Report No. TR-250-06
BIO/WEST, Inc.

CHARACTERIZATION OF THE LIFE HISTORY AND ECOLOGY OF THE HUMPBACK CHUB (Gila cypha) IN THE GRAND CANYON

ANNUAL REPORT - 1992
(CONTRACT NO. 0-CS-40-09110)

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Upper Colorado River Region
Salt Lake City, Utah 84147

Submitted By

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DISCLAIMER

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The following were key BIO/WEST personnel in data collection and contributed to this report.

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Our deepest gratitude to the volunteers: Paul Lauck, Karren Grady, Joe Mansour, Tom Martin, Illa Bromberg, Stuart Houston, Deb Combly, Sue Shuhardt, Peg Abbott, S. Trimmer, Ralf Buckley, Diane Wydoski, Debbie Reynolds, Debbie Kuznitz, Mark Littlefield, Merideth Gregg, Jody Williams, Miles Moretti, Drew Erickson, Sandy Kaplan, Jeff Wasowicz, Juan Pedro Sustaita, Adele Fegley, Walt Burkhardt, Mike Cooper, Brian Roberts, Lorraine Wasowicz, Peggy Wood, Margie Hensley, Patrick Cone, Gabe Jaramillo, Marjorie Preus, Paula Trater, S. Saunders, and Dave Phillips.

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Finally, we pay tribute to the late Dr. Merec Kalizewski of Brigham Young University, for his dedication and efforts at providing a better understanding of the genetics of the Colorado River fishes.

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CHAPTER 1 - INTRODUCTION AND STUDY REGION

Primary Authors: Richard A. Valdez and Craig Goodwin

This Annual Report was submitted to Bureau of Reclamation (Reclamation) by BIO/WEST, Inc. (B/W), in partial fulfillment of Reclamation Contract No. 0-CS-40-09110, entitled Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. This investigation was initiated on September 1, 1990, and is scheduled for completion on October 15, 1994 (due date for Final Report). This report summarizes the results of this investigation for the calendar year 1992. A previous report (Valdez et al. 1992) integrated our findings from the beginning of the investigation, in October 1990, through December 1991. Eleven monthly field trips were conducted in 1992, and a trip report was submitted to Reclamation and interested parties following each trip. A complete project schedule is included in Figure 1-1.

PURPOSE

The purpose of this investigation is as follows:

> To conduct in cooperation with the U.S. Fish and Wildlife Service and Arizona Game and Fish Department ecological studies to determine the relationship between operations of Glen Canyon Dam and the ecology and life history requirements of the endangered humpback chub population in Grand Canyon.

This 4-year investigation focuses on the collection and analysis of biological information to test hypotheses on the effects of Glen Canyon Dam operations on the life history and ecology of the endangered humpback chub in Grand Canyon. This investigation is being conducted in conjunction with the Glen Canyon Environmental Studies (GCES), to aid federal and state agencies in their mandated responsibility to protect and, where possible, promote the continued existence and recovery of the species. This research was designed to collect information to address portions of two of seven conservation measures arising from the 1978 Biological Opinion on Glen Canyon Dam operations. This includes Conservation Measure 5, "Conduct research to identify impacts of glen canyon dam operations on the humpback chub in the mainstem and tributaries" and Conservation Measure 7, "Establish a second spawning population of humpback chub in the Grand Canyon". Information from this investigation is also being incorporated into the Glen Canyon Dam Environmental Impact Statement (EIS).

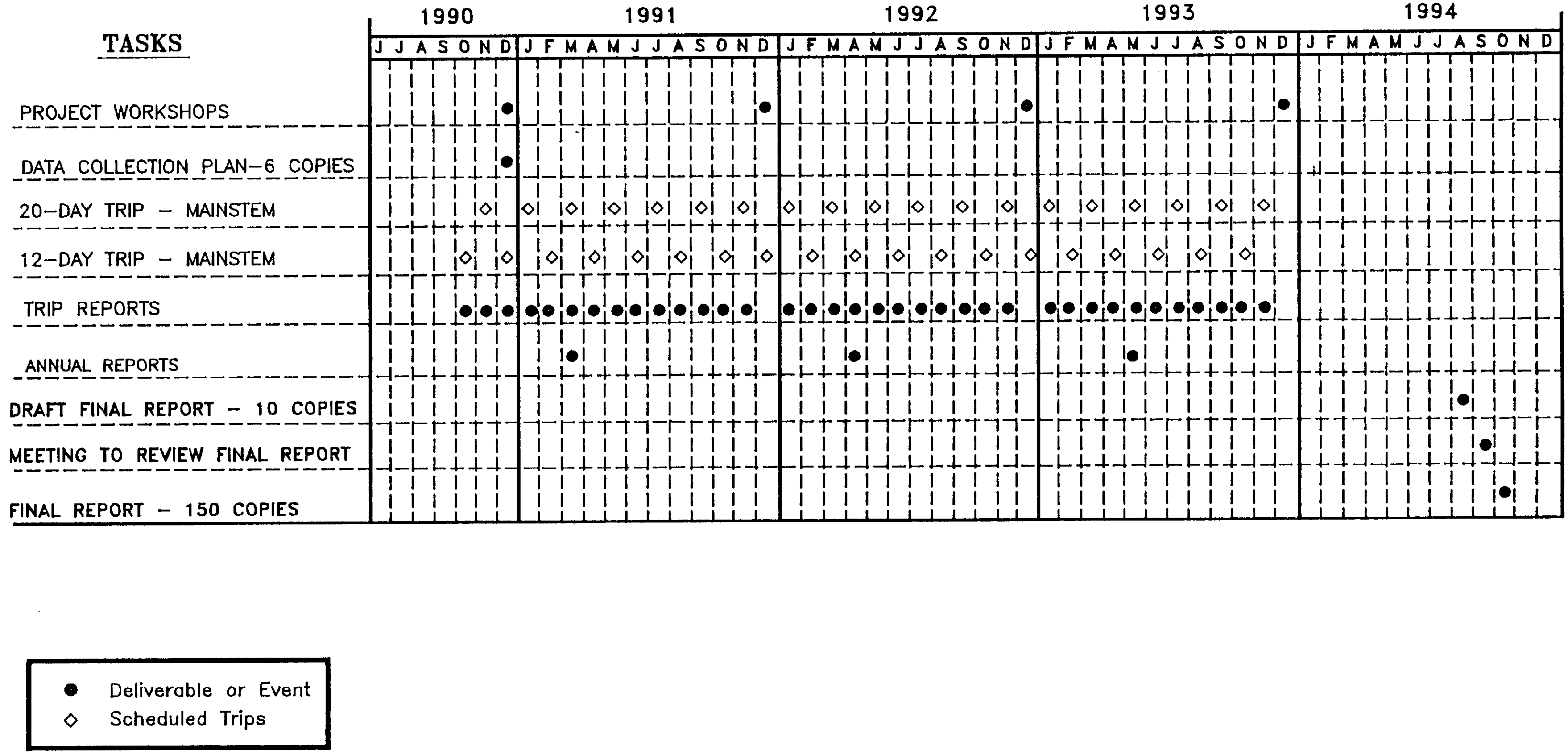

Figure 1-1. BIO/WEST project schedule, Grand Canyon Humpback Chub Study

OBJECTIVES

This mainstem investigation is being conducted by B/W, concurrent with Arizona Game and Fish Department (AGF). Tributary studies by the U.S. Fish and Wildlife Service (Service), AGF, and Arizona State University (ASU), in cooperation with the Navajo Nation, the Hopi Tribe, and the Hualapai Tribe, are designed to complement the mainstem studies. These entities, together with the National Park Service (NPS), Reclamation, and GCES, comprise the Aquatic Coordination Team (ACT)--a body of researchers that coordinate aquatic studies and advise GCES. The objectives of the combined humpback chub investigations are as follows:

Objective 1: To determine the ecological and limiting factors of all life stages of humpback chub in the mainstem Colorado River, Grand Canyon, and the effects of Glen Canyon Dam operations on the humpback chub.

- 1A: Determine resource availability and resource use (habitat, water quality, food, etc.) of humpback chub in the mainstem Colorado River.
- 1B: Determine reproductive capacity and success of humpback chub in the mainstem Colorado River.
- 1C: Determine survivorship of early stages of humpback chub in the mainstem Colorado River.
- 1D: Determine distribution, abundance and movement of humpback chub in the mainstem Colorado River, and effects of dam operations on the movement and distribution of humpback chub.
- 1E: Determine important biotic interactions with other species for all life stages of humpback chub.

Objective 2: Determine the life history schedule for the Grand Canyon humpback chub population.

- 2A: Develop or modify an existing population model from empirical data collected during the study for use in analyses of reproductive success, recruitment and survivorship.

REACH DESCRIPTIONS

This investigation was conducted in a 170-mile (275-km) region of the Colorado River in Grand Canyon, from Kwagunt Rapid (River Mile [RM] 56) to Diamond Creek (RM 226) (Fig. 1-2). This region was divided into three study reaches, including: (1) Reach 1--20.6 miles from Kwagunt Rapid (RM 56.0) to Hance Rapid (RM 76.6), (2) Reach 2--83.4 miles from Hance Rapid to below Havasu Creek (RM 160.0), and (3) Reach 3--66.0 miles from below Havasu Creek to Diamond Creek (RM 226.0).

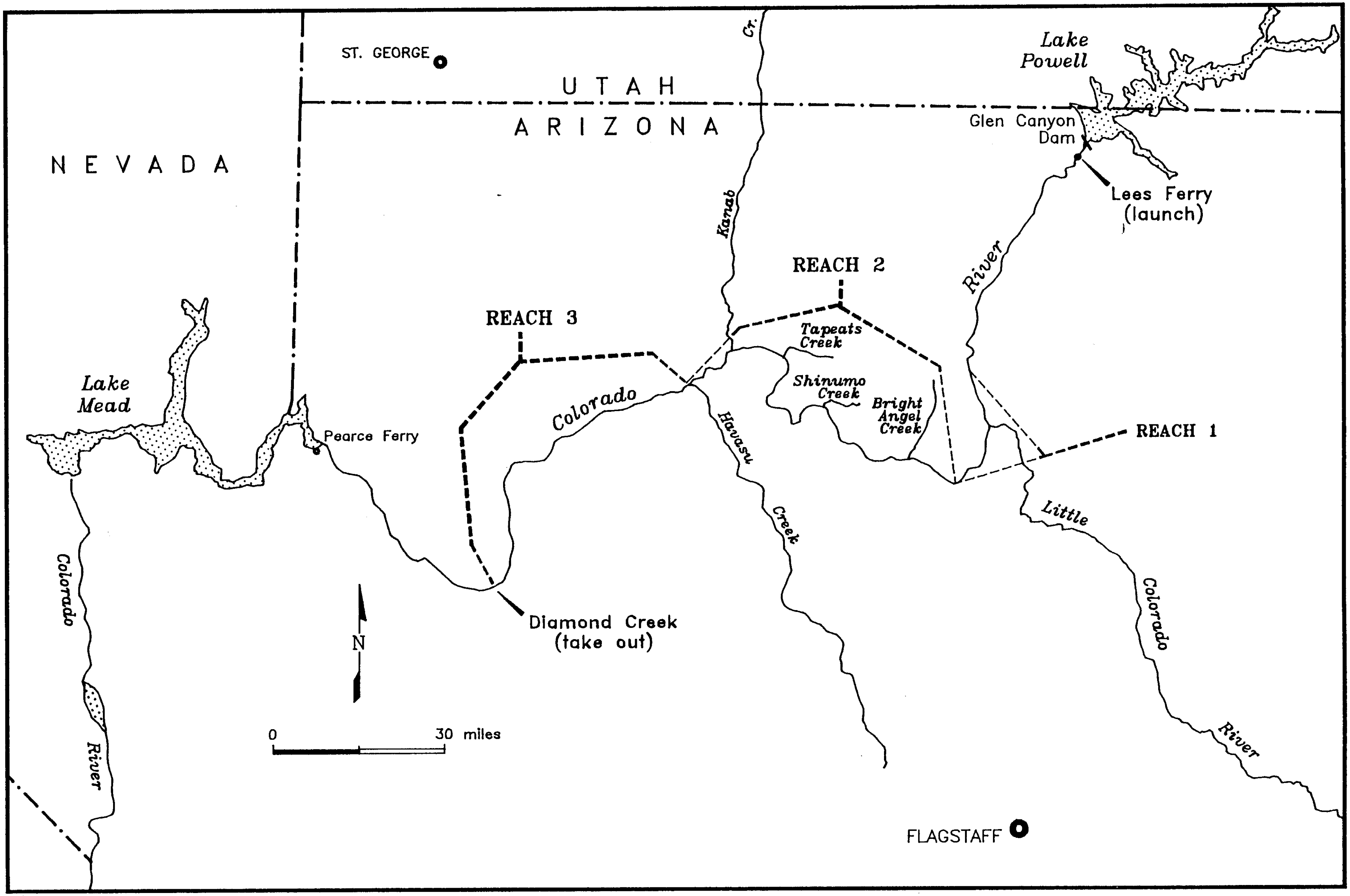

Figure 1-2. BIO/WEST study region in Grand Canyon and three sampling reaches.

Landmarks along the river corridor were located to the nearest tenth (0.1) of a river mile (i.e., the distance downstream from Lees Ferry along the center of the river). Sample locations were entered in the database to the nearest twentieth (0.05) of a river mile. It should be noted that Lees Ferry is 15.1 river miles downstream of Glen Canyon Dam, and river miles cited in this report are in reference to Lees Ferry rather than Glen Canyon Dam.

Reach 1 (Kwagunt Rapid to Hance Rapid)

Reach 1 was the uppermost reach of the study region, and extended 20.6 miles (33.2 km) from Kwagunt Rapid to Hance Rapid. The reach was characterized by two geomorphic strata—Lower Marble Canyon and Furnace Flats (Table 1-1; Howard and Dolan 1981, Schmidt and Graf 1990). The river channel in these strata averaged 350 feet (107 m) and 390 feet (119 m) in width, respectively, and channel slope was low to moderate at 0.10 and 0.21 percent, respectively. Substrate was composed of 30-36 percent bedrock and boulders, and shoreline was typically rock talus, tapeats ledges, or vertical cliffs with intermittent tributary alluvial fans, sand bars, or earthen banks with vegetation.

Shoreline features in Reach 1 were formed primarily by Bright Angel Shale (RM 47-58), Tapeats Sandstone (RM 58-63), and the Unkar Group (RM 63-76.5) of the Great Unconformity (Belknap and Evans 1989). Soft shales and sandstones of Bright Angel Shale and Tapeats Sandstone created talus shorelines with emergent boulders, which enhanced fish habitat. Tapeats Sandstone also created characteristic ledge habitat, which provided lateral and overhead cover for fish as well as substrate and cover for food organisms.

The Precambrian sedimentary series first appeared in the Nankoweap Formation as an angular uncomformity at RM 63, and from that point to RM 65.5, the shoreline was characterized by steep vertical walls, short talus slopes and large angular blocks. The Cardenas Basalt and Dox Sandstone of the Unkar Group were angularly juxtaposed downstream of the Palisades Fault, so that from Lava Canyon (RM 65.5) to Escalante Creek (RM 75), the channel was wider and the shoreline composed of boulders and cobble, with intermittent talus slopes and occasional vertical walls.

The Little Colorado River (LCR) was the only perennial tributary in this reach, and converged with the mainstem at RM 61.3. Several local drainages flowed intermittently during rain spates in June, July, and August, introducing large amounts of sediment into the river. Large alluvial boulder fans at these inflows constricted the river channel forming numerous rapids. Five major rapids (60-Mile, Lava Canyon, Tanner, Unkar, Nevills) occurred in Reach 1, together with nine minor rapids.

Table 1-1. Characteristics of geomorphic strata[a] within the three study reaches of the Colorado River in Grand Canyon.

Study Reach	Geomorphic Strata	Extent of Stratum (river miles)	Average Ratio of Top Width to Mean Depth	Average Channel Width (feet)	Width Character	Channel slope	Percentage of Bed Composed of Bedrock and Boulders
1	Lower Marble Canyon	35.9-61.5	19.1	350	Wide	.0010	36
	Furnace Flats	61.5-77.4	26.6	390	Wide	.0021	30
2	Upper Granite Gorge	77.4-117.8	7	190	Narrow	.0023	62
	Aisles	117.8-125.5	11	230	Narrow	.0017	48
	Middle Granite Gorge	125.5-140.0	8.2	210	Narrow	.0020	68
	Muav Gorge	140.0-160.0	7.9	180	Narrow	.0012	78
3	Lower Canyon	160.0-213.9	16.1	310	Wide	.0013	32
	Lower Granite Gorge	213.9-225.0	8.1	240	Narrow	.0016	58

[a]Adopted from Schmidt and Graf (1990), with slight variation in river miles (0.1 mile) for Middle Granite Gorge, Muav Gorge, Lower Canyon, and Lower Granite Gorge.

Quantity and quality of the Colorado River in Reach 1 were influenced primarily by releases from Glen Canyon Dam. Flow from tributaries such as the Paria River (RM 1.0), Nankoweap Creek (RM 52.2), and the LCR (RM 61.3) had little effect on mainstem water quantity and quality, except during high spring runoff and occasional localized rain spates. Flow from these tributaries affected water quality and temperature only locally, in the inflows. Runoff from ephemeral drainages also added water volume, chemicals, and sediment to the river at various times of year.

Reach 2 (Hance Rapid to below Havasu Creek)

Reach 2 was 83.4 miles (134.2 km) long, and extended from Hance Rapid to below Havasu Creek. This reach was composed of four major geomorphic strata, including Upper Granite Gorge, The Aisles, Middle Granite Gorge, and Muav Gorge (Table 1-1). Upper Granite Gorge (RM 77.4-117.8) had the lowest average ratio of top width to mean depth (7), and the second narrowest average channel width (190 feet or 60 m) of any geomorphic strata of Grand Canyon. These strata also had the steepest channel slopes, ranging from 0.12 to 0.23 percent. The river in Upper Granite Gorge flowed primarily through Vishnu Schist (black), Zoroaster Granite (pink), and Hotautu Conglomerate—hard Precambrian formations about 1.8 billion years old which formed steep canyon walls and smooth, scoured shorelines with little talus. This geomorphic stratum resembled the exposed schist and gneiss formations of Black Rocks, Colorado, and Westwater Canyon, Utah, which support the largest populations of humpback chub in the upper Colorado River basin (Valdez and Clemmer 1982).

The Aisles (RM 117.8-125.5) included Stephen Aisle and Conquistador Aisle. This geomorphic stratum was characterized by the reappearance of Tapeats Sandstone, found in the Lower Marble Canyon stratum of Reach 1 (RM 56.0-61.5). Average channel width in The Aisles was 230 feet (70 m), and 48 percent of the bed was composed of bedrock and boulders. Fish habitat in this geomorphic stratum was similar to that upstream of the LCR confluence.

The river in Middle Granite Gorge (RM 125.5-140.0) flowed through a combination of Precambrian sedimentary rock, volcanic and metamorphic rock consisting of amphibolitic schist, limestones, diabase intrusives, and granitic plutons. These relatively hard materials constricted the river to its narrowest point in Grand Canyon—76 feet (23 m) at RM 135.0. Average channel width in this stratum was 210 feet (64 m), and the bed was composed of 68 percent bedrock and boulders. Fish habitat resembled that of Upper Granite Gorge.

The river in Muav Gorge (RM 140.0-160.0) flowed through Vishnu Schist and Zoroaster Granite. This geomorphic stratum contained the river to the narrowest average channel width of any geomorphic stratum in Grand Canyon—180 feet (55 m). The channel bed in this stratum had the highest percentage of bedrock and boulders (78%) of any geomorphic strata.

Eight perennial tributaries flowed into the Colorado River in Reach 2 (Clear, Bright Angel, Crystal, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks). These streams typically had low base flows with little effect on mainstem flows, and only local effects on inflow water chemistry and biology. The majority of humpback chub found in this reach were in close proximity to these perennial tributary inflows (Maddux et al. 1986, Valdez et al. 1992), although the reach contained steep, rocky shorelines with deep eddies, pools, and runs—typical of areas occupied by humpback chub in the upper Colorado River basin (Valdez and Clemmer 1982). The shoreline in Reach 2 contained a short section of exposed Tapeats Sandstone (RM 120-130), with habitat similar to that found in Reach 1 (RM 56.0-61.5).

Reach 2 contained 36 major rapids (Hance, Sockdolager, Grapevine, 83-Mile, Zoroaster, Pipe Springs, Horn Creek, Salt Creek, Granite Creek, Hermit, Boucher, Crystal, Tuna Creek, Sapphire, Turquoise, 104-

Mile, Ruby, Serpentine, Bass, Shinumo, 110-Mile, Waltenberg, Forster, Fossil, 128-Mile, Specter, Bedrock, Dubendorff, Tapeats, 135-Mile, Fishtail, Kanab, Matkatamiba, Upset, Sinyala, and Havasu) and numerous minor rapids. Most rapids in this reach were formed by alluvial fans of boulders at tributary inflows.

Quantity and quality of the Colorado River in Reach 2—as in Reach 1—were influenced primarily by releases from Glen Canyon Dam. Flow from the eight tributaries in this reach—Clear Creek (RM 84.1), Bright Angel Creek (RM 87.7), Crystal Creek (RM 98.1), Shinumo Creek (RM 108.6), Tapeats Creek (RM 133.7), Deer Creek (RM 136.3), Kanab Creek (RM 143.5), and Havasu Creek (RM 156.7)—had little effect on mainstem water quantity and quality, except during high spring runoff and occasional localized rain spates. Flow from these tributaries affected water quality and temperature only locally, in the inflows. Runoff from ephemeral drainages also added water volume, chemicals, and sediment to the river at various times of year.

Reach 3 (Below Havasu Creek to Diamond Creek)

Reach 3 extended 66.0 miles (106 km) from below Havasu Creek (RM 160) to Diamond Creek (RM 226.0), and was divided into two geomorphic strata—Lower Canyon and Lower Granite Gorge (Table 1-1). Lower Canyon (RM 160.0-213.9) had an average channel width of 310 feet (94 m), and a bed composition of only 32 percent bedrock and boulders. The channel in this stratum was wide, the slope moderate (0.13%), and the river flowed primarily through sedimentary strata consisting primarily of the Bright Angel Shale. The shoreline was characterized by talus slopes, with intermittent alluvial boulder fans. Tertiary lava flows extended downstream of RM 180, shaping much of the shoreline and fish habitat with emergent boulders and cliffs formed by columnar basalt.

Lower Granite Gorge (RM 213.9-225.0) had an average channel width of 240 feet (73 m), a slope of 0.16 percent; and a bed composed of 58 percent bedrock and boulders. This stratum consisted of metamorphic and sedimentary features similar to those in the lower portion of Upper Granite Gorge. The geologic formations consisted primarily of granitic and granodioritic rock of the Zoroaster Granite Complex, intermixed with Tapeats Sandstone of the Paleozoic strata.

This reach contained 11 major rapids (164-Mile, Fern Glen, Gateway, Lava Falls, 185-Mile, Whitmore, 205-Mile, 209-Mile, 217-Mile, Granite Spring, and 224-Mile), and several minor rapids, formed mostly by alluvial tributary fans. There were no significant perennial tributaries in Reach 3.

Reach 3 was identified as an important nursery and rearing area for native fishes (Maddux et al. 1987). Although young-of-year (YOY) and juvenile humpback chub were captured, spawning sites and larvae were not found to confirm spawning in this reach.

HYDROLOGY

Mainstem Colorado River

Flow of the Colorado River in Grand Canyon varies seasonally, weekly, and daily, depending on flow releases from Glen Canyon Dam. During 1992, flow releases were based on interim flow criteria, in effect since August 1, 1991. Under the interim criteria, flows are limited to a maximum of 20,000 cubic feet per second (cfs) and a minimum of 5,000 cfs. Daily flow variation is no greater than 5,000 cfs for low-volume (< 600,000 acre-feet) months, 6,000 cfs for medium-volume (600,000 to 800,000 acre-feet) months, and 8,000 cfs for high-volume (> 800,000 acre-foot) months. The rate of release change for rising flows ("upramp") is no greater than 2,500 cfs per hour, with no more than an 8,000 cfs change during any 4-hour period. The rate of flow decrease ("downramp") is no more than 1,500 cfs per hour.

Discharges herein were evaluated using the records from the U.S. Geological Survey (USGS) gaging station on the Colorado River above the confluence with the LCR. Provisional records, which are subject to verification and change, were utilized for the analyses. Because of their provisional nature, some records were substantially modified where there were obvious data irregularities. Gaging station records from the Colorado River at Lees Ferry (#9380000) and the Colorado River near the LCR (#9402500) were used to adjust flows above the LCR. Final published records of the USGS are not expected to vary significantly from those presented here.

Annual discharge in the study reach was 8.3 million acre-feet in 1992, or about 2 million acre-feet below the 30-year average of 10.5 million acre-feet. Figure 1-3 illustrates the 1992 annual discharge hydrograph for the Colorado River immediately above the LCR, and Table 1-2 shows the mean daily flows for each month of the year. Flows were highest during the high volume months of July and August—averaging about 14,200 cfs daily. The highest average daily flow of 15,700 cfs occurred on July 10, and the greatest instantaneous peak discharge of 18,800 cfs occurred on July 24. Mean daily discharge during the winter months averaged about 11,800 cfs. Flows were lowest in spring and fall, with the lowest daily discharge of 7,300 cfs on April 27, and the lowest instantaneous discharge of 6,300 cfs on October 4.

