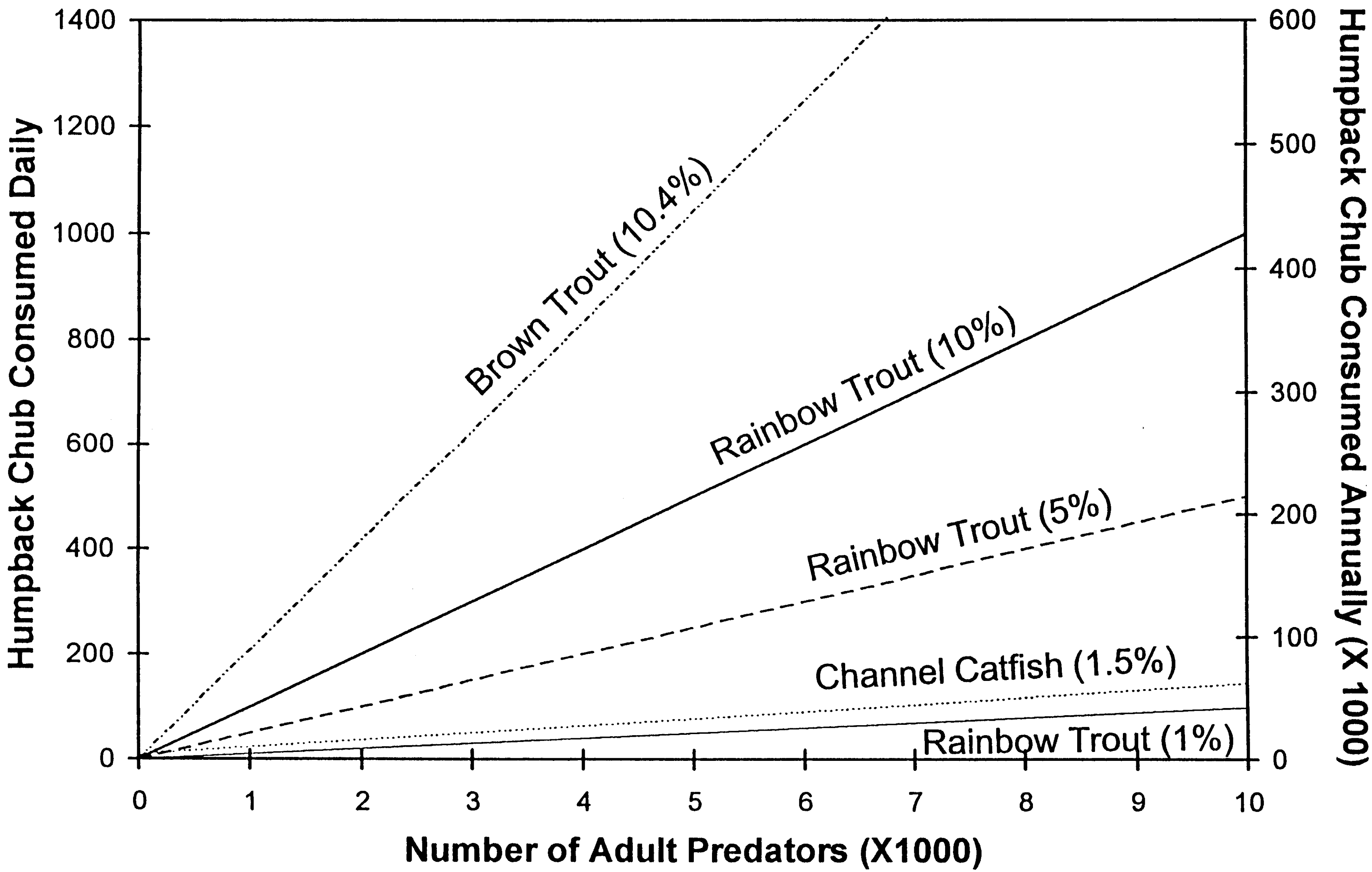



Fig. 14. Potential daily and annual consumption of humpback chub by adults of three predator fish species in the Colorado River in Grand Canyon. Relationships assume 2.0 chubs consumed daily by 10.4% of adult brown trout, 1.0 chub consumed daily by 1, 5, or 10% of adult rainbow trout; 1.0 chub consumed daily by 1.5% of adult channel catfish.