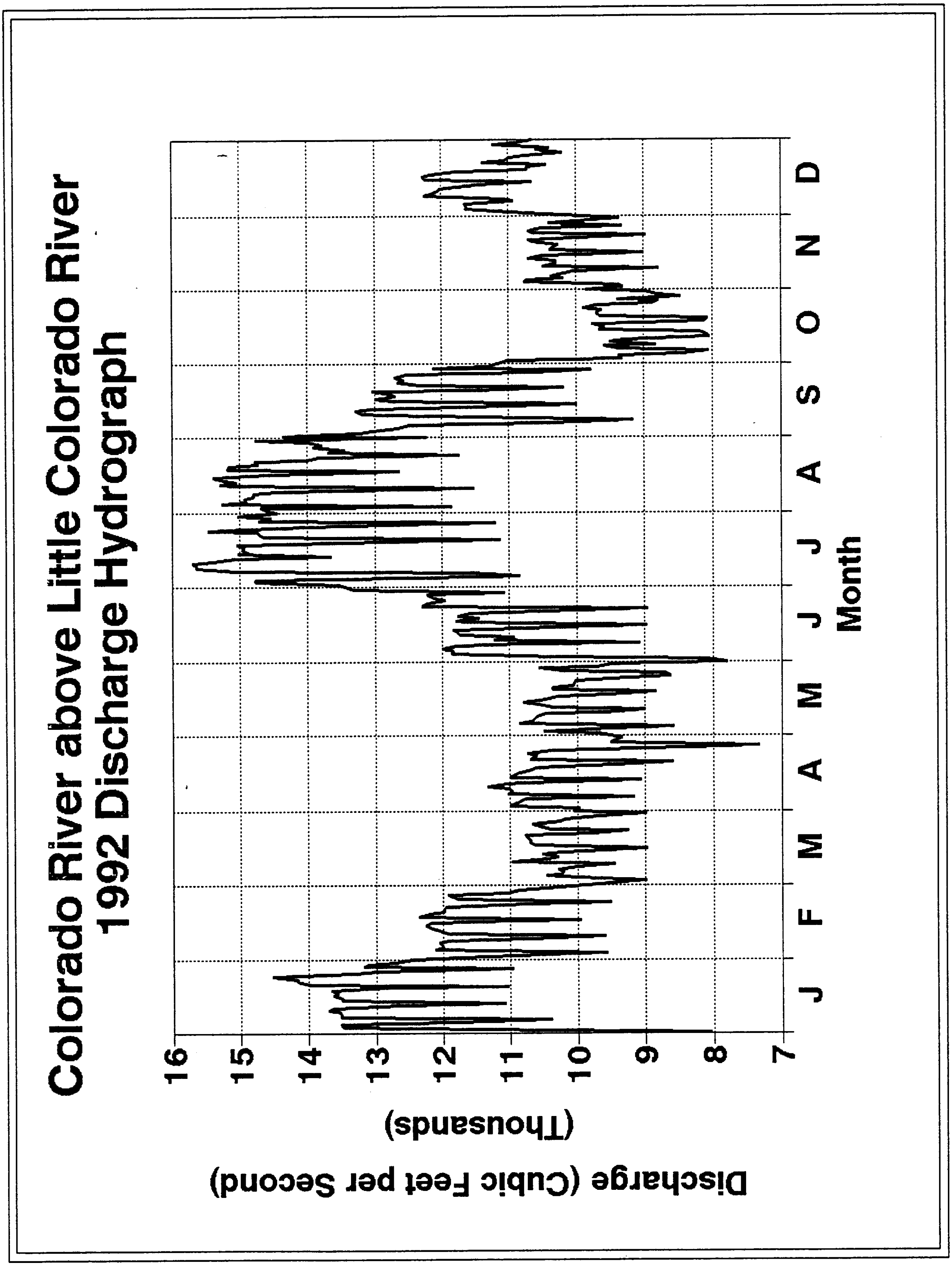

Figure 1-3. Flow of the Colorado River above the LCR (gage #9402500) in 1992.

Table 1-2. Mean daily discharge of the Colorado River immediately above the Little Colorado River by month for 1992.

Month	Mean Daily Discharge (cfs)
January	12,800
February	11,400
March	10,100
April	10,200
May	9,900
June	11,200
July	14,200
August	14,200
September	12,100
October	9,100
November	10,100
December	11,300

In addition to seasonal flow variations, Colorado River streamflow showed both weekly and daily flow variations during 1992. Flow releases from Glen Canyon Dam were generally greater from Monday through Friday and less on Saturday and Sunday. Weekend stream discharge averaged about 2,000 cfs less than weekday discharge during spring and autumn, and from 4,000 to 6,000 cfs less during winter and summer. The irregular nature of the hydrograph is the result of releases made in response to weekly power demand variations.

River flows also cycled on a daily basis in response to dam releases. Releases were at a minimum level in the early morning hours—when power demand was low—and increased to a high in the early afternoon. The rates of increase and decrease were regulated by the previously described interim flow criteria. There was an approximately 16-hour lag time before release variations from Glen Canyon Dam appeared at the LCR confluence. Thus, the lowest releases of the day occurred shortly after midnight, but were observed at the LCR confluence during afternoon hours of that day.

Detailed discharge hydrographs are presented in Appendix A, Figures A-1 through A-11 for each of the 11 BIO/WEST field trips in 1992. These are presented to provide a perspective of flow and flow variation during each field effort. These hydrographs illustrate the daily cycle of discharge fluctuation, as well as decreased weekend flows. The steady release of 8,000 cfs on October 10 through 12 for aerial videography is reflected in Figure A-10. The sharp spikes in the detailed hydrographs most likely represent data errors from USGS records, which were not corrected.

Little Colorado River

The LCR contributes an average of about 170,000 acre-feet of runoff annually to the Colorado River. Though the LCR basin comprises nearly 20 percent of the area of the Colorado River basin, it contributes less than 2 percent of the mainstem runoff. The LCR basin lacks the high mountainous areas characteristic of the upper Colorado River basin, and therefore, does not have the capability of generating a large snowmelt runoff. Flows of the LCR are highly variable, ranging from no flow at times during fall and winter to flows of several thousand cfs during spring runoff. Storm runoff may change river flows from nearly zero discharge to several thousand cfs within a period of a few hours.

A streamflow gage was operated on the LCR above its mouth during 1992. Flow near Cameron and at the mouth are presented in Figure 1-4. Also, hydrographs for March, April, and May are presented in Appendix A, Figures A-12 through A-14. Snowmelt was occurring during March and April, increasing flows at those times.

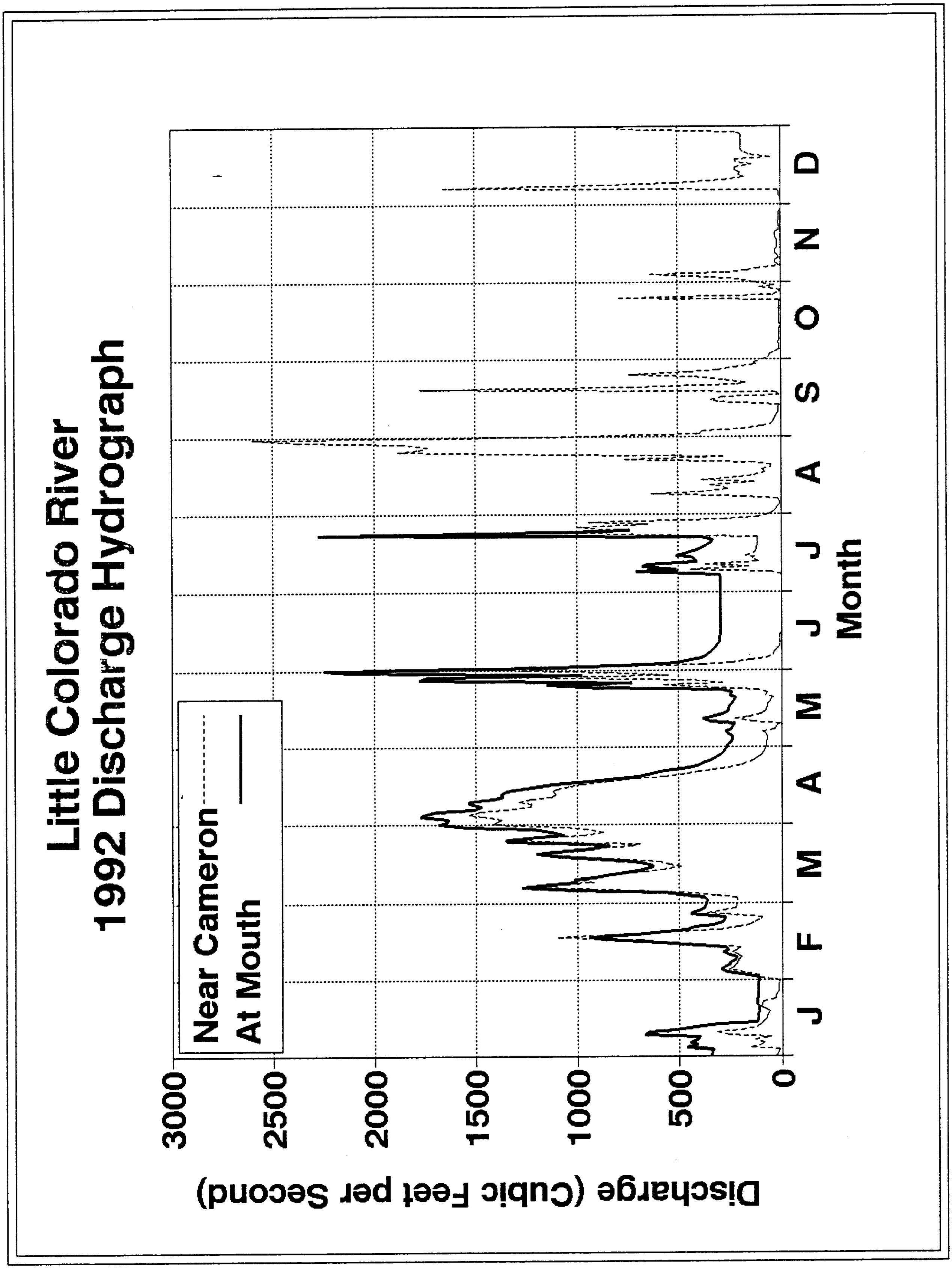

Figure 1-4. Flow of the Little Colorado River near Cameron, Arizona, and at the Mouth in 1992.

CHAPTER 2 - METHODS

Primary Author: Richard A. Valdez

The methodologies used in this investigation were described in a Data Collection Plan issued by B/W on January 1, 1991, and revised in May 1992. This plan contains detailed descriptions of field sampling methods, care and handling of fish, and database management.

A description of methods specific to particular aspects of the investigation are presented in respective chapters of this report. This chapter contains a description of the sampling schedule, and the sampling design as a framework for the more specific methods described in each chapter.

SAMPLING SCHEDULE

Monthly field trips were conducted on the Colorado River in Grand Canyon, from Lees Ferry (RM 0) to Diamond Creek (RM 226) (Table 2-1). Field trips were conducted every month of the year, except December. The duration of each trip alternated monthly between 12 and 20 days, resulting in five 12-day trips (February, April, June, August, and October) and six 20-day trips (January, March, May, July, September, November). This trip schedule was continued from the start of the field investigation in October 1990, resulting in a total of 25 trips--3 in 1990, 11 in 1991, and 11 in 1992. Launch dates and sampling locations were coordinated with AGF to provide concurrent sampling and comparable data.

Twelve-Day Trips

The primary purpose for the 12-day trips was to recontact previously radiotagged adult humpback chub, and monitor movement and habitat use in Reach 1. Fish were usually equipped with radiotransmitters during 20-day trips, and tracked and monitored during 12-day trips (Fig. 2-1).

Each 12-day trip involved one field team with 6 B/W and 2 ACT biologists. Following sampling, 3 or 4 B/W people hiked out at the Bright Angel Trail (Phantom Ranch), while the remaining 2 or 3 proceeded to the Diamond Creek takeout to disassemble gear and return to Flagstaff. The team used two 17-foot research boats (Achilles SH-170) for radiotracking, and two OARS support boats, one 33-foot S-rig and one 23-foot J-rig. An additional 16-foot electrofishing research boat (Achilles SU-16) was used on selected trips to capture additional fish for radioimplant, when necessary. The research boats were usually rolled and loaded on the support boats for transport to and from Reach 1 to reduce boat activity in the canyon, and to minimize personal risk and damage to equipment.

Table 2-1. Planned BIO/WEST field trips (12, 16 and 20 days) and number of people per trip on the Colorado River in Grand Canyon, 1990-1993.

	1990		1991		1992		1993	
Month	12-Day	20-Day	12-Day	20-Day	12-Day	20-Day	16-Day	20-Day
January				X		X	X	
February			X		X		X	
March				X		X	X	
April			X		X		X	
May				X		X		X
June			X		X		X	
July				X		X		X
August			X		X		X	
September				X		X		X
October	X		X		X		X	
November		X		X		X	X	
December	X							
Total Trips	2	1	5	6	5	6	8	3
B/W Personnel per Trip	6	10	6	10	6	10	6/10	10

Twenty-Day Trips

Twenty-day trips were conducted to capture humpback chub for implanting radiotransmitters, monitor habitat use and availability with flow, determine important biotic interactions between humpback chub and other fish species, and assess composition and distribution of fish in the Colorado River in Grand Canyon. Twenty-day trips included two independent field teams, each with a designated project leader having extensive river fisheries experience. Team 1 had 6 B/W and 1 ACT biologists working in Reach 1, while Team 2 had 4 B/W and 1 ACT biologists working concurrently in Reach 2. The two teams jointly sampled Reach 3 during the last 5 days of the trip, so that each of the three reaches was sampled with equal effort of about 10 days.

Team 1 used two 17-foot research boats (Achilles SH-170) for radiotracking and netting, and one 16-foot research boat for electrofishing (Achilles SU-16). Team 2 used one SH-170 for netting, and one SU-16 for electrofishing. The research boats were rolled and loaded on support S-rigs whenever possible

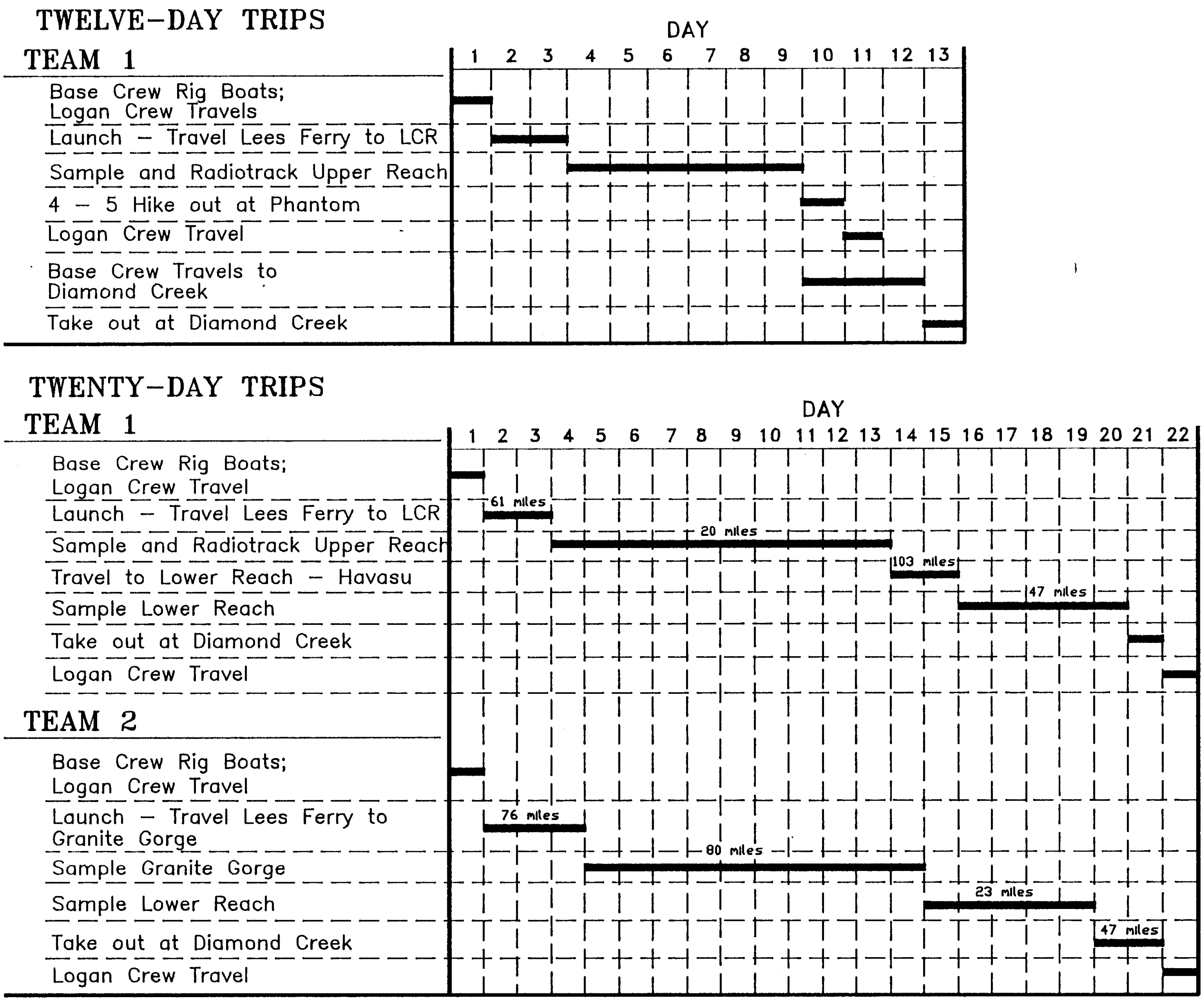

Figure 2-1. BIO/WEST's travel and sample schedules for 12 and 20-day trips.

to minimize human risk, reduce damage and loss of research equipment in whitewater, and minimize researcher visibility in the Grand Canyon. One S-rig (33 or 37-footer) and one J-rig (23-foot snout boat) accompanied each of the two teams. These support rafts were provided by OARS, a commercial river concessionaire from Flagstaff, Arizona, contracted by GCES to provide logistical support for research efforts in Grand Canyon.

SAMPLING DESIGN

A stratified random sampling design was implemented to ensure complete, thorough, and even sampling of the three study reaches. This is important when defining distribution of humpback chub, because of their affinity to specific river locales (Valdez and Clemmer 1982, Kaeding et al. 1990). The three study reaches were divided into eight geomorphic strata, which were subdivided into 24 sampling substrata (Table 2-2). These sampling substrata ranged from 2.0 to 12.1 miles in length, and included five tributary inflows areas (Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek, and Havasu Creek).

Sampling substrata were randomly selected within each of the three study reaches for sampling during each 20-day trip. Tributary inflows were treated as individual substrata to be sampled at least once seasonally since these were areas in which humpback chub were captured in the past. The number of sampling substrata selected was dependent on the particular trip schedule and accessibility and size of selected substrata.

Table 2-2. Lengths of sample substrata within the three study reaches of the Colorado River in Grand Canyon.

Study Reach	Geomorphic Strata	Sample Substrata	River Miles	Length (miles)
1	Lower Marble Canyon	a. Kwagunt - LCR	56.0-61.5	5.5
	Furnace Flats	b. LCR - Chuar Rapid	61.5-65.5	4.0
		c. Chuar Rapid - Unkar Rapid	65.5-72.5	7.0
		d. Unkar Rapid - RM 77.4	72.5-77.4	4.9
2	Upper Granite Gorge	a. Hance Rapid - Cremation Canyon	77.4-86.5	9.1
		*b. Bright Angel Creek	86.5-89.0	2.5
		c. Pipe Creek - Crystal Rapid	89.0-96.0	7.0
		d. Crystal Rapid - Bass Rapid	96.0-107.8	11.8
		*e. Shinumo Creek	107.8-109.8	2.0
		f. 110-mile Rapid - RM 117.8	109.8-117.8	8.0
	Aisles	g. Aisles	117.8-125.5	7.7
	Middle Granite Gorge	h. RM 125.6 - Dubendorf SSR	125.5-131.7	6.2
		*i. Tapeats Creek	131.7-134.5	2.8
		j. 134 Mile Rapid - RM 140.0	134.5-140.0	5.5
	Muav Gorge	*k. Kanab Creek	140.0-143.6	3.8
		l. Kanab Rapid - Sinyala Rapid	143.6-153.5	9.9
		*m. Havasu Creek	153.5-160.0	6.5
3	Lower Canyon	a. RM 160 - RM 169.9	160.0-169.9	9.9
		b. RM 169.9 - Lava Falls	169.9-179.4	9.5
		c. Lava Falls - RM 189.1	179.4-189.1	9.7
		d. RM 189.1 - RM 200.0	189.1-200.0	10.9
		e. RM 200.0 - 209-Mile Rapid	200.0-208.9	8.9
		f. 209-Mile Rapid - 214 Mile Cr	208.9-213.9	5.0
	Lower Granite Gorge	g. 214-Mile Cr - Diamond Creek	213.9-226.0	12.1

* Tributary substrata

CHAPTER 3: HABITAT AVAILABILITY AND USE

Primary Author: Richard A. Valdez

INTRODUCTION

This chapter addresses primarily Objective 1A: Determine resource availability and resource use (habitat, water quality, food, etc.) of humpback chub in the mainstem Colorado River. Fish habitat is probably the most directly affected resource in Grand Canyon as a result of Glen Canyon Dam operations. The fluid medium that surrounds the fish can be quickly and significantly altered with increased or decreased flows, reflective of power generation. Similarly, riverine conditions along shorelines and around underwater structure—used by fish for cover, spawning, nursing, and feeding—can quickly change with operations. This relationship is driven by dam releases which, in short-term influence depth and velocity, and in long-term shape channel geomorphology. Depending on the river or stream, fish habitat may not respond directly or proportionately to changes in flow, but may exhibit thresholds in response (Carter et al. 1985).

Fish of different species and life stages rely on various components or aspects of the river for habitat. Early life stages of humpback chub use shallow, sheltered, shoreline habitats, such as eddy return channels (backwaters), talus shorelines, tributary inflows, and side channels, while adults inhabit large eddy complexes and steep, rocky shorelines. Understanding the relationship of flow level, magnitude, and ramping rate to habitat of all life stages of fishes in Grand Canyon is vital to understanding one of the most direct ways in which Glen Canyon Dam operations affect aquatic resources.

Quantifying fish habitat in a large, swift, turbid, turbulent river, such as the Colorado River in Grand Canyon, is very difficult. Since the fish cannot be directly observed (turbidity usually prohibits underwater observation), their presence and use of specific habitats can only be determined indirectly from fish capture information and radiotelemetry. Once habitat use is determined, habitat quantification can be difficult. Because the Colorado River in Grand Canyon is deep and swift, accurate measures of depth are demanding, and meaningful measures of velocity are virtually impossible because of constantly changing flows and multitudes of multi-directional velocity shears in a single vertical transect.

Because measurements of depth and velocity are so difficult to obtain, BIO/WEST implemented a habitat mapping program of selected areas of the Colorado River in Grand Canyon, similar to concurrent mapping techniques used by river geomorphologists. These mapping techniques provided an assessment of major habitat categories relative to fish use in 1991 (Valdez et al. 1992). Site-specific measurements of shorelines used to various degrees by juvenile humpback chub were also collected in order to quantify changes in depth, velocity, and substrate with changes in flow. These techniques proved useful for habitat assessment in 1991 and 1992. In 1992, two other habitat components were assessed, with the aid of GCES and other investigators. The Survey Department of GCES provided the expertise and personnel to develop bathymetry (depth isopleths) and some velocity isopleths of selected reaches of the Colorado River near the LCR inflow. Furthermore, collaboration with Dr. Jack Schmidt, Scientific Advisor on Geomorphology to the Senior Scientist for GCES, proved valuable in integrating geomorphic maps and descriptions with fishery capture information and radiotelemetry.

METHODS

Fish habitat availability was assessed in 1992 by the following four ways: (1) habitat mapping, (2) shoreline categorization, (3) shoreline habitat measurements, and (4) depth and velocity isopleths of selected mainstem areas. Habitat use by fish was determined from (1) capture information and (2) radiotelemetry.

Habitat Availability

Habitat mapping was conducted in the same manner described for 1991 (Valdez et al. 1992). Seven areas in the vicinity of the LCR (Fig. 3-1, Table 3-1) were mapped, including ESPN (RM 60.8-61.0), CAMP (RM 61.0-61.2), LCRI (RM 61.2-61.5), HOPI (RM 62.2-62.4), SALT (RM 62.4-62.6), WHAL (RM 62.6-62.9), and WEEP (RM 63.9-64.2). Aerial photographs at a 1:1200 scale (1 cm = 12 m) were used as base maps for an area of river about 400 m long. Major fish habitat categories (i.e., eddies, runs, pools, riffles, rapids, eddy return channels, side channels, Table 3-2) were lined from visual interpretation on clear acetate overlays on the 1:1200 aerial photographs. The same observer developed maps for each area at as many flows as possible, under interim flow criteria, in order to identify relationships between fish habitat category and river flow. Additional habitat maps were generated in 1991-92 for areas downstream of the LCR inflow, but were not available for this report.