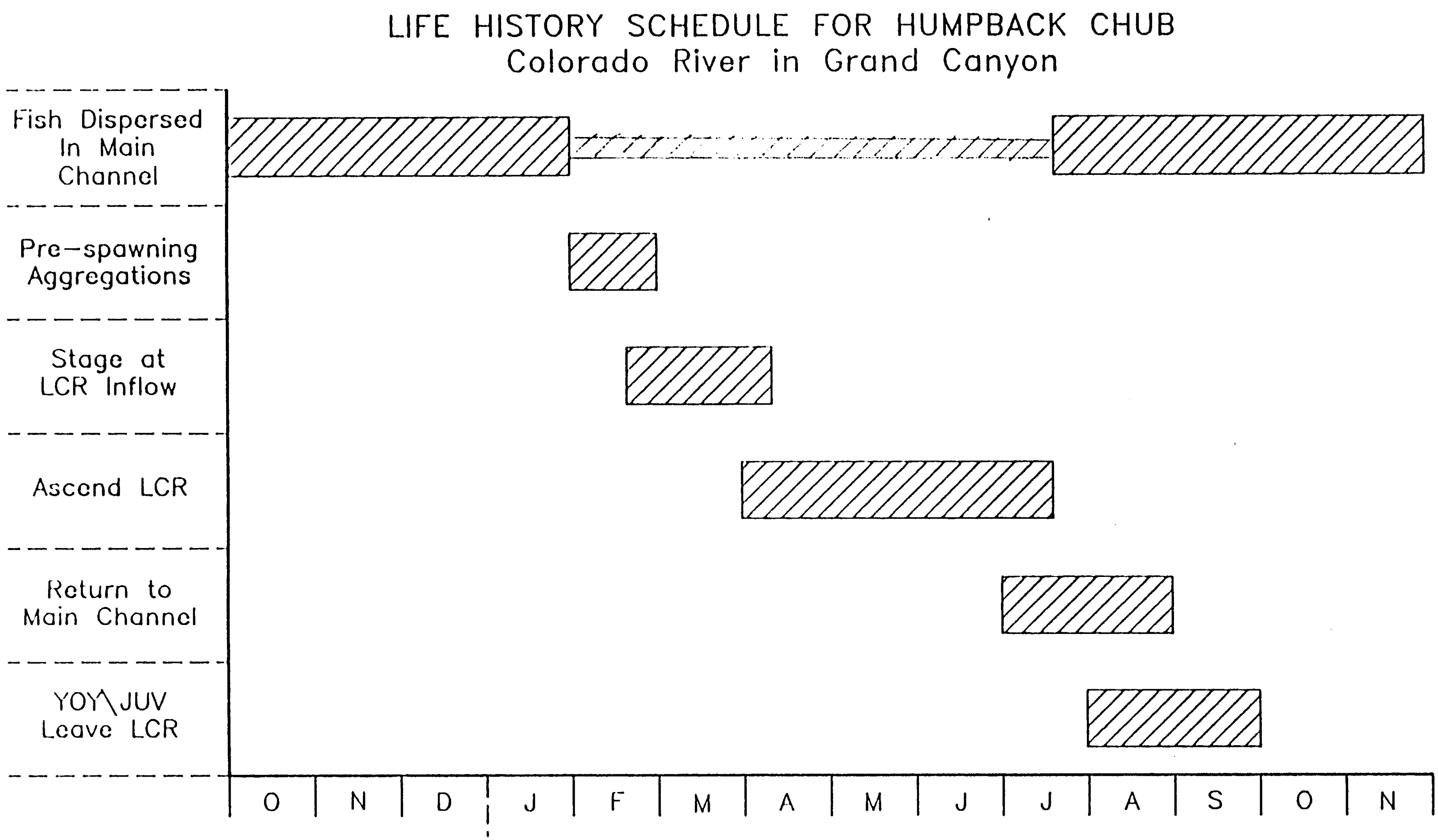



Fig. 15. Life history schedule for the LCRI aggregation of humpback chub in the mainstem Colorado River in Grand Canyon.

**LIFE HISTORY AND ECOLOGY OF THE**
**HUMPBACK CHUB IN GRAND CANYON**
**(Mainstem Colorado River Studies)**

**Preliminary Executive Summary**
**March 1, 1994**

Richard A. Valdez, Ph.D.
Principal Investigator

**INTRODUCTION**

# BIO/WEST, Inc.

*Resource Management*
*and Problem Solving Services*

# LIFE HISTORY AND ECOLOGY OF THE HUMPBACK CHUB IN GRAND CANYON
## (Mainstem Colorado River Studies)

**Preliminary Executive Summary**
**March 1, 1994**

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## INTRODUCTION

BIO/WEST, Inc. conducted investigations of the endangered humpback chub (Gila cypha) in Grand Canyon from October 1990 through November 1993, as part of the Glen Canyon Environmental Studies (GCES). The purpose of the investigation was to determine the relationship between operations of Glen Canyon Dam and the ecology and life history of the humpback chub in the mainstem Colorado River in Grand Canyon. The objectives of the study were to describe and identify limiting factors to distribution, abundance, movement, resource availability and use (habitat, food, water quality), reproductive capacity and success, survivorship, and important biotic interactions.

## DISTRIBUTION

The largest remaining self-sustaining population of humpback chub exists in the Colorado River in Grand Canyon in the vicinity of the Little Colorado River (LCR) inflow. The population consists of two components--an LCR resident component and a mainstem Colorado River component that reproduces in the LCR. The degree of genetic exchange and component overlap is unknown. The mainstem component occurs primarily between RM 58 and RM 77, with the majority of adults between RM 58 and RM 66, and most juveniles between the LCR confluence (RM 61) and RM 77. Of 6,294 humpback chub handled by B/W (2,865 YOY, 1,638 juveniles, 1,791 adults), 95% were captured between RM 58 and RM 77. Small disjunct aggregations of humpback chub were also located at RM 30 and between RM 126 and 129. Small numbers or individuals were captured at RM 83-84 (Clear Creek), RM 92-93, RM 108-109 (Shinumo Creek), RM 114-115, RM 119-120, RM 143-144 (Kanab Creek), RM 156-157 (Havasu Creek), and RM 195 (Figure 1).

The humpback chub population in Grand Canyon is concentrated in the vicinity of the LCR because cold water dam releases limit widespread mainstem spawning and food production. The LCR is the largest accessible tributary available for spawning, and its warm waters enhance food production and delivery in the inflow. Other aggregations of humpback chub in Grand Canyon are primarily associated with other tributary inflows, local tempid springs, and abundant suitable habitat. Very localized spawning may occur in the tempid springs near RM 30 and perhaps in other tributary inflows.

## ABUNDANCE

Humpback chub were the second most abundant of 15 fish species found in the mainstem Colorado River in Grand Canyon. Rainbow trout dominated catch rates from Lees Ferry (RM 0) to Havasu Creek (RM 156), and carp were dominant from Havasu Creek to Diamond Creek (RM 226). The mainstem component of juvenile and adult humpback chub (TL>=175 mm) in the vicinity of the LCR (RM 58-77) was estimated at 3,500 individuals (95% C.I. = 3,104-3,737). Mean monthly shoreline densities (arithmetic mean CPE, excluding backwaters) of humpback chub less than about 175 mm TL varied seasonally from 1.81 fish/100 $m^2$ seined in May to 3.76 fish/100 $m^2$ in August, 1992; and 1.38 fish/100 $m^2$ in May to 19.63 fish/100 $m^2$ in September, 1993. Young and juveniles descended from the LCR to the mainstem primarily during high summer floods in September 1991 and May 1992. Downstream descent in July and August, 1993, occurred in the absence of floods, and may have been the result of high fish densities in the LCR.