Shoreline categorization is part of habitat mapping, and was initiated in 1991. Each shoreline of the 400-m river area mapped was categorized into one of 11 shoreline types (Table 3-3) (Valdez et al. 1992). The availability of various shoreline types to young fish was determined for each flow in which the area

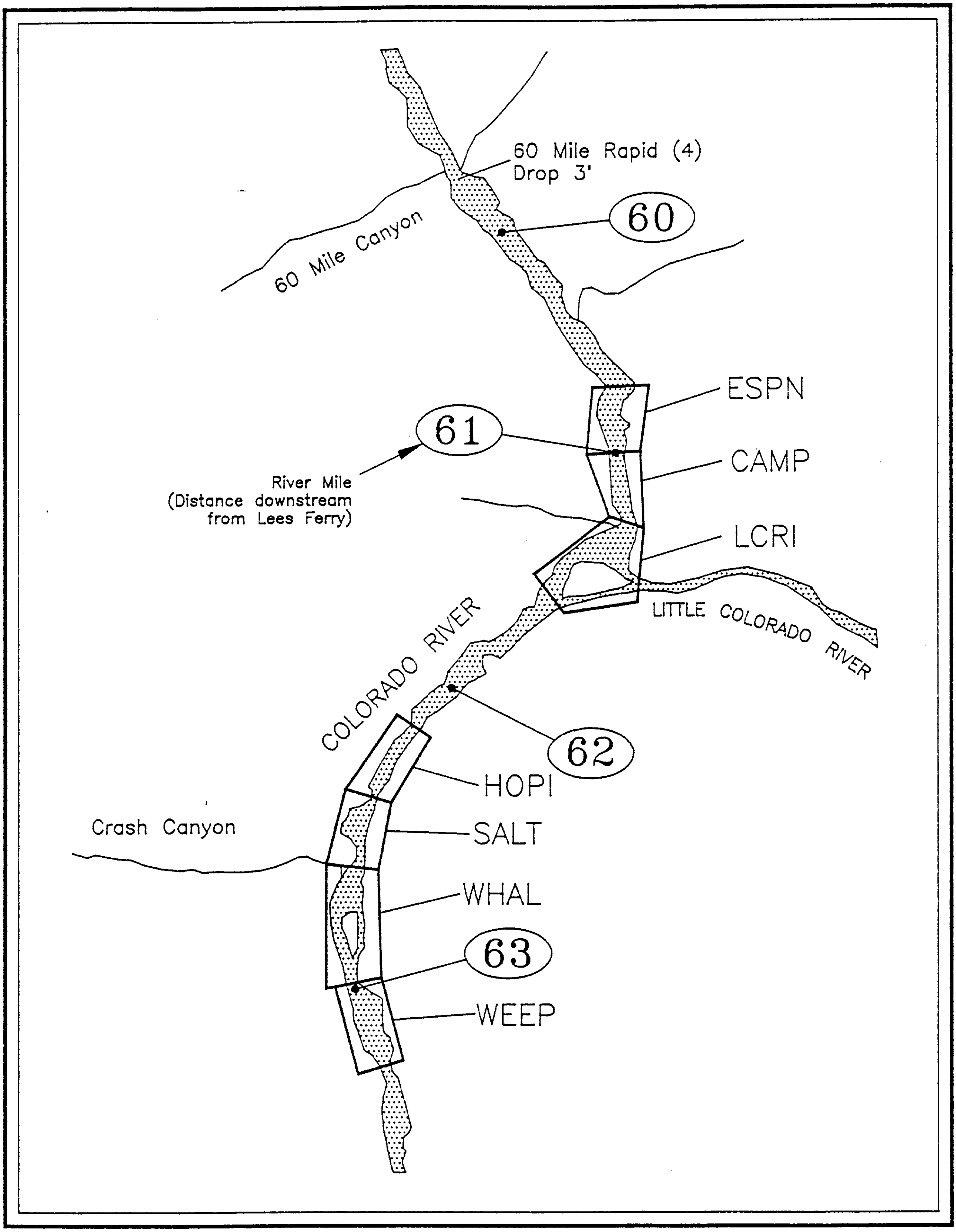

Figure 3-1. Locations of seven macrohabitat mapping areas on the Colorado River in Grand Canyon.

Table 3-1. Habitat map areas completed at various flows of the Colorado River in Grand Canyon, 1990-1992.

AREA	FLOW RANGE	MIDPOINT	DATE (time)
ESPN	4,290-4,410	4,350	May 19, 1991 (1300-1400)
	9,870	9,870	August 19, 1991 (1830-1856)
	13,400-14,200	13,800	May 22, 1991 (1130-1230)
	16,000-15,600	15,800	August 18, 1991 (0850-0920)
	4,410-4,300[a]	4,355	May 19, 1991 (1400-1530)
	15,000-14,000	15,000	June 17, 1992 (1130-1245)
CAMP	4,290-4,220	4,255	May 20, 1991 (0830-0930)
	10,000	10,000	August 19, 1991 (1730-1750)
	13,500	13,500	May 21, 1991 (1515-1630)
	16,600-16,100	16,350	August 18, 1991 (0800-0834)
	4,220-4,210[a]	4,215	May 20, 1991 (0930-1000)
	12,000-13,000	12,000	June 17, 1992 (1015-1100)
LCRI	4,300-4,390	4,345	May 19, 1991 (1000-1130)
	10,200-10,100	10,150	August 18, 1991 (1800-1830)
	13,500-13,700	13,600	May 21, 1991 (1330-1430)
	15,200-14,900	15,050	August 18, 1991 (1000-1032)
	4,390-4,350[a]	8,740	May 19, 1991 (1130-1200)
HOPI	~10,000	~10,000	September 16, 1991 (1530-1618)
	14,900-14,200	14,550	August 20, 1991 (1030-1050)
	~12,000	~12,000	June 18, 1992 (1215-1250)
SALT	7,250-9,640	8,445	May 20, 1991 (1720-1815)
	~8,000	8,000	September 16, 1991 (1415-1508)
	13,500	13,500	May 22, 1991 (0830-0930)
	13,600-13,200	13,400	August 20, 1991 (1200-1230)
	7,250-9,640[a]	8,445	May 20, 1991 (1720-1815)
WHAL	13,700-13,600	13,650	May 22, 1991 (1810-1900)
WEEP	~10,000	~10,000	September 16, 1991 (1630-1718)
	16,400-16,300	16,350	August 20, 1991 (0830-0850)

[a]Substrate Map

Table 3-2. Fish macrohabitat types and definitions for the Colorado River in Grand Canyon.

MACROHABITAT TYPE	DEFINITION
Eddy	A portion of river usually deeper than the adjacent channel with a distinct whirlpool or counter-current. An eddy is usually created by obstructions in the channel or projections of land or rock jetties. Lateral and upstream boundaries are denoted by an eddy line, shear zone, or land mass; downstream boundary is denoted by the release of flow from the region of counter-current.
Pool	A portion of river that is significantly deeper than average river depth. A pool generally has low surface velocity and may have small surface boils and upwellings. The boundaries of a pool are marked by dramatic increases in velocity and decreases in depth.
Rapid	A relatively deep region of river with fast flow and standing waves formed by a river constriction.
Return Channel/ Backwater	A sheltered body of water bound on three sides by land with one opening to the river. Frequently formed between a reattachment sand bar and the river bank. It is created by return flow from an eddy at high water.
Riffle	A relatively shallow region of river with a broken, rippled surface formed by the underlying substrate, typically cobble or gravel.
Run	A reach of river with laminar, downstream flow and approximately average depth. A run has no large surface boils, upwellings, or countercurrent.
Slackwater	An area of very low velocity formed by instream structure such as sand shoals or rock piles. Unlike pools, slackwaters have no surface boils or upwellings, and may be deeper than adjacent areas with little or no detectible velocity.

Table 3-3. Shoreline types and definitions associated with fish habitat of the Colorado River in Grand Canyon.

SHORELINE TYPE	DEFINITION
Alluvial Fan	Debris outflow from tributary, usually dominated by boulders and cobble.
Boulders	Large standing rocks greater in diameter than talus.
Earthen Bank	Exposed soil with few rocks and little vegetation.
Precambrian Schist	Vertical and broken cliffs and outcrops of precambrian formation.
Rock Ledge	Vertical ledges of formation other than Tapeats with overhanging structure.
Rock Face	Vertical cliff with no overhang.
Root Wads	Significant exposure of roots.
Sand Beach	Predominantly exposed sand.
Talus Slope	Unconsolidated rock on a steep slope spilling into the river forming an irregular shoreline.
Tapeats Ledge	Vertical ledges of the Tapeats Formation, typically with overhanging broken surfaces.
Vegetated Bank	Bank with vegetation (tamarisk, willow, Phragmites).

was mapped. Habitat maps and shoreline categories are currently being digitized into a GIS by BIO/WEST. These files are not available at this time.

Shoreline habitat measurements were taken under an established protocol (Valdez et al. 1992) along four different shoreline types (Fig. 3-2), including (1) CRASH: a boulder/talus slope on river right above Crash Canyon at RM 62.6, (2) SALT: a talus slope on river right upstream of the Hopi Salt Mines at RM 63.1, (3) WEEP: a vertical wall on river left upstream of the Hopi Salt Mines at RM 63.0, and (4) SAND: a sand beach on river right below the Hopi Salt Mines at RM 63.5. Sites 1 and 2 yielded large numbers of juvenile humpback chub during electrofishing in July, September, and November of 1991 and 1992, while areas 3 and 4 yielded few chub. The purpose for selecting these four distinct sites was to measure habitat occupied by large numbers of juveniles as well as adjacent habitats with fish. These sites were remeasured at various river flows to determine the range of flows needed for suitable juvenile habitat. Depth, velocity, and substrate were assessed at three 1-m intervals from shore, along each of ten transects.

Depth and velocity isopleths were determined for selected areas of the Colorado River in Grand Canyon by the Survey Department of GCES (M. Gonzales, F. Protiva, C. Brode). Bathymetry (depth isopelths) was developed for four areas, including RM 58.5 (Awatubi Canyon), 60.1, 60.8 (ESPN Rock), and 64.7 (Carbon Creek). The bathymetry survey was provided at a scale of 1:1200 to match the aerial photographs used for habitat mapping. Since each area required 4-6 hours for the complete bathymetry, flow varied from about 8,000 to 13,000 cfs. Contour intervals were 0.5 m, consistent with GIS map contour interval and scale. The elevational starting point was based on a local coordinate system above the high water line. Locations for each bathymetry were selected for areas of highest use by humpback chub. All measurements were accurately located by coordinate values along transect lines spaced 10 m apart, and velocity was measured 1 m below the water surface. GCES survey protocol was followed in order to reliably reestablish control points and allow for future resurveys. Calculated points on each shore located transects 10 m apart and helped to direct a traversing boat. Survey readings, including distance and angle, were taken with the aid of a prism on the traversing boat, and simultaneous to measurements of depth and velocity. Additional instrumentation ("Super-Hydro" hydrographic system) acquired by the Survey Department in 1992 will provided for greater efficiency and accuracy of depth bathymetry, with a survey location speed of about 4 points per second.

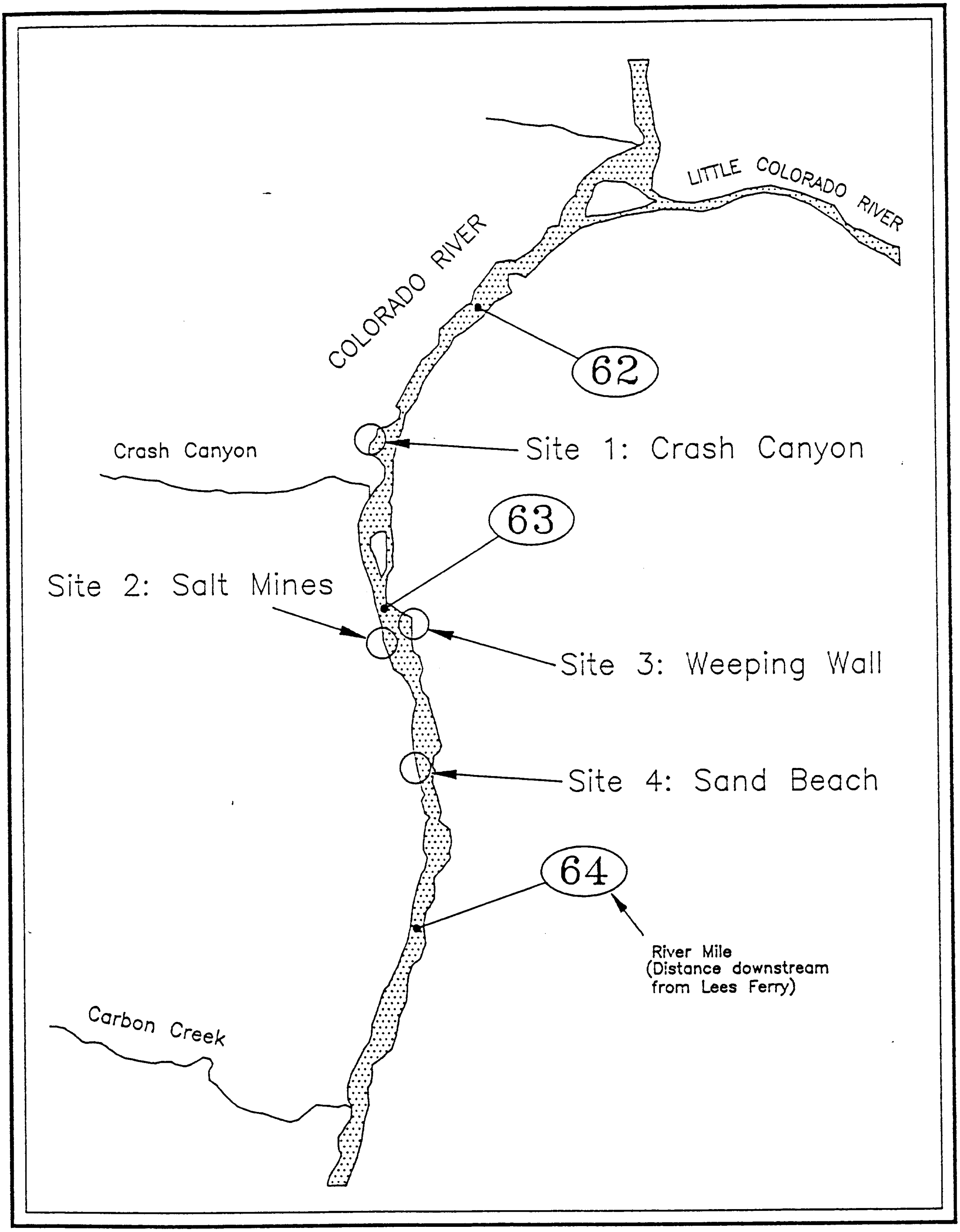

Figure 3-2. Locations of four microhabitat measurement sites for juvenile humpback chub on the Colorado River in Grand Canyon.

Data processing included editing of erroneous points, generation of database from surveyed points, visual reality check of all data points, depth reductions to relative elevation, generation of a surface model, and orientation to established coordinate points. Bathymetric plots were generated with contours spaced every 0.5 m, and velocity plots contained contours spaced every 0.1 m/sec. The velocity plots are not considered accurate, because (1) river flow changed by nearly 8,000 cfs during the 5 hours required to collect the field data, and (2) multitudes of multi-directional velocity shears can occur in a single vertical transect, even at constant flow. Nevertheless, the velocity plots for RM 60.8 (ESPN Rock) and RM 64.7 (Carbon Creek) are included in this report to provide a perspective of magnitude of velocity and velocity regions.

Habitat Use

Habitat use of all fish species was determined by capture information, using electrofishing, nets, seines, minnow traps, and hoop nets. Habitat use by adult humpback chub was determined primarily by radiotelemetry, and was determined for juveniles and YOY from capture information. This report presents habitat use of humpback chub only, but we intend to later integrate use by other species to illustrate specific interactions. A complete description of microhabitat and macrohabitat distinction and quantification was presented in the 1991 Annual Report (Valdez et al. 1992).

RESULTS AND DISCUSSION

Habitat Mapping

A total of 28 habitat maps were generated for the mainstem Colorado River near the LCR inflow (RM 60.8-64.2) in 1991 and 1992 (Table 3-1). Examples of the LCR inflow maps at 5,000 cfs (Fig. 3-3) and 15,000 cfs (Fig. 3-4) show decreases in surface area of eddies, rapids, and runs, and increases in riffles.

Average percentage surface area was highest for runs (69%), while eddies and pools composed only 19 and 11 percent of surficial area (Table 3-4). Eddy return channels, riffles, and rapids each made up less than 1 percent of surface area of habitat. Habitat maps from other areas of Grand Canyon have not been processed, and it is not known if this habitat composition is consistent throughout the canyon.

The greatest percentages of humpback chub captured by B/W in 1990-91 and 1992 were in eddy complexes (active recirculating eddies and eddy return channels). Although these complexes composed only about 20 percent of surficial area, 93.5 and 86.4 percent of humpback chub over 200 mm TL were

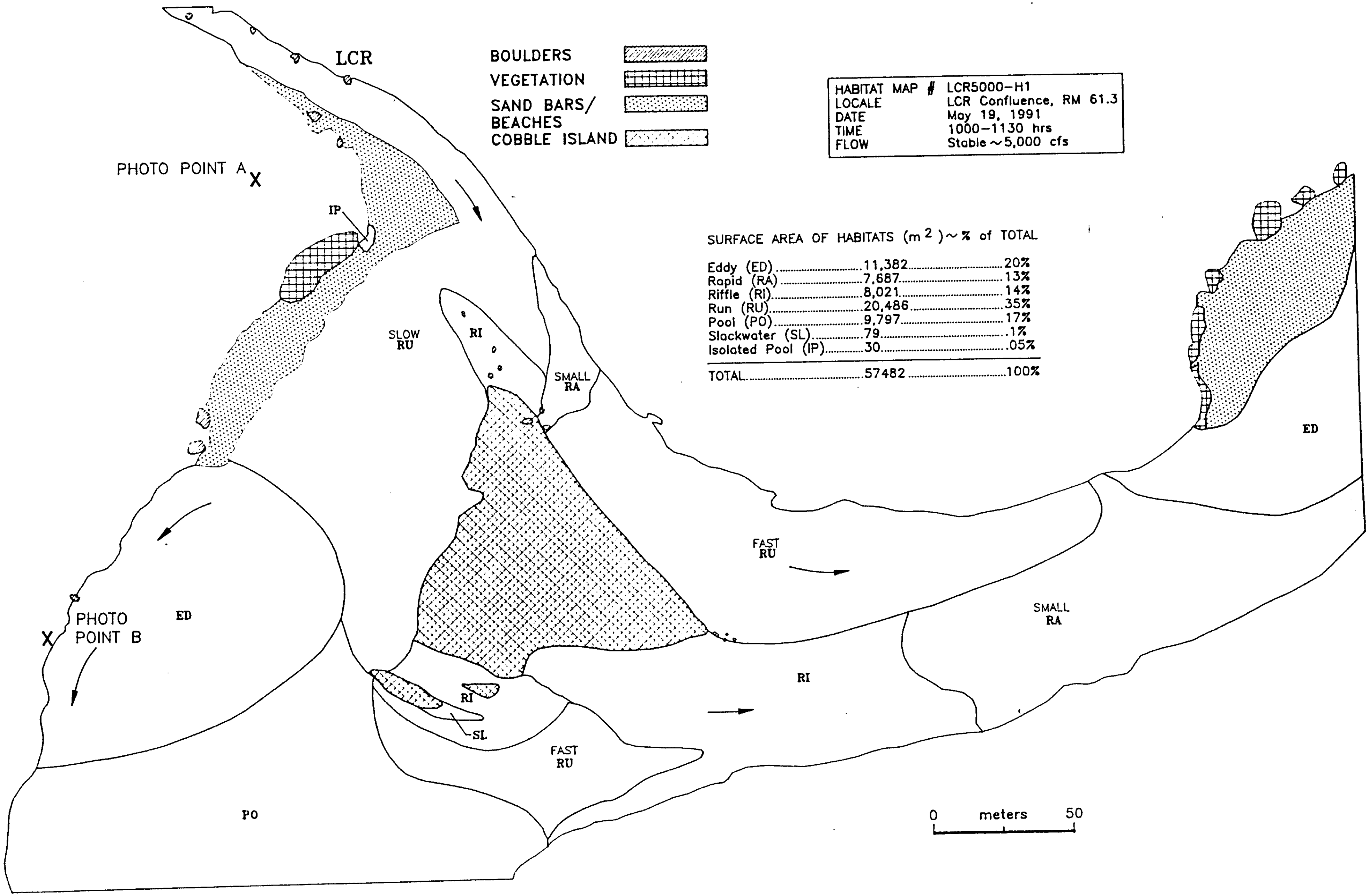

Figure 3-3. **Habitat map of the Colorado River at 5,000 cfs at the LCR Inflow, RM 61.3, Map 19, 1991.**

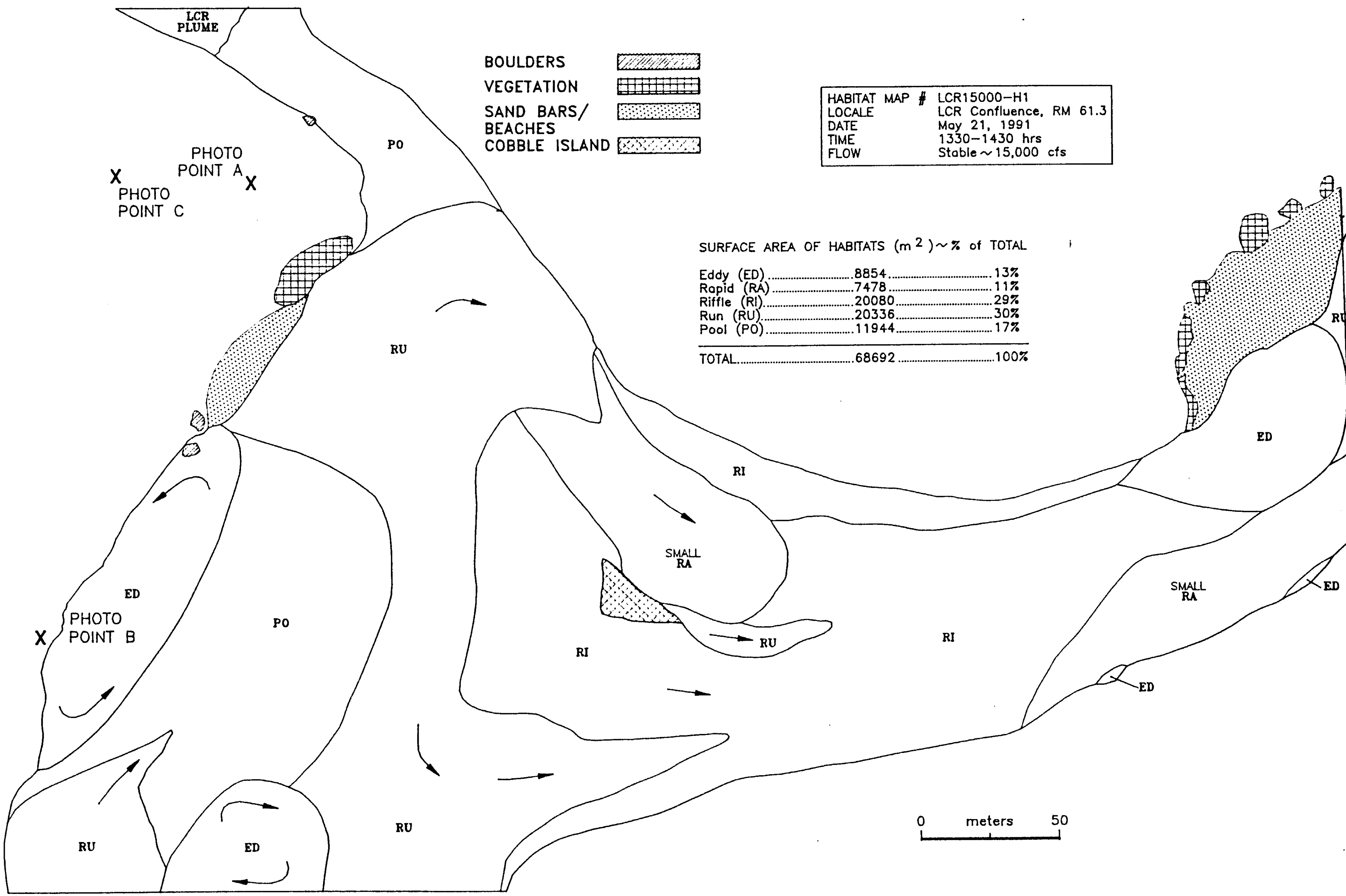

Figure 3-4. Habitat map of the Colorado River at 15,000 cfs at the LCR inflow, RM 61.3, May 19, 1991.

Table 3-4. Average percentage surface area of macrohabitats in Reach 1 of the Colorado River at a flow range of 4,000 to 16,000 cfs, compared to percentage captured and radiotagged adult humpback chub (200 mm TL) in 1990-91 and 1992.