Young humpback chub of the 1993 year class were the most abundant of three years classes studied--1991, 1992, and 1993. The strong 1993 cohort followed a near record early spring flood from the LCR (17,000 cfs in January, 1993) and the highest observed adult condition factor, in March 1993, just prior to spawning.

## MOVEMENT

Radiotagged adult humpback chub (n=74) moved an average of only 1.42 km from first to last contact during an average of 85 days of monitoring. Greatest movement was to the LCR during spring spawning movements in February, March, and April. Average net movement of pre-spawning fish was 2.47 km (0.8-13.27), while movement of non-spawning fish was only 0.61 km (0.05-2.5). About 80% of radiotagged adults moved less than 2 km from their original release locations. PIT-tagged fish (>150 mm TL, n=124) were recaptured an average of 1.45 km from release locations during an average of 154 days at large.

Of approximately 3,000 juvenile and adult humpback chub (>175 mm TL) PIT-tagged and released between RM 58 and RM 77, none was recaptured downstream or upstream of this river reach, suggesting no exchange of juveniles and adults with disjunct aggregations. One PIT-tagged fish moved from RM 127.6 to RM 108.5. Movement of radiotagged adults and net catch information showed simultaneous movement by mainstem fish to the LCR from above and below its inflow, suggesting external reproductive cues, such as photoperiod. Pre-spawning adults moved into the LCR under a wide range of mainstem flows. Timing of movement and actual ascent were delayed by high flows and sediment loads in the LCR.

Season, time of day, water clarity, and possibly flow magnitude and ramping rate affected near-surface activity of humpback chub. Adults were significantly more active near-surface during spawning (February-May) than other seasons. These fish were also significantly more active at night during high water clarity, but activity was not significantly different between day and night during moderate to high turbidity (>30 NTU's). These findings and radiotelemetry monitoring showed greatest movement by humpback chub during crepuscular periods, and use of turbidity as cover to extend activity during both day and night.

Implementation of interim flows in August 1991 resulted in a reduction in average rate of stage change of 14.4 cm/hour to 5.4 cm/hour, and a 28% decrease in movement by adult humpback chub. Although not significant, decreased activity indicates less energy expenditure by adults under interim flows.

## HABITAT AVAILABILITY AND USE

Length analysis of humpback chub indicates a major transition from shoreline to offshore habitats of fish larger than 175 to 200 mm TL, or 2-3 years of age. Run habitat made up an average of 69% of surface area between RM 60 and RM 64, while eddies and pools were only 19% and 11% of surface area, and eddy return channels, riffles, and rapids each made up less than 1 percent of surficial habitat. Approximately 85% of humpback chub over 200 mm TL (adults) were captured in eddy complexes, and about 80% of radiocontacts were from eddies. Bathymetric maps of these eddies revealed maximum depths of 12-14 m, with nearly 70% of the complex less than 4 m deep and less than 0.5 m/sec velocity.

The majority of YOY and juvenile humpback chub were found along talus and vegetated shorelines, and in eddy return channels (backwaters). Water depth and velocity did not change significantly relative to the shoreline under the range of flows seen during interim operations. These young fish used shorelines with pocket water cover of 1.0 to 1.8 m deep and 0.08 to 0.10 m/sec.

## FOOD HABITS

Adult humpback chub in the Colorado River in Grand Canyon ate primarily simuliids (62% by volume), Gammarus lacustris (24%), midges (13%), and annelid worms, terrestrial insects, and algae, Cladophora glomerata (1%). The proportion of terrestrial insects in the diet increased downstream of Havasu Creek, indicating decreased abundance of aquatic invertebrates. The numbers of organisms in drift above the LCR, from LCR to Hance, and from Hance to Diamond Creek decreased from 248 organisms/100 $m^3$ to 190 to 96, showing decreased drift food availability from eastern to western Grand Canyon. Densities of drifting organisms was significantly greater during falling flows (380/100 $m^3$) than during rising flows (177/100 $m^3$), indicating that food organisms were dislodged with rising flows.