Habitat	Percentage Surface Area x (range)	Fish Captured 1990-91 n	Fish Captured 1990-91 %	Fish Captured 1992 n	Fish Captured 1992 %	Radio Contacts 1990-91 n	Radio Contacts 1990-91 %	Radio Contacts 1992 n	Radio Contacts 1992 %
Eddies	19 (10-34)	499	87.9	289	83.0	251	68.4	366	74.1
Runs	69 (48-86)	16	2.9	42	12.1	34	9.3	99	20.0
Return Channels	<1 (<1)	26	4.6	12	3.4	53	14.4	3	0.6
Pools	11 (0-41)	8	1.4	1	0.3	8	2.2	18	3.6
Riffles	<1 (0-1)	0	-	0	-	0	-	3	0.6
Rapids	<1 (0-1)	0	-	0	-	0	-	0	0.6
Others	0	12	2.1	4	1.1	21	5.7	5	-
TOTALS		561	100	348	100	367	100	494	100

captured in eddy complexes in 1990-91 and 1992, respectively (Table 3-4). Also, 82.8 and 74.7 percent of contacts with radiotagged adults were from eddy complexes in 1990-91 and 1992, respectively. Although the catch information may be biased by disproportionately greater sample effort in eddy complexes, radiotelemetry supported the findings that the majority of adult humpback chub used eddy complexes.

Shoreline Habitat

Average water velocity of a talus shoreline habitat (SALT site) used by juvenile humpback chub increased from 0.083 mps (n=90, s.d.=0.034) to 0.103 mps (n=87, s.d.=0.037), and average water depth increased from 1.067 (n=90, s.d.=0.322) to 1.845 (n=87, s.d.=0.548) at low (10,000-12,000 cfs) and medium observed flows (12,000-14,000 cfs). This analysis showed that velocity and depth along talus shoreline did not change significantly ('t' test, alpha=.05) in the magnitude of flows observed during measurements. Additional analyses are being done on the other sites, with additional data to be collected in 1993 at higher and lower flows, to determine changes in habitat parameters with flow.

A length-frequency distribution of all humpback chub captured in 1992, partitioned by gears effective in shoreline habitats (electrofishing, seines, minnow traps) and in off-shore habitats (gill and trammel nets), revealed distinct length modes (Fig. 3-5). Although fish from about 30 mm to 460 mm TL were captured along shorelines, the mode of distribution was 80-100 mm TL. In comparison, fish captured in off-shore habitats ranged from 100 mm to 460 mm TL, with a mode of 360-390 mm TL. These findings suggest a change in habitat use at about 180 mm TL, from nearshore habitats to off-shore habitats. The age at which this change occurs is not known, but length-frequency histograms suggest that chubs 180 mm TL are about 3 years of age. Scales of young humpback chub (<200 mm TL) are being examined by B/W in order to determine length to age relationships. The wide range of fish sizes and width of these two length distributions indicate a transition in habitat use with age, although many of the larger fish caught from shorelines were captured with nighttime electrofishing, when adults frequent shallow shorelines. These results do not appear to be biased by size efficiency of certain gear types and are believed to be a true reflection of fish habitat use (see Chapter 4 for explanation of gear types).

Bathymetry (Depth and Velocity Isopleths)

Bathymetry (depth isopleths) of the Colorado River channel upstream of the LCR inflow (ESPN Rock, RM 60.8) revealed a maximum depth of about 14 m (water line at about the 94.5 m contour to a maximum depth of 80.5) (Fig. 3-6). Much of the area in the eddy complex (upper left portion of Fig. 3-6)

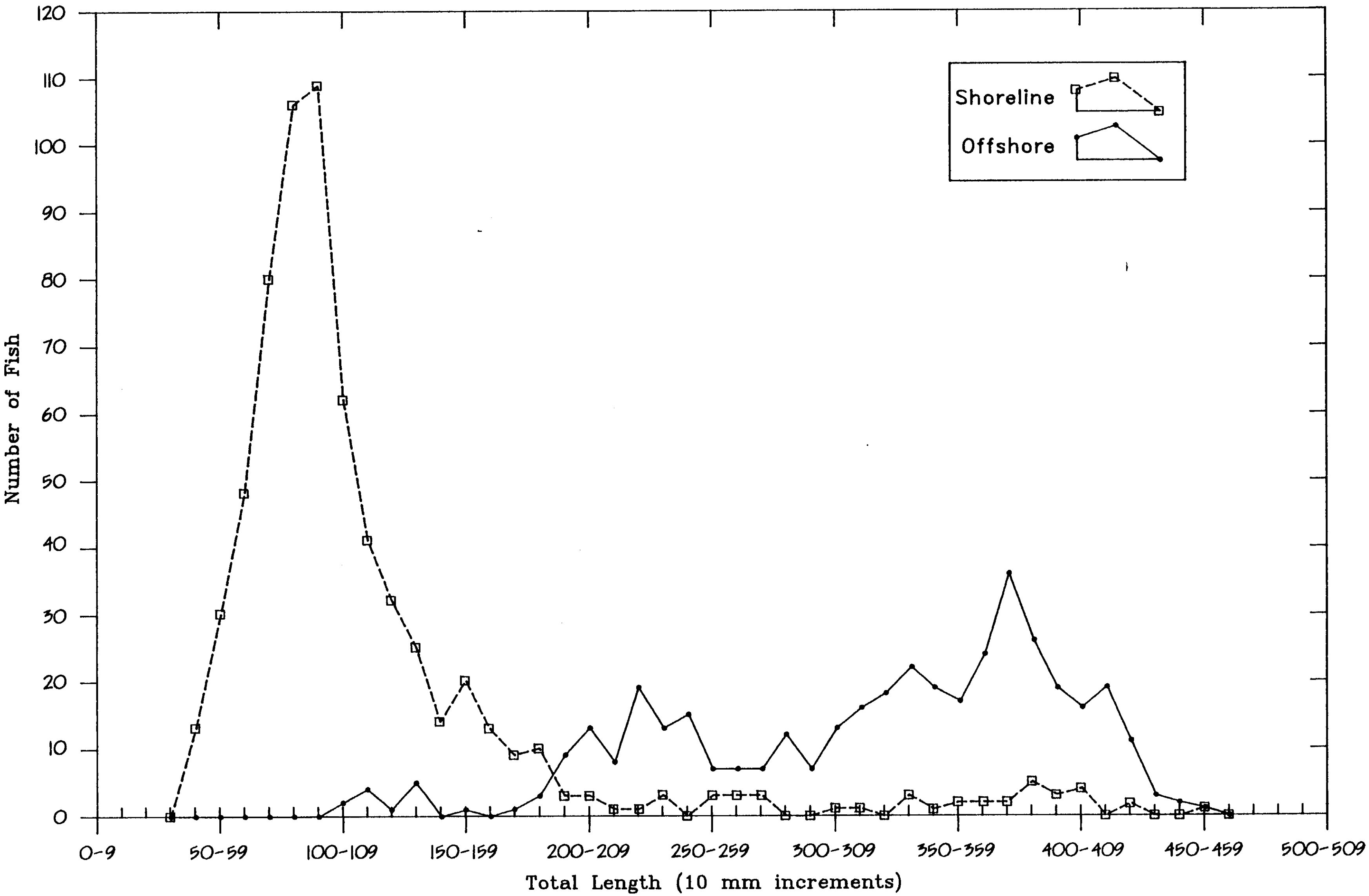

Figure 3-5. **Length-frequency distribution of humpback chub captured in shoreline habitats (with electrofishing, seines, minnow traps) and in offshore habitats (with gill nets, trammel nets) for 1992.**

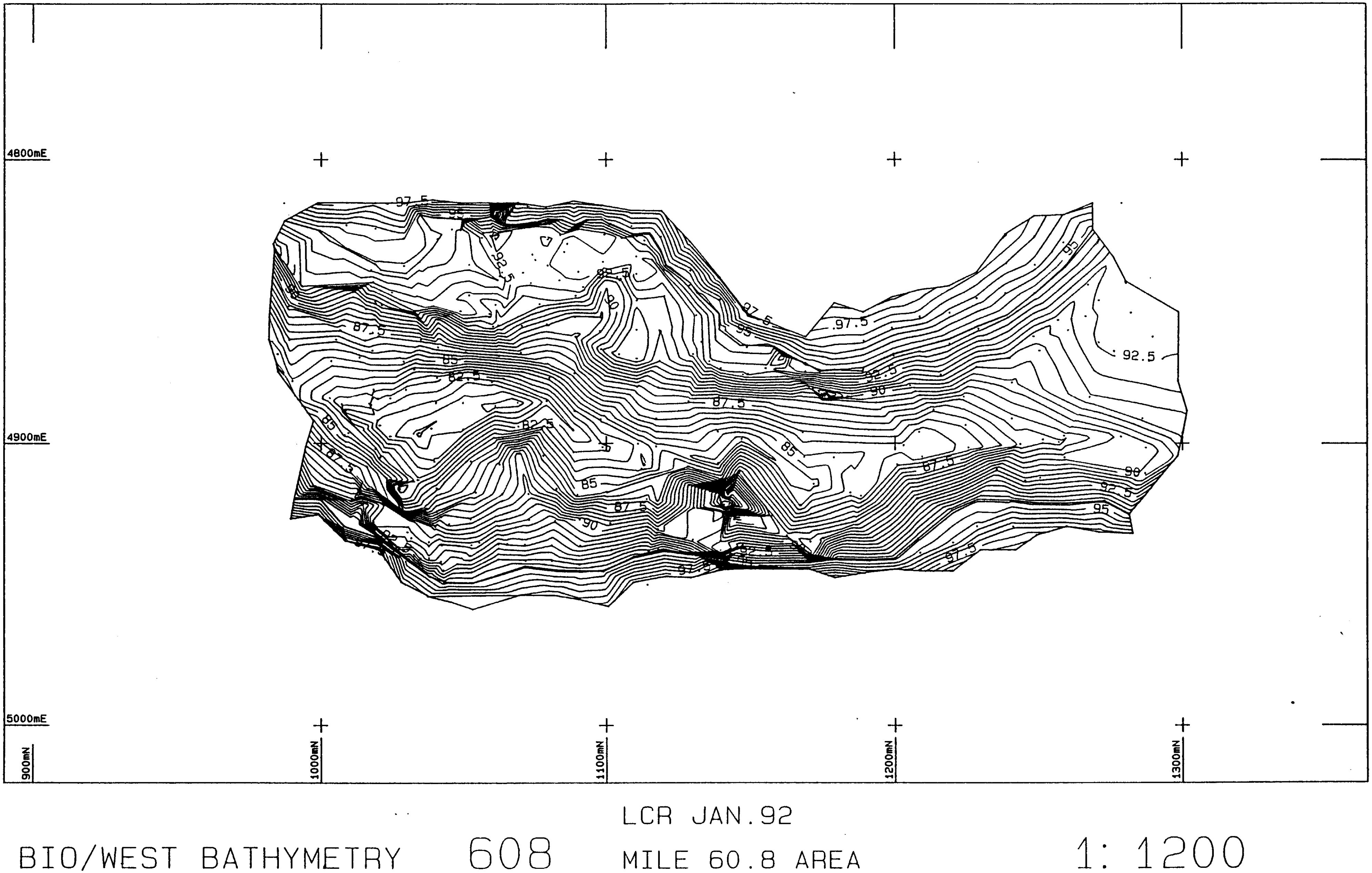

Figure 3-6. **Bathymetric map of the Colorado River channel at RM 60.8, (ESPN Rock) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.**

and behind ESPN Rock (lower center portion of Fig. 3-6) was less than 5 m deep. These were areas frequently used by radiotagged adult humpback chub. A bathymetry of the area was also produced to show the contour of the channel below 4 m in depth, since radiotelemetry signals were audible from radiotagged fish in less than 4 m of water (Fig. 3-7). As expected, approximately one-fourth of the channel width, along each shoreline, was less than 4 m deep. Also, most of the eddy complex was less than 4 m deep. Velocity isopleths are also included for this area to provide a perspective of velocity regions in the channel (Fig. 3-8). Although these velocity readings are probably not accurate, they reflect a high-velocity center channel with lower velocity shorelines and eddy complexes that further explain the occurrence of most humpback chub in these habitats.

Depth and velocity isopleths were also developed for Carbon Creek at RM 64.7 (Fig. 3-9, 3-10, 3-11), and showed similar relationships between depth and velocity regions and eddy complexes to the ESPN Rock area. In the case of Carbon Creek, maximum depth was approximately 12 m, and nearly two-thirds of the area was less than 4 m deep (Fig. 3-10). This depth distribution and the velocity isopleths (Fig. 3-11) showed that the large eddy complex frequently used by radiotagged adult humpback chub is relatively shallow with regions of low velocity.

Bathymetric maps of RM 60.1 (Fig. 3-12) and RM 58.5 (Awatubi Canyon) (Fig. 3-13) are also provided in this report. Maximum depth was about 13.5 m at RM 60.1 and about 17.5 m at RM 58.5. Large eddy complexes in both areas contain relatively shallow water of less than about 5 m.

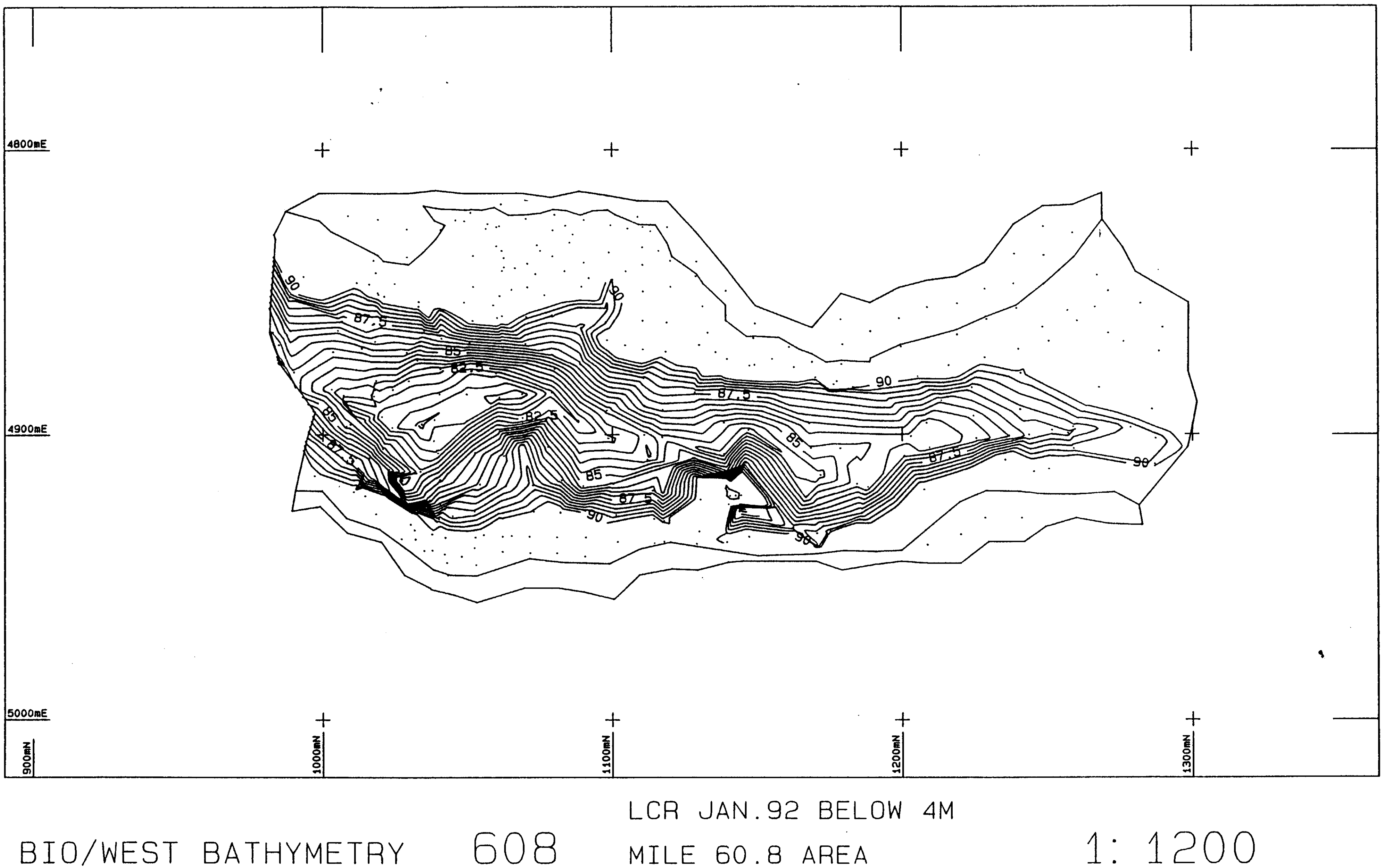

Figure 3-7. **Bathymetric map of the Colorado River channel below 4 m at RM 60.8, (ESPN Rock) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.**

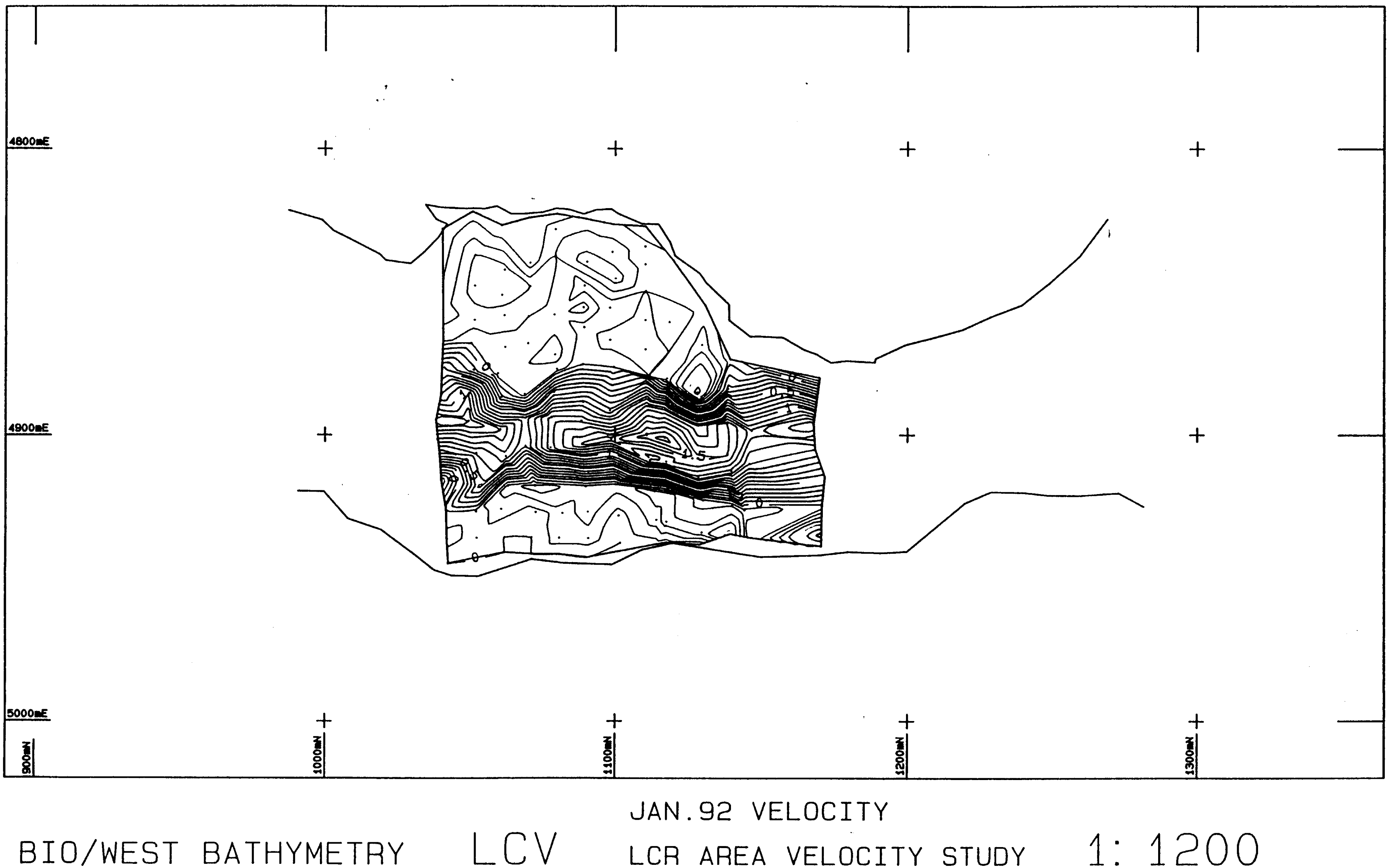

Figure 3-8. Velocity Isopeths for the Colorado River at RM 60.8 (ESPN Rock) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department

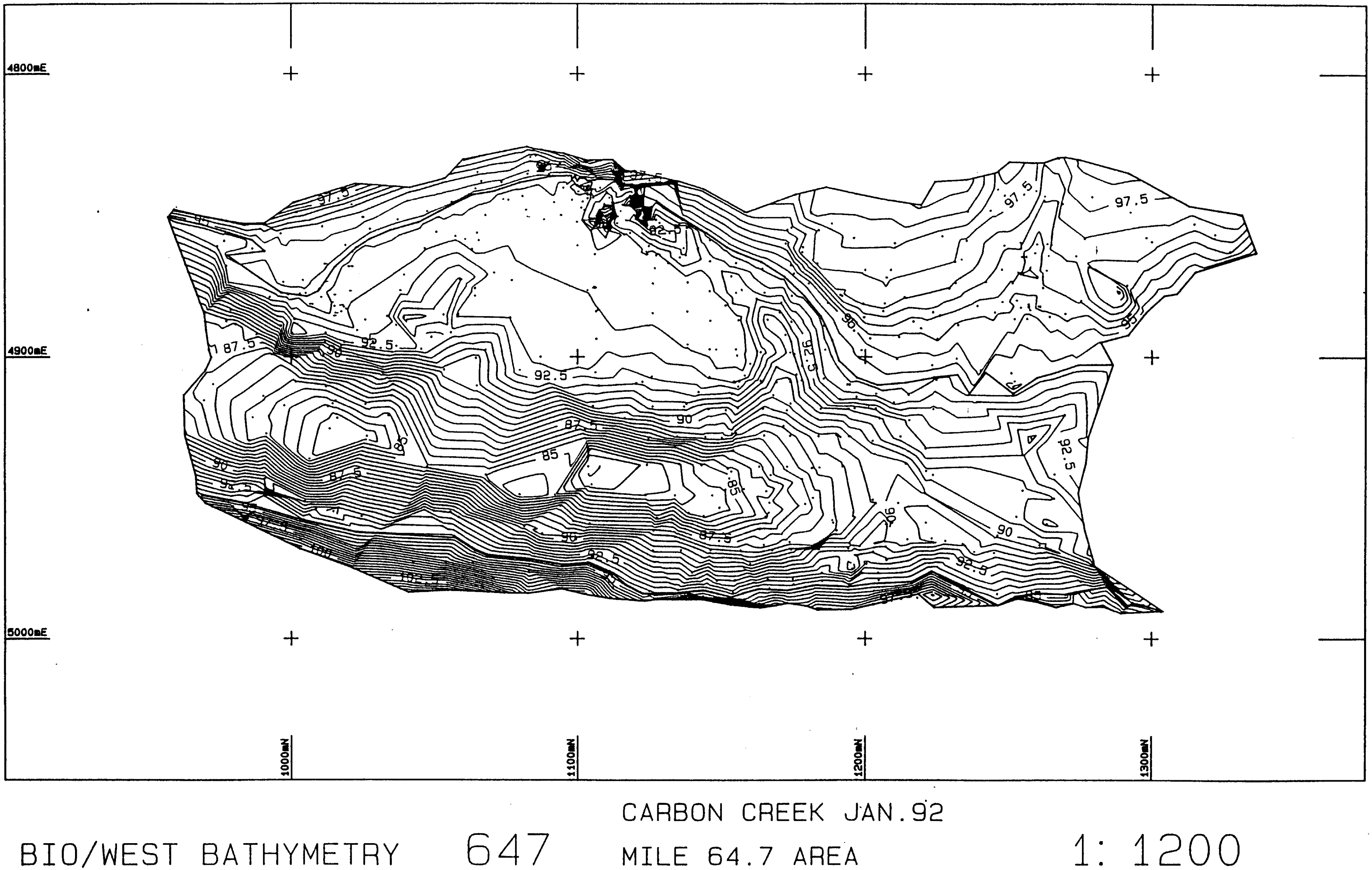

Figure 3-9. Bathymetric map of the Colorado River channel at RM 64.7, (Carbon Creek) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.

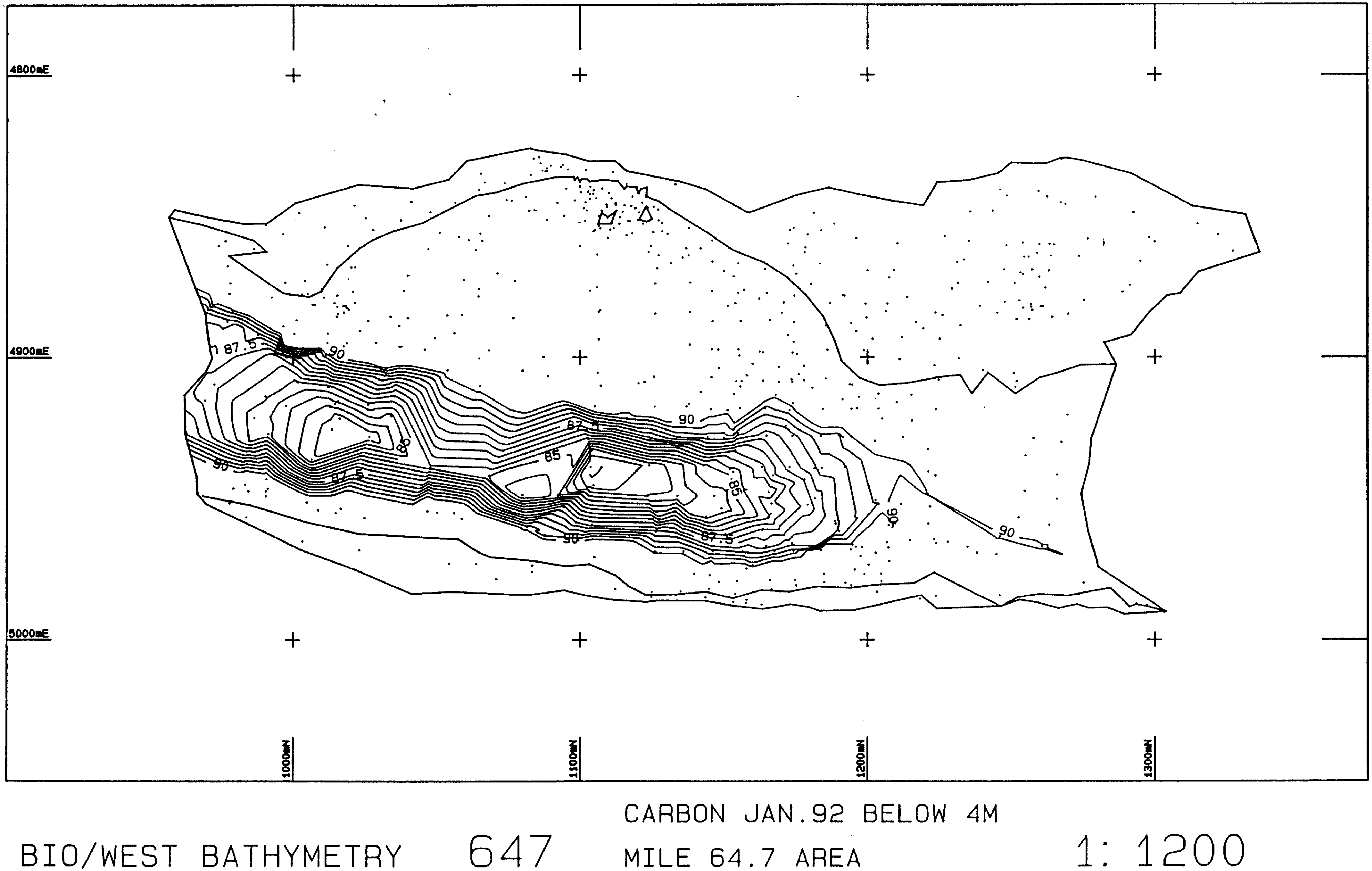

Figure 3-10. Bathymetric map of the Colorado River channel below 4 m at RM 64.7, (Carbon Creek) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.

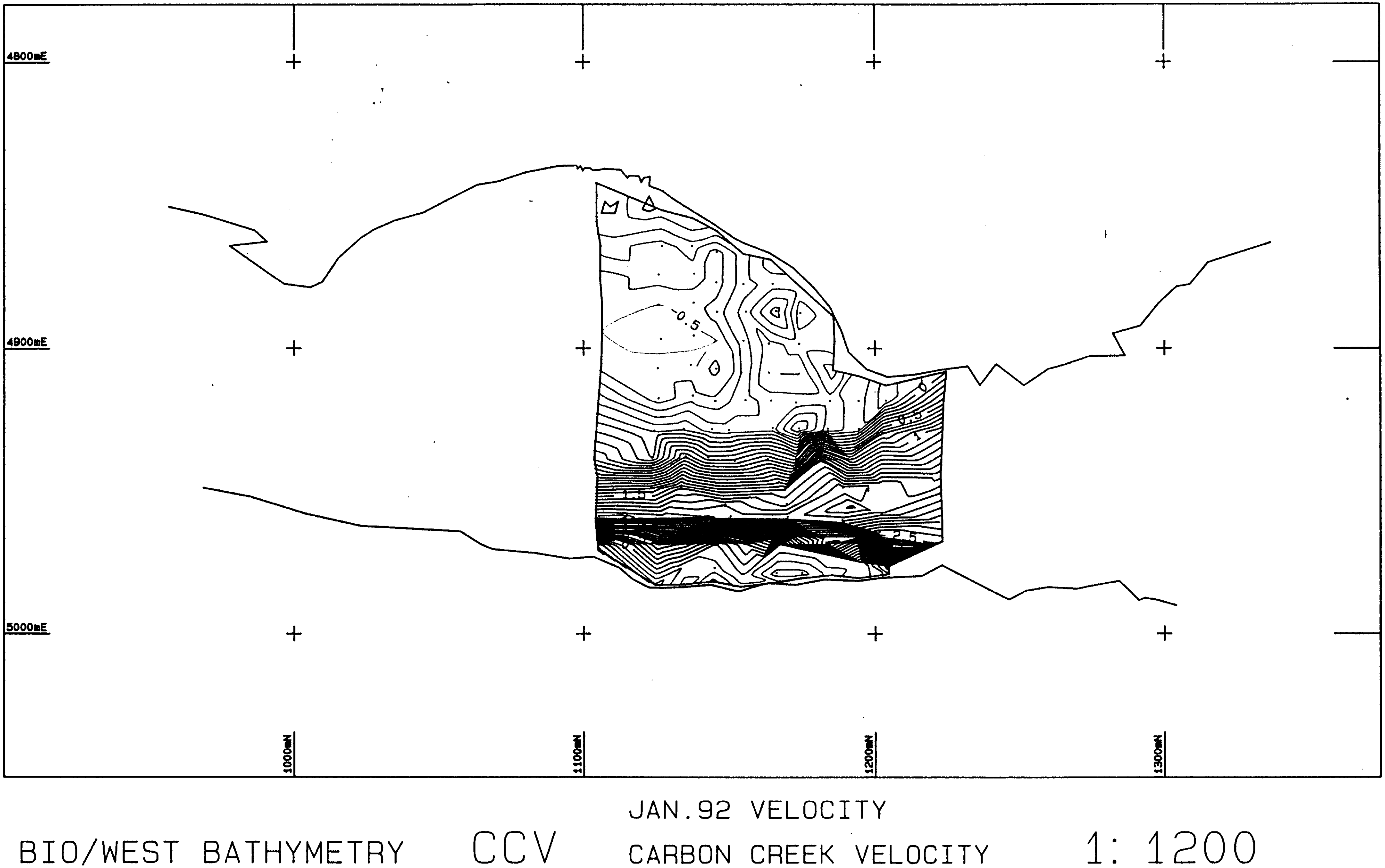

Figure 3-11. **Velocity Isopeths for the Colorado River at RM 64.7 (Carbon Creek) January 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.**

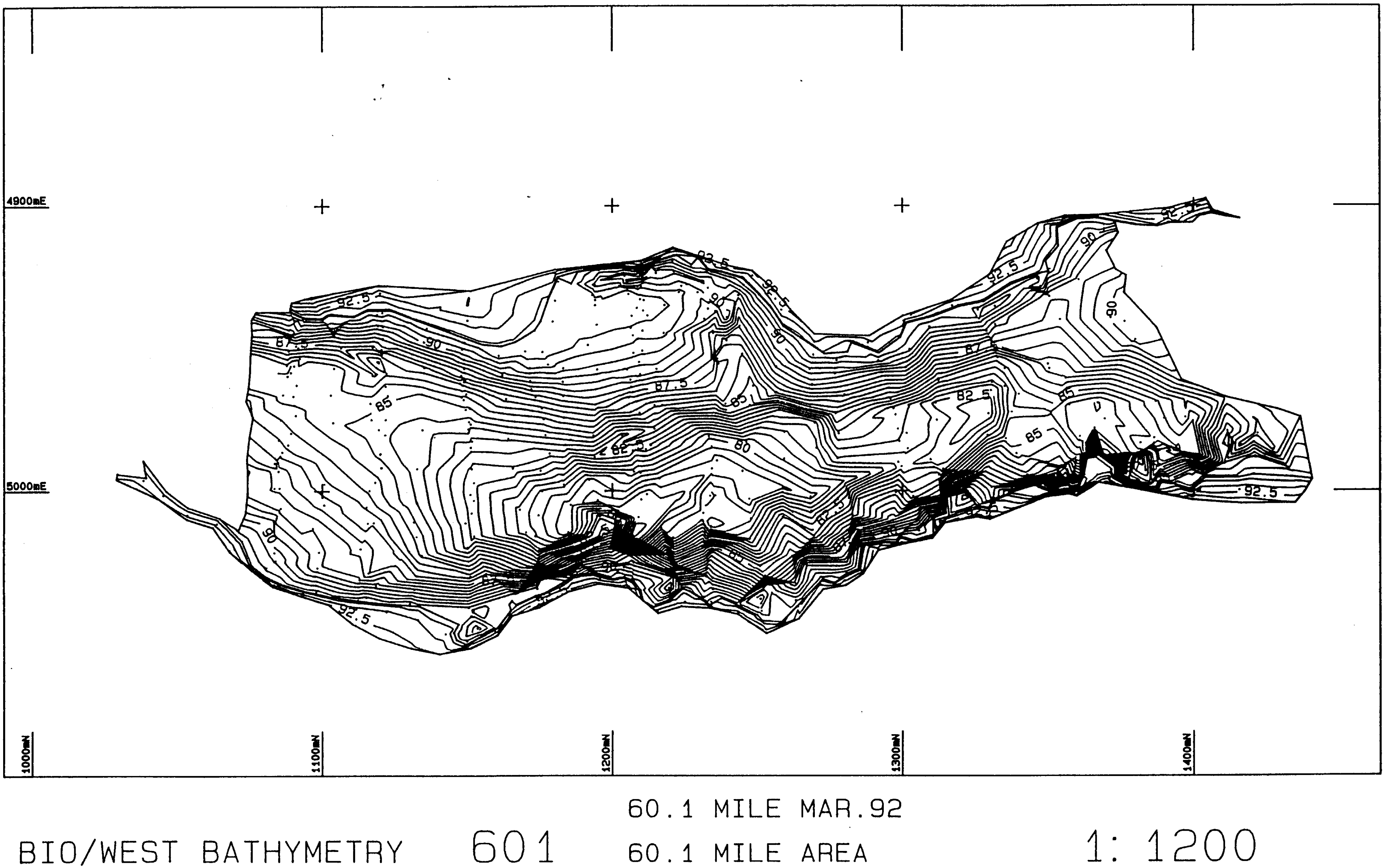

Figure 3-12. **Bathymetric map of the Colorado River channel at RM 60.1, March 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.**

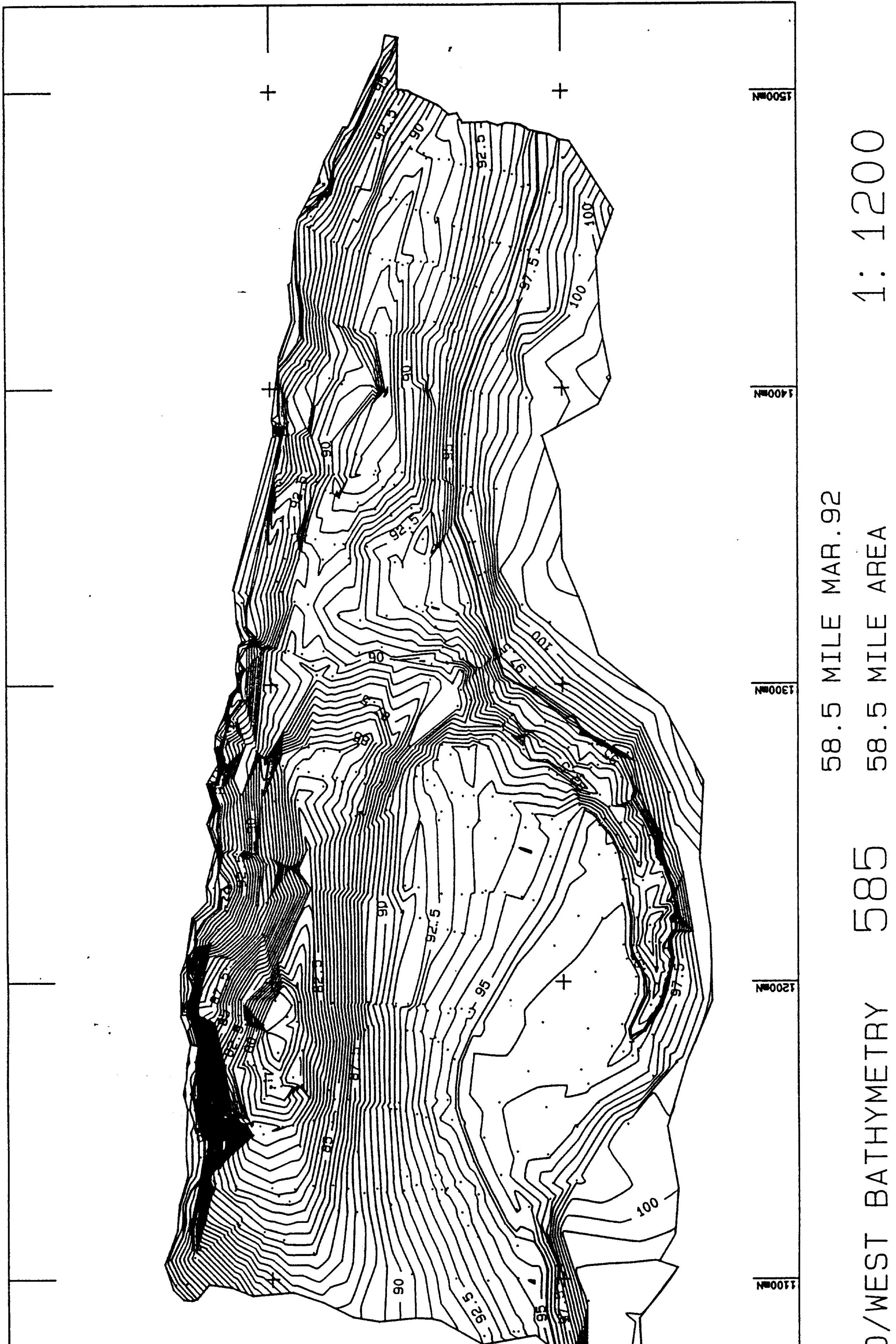

Figure 3-13. Bathymetric map of the Colorado River channel at RM 58.5 (Awatubi Canyon), March 1992. Bathymetric survey by M. Gonzales, F. Protiva, C. Brode, GCES Survey Department.

CHAPTER 4 - SPECIES COMPOSITION, DISTRIBUTION, ABUNDANCE

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INTRODUCTION

This chapter address Objective 1D: Determine distribution, abundance and movement of humpback chub in the mainstem Colorado River, and effects of dam operations on the movement and distribution of humpback chub.

This chapter summarizes fish sampling data collected from the Colorado River in Grand Canyon between January and November of 1992. Occasionally, data collected from October 1990 through November 1991 are presented when comparisons with 1992 data are considered relevant. Detailed comparative analysis of all data will be presented in the 1994 Final Report.

METHODS

Fish Sampling Methods

Nets

Gill and trammel nets were used extensively as primary sampling gear to characterize fish assemblages in shallow to deep shoreline habitats and to capture adults for implanting radiotransmitters. This gear type was used to compare fish distribution and abundance by area and time, as well as to characterize general fish habitat use in support of radiotelemetry data. Netting was a safe, effective means of sampling humpback chub in the Colorado River in Grand Canyon. There was no direct evidence of net-caused mortality of this species during an entire year of intensive sampling. Chub, in contrast to trout, struggled very little following entanglement, sustained few external abrasions, and were quickly and easily removed from nets. Occasionally, a chub swallowed air when removed from the water and had difficulty maintaining equilibrium in the live well. Most fish seemed able to self-regulate within minutes, but in extreme cases, gentle massaging of the fish's belly helped expel the air.

A variety of mesh sizes was used to capture adults and juveniles. The number of fish captured by species from a net set was recorded for calculation of catch per unit effort (CPE) expressed as number of fish per 100 feet of net per 100 hours. Three types of gill nets were used, including: 1) standard 1.5-inch gill net, 2) standard 2-inch gill net, and 3) experimental gill nets consisting of four panels each with uniform mesh sizes of 2, 1.5, 1, and 0.5 inches. All gill nets were 100 feet long, 6 feet deep, and constructed of double knotted #139 nylon multifilament twine. Trammel nets consisted of three panels of netting, two outer walls of large mesh and one inner panel of a small mesh, all constructed of double knotted #139 multifilament twine. The outer walls consisted of 12-inch mesh, and the inner panel consisted of one of two different mesh sizes, 1-inch or 1.5-inch; these mesh sizes were most effective for capturing humpback chub with a minimum of stress and injury.

Float lines on all nets were 0.5-inch diameter braided poly foamcore float line, and lead lines were 5/16-inch braided leadcore. White mooring boat bumpers were used as net floats and markers for high visibility. These were labeled to identify the research group, and to alert boaters of submerged nets. Polypropylene mesh bags filled with rocks served as convenient net weights. Nets were checked at intervals of no longer than 2 hours to minimize stress and reduce mortality of entangled fish. Nets clogged with algae (Cladophora glomerata) or debris were replaced and cleaned regularly. Catch per unit effort statistics were used as an index of fish abundance. Netting catch rates were expressed as number of fish per 100 feet of net per 100 hours of sampling effort.

Hoop Nets

Hoop nets were used in various low velocity habitats such as slow runs, pools, and side channels. Two sizes of hoop nets were used, including 2 ft x 10 ft x ½ inch and 4 ft x 16 ft x ½ inch (diameter x length x square mesh). Two wings made of 1-inch #15 knotless nylon were attached to the opening of the hoop nets. Each wing was 25 feet long.

Hoop nets were set by anchoring the rear of the net to the substrate with a length of rebar or fence post and orienting the mouth in a downstream direction to capture fish moving upstream. Nets were checked at least every 8 hours to minimize stress and mortality. Fish captured in hoop nets were placed in live wells for processing and released immediately near the point of capture. Hoop net catch rates were expressed as number of fish per 100 hours of sampling effort.

Minnow Traps

Unbaited minnow traps were used in 1992 to sample small fish in a variety of habitats including small embayments, rocky shorelines, sand beaches, and pools. Minnow traps were standard Gee minnow traps, 17.5 inches long, 9 inches in diameter, and constructed of galvanized wire and steel. Openings were located at each end of the trap.

Traps were placed on the bottom or suspended in the water column depending on conditions. Each trap was tethered to a secure anchor point and flagged for easy location. Traps were checked at intervals of no longer than 24 hours to minimize stress and mortality. Fish captured in traps were transferred to live wells for immediate processing. Numbers of fish captured by species in discrete efforts were recorded and related to time for calculation of CPE, expressed as number of fish per 100 hours.

Escape of juvenile humpback chub from minnow traps was documented in 1992. While conducting habitat measurements in the late afternoon along a shoreline set with minnow traps, a biologist noticed two juvenile chubs in a minnow trap which had been set several hours earlier that day. When the trapline was run the following morning the trap was empty. It may be necessary to check traps more frequently to lessen the potential for escape. Minnow trap catch rates were expressed as number of fish per 100 hours of sampling effort.

Electrofishing

Electrofishing was used to sample fishes of all sizes in shallow shoreline habitats. It was a primary sampling method for comparing fish assemblages between sample areas and over time. Electrofishing was also used to capture humpback chub for implanting radiotransmitters. Most electrofishing efforts were separated by geomorphic shoreline type (e.g., sheer wall, talus, sand beach) by conducting discrete runs within each habitat type. Numbers of fish captured by species in discrete efforts were recorded and related to time for calculation of CPE, expressed as number of fish per 10 hours.

Electrofishing was conducted from SU-16 Achilles research boats capable of ascending and navigating small and medium-sized rapids for increased access to sample areas. Each was designed to meet Occupational Safety and Health Administration (OSHA) safety standards with specialized features such as pressure safety switches, insulated railing, separate line-channeling for circuits, and lights. Safety standards required that the boat operator and netters wear rubber gloves and boots and use fiberglass-lined dip nets. Each system was powered by a 5000-watt Yamaha industrial grade generator (Model YG-500-D) or a Honda 5000-watt generator (Model EB 5000X) generator. Power from the generator was routed through a Mark XX Complex Pulse System (CPS) developed by Coffelt Manufacturing), in which current was transformed from 220-volt AC to pulsed DC current. Pulsed DC current was supplied to the water through one anode (positive electrode) mounted on a boom projecting from the bow of the boat and a cathode (negative electrode) suspended from the stern. Stainless steel spheres manufactured by Coffelt Manufacturing were used as electrodes. The anode and cathode were interchanged every 45 to 60 minutes of electrofishing to allow for cleaning of the cathode surface by reversing the electroplating process.

Fish captured during electrofishing were processed immediately upon completion of a run within a specific habitat type. Nontarget fish were released immediately after processing, generally within 0.1 to 0.2 mile of the point of capture. Initially, humpback chub were transported to a central processing station near camp and returned to their capture location for release. This practice was changed starting in August 1991, when all humpback chub were released near their capture site after processing on location, except for fish destined for radioimplant at the central processing station. This change was made when video photography of each humpback chub was discontinued, eliminating the need to transport fish to a central processing station.

In 1991, output settings on the CPS ranged from 15 to 20 A and 300 to 350 V, as recommended by Coffelt Manufacturing for electrofishing in the Colorado River below Glen Canyon Dam (Personal Communication with Norm Scharber, October 9, 1990). Toward the end of 1991, the output setting was reduced to 8 to 10 A and 200 to 250 V after blackened "bruise marks" were observed on trout. The lower setting seemed to reduce the incidence of these marks. Any evidence of external effect of electrofishing was recorded and later categorized as "bruise marks" (blackened, saddle-shaped area extending across the back at the posterior end of the dorsal fin), "spinal deformity" (evident spinal misalignment or swimming difficulty), "equilibrium loss" (inability of fish to upright), "extended narcosis" (apparent loss of consciousness for more than 5 minutes), or "unspecified" (undetermined or undescribed, but apparent effect).

In May and July of 1992, a total of three juvenile humpback chub mortalities occurred during electrofishing. The mortalities were not a direct result of electrofishing. These fish were found dead on the floor of the electrofishing boat or wedged between the live well and boat frame, suggesting that the fish jumped from the live well during electrofishing. To alleviate this problem a change in procedure was implemented in August 1992. A bucket of water was placed to one side of the half-full live well on the electrofishing boat. Sub-adult chubs captured by electrofishing were placed in the bucket and the split lid to the live well closed over the top of the bucket, preventing the fish from jumping out. No juvenile chub mortalities have occurred since implementation of this procedure. Electrofishing catch rates were expressed as number of fish per 10 hours of electrofishing.

Seines

Seines were used to sample various shoreline habitats including runs, riffles, and pools. AGF sampled backwaters in conjunction with our sampling of adjacent habitats. Seines were used primarily to characterize small fish assemblages in relatively shallow habitats (up to about 1.5 m in depth). Due to time constraints, seines were not used extensively in 1990 and 1991, but increased effort in 1992 show that seining was a valuable tool for capturing sub-adult chub. However, seining efficiency was greatly higher during high turbidity, which limited sampling opportunities with this gear type.

Length and width of each seine haul were measured and three water depths recorded; one at the deepest point of the haul, and one each midway between the deepest point and the nearest shore. Numbers of fish captured by species in discrete efforts were recorded and related to time for calculation of CPE, expressed as number of fish per 100 square meters. Length and width of the habitat sampled were also recorded, where applicable.

Fish captured in seines were kept in the river while all endangered and native fishes were removed and placed in live wells (bail buckets). The seine was beached and a second intensive search made. After all endangered and native fish were removed, the remainder of the fish were placed in a live well. Fish captured with seines were identified in the field and released live at capture locations.

Three sizes of seines were used for this study including 30 feet x 6 feet x 1/4 inch, 15 feet x 6 feet x 1/4 inch, and 10 feet x 4 feet x 1/8 inch (length x height x square mesh). The top, or float line was constructed of 5/16-inch braided polypropylene with hard foam floats at 18-inch intervals. The bottom line was made of braided polypropylene line with lead sinkers at 6-inch intervals. Seining catch rates were expressed as number of fish per 100 m^2 of area sampled.

Angling

Angling has been used as an effective method for capturing humpback chub in the upper Colorado River basin, in Black Rocks and Westwater Canyon (Valdez et al. 1982) and in Yampa Canyon (Tyus and Karp 1989). However, because of the relative high efficiency and low impact of other sampling gear types used in the Grand Canyon, angling for humpback chub was considered too time intensive and the data too limited. Angling may be a valuable tool to assess rainbow trout predation on YOY and juvenile humpback chub around and below the LCR confluence, where the highest concentrations of young chub occur. Angling was not used extensively in 1992 due to time constraints and a general lack of clear water conditions necessary to capture trout by angling. If time and conditions permit, angling effort will be increased substantially in 1993. Stomachs of all non-native fish captured by angling will be removed, preserved, and processed in the laboratory for identification of fish remains. Angling effort will be recorded as time spent actively fishing. Angling catch rates were expressed as number of fish per 100 hours of fishing.