## WATER QUALITY

Water temperature and turbidity had the greatest effect on humpback chub in the mainstem Colorado River in Grand Canyon. Low mainstem temperatures restricted spawning primarily to the LCR. Greatest downstream longitudinal warming was in July from 9 C at the dam to 11 C at RM 75, to 16 C at RM 214, or an increase of about 1 C for every 28 miles. Although western Grand Canyon may be warmer in mid-summer, low food production may preclude establishment of additional populations of humpback chub in lower canyon reaches.

A prolonged period of turbidity in winter 1992-93 from early runoff in the LCR and Paria River, greatly reduced numbers of rainbow trout near and below the LCR inflow. A large immigration of young humpback chub into the mainstem from the LCR resulted in a dominance of the mainstem ichthyofauna near the LCR.

## REPRODUCTIVE CAPACITY AND SUCCESS

The majority of reproduction by humpback chub in Grand Canyon is limited to the LCR from March through May. Reproduction appears to occur in the mainstem, but it is very limited and localized. Discovery of larvae by AGF indicates spawning in the tempid springs nearly RM 30, and possibly in tributary inflows or unknown springs in the lower canyon. B/W has also captured tubercled adults at RM 30 and near RM 126 in mid to late summer, indicating that mainstem spawning attempts occur later than the LCR spawning activity. Additional investigations are needed to ascertain the size and extent of disjunct humpback chub aggregations, and to carefully sample for recently emerged larvae.

## IMPORTANT BIOTIC INTERACTIONS

Brown trout, rainbow trout, and channel catfish are documented predators of humpback chub in Grand Canyon. Brown trout were the most significant mainstem predator, with 10% of individuals captured containing one to seven humpback chub. Of 40 striped bass captured, none contained identifiable stomach contents.

Rainbow trout may also compete for food with humpback chub, since favored food items by both species were simuliids, amphipods, and midges. Limited food resources may be limiting additional fish populations and densities in western Grand Canyon. Asian tapeworms (<u>Bothriocephalus</u> <u>acheilognathi</u>) were first reported in humpback chub in Grand Canyon in 1989, and were in found in about 10% of adult guts evacuated with a stomach pumped.

Of four native species captured in the mainstem Colorado River in Grand Canyon, total numbers were humpback chub (6,294), flannelmouth suckers (2,775), speckled dace (1,491), and bluehead suckers (1,040). Approximately 79% and 66% of flannelmouth suckers and bluehead suckers were adults, while only 7% and 10% were YOY, respectively.