Fish Handling Methods

A Fish Handling Protocol was developed by B/W that details the methods used for handling fish. Every effort was made to minimize stress to fish. Gill and trammel nets were checked at intervals of no longer than 2 hours and all fish captured were placed immediately in live wells with fresh water. Electrofishing was monitored closely and all fish were checked for evidence of injury so that adjustments could be made in settings or technique.

Non-target species (rainbow trout, brown trout, brook trout, carp, channel catfish, and plains killifish) were measured, weighed, and released immediately at the point of capture. All native fish (humpback chub, razorback suckers, flannelmouth suckers, bluehead suckers, and speckled dace) were measured, weighed and those over 150 mm TL were marked with PIT (Passive Integrated Transponder) tags, and released at the point of capture. PIT tags were injected into the peritoneal cavities with a special hypodermic needle (Burdick et al. 1992).

Humpback chub were placed in live wells, processed, and released near the capture location unless the fish was destined for radioimplant, in which case it was taken to a central processing station at base camp. Each chub was measured as total (TL), standard (SL), and forked length (FL); weighed in grams; and PIT tagged if over 150 mm TL. One of every ten chub over 200 mm TL was measured for meristics including depth of nuchal hump, head length, distance between insertion of pelvic and pectoral fins, maximum body depth, maximum caudal peduncle depth, minimum caudal peduncle depth, length of anal fin base, length of dorsal fin base, and dorsal and anal ray counts. Fish measured for meristics were also photographed on a centimeter grid board. Humpback chub large enough to radiotag (550 g for 11-g tags) were isolated in a live well and taken to the surgery tent.

RESULTS AND DISCUSSION

Sampling Gear Efficiency

Seventeen gear types were used to sample three study reaches of the Colorado River in Grand Canyon in 1992: eight types of nets, three types of traps, four sizes of seines, electrofishing, and angling (Table 4-1). Adult humpback chub were captured with eleven of these gears, juveniles with nine, and YOY with three. The distribution of these sample efforts and catch rates by reach for flannelmouth sucker, bluehead sucker, and rainbow trout are presented in Appendices 4-1, 4-2, 4-3.

Collectively, sampling gear used in the Grand Canyon effectively captured all life stages of humpback chubs (Fig. 4-1); fish ranged in size from 37 to 455 mm TL in 1992. Based on the average total length of fish collected by each gear type, minnow traps and seines were most effective for collecting YOY chub; electrofishing, seining, and experimental gill nets for juveniles; and, gill nets, trammel nets, and angling for adults.

Table 4-1. Description of fish sample gears and numbers of humpback chub captured in the Colorado River in Grand Canyon, 1992.

Sample Gear Code-Description	Total No. Samples	Total Hours	Number of Chub[a]				Gross CPE (no/hrs)[b]
			Y	J	A	T	
Gill Nets		per 100 hrs					
GP - 100'x6'x1.5" gill net	431	897.1	0	0	29	29	3.2
GM - 100'x6'x2" gill net	248	531.4	0	0	25	25	4.7
GX - Experimental gill net, 100'	157	332.3	0	14	10	24	7.2
Trammel Nets							
TL - 75'x6'x1.5"x12" trammel net	821	1,735.0	0	1	124	125	9.6
TK - 75'x6'x1"x12" trammel net	762	1,595.4	0	9	126	135	11.3
TM - 50'x6'x1"x12" trammel net	328	669.0	0	2	35	37	11.1
TN - 50'x6'x1.5"x12" trammel net	338	695.7	0	0	19	19	5.5
TW - 75'x6'x0.5"x10" trammel net	10	19.0	0	0	0	0	0
Hoop Nets							
HL - Large hoop net (4' diameter)	15	314.4	0	0	0	0	0
HS - Small hoop net (2' diameter)	19	347.8	0	0	0	0	0
Minnow Traps							
MT - Commercial minnow trap	813	20,481.6	29	48	0	77	0.4
Electrofishing		per 10 hrs					
EL - 220-V DC	932	270.2	75	340	42	457	16.9
Seines		per 100m² Area(m²)					
SA - 10'x3'x1/8" seine	40	10,307.5	0	19	0	19	0.2
SB - 30'x4'x1/4" seine	22	3,159.0	0	34	2	36	1.1
GF - Floated gill net	6	1,350.0	0	0	2	2	0.2
SG - 30'x5'x0.25" seine	53	11,975.5	16	58	0	74	0.6
Angling		per 100 hrs					
AN - standard gear	6	34.8	0	0	2	2	5.7
TOTAL	**5,001**		**120**	**525**	**417**	**1,062**	

[a]Y = young-of-the-year, J = juvenile, A = adult, T = total.
[b]Gross catch-per-effort (CPE computed from total hours; all nets adjusted to 100 feet.)

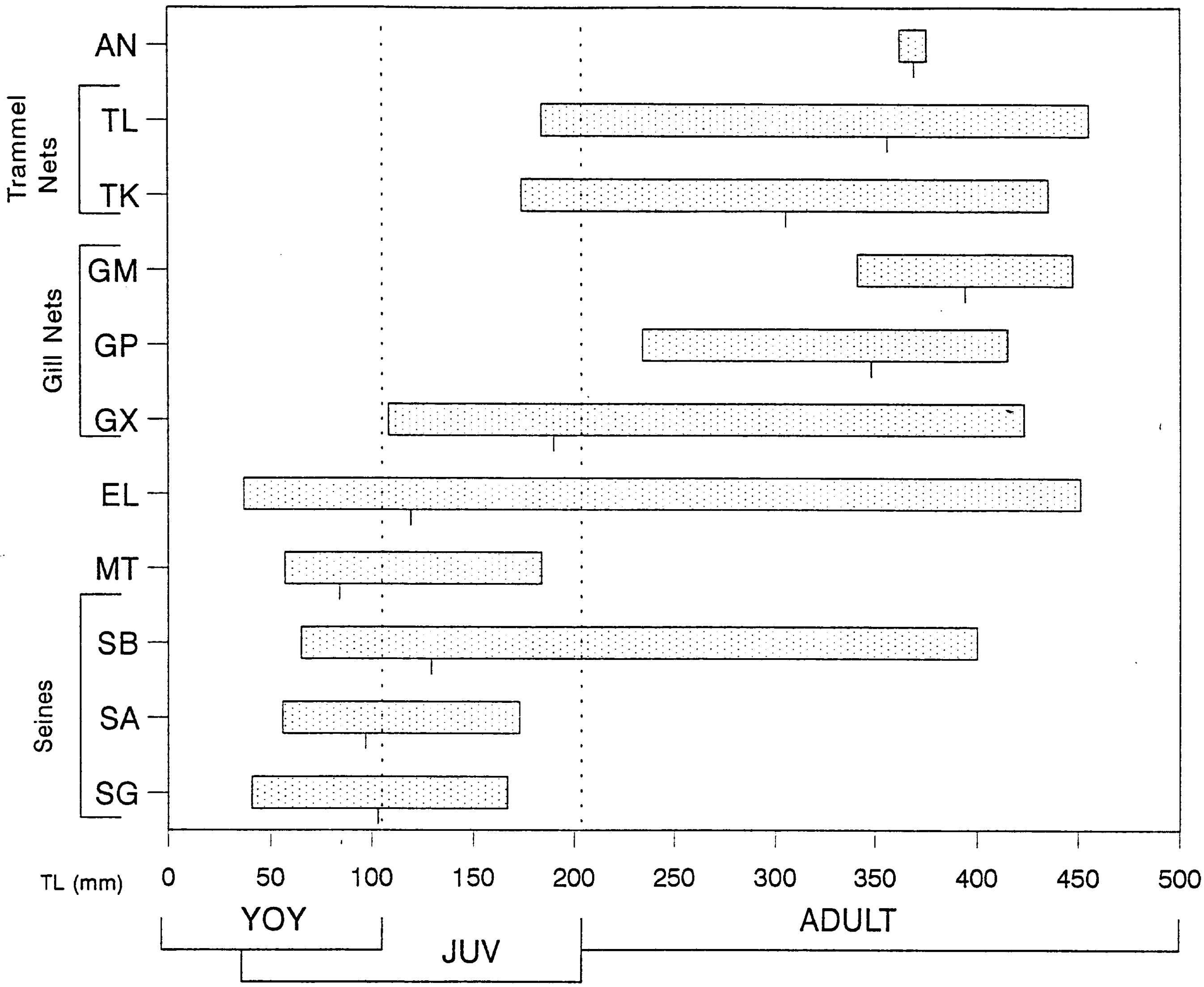


Figure 4-1. **Minimum, maximum, and mean TL of humpback chubs collected with 11 gear types in the Colorado River in Grand Canyon, 1992. See Table 4-1 for explanation of gear codes.**

Nets

Gill and trammel nets were set 3,095 times in 1992, for a total of 6,475 hours (Table 4-1). Humpback chub were captured with all net types used in Reach 1 (Table 4-2). Trammel nets were about three times more effective than gill nets in capturing adult humpback chub. This is at least partly due to restrictions in use of gill nets due to their length (25 feet longer than trammel nets). In 1992, 50-foot trammel nets (gear codes TM and TN) were used to effectively sample areas where longer nets would get twisted and fouled. There was no significant difference in humpback chub catch rates between 1.5- and 2-inch mesh gill nets, or between 1-inch and 1.5-inch mesh trammel nets (Student's T-Test; $P \leq 0.05$). There was a positive relationship, however, between net mesh size and humpback chub TL (Fig. 4-1); 2-inch gill nets (GM) collected significantly larger chub than 1.5-inch gill nets (GP), and 1.5-inch trammel nets (TL) caught significantly larger chub than 1-inch trammel nets (TK) (Student's T-Test; $P \leq 0.05$). No YOY chub were collected in nets in 1992, although both types of trammel nets captured larger-sized juveniles (Fig. 4-1). It is suspected that experimental gill nets are capable of capturing both YOY and juvenile chub, but their use and effectiveness is restricted by their susceptibility to fouling from drifting Cladophera and other debris.

Hoop Nets

In 1992, large hoop nets (HL) and small hoop nets (HS) were set a total of 15 and 19 times, respectively, for total fishing times of 314 and 348 hours (Table 4-1). No humpback chub were collected from these sets. The use of hoop nets in the Colorado River in Grand Canyon was restricted by relatively high maintenance (i.e., cleaning the traps of Cladophera) and better efficiency of other gears.

Minnow Traps

Unbaited minnow traps (MT) were set 813 times in 1992, for a total sample time of 20,482 hours (Table 4-1). A total of 77 YOY and juvenile chub were captured at a rate of 0.38 fish/100 hour. Minnow traps have proven valuable at capturing sub-adult chub in low velocity habitat with relatively little effort.

Three chub died in minnow traps in 1992: one juvenile chub (89 mm TL) in July, and two juvenile chub (82 and 89 mm TL) in November. The cause of death of all three chubs was undetermined. It is possible that changes in flow pulled the traps into deeper, more turbulent water, subjecting the entrapped chubs to stressful conditions.

Table 4-2. Catch rate (CPE) of adult, juvenile and YOY humpback chub by gear in the Colorado River in Grand Canyon, October 1990-November 1992.

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult HB			Juvenile HB			YOY HB		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
NETS[b]															
GM	140	66	42	301.8	136.9	92.6	8.3 (25)	0	0	0	0	0	0	0	0
GP	165	160	106	353.4	327.1	216.6	7.4 (28)	0.3 (1)	0	0	0	0	0	0	0
GX	47	55	55	101.6	114.7	116.0	7.2 (7)	4.1 (3)	0	13.4 (13)	1.1 (1)	0	0	0	0
TK	246	315	201	537.0	636.0	422.3	27.5 (115)	2.3 (11)	0	2.0 (7)	0.5 (2)	0	0	0	0
TL	250	361	210	533.3	735.7	466.0	29.0 (116)	1.6 (8)	0	0.2 (1)	0	0	0	0	0
TM	35	192	101	75.1	385.8	208.2	28.4 (10)	13.2 (23)	1.8 (2)	3.1 (1)	0.5 (1)	0	0	0	0
TN	55	159	124	121.9	320.4	253.4	22.9 (14)	3.2 (5)	0	0	0	0	0	0	0
TW	0	10	0	0	19.0	0	0	0	0	0	0	0	0	0	0
Totals	**938**	**1318**	**839**	**2024.1**	**2675.6**	**1775.1**									
TRAPS[c]															
HL	0	11	4	0	209.1	105.3	-	0	0	0	0	0	0	0	0
HS	0	16	3	0	308.0	39.8	-	0	0	0	0	0	0	0	0
MT	702	91	20	17712.9	2199.6	569.2	0	0	0	0.3 (48)	0	0	0.2 (29)	0	0

Table 4-2 continued

GEAR[a]	Total samples REACH 1	2	3	Total time (hr) REACH 1	2	3	Catch Per Effort (number of fish) Adult HB REACH 1	2	3	Juvenile HB REACH 1	2	3	YOY HB REACH 1	2	3
Totals	**702**	**118**	**27**	**17712.9**	**2716.8**	**714.2**									
ELECTROFISHING[d]															
EL	432	293	207	102.4	103.4	64.5	6.1 (36)	0.4 (5)	0.3 (1)	29.5 (334)	0.4 (6)	0	8.9 (75)	0	0
SEINES[e]															
				Total Area (m^2)											
SA	23	13 (11)	4 (10)	6345.5	3644	318	0	0	0	3.4 (14)	1.3 (5)	0	0	0	0
SB	22	0	0	3159	0	0	0.1 (2)	-	0	2.4 (34)	-	0	0	-	0
GF	5	0	0	1035	0	0	0.1 (2)	-	-	0	-	-	0	-	-
SG	53	0	0	11975.5	0	0	0	-	-	1.6 (58)	-	-	0.5 (16)	-	-
Totals	**103**	**13**	**4**	**22515.0**	**3644**	**318**									
ANGLING[f]															
AN	3	0	3	24.1	0	10.7	0.1	0	0	0	0	0	0	0	0

[a]See Table 4-1 for gear codes
[b]CPE = no. fish/100 ft/100 hr
[c]CPE = no. fish/100 hr
[d]CPE = no fish/10 hr
[e]CPE = no. fish/100m^2
[f]CPE = no. fish/100 hr

Electrofishing

A total of 932 electrofishing runs (270 hours) were conducted in 1992 (Table 4-1). Electrofishing accounted for the largest number of chub captured by any gear type with a total of 457 fish and a catch rate of 16.92 fish/10 hour. This was the only gear type with which all three life stages of chub were collected, including 75 YOY, 340 juveniles, and 42 adults. All YOY were captured from May through November of 1992, following movement of these young fish from the LCR into the mainstem Colorado River.

Seines

A total of 115 standard seine hauls (three types of seines: SB, SA, SG) and six sweeps with floated gill nets (GF) were taken in 1992 (Table 4-1). Standard seine hauls produced 129 chubs: 16 YOY, 111 juveniles, and 2 adults. Two adults were captured with sweeping gill nets. Efficiency of seine hauls was found to be directly related to water turbidity, i.e., higher catch rates occurred at higher turbidity. In 1992, seining CPE for YOY humpback chub during low and high turbidity was 0 and 0.175 fish/100 m^2, respectively, and 0.238 and 1.508 fish/100 m^2 for juvenile chub, respectively. Kaeding and Zim^Aerman (1983) reported similar findings and speculated that sub-adult humpback chub used shallow littoral areas only during darkness and periods of high turbidity; increased escape of chubs because of high researcher visibility in the daytime was discounted based on field observations.

Angling

Angling effort in 1992 was limited to the months of March and July. Total effort in Reaches 1 and 3 were 24.1 and 10.7 hours, respectively (Table 4-1). Six fish were collected in Reach 1; four rainbow trout and two humpback chub. No fish were collected in Reach 3. Both chub captured angling were in good condition and processed as normal. Both bait (salmon eggs and stink bait) and lures (various spinners and rapalas) were used in each reach, depending on water clarity.

Distribution of Effort

Longitudinal Sampling

Each sample substrata in the three study reaches was sampled at least twice in 1992, except for RM 96.0-107.8 which was sampled only once (Table 4-3). Sample substrata within RM 56.0-65.5 (Kwagunt Canyon to Lava Canyon in Reach 1) were visited each month. In Reaches 2 and 3, sampling within the substrata was relatively evenly spread, with somewhat more focus on areas with major tributaries (e.g., Kanab Creek within RM 140.0-143.6).

Table 4-3. Sample substrata sampled during monthly field trips, Colorado River in Grand Canyon, 1990-1992.

Sample Substrata (river miles)	1990		1991								1992										
	Oct	Nov	Jan	Mar	Apr	May	Jun	Jul	Sep	Nov	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
0.0 - 56.0										X	X		X				X				
56.0 - 61.5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
61.5 - 65.5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
65.5 - 72.5	X						X		X	X	X				X		X		X		X
72.5 - 77.4		X		X					X								X		X		
77.4 - 86.5			X	X				X	X	X			X		X				X		X
86.5 - 89.0		X		X		X			X	X			X		X				X		X
89.0 - 96.0																	X				X
96.0 - 107.8			X			X		X			X										
107.8 - 109.8		X	X	X		X		X	X	X	X		X		X				X		X
109.8 - 117.8							X	X	X								X		X		
117.8 - 125.5			X				X	X	X	X	X						X		X		X
125.5 - 131.7						X	X	X	X	X			X		X		X		X		X
131.7 - 134.5			X	X		X				X			X		X						X
134.5 - 140.0				X		X							X		X						
140.0 - 143.6		X		X		X			X	X			X		X		X		X		X
143.6 - 153.5							X	X					X				X				
153.5 - 160.0		X		X		X	X	X		X			X		X				X		X
160.0 - 169.9		X	X				X	X	X		X						X		X		
169.9 - 179.4			X					X	X		X						X				
179.4 - 189.1				X			X	X		X			X		X		X				
189.1 - 200.0		X					X	X	X				X		X		X		X		
200.0 - 208.9		X	X	X		X			X	X			X				X		X		
208.9 - 213.9		X		X		X	X		X	X	X		X		X		X				X
213.9 - 226.0		X	X	X		X	X	X	X	X	X		X		X		X		X		X

Netting in Reach 1 occurred primarily between RM 58.0 and 65.9 (Awatubi Canyon and Lava Canyon), with peak effort between RM 61.0 and 61.9 (around the LCR confluence) (Fig. 4-2). In Reaches 2 and 3, peak netting effort was between RM 108.0 and 108.9 (around Shinumo Creek), and between RM 156.0 and 156.9 (around Havasu Creek), respectively. Most netting in Reach 2 occurred near mouths of tributaries (i.e., Bright Angel Creek, Shinumo Creek, Tapeats Creek, and Kanab Creek). Netting effort in Reach 3 was more evenly distributed than in Reach 2. The percentages of 1-mile sections sampled with nets in Reaches 1, 2, and 3 were 77.3, 39.7, and 62.9, respectively.

Distribution of electrofishing effort was similar to that of netting in all reaches. Peak electrofishing effort in Reach 1 occurred between RM 62.0 and 62.9 (Crash Canyon area), and the general range of intensive sampling was between RM 57.0 and 64.9 (Blue Moon Graben Camp and Lava Canyon) (Fig. 4-3). As with netting, peak electrofishing effort in Reach 2 was around Shinumo Creek, RM 108.0-108.9. In Reach 3, effort peaked between RM 214.0 and 214.9. The percentages of 1-mile sections sampled by electrofishing in Reaches 1, 2, and 3 were 86.4, 55.1, and 77.1, respectively.

Diel Sampling

In all reaches in 1992, most netting occurred between early morning (0601 hours) and late evening (2400 hours) (Table 4-4, Fig. 4-4). Limited sampling occurred during early morning hours. Sampling with nets occurred in all 2-hour time blocks within Reach 1 in 1992, with the largest number of sets between 2001 and 2200 hours. Diel sampling was normally distributed (bell-shaped) around this time block. Netting efforts in Reaches 2 and 3 were similar; a bimodal distribution with peaks around noon and late evening. Peak effort in Reaches 2 and 3 occurred between 2001 and 2200 hours and between 1801 and 2000 hours, respectively. Few or no nets were set between 0001 and 0600 hours in any reach.

Most electrofishing took place between 0601 and 2400 hours in all reaches (Table 4-4, Fig. 4-5). Peak effort occurred between 2001 and 2200 hours in Reach 1, and between 1801 and 2000 hours in Reaches 2 and 3. Distribution of electrofishing for all reaches was approximately bimodal, with peak effort occurring in morning (0601-1000) and evening (1801-2200) hours. There was no electrofishing between 0001 and 0400 hours in Reaches 1 and 3, and between 0001 and 0600 hours in Reach 2; primarily because of the risk of nighttime electrofishing in swift canyon reaches adjacent to whitewater rapids.

Table 4-4. Diel analysis of sampling efforts in the Colorado River in Grand Canyon by study reach and gear type, 1992.

Time Block	Netting by Reach						Electrofishing by Reach					
	1		2		3		1		2		3	
	N	Time Elapsed (hr)	N	Time Elapsed (hr)	N	Time Elapsed (hr)	N	Time Elapsed (hr)	N	Time Elapsed (hr)	N	Time Elapsed (hr)
0001-0200	12	25.1	1	1.8	5	9.4	0	0	0	0	0	0
0201-0400	4	9.3	0	0	1	2.2	0	0	0	0	0	0
0401-0600	4	6.7	0	0	1	3.0	12	2.0	0	0	5	1.0
0601-0800	16	38.5	65	133.0	33	96.6	88	16.1	71	20.9	37	8.7
0801-1000	42	88.7	222	450.7	109	397.0	18	5.9	61	20.5	24	10.7
1001-1200	34	71.4	222	500.3	112	349.2	22	9.6	47	16.4	18	6.3
1201-1400	22	50.6	110	255.6	76	182.2	18	4.3	5	1.0	14	2.5
1401-1600	41	140.5	20	55.5	26	54.6	82	18.3	12	3.7	7	1.7
1601-1800	86	190.5	32	56.4	30	94.2	50	9.4	43	13.5	7	3.7
1801-2000	194	408.8	233	457.7	165	596.6	67	13.7	67	23.4	52	16.3
2001-2200	297	761.2	257	523.5	190	585.4	120	30.7	54	20.0	42	14.4
2201-2400	195	394.1	157	291.6	95	381.2	41	10.4	5	2.9	6	1.6

N = Number of sampling efforts

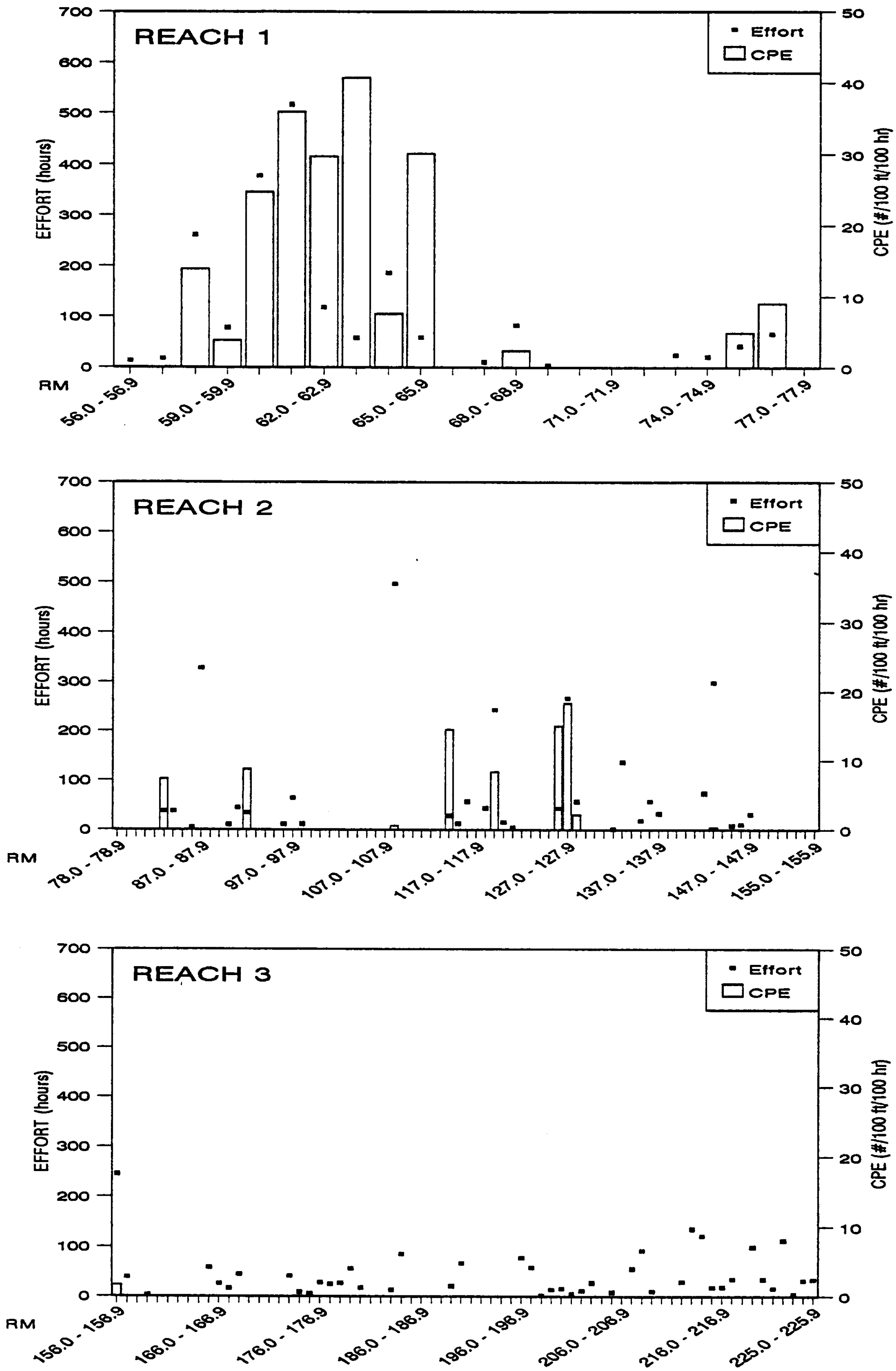


Figure 4-2. Total netting effort and catch rates of adult humpback chub in three study reaches of the Colorado River in Grand Canyon, 1992.

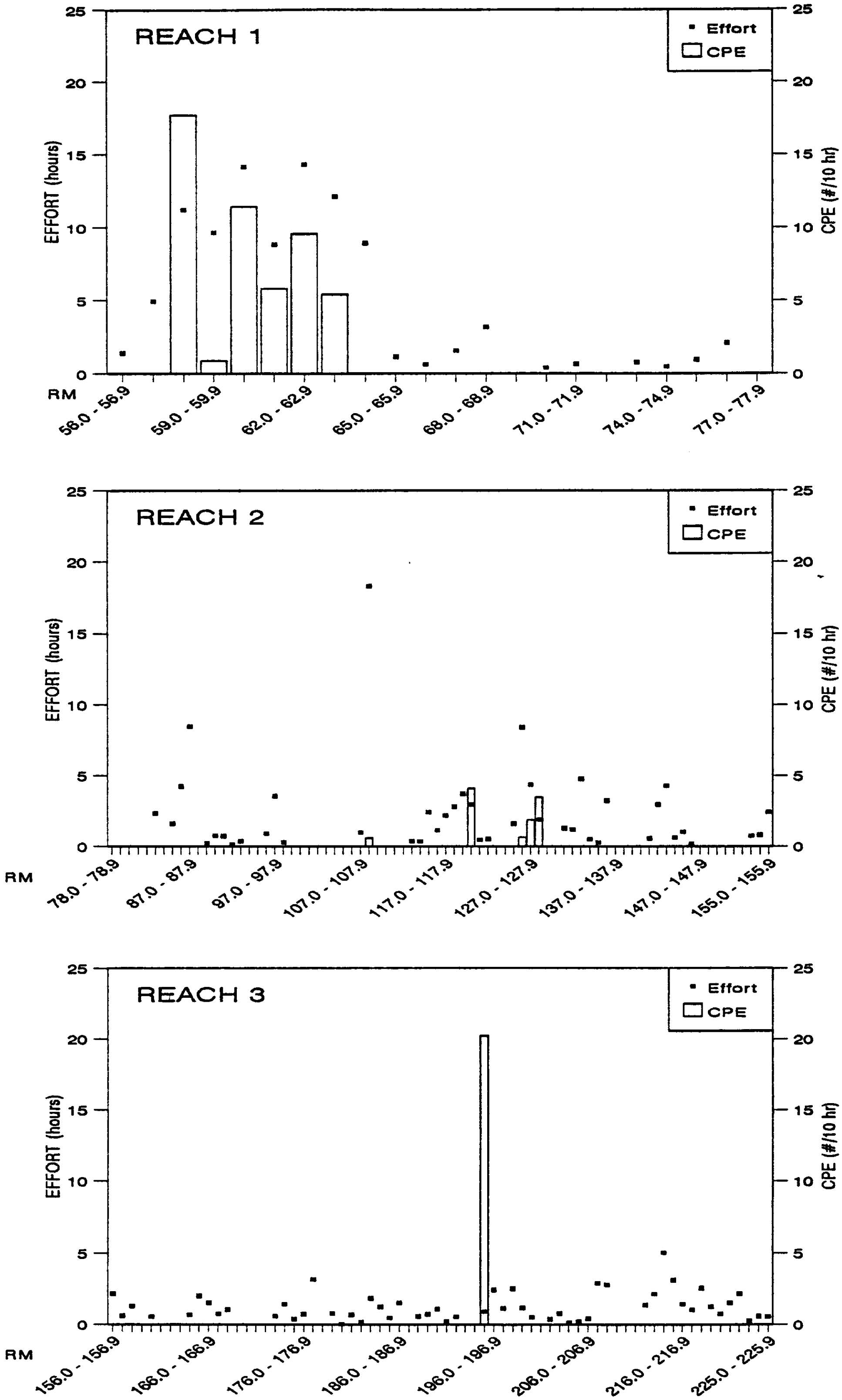


Figure 4-3. Total electrofishing effort and catch rates of adult humpback chub in three study reaches of the Colorado River in Grand Canyon, 1992.

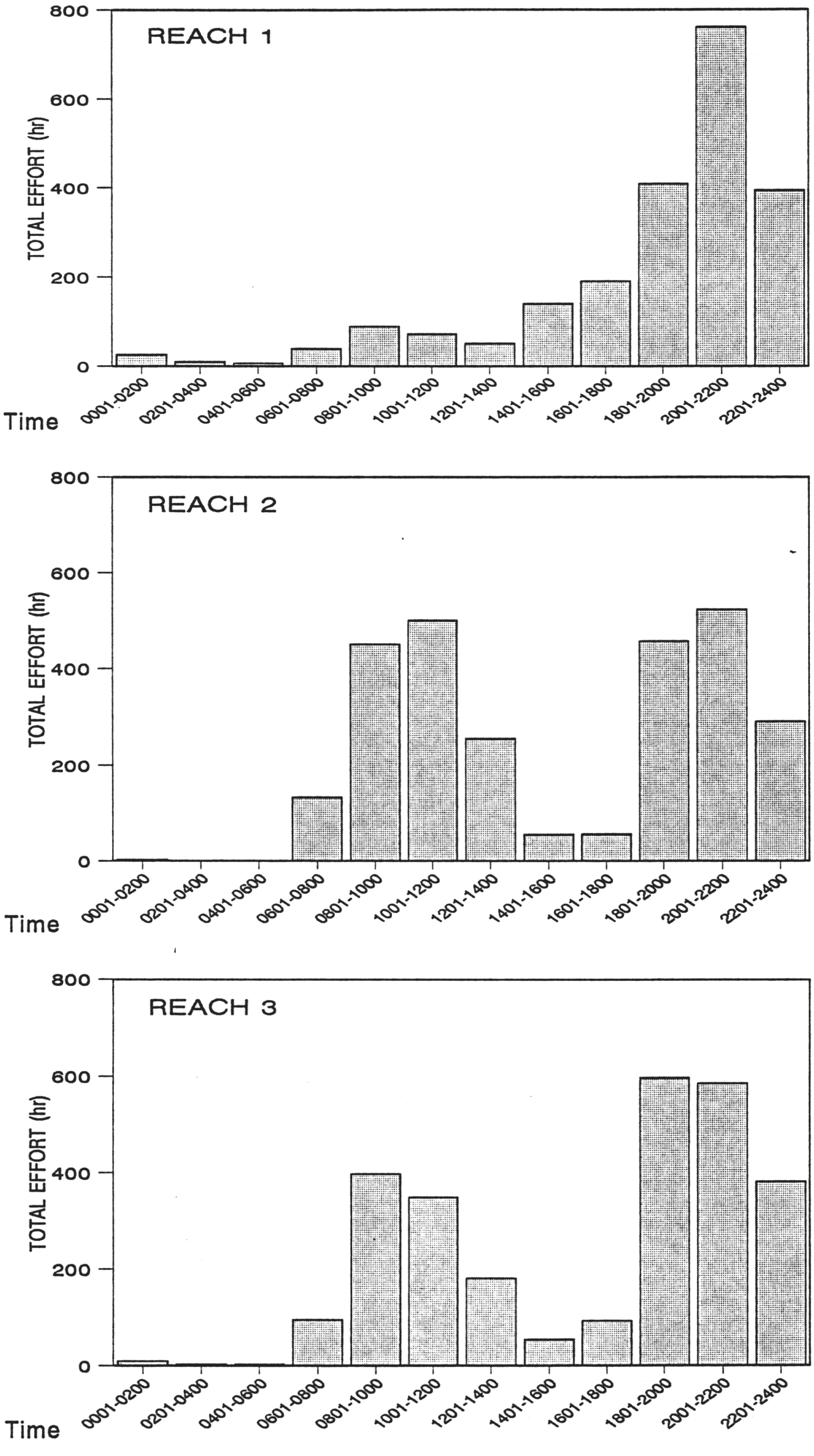


Figure 4-4. Total netting effort by 2-hour time blocks in three study reaches of the Colorado River in Grand Canyon, 1992.

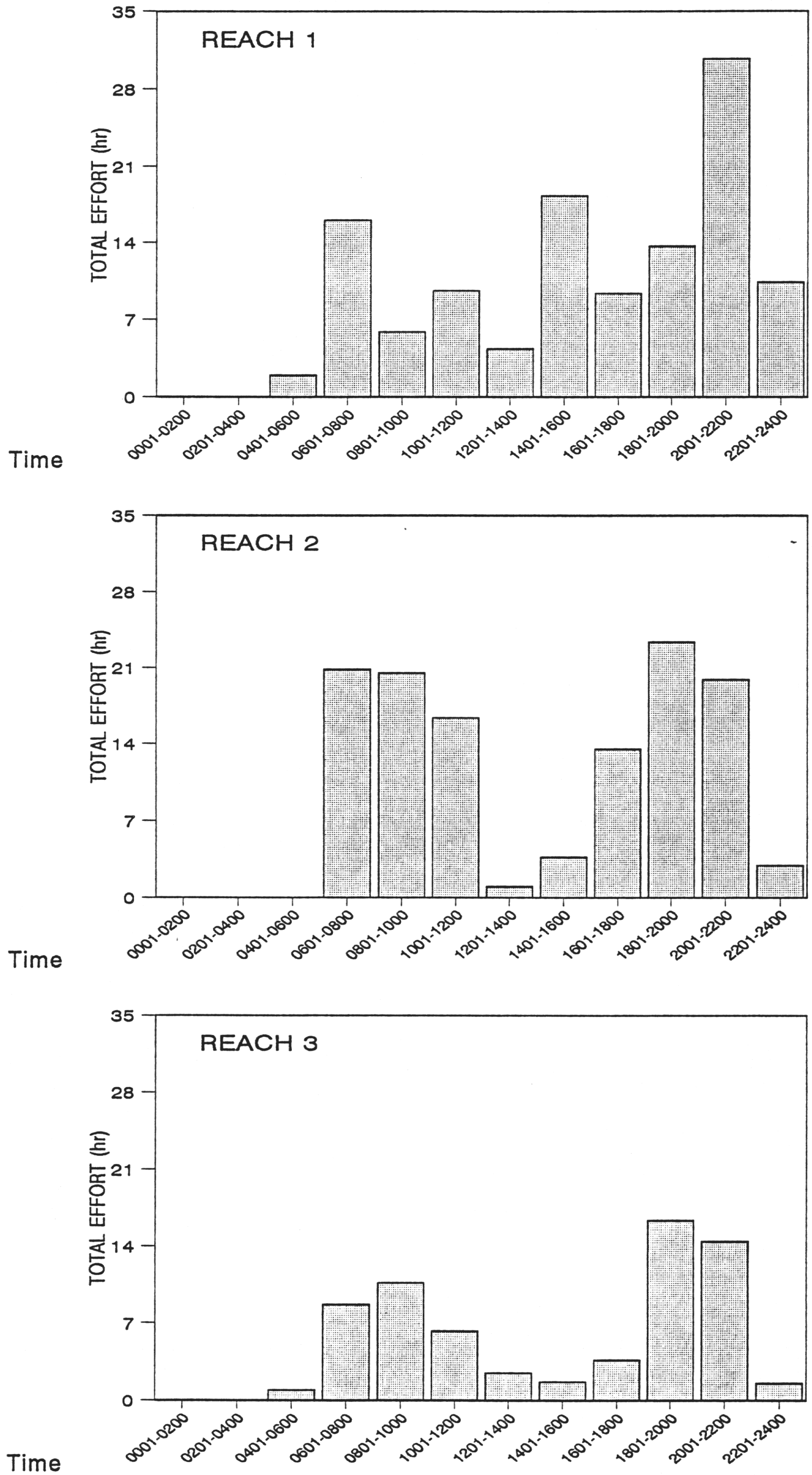


Figure 4-5. **Total electrofishing effort by 2-hour time blocks in three study reaches of the Colorado River in Grand Canyon, 1992.**

In 1991 and 1992, most sampling occurred when catch rates of humpback chub were highest (i.e., morning and evening) in order to capture sufficient numbers of fish for radiotagging and PIT tagging. With the elimination of radiotelemetry in Reach 1 and relatively high recapture rates of PIT-tagged fish, sampling with nets in 1993 will shift to focus on characterization of diel behavior of humpback chubs. Effort will be shifted to cover the entire 24-hour period, with emphasis on sampling before, during, and after the morning crepuscular period. Both radiotelemetry and fish sampling catch rates have indicated increased chub activity around the evening crepuscular period; more data are needed to determine if such activity also occurs around the morning crepuscular period.

Species Composition

Fourteen species of fish were captured in the Colorado River in Grand Canyon in 1992 (Table 4-5), including 4 native and 10 non-natives. Two the 4 native species, were endemic including flannelmouth sucker and humpback chub. The 10 non-native species represented 6 families. The only species collected in 1990-91 but not in 1992 was the walleye (Stizostedion vitreum). The collection of a single juvenile green sunfish was unique to 1992.

Nets

Eight species of fish were captured in gill and trammel nets in 1992. The majority of adult fish captured in nets in all reaches were rainbow trout (30.7%), flannelmouth sucker (27.3%), and humpback chub (22.0%) (Appendix B, Table B-4). Rainbow trout were the dominant species in Reach 1, comprising 40.5 percent of the total catch compared to 31.2 percent for humpback chub (Appendix B, Table B-5). Flannelmouth suckers were dominant in Reaches 2 and 3, comprising 28.0 and 41.4 percent of the total catch, respectively (Appendix B, Tables B-6 and B-7). Humpback chub represented 11.8 and 0.8 percent of the catch in the respective reaches. Striped bass was the only species unique to Reach 3, comprising only 0.8 percent of the total catch. Native species comprised 57.6, 46.1, and 52.3 percent of the total adult catch in nets in Reaches 1, 2, and 3, respectively (Fig. 4-6).

Electrofishing

Twelve species of adult fish were captured by electrofishing in 1992. The majority of adult fish captured electrofishing in all reaches were rainbow trout (53.2%), common carp (19.1%), and brown trout (15.9%) (Appendix B, Table B-8). Rainbow trout were by far the most common species captured in Reach 1 with electrofishing, comprising 83.4 percent of total catch, compared to 2.7 percent for

Table 4-5. Fish species captured in the Colorado River in Grand Canyon, 1992.

Species Code	Common (Scientific) Name	Y[a]	J	A	Tot	Per	Status[b]
Family:	Catostomidae (suckers)						
BH	bluehead sucker (Catostomus discobolus)	8	47	174	229	3.5	NA
FM	flannelmouth sucker (C. latipinnis)	42	138	546	726	11.2	EN
FR	flannelmouth x razorback sucker	0	0	2	2	>0.1	EN
FV	flannelmouth sucker variant	0	0	8	8	0.1	EN
SU	unidentified sucker	23	0	0	23	0.4	
Family:	Centrarchidae (sunfish)						
GS	green sunfish (Lepomis cyanellus)	0	1	0	1	>0.1	NN
Family:	Cyprinidae (minnows)						
CP	common carp (Cyprinus carpio)	2	8	622	632	9.7	EX
FH	fathead minnow (Pimephales promelas)	11	0	351	362	5.6	NN
HB	humpback chub (Gila cypha)	119	526	420	1,065	16.4	EN
SD	speckled dace (Rhinichthys osculus)	1	0	268	269	4.1	NA
Family:	Cyprinodontidae (killifishes)						
RK[c]	plains killifish (Fundulus zebrinus)	0	0	42	42	0.6	NN
Family:	Ictaluridae (catfishes, bullheads)						
BB	black bullhead (Ameiurus melas)	0	2	0	2	>0.1	NN
CC	channel catfish (Ictalurus punctatus)	2	2	22	26	0.4	NN
Family:	Percichthyidae (temperate basses)						
SB	striped bass (Morone saxatilis)	0	0	3	3	>0.1	NN
Family:	Salmonidae (trout)						
BK	brook trout (Salvelinus fontinalis)	0	0	1	1	>0.1	NN
BR	brown trout (Salmo trutta)	2	58	551	611	9.4	EX
RB	rainbow trout (Oncorhynchus mykiss)	42	253	2195	2,490	38.4	NN
TOTALS:		252	1,035	5,205	6,492		

[a]Y = YOY, J = juvenile, A = adult, T = total

[b]NA = native to the drainage
EN = endemic to the drainage
EX = introduced from another continent
NN = introduced from another drainage in North America

[c]Formerly identified as Rio Grande killifish

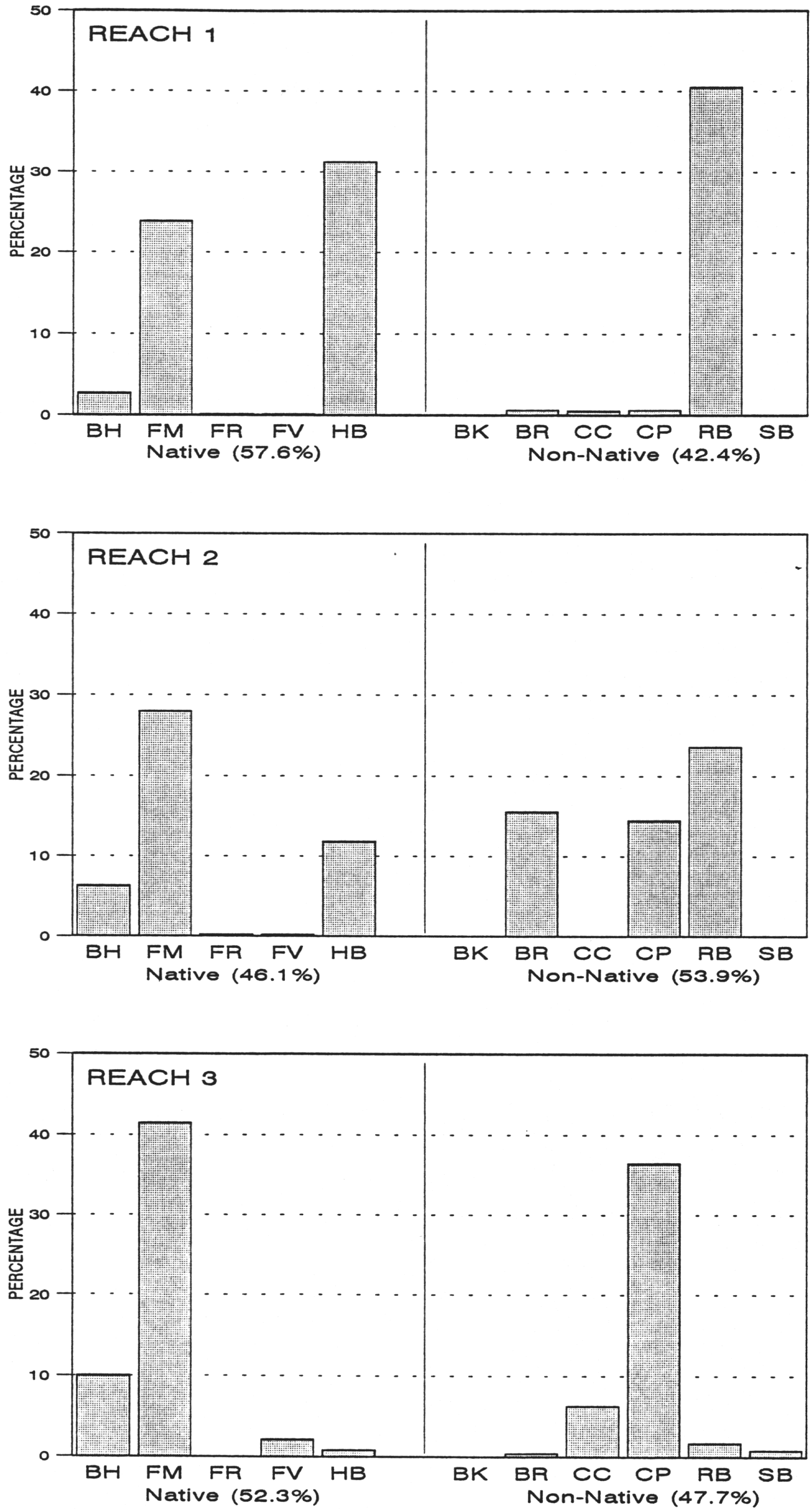


Figure 4-6. **Species composition of fish collected with nets in three study reaches of the Colorado River in Grand Canyon, 1992. See Table 4-6 for explanation of species codes.**

humpback chub (Appendix B, Table B-9). Two species were unique to Reach 1: green sunfish and brook trout, of which only one of each was collected. Rainbow trout and brown trout were most abundant in Reach 2, comprising 36.9 and 32.8 percent of the total electrofishing catch, respectively (Appendix B, Table B-10). A total of five adult humpback chub were collected in Reach 2, or 0.3 percent of the total catch. Common carp were the dominant fish in Reach 3, comprising 67.0 percent of the catch (Appendix B, Table B-11). Only one (0.3%) adult humpback chub was captured electrofishing in Reach 3. Single collections of both plains killifish and striped bass were unique to Reach 3. The percentage of native species captured by electrofishing in Reaches 1, 2, and 3 was 3.8, 3.2, and 6.4 percent, respectively (Fig. 4-7).

Geomorphic Substrata Comparisons were made in species composition between 1-mile subreaches around mouths of major tributaries and 1-mile subreaches away from tributaries in the same geomorphic substrata. Numbers and percentages of fish of all ages captured by netting around the LCR, Bright Angel Creek, Havasu Creek, and Kanab Creek were dominated by native species (flannelmouth suckers near Bright Angel, Kanab, and Havasu, and flannelmouth suckers and humpback chub near the LCR) (Table 4-6). Rainbow trout were dominant near the other two major tributaries, Shinumo and Tapeats creeks. Species diversity and total fish numbers were higher near tributary inflow areas than adjacent areas for each of the six major tributaries except for Tapeats Creek. Common carp were dominant in electrofishing catches near Tapeats, Kanab, and Havasu creeks (Table 4-7). Rainbow trout were most abundant in the LCR and Shinumo Creek, and brown trout in Bright Angel Creek. Total fish numbers were higher near tributary inflow areas than adjacent areas for each of the tributaries except for the LCR and Tapeats Creek. Species diversity near tributaries was higher than in adjacent areas for all but Tapeats and Havasu creeks.

Distribution and Abundance

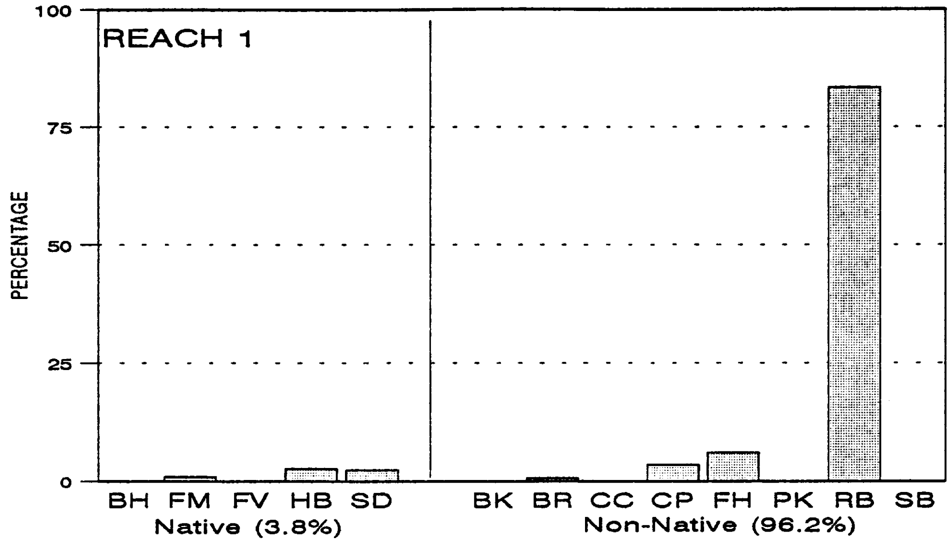
Humpback Chub

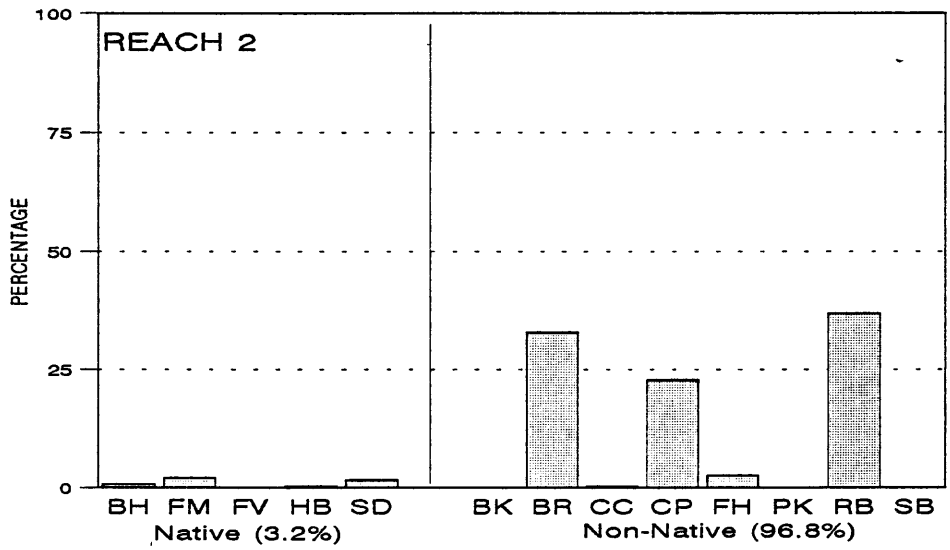
A total of 1,065 humpback chub were captured and processed by B/W in 1992, including 119 YOY, 526 juveniles, and 420 adults (Table 4-8). Of these fish, 252 were unmarked and given new PIT-tags (39 juveniles and 213 adults), 22 adults were radiotagged and PIT-tagged (included in 252), 32 YOY and juveniles were marked with fin punches, and meristics were taken on 19 adults. A total of 2,029 humpback chub have been handled by B/W from October 1990 through November 1992, and a total of 1,082 have been PIT-tagged. In 1992, a total of 230 humpback chub were recaptured by B/W (201 PIT-tagged fish, 16 fin clip/punched, 13 Carlin/Floy tagged).