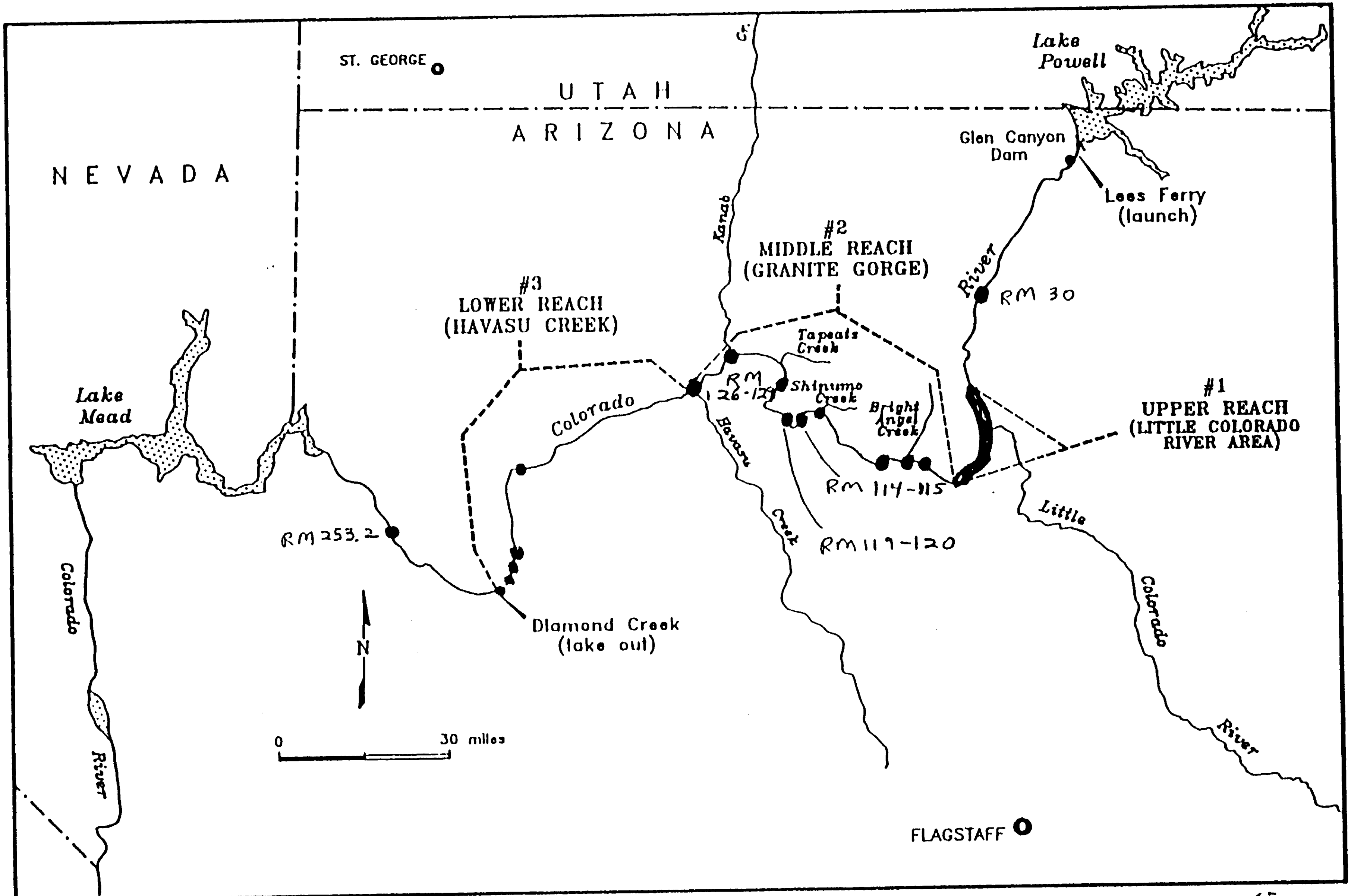


Figure 1. BIO/WEST study area in Grand Canyon and three study reaches, with distribution of humpback chub (Gila cypha)

February 15, 1994

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**BIO/WEST Reports October 1990 - December 1993**

## Trip Reports

Valdez, R.A. and W.J. Masslich. 1990. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 1, October 1990. PR-250-01.

Valdez, R.A., W.J. Masslich, and L. Crist. 1990. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 2, November 1990. PR-250-02.

Valdez, R.A., W.J. Masslich, and L. Crist. 1990. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 3, December 1990. PR-250-03.

Valdez, R.A., W.J. Masslich, and L. Crist. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 1, January 1991. PR-250-04.

Valdez, R.A., W.J. Masslich, and L. Crist. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 2, February 1991. PR-250-05.

Valdez, R.A., W.J. Masslich, and L. Crist. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 3, March 1991. PR-250-06.

Valdez, R.A., W.J. Masslich, and L. Crist. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 4, April 1991. PR-250-07.

Valdez, R.A., W.J. Masslich, and L. Crist. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 5, May 1991. PR-250-08.

Valdez, R.A. and W.J. Masslich. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 6, June 1991. PR-250-09.

Valdez, R.A., W.J. Masslich, W. Leibfried, and D.R. VanHaverbeke. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 7, July 1991. PR-250-10.

Valdez, R.A., W.J. Masslich, and W.C. Leibfried. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 8, August 1991. PR-250-11.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 9, September 1991. PR-250-12.

Valdez, R.A. and B.R. Cowdell. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 10, October 1991. PR-250-13.

Valdez, R.A., W.J. Masslich, and W.C. Leibfried. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 11, November 1991. PR-250-14.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 1, January 1992. PR-250-15.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 2, February 1992. PR-250-16.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 3, March 1992. PR-250-17.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 4, April 1992. PR-250-18.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 5, May 1992. PR-250-19.

Valdez, R.A. and B.R. Cowdell. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 6, June 1992. PR-250-20.

Valdez, R.A., A. Wasowicz, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 7, July 1992. PR-250-21.

Valdez, R.A. and W.J. Masslich. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 8, August 1992. PR-250-22.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 9, September 1992. PR-250-23.

Valdez, R.A. and B.R. Cowdell. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 10, October 1992. PR-250-24.

Valdez, R.A., A. Wasowicz, W.J. Masslich, and W. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 11, November 1992. PR-250-25.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 1, January 1993. PR-250-26.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 2, February 1993. PR-250-27.

Valdez, R.A., W.J. Masslich, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 3, March 1993. PR-250-28.

Valdez, R.A., A. Wasowicz, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 4, April 1993. PR-250-29.

Valdez, R.A., W. Masslich, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 5, May 1993. PR-250-30.

Valdez, R.A., W. Masslich, and B. Cowdell. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 6, June 1993. PR-250-31.

Valdez, R.A., W. Masslich, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 7, July 1993. PR-250-32.

Valdez, R.A. and B. Cowdell. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 8, August 1993. PR-250-33.

Valdez, R.A., W. Masslich and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 9, September 1993. PR-250-34.

Valdez, R.A. and W. Masslich. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 10, October 1993. PR-250-35.

Valdez, R.A., A. Wasowicz, and W. Leibfried. 1993. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Trip Report No. 11, November 1993. PR-250-36.

**Annual Reports**

Valdez, R.A. 1991. Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. Annual Report - 1990 to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-02. 74 pp.

Valdez, R.A., W.J. Masslich, W.C. Leibfried. 1992. Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. Annual Report - 1991 to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-04. 222 pp.

Valdez, R.A., and M. Hugentobler (editors). 1993. Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. Annual Report - 1992 to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-06. 168 pp + appendices.

Valdez, R.A. (editor). In preparation - Due October 1994. Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. Final Report to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08.

**Other Reports**

Valdez, R.A. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Data Collection Plan. BIO/WEST, Inc., Logan, Utah. Submitted to Bureau of Reclamation, Salt Lake City, Utah. BIO/WEST Report No. TR-250-01.

Valdez, R.A. and L.P. Trinca. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Data Collection Handbook. BIO/WEST, Inc., Logan, Utah, Revised July, 1991, Revised September, 1992.

Valdez, R.A. 1992. Long-Term Monitoring Plan for Native Fishes of the Colorado River in Grand Canyon, Arizona. Environmental Monitoring of Glen Canyon Dam Operations. Draft. BIO/WEST, Inc., Logan, Utah. Submitted to National Research Council Water Science and Technology Board, Washington, D.C.

Valdez, R.A. and W.J. Masslich. 1991. Characterization of the Life History and Ecology of the Humpback Chub in the Grand Canyon. Boating Safety and Operations Protocol. Prepared for Team Members and Volunteers, BIO/WEST Field Teams. BIO/WEST Report No. TR-250-03.

Valdez, R.A. and T. Wasowicz. 1992. Non-lethal Stomach Pumping Technique to Recover Gut Contents of Roundtail Chub (Gila robusta). BIO/WEST Inc. Logan Utah, submitted to Aquatic Coordination Team, Glen Canyon Environmental Studies, BOR.

Ryel, R.J. and R.A. Valdez. 1993. Development of a Population Model for Humpback Chub (Gila cypha) in Grand Canyon. Phase I: A Feasibility Evaluation. BIO/WEST Inc. Logan, Utah. Submitted to Glen Canyon Environmental Studies, BOR. BIO/WEST Report No. TR-250-07.

## Papers and Presentations

Cowdell, B. and R. Valdez. 1993. Effects of Pulsed DC Electroshock on Adult Roundtail Chub. Upper Basin Researchers Meeting, Grand Junction, CO, January 19-22, 1993; American Fisheries Society, Bonneville Meeting, St. George, UT, February 24-26, 1993.

Cowdell, B. and R. Valdez. In Review. Effects of Pulsed DC Electroshock on Adult Roundtail Chub. North American Journal of Fisheries Management.

Hougaard, T.R. and R.A. Valdez. In Review. A Multi-Temporal, Multi-Accuracy Fisheries GIS Database for the Colorado River in Grand Canyon. Arizona. American Society for Photogrammetry and Remote Sensing American Congress on Surveying and Mapping.

Masslich, W.J., B. Cowdell, and R.A. Valdez. 1992. Radiotelemetry Studies of Humpback Chub (Gila cypha) in the Colorado River, Grand Canyon, Arizona. Desert Fishes Council 24th Annual Symposium, Mesa, AZ, November 18-21, 1992.

Masslich, W.J. and R.A. Valdez. In Review. The Effects of Turbidity on Movement and Activity of Humpback Chub in Grand Canyon. North American Journal of Fisheries Management.

Valdez, R.A. 1992. Habitat Use of Humpback Chub in the Grand Canyon. Upper Basin Researchers Meeting, Moab, UT, February 11-12, 1992.

Valdez, R.A. 1992. Humpback Chub in the Grand Canyon, AZ. American Fisheries Society, Bonneville Meeting, Grand Junction, CO, February 26-28, 1992; Desert Fishes Council 24th Annual Symposium, Mesa, AZ, November 18-21, 1992.

Valdez, R.A. 1993. Update on Humpback Chub Studies in the Grand Canyon. Upper Basin Researchers Meeting, Grand Junction, CO, January 19-22, 1993.

Valdez, R.A., W.J. Masslich, L. Crist, and W.C. Leibfried. 1991. Field Methods for Studying the Colorado River Fishes in Grand Canyon National Park. First Biennial Conference on Research in Colorado Plateau National Parks, Flagstaff, AZ, July 22-25, 1991, pp. 23-36.

Valdez, R.A., W.J. Masslich, L. Crist and W. Leibfried. 1991. Investigations of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. Desert Fishes Council 23rd Annual Symposium, Furnace Creek, CA, November 21-23, 1991.

Valdez, R.A. and W.J. Masslich. 1992. Activity of Humpback Chub Under Fluctuating Flows in the Colorado River, Grand Canyon. American Fisheries Society, Western Division Meeting, Ft. Collins, CO, July 13-16. 1992.

Valdez, R.A, W.J. Masslich, and W. Leibfried. 1992. Present Distribution of Humpback Chub (Gila cypha) in the Mainstem Colorado River, Grand Canyon, Arizona. Desert Fishes Council 24th Annual Symposium, Mesa, AZ, November 18-21, 1992.

Wasowicz, T., R.A. Valdez, W.J. Masslich, B.R. Cowdell and W. Leibfried. 1992. Non-lethal stomach Pumping Technique to Recover Gut Contents of Roundtail Chub. Desert Fishes Council 24th Annual Symposium, Mesa, AZ, November 18-21, 1992; Upper Basin Researchers Meeting, Grand Junction, CO, January 19-22, 1993; American Fisheries Society, Bonneville Meeting, St. George, UT, February 24-26, 1993.

Wasowicz, A. and H. Yard. 1993. Predation by Osprey on Endangered Humpback Chub. Great Basin Naturalist. 53(3):314-315.

Wasowicz, T. and R. Valdez. In Review. Non-Lethal Stomach Pumping Technique to Recover Gut Contents of Endangered Humpback Chub. North American Journal of Fisheries Management.