Table 4-6. Numbers and percentage of fish species captured by gill and trammel nets in 1-mile sections of tributary inflow areas (I) and adjacent main channel areas (A) in the same geomorphic substrata, Colorado River in Grand Canyon, 1992.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	242	85	153	30	234	30	57	133	147	17	118	17
Effort (hrs)	547.4	186.5	306.5	64.5	497.0	57.5	110.2	266.3	298.8	31.2	250.9	31.2
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	116-117	133.2-134.2	127-128	143-144	147-148	156.2-157.2	147-148
Species[a]												
BH	17 (4.3)	1 (3.1)	5 (4.1)		5 (16.1)			1 (2.0)	9 (14.8)		15 (12.7)	
BR	2 (0.5)	1 (3.1)	36 (29.8)		4 (12.9)	1 (12.5)						
CP	2 (0.5)		3 (2.5)		2 (6.5)	1 (12.5)	2 (20.0)	13 (25.5)	16 (26.2)		8 (6.8)	
FM	165 (42.2)		47 (38.8)		6 (19.4)			5 (9.8)	33 (54.1)		88 (74.6)	
FR	1 (0.3)											
FV	2 (0.5)										5 (4.2)	
HB	159 (40.7)	25 (78.1)	1 (0.8)		3 (9.7)			28 (54.9)	1 (1.6)		2 (1.7)	
RB	43 (11.0)	5 (15.6)	29 (24.0)	2 (100)	11 (35.5)	6 (75.0)	8 (80.0)	4 (7.8)	2 (3.3)			
TOTAL	391	32	121	2	31	8	10	51	61		118	

[a]See Table 4-5 for species codes





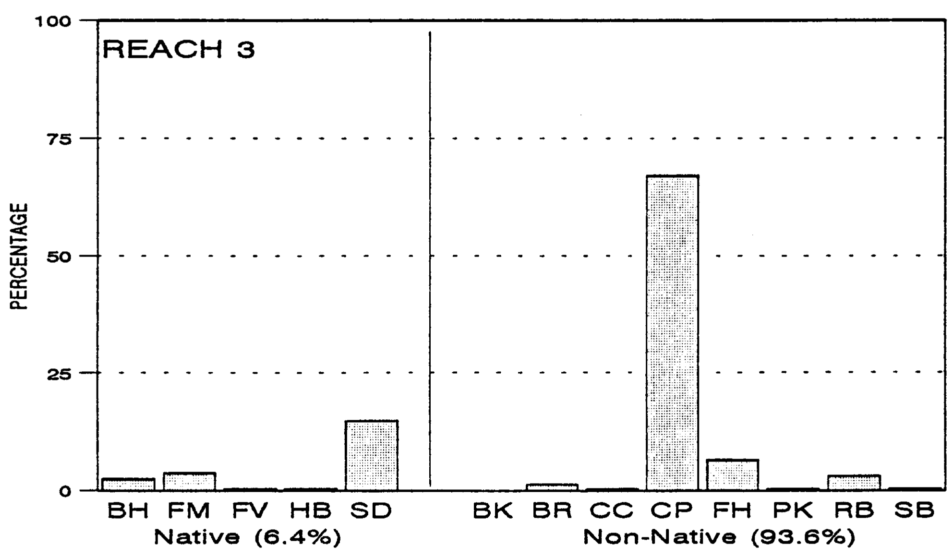


Figure 4-7. **Species composition of fish collected electrofishing in three study reaches of the Colorado River in Grand Canyon, 1992. See Table 4-6 for explanation of species codes.**

Table 4-7. Numbers and percentage of fish species captured by electrofishing in 1-mile of tributary inflow areas (I) and adjacent main channel areas (A) in the same geomorphic substrata, Colorado River in Grand Canyon, 1992.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	37	44	26	5	57	6	15	25	11	2	6	2
Effort (hrs)	8.6	8.9	7.4	3.5	18.3	2.4	4.0	8.4	4.3	1.0	1.7	1.0
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	115-116	133.2-134.2	126-127	143-144	145-146	156.2-157.2	145-146
Species[a]												
BB	1 (0.8)											
BH							1 (1.8)	1 (1.8)	1 (2.6)	5 (29.4)	1 (5.3)	5 (29.4)
BR		1 (0.7)	209 (78.9)	16 (31.4)	82 (22.3)	13 (40.6)	1 (1.8)	5 (8.9)		1 (5.9)		1 (5.9)
CC	1 (0.8)											
CP	6 (4.9)	6 (3.9)	7 (2.6)	5 (9.8)	62 (16.8)	4 (12.5)	28 (50.0)	9 (16.1)	16 (41.0)	5 (29.4)	15 (78.9)	5 (29.4)
FH	1 (0.8)	26 (17.0)				1 (3.1)			10 (25.6)			
FM	4 (3.3)	2 (1.3)	7 (2.6)		6 (1.6)	1 (3.1)		8 (14.3)	7 (17.9)	1 (5.9)	2 (10.5)	1 (5.9)
HB	39 (31.7)	73 (47.7)			1 (0.3)			3 (5.4)				
RB	66 (53.7)	40 (26.1)	42 (15.8)	30 (58.8)	209 (56.8)	13 (40.6)	26 (46.4)	30 (53.6)	1 (2.6)		1 (5.3)	

Table 4-7 continued

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	37	44	26	5	57	6	15	25	11	2	6	2
Effort (hrs)	8.6	8.9	7.4	3.5	18.3	2.4	4.0	8.4	4.3	1.0	1.7	1.0
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	115-116	133.2-134.2	126-127	143-144	145-146	156.2-157.2	145-146
Species[a]												
SD	6 (4.9)	5 (3.3)			8 (2.2)				4 (10.3)	5 (29.4)		5 (29.4)
TOTAL	123	153	265	51	368	32	56	56	39	17	19	17

[a]See Table 4-5 for species codes

Table 4-8. Summary of humpback chub captured and recaptured by BIO/WEST in the Colorado River in Grand Canyon, 1992.

		New Marks Given				Recaptures								
						BIO/WEST				Other				
	Total Catch	PIT Tag	Radio Tag[a]	Dorsal Fin Punch	Caudal Fin Punch	PIT Tag	Radio Tag	Dorsal Fin Punch	Caudal Fin Punch	PIT Tag	Fin Clip	Carlin Tag	Floy Tag	Fish Not Marked
YOY	119	0	0	16	4	0	0	0	0	0	0	0	0	99
Juvenile	526	39	0	12	0	1	0	1	0	9	15	2	0	447
Adult	420	213	22	0	0	73	7	0	0	118	0	9	2	5
Total	1065	252	22	28	4	74	7	1	0	127	15	11	2	551

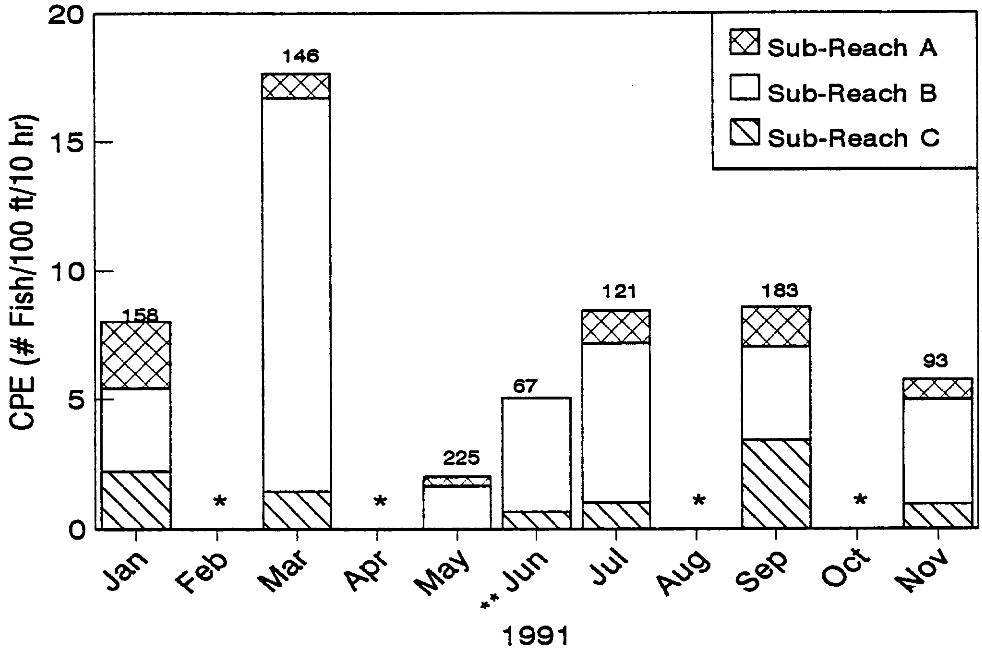
[a]Radio tagged fish are a subset of newly PIT tagged fish, one fish was captured with a carlin tag, two fish were originally PIT tagged by another agency and one fish had been previously PIT tagged by BIO/WEST.

Seventy-four of the recaptured PIT-tagged fish were originally tagged by B/W (including 7 radiotagged fish), and 127 were PIT-tagged by other researchers. In 1992, recapture rates were 17.6 percent for adult chubs PIT-tagged by B/W, 30.2 percent for adult chubs PIT-tagged by other researchers, and 45.5 percent for the overall adult recapture rate. The recapture rate of YOY and juvenile chubs with fin punches or clips was 2.5 percent.

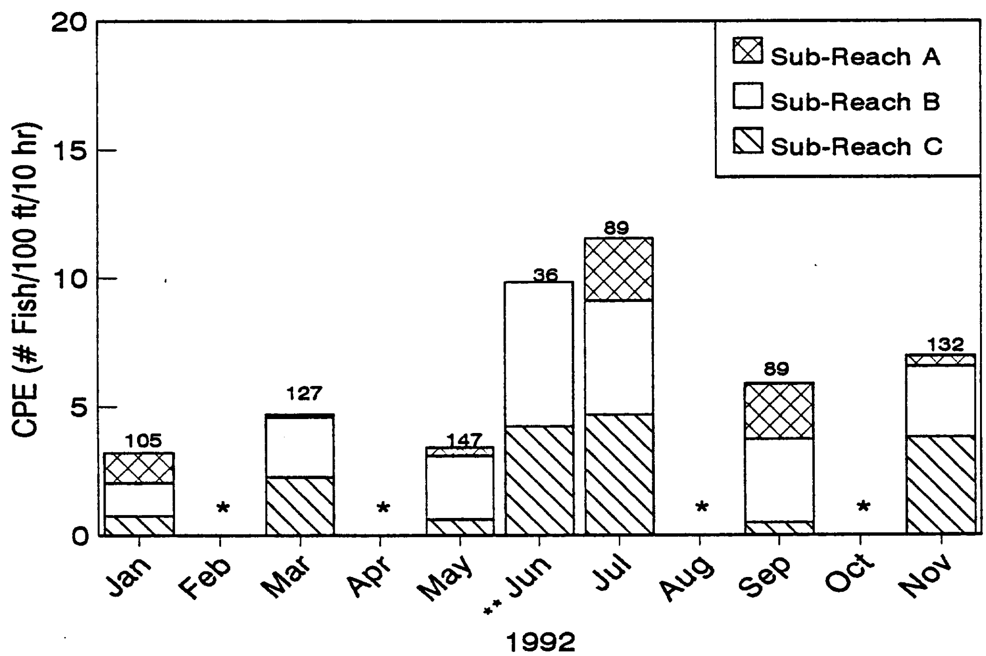
Longitudinal Distribution in Study Region. Pooled netting catch rates for adult humpback chub in 1992 were highest, about 40 fish/100 feet/100 hours, between RM 63.0 and 63.9 (between Crash Canyon and Carbon Creek) (Fig. 4-2). In Reach 1, nearly all adult chub were captured between RM 58.0 and 65.9 (Awatubi Canyon to Lava Canyon). Pooled netting catch rates for humpback chub in Reach 2 did not exceed 18 fish/100 feet/100 hours for any 1-mile block. The highest CPE was between RM 127.0 and 127.9 (upper end of Middle Granite Gorge). Within Reach 2, adult chub were also captured with nets between RM 83.0 and 83.9 (above Clear Creek), RM 92.0-92.9 (around Salt Creek), RM 108.0-108.9 (Shinumo Creek inflow), RM 114.0-114.9 (near Garnet Canyon), RM 119.0-119.9 (upper end of Middle Granite Gorge), RM 126.0-128.9 (below Fossil Canyon), and RM 143.0-143.9 (Kanab Creek inflow). In Reach 3, two adult humpback chub were collected from the same net at RM 156.7 (Havasu Creek inflow) in May, comprising the total chub catch within this Reach in 1992.

Highest electrofishing CPE for adult chub in Reach 1 in 1992 was over 17 fish/10 hour between RM 58.0 and 58.9 (around Awatubi Canyon) (Fig. 4-3). No adult chub were caught electrofishing above RM 59.0 or below RM 63.9. In Reach 2, electrofishing CPE peaked at over 4 fish/10 hour between RM 120.0 and 120.9 (around Blacktail Canyon). Chub were also collected between RM 108.0 and 108.9 (around Shinumo Creek), and between RM 126.0 and 128.9 (upper end of Middle Granite Gorge). One adult chub was captured electrofishing in Reach 3, at RM 195.6, in March.

Longitudinal Distribution Within Reach 1: Adult Humpback Chub. Distribution and movement of humpback chub near the LCR were described from catch rates in three subreaches (SR) within Reach 1: SR-A (upstream of LCR) from RM 57.0-59.7, SR-B (LCR area) from RM 59.75-62.40, and SR-C (downstream of the LCR) from RM 62.45-65.40. In 1991, catch rates in SR-B were substantially higher in March, indicating movement to and staging by fish at the mouth of the LCR during this month (Fig. 4-8). In 1992, however, this trend was not as apparent. Catch rates of humpback chub were not statistically different (Fisher's LSD, $P \leq 0.05$) within the three sub-reaches in January, indicating relatively even distribution among sub-reaches. In March the CPE in SR-B was significantly higher than the CPE in SR-A, but there was no difference between SR-B and SR-C (Fig. 4-8). The absence of adequate



** No samples taken in Sub-Reach A



** No samples taken in Sub-Reach A

Figure 4-8. **Monthly mean catch per effort of adult humpback chub collected in nets within three subreaches (SR) in Reach 1 of the Colorado River in Grand Canyon, 1991-1992. SR-A = RM 57.0-59.7, SR-B = RM 59.75-62.4, SR-C = RM 62.45-65.4. Total sample size is listed above each bar. An asterisk denotes no samples taken or sample size too small to be included in analysis.**

samples in February and March precludes complete analysis of movement of chubs toward the LCR in the spring.

The remainder of the year showed similar trends to 1991 data. In May 1992, catch rates in SR-B were significantly higher than in SR-A and SR-C, and overall CPE was lower than every other month except January. This is likely indicative of the movement of chubs into the LCR, probably peaking in May, with the majority of the remainder of the individuals continuing to stage around the confluence during this month. Kaeding and Zimmerman (1983) found similar spawning-related movements into the LCR in April and May. CPE of chub in the three subreaches returned to pre-spawning levels in June and July, and there were no significant differences in catch rates within sub-reaches during these months, indicating that the fish had returned to the main channel and dispersed.

Movement of humpback chub to the LCR inflow was further assessed by comparing monthly CPE's between RM 60.9 and 61.9, a 1-mile section including the LCR inflow. In 1991, catch rates in this sub-reach peaked in March, dropped to a low in May, and increased again in June and July (Fig. 4-9). This analysis supports the previous evidence that in 1991 chub congregated at the mouth of the LCR in March, with numbers peaking in April; moved into the LCR in May; returned to the main channel in June and July; and dispersed in fall and early winter. In 1992, the peak CPE around the LCR inflow occurred one month later, in April, and the peak was not nearly as dramatic as in 1991 (Fig. 4-9). Netting CPE in 1992 for adult chub was significantly higher (Fisher's LSD, $P < 0.05$) in April than January or March (small sample size precludes a significant difference in February). The trend for the remainder of the year (May through November) was similar to 1991. This apparent difference in the timing of staging between 1991 and 1992 may reflect temperature differences in the LCR in the spring. In 1991, water in the LCR warmed earlier (exceeded 15°C in mid-February) than in 1992 (exceeded 15°C in mid-April) (see Chapter 9). If humpback chub rely on LCR water temperature as a staging cue, this could explain the earlier migration of chub in 1991. However, the difference may be an artifact of differences in sampling efficiency. The two data sets are not directly comparable due to differences in mainstem turbidity and flows at the time of sampling, which could affect the efficiency of the nets. Also, preliminary data suggests chubs staging in the spring may have been congregating in different areas around the LCR between 1991 and 1992, because their preferred habitat in 1992 was less accessible to sampling with nets (see Chapter 6 for further discussion).

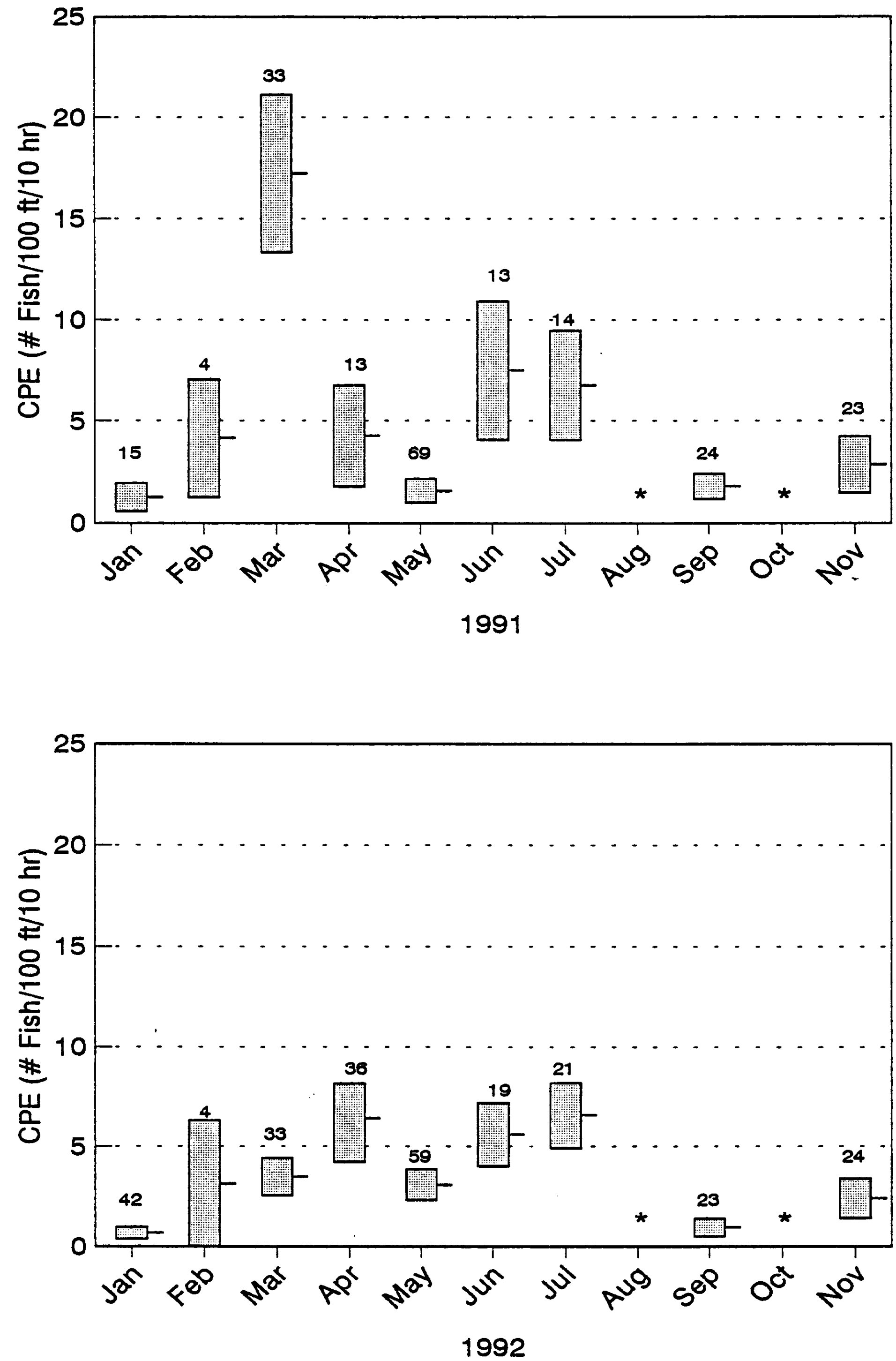


Figure 4-9. **Monthly mean and standard error of catch per effort of adult humpback chub collected with nets within Reach 1, RM 60.9-61.9, in the Colorado River in Grand Canyon, 1991-1992. Total sample size is listed above each bar. An asterisk denotes no samples taken or sample size too small to be included in analysis.**

Longitudinal Distribution Within Reach 1: Sub-Adult Humpback Chub. Figure 4-10 depicts the distribution of YOY and juvenile humpback chub within Reach 1 by month in 1992. Juveniles were collected every 20-day trip, and YOY were collected every trip except for May. Other than a pulse of YOY chub occurring between RM 68.4 and 70.4 (around Tanner Canyon), abundance was restricted mainly between RM 60.4 and 68.4 (LCR to above Tanner Canyon), peaking nearly every month between RM 63.4 and 65.4 (Hopi Salt Mines to Lava Canyon). Distribution of juvenile chub was similar to YOY, with most fish concentrated between the LCR and Lava Canyon. Downstream collections of juvenile chub extended as far as RM 76.4 through 77.4 (around Hance Rapid). Small sample size and large gaps between sampled areas hindered our ability to discern discrete patterns of downstream movement of YOY and juvenile chub from the LCR. In 1993, electrofishing and seining effort will be intensified and distributed throughout Reach 1 to fill these gaps.

No definitive collections of YOY chub occurred in Reaches 2 and 3 in 1992, although several specimens were just over the arbitrary size range for YOY. Eight small sub-adult chub were collected at RM 119.0 (10 miles below Shinumo Creek) in July; however, their sizes fell within the size range of sub-adults collected in Reach 1 that same month. Collection of other sub-adult chub in Reaches 2 and 3 included one at RM 87.7 (Bright Angel inflow) in May, one at RM 108.5 (Shinumo Creek inflow) in September, and a total of five between RM 126.6 and 128.9 in the months of May (one), July (one), September (one), and November (two). Although it is likely that these fish were migrants from the LCR in Reach 1, the possibility that these fish were spawned in other tributaries or the mainstem cannot be discounted.

Longitudinal Size Distribution of Adult Humpback Chub. Average total length of adult humpback chub (TL $\geq$ 200 mm) was compared between three sub-reaches in the Grand Canyon: RM 56.0-60.8 (Kwagunt Canyon to 0.5 mile above LCR), RM 61.9-RM 65.5 (0.5 mile below LCR to Lava Canyon), and RM > 65.5 (below Lava Canyon). Average total length was significantly less (Student's T-Test; $T \leq 0.05$) from upstream to downstream between each sub-reach (Fig. 4-11). There are several possible explanations for this phenomenon. First, it is not known whether differences in size between sub-reaches represent a difference in the ages of individual fish, a difference in their growth rates, or a combination of the two. That is, are upstream fish older (and, hence, larger) individuals or are the upstream fish similar-aged but faster growing and larger? If similar-aged fish are exhibiting different growth rates (i.e., upstream residents are growing faster than downstream residents) then it is likely that differences in habitat, productivity, or feeding habits/efficiency exist between the sub-reaches.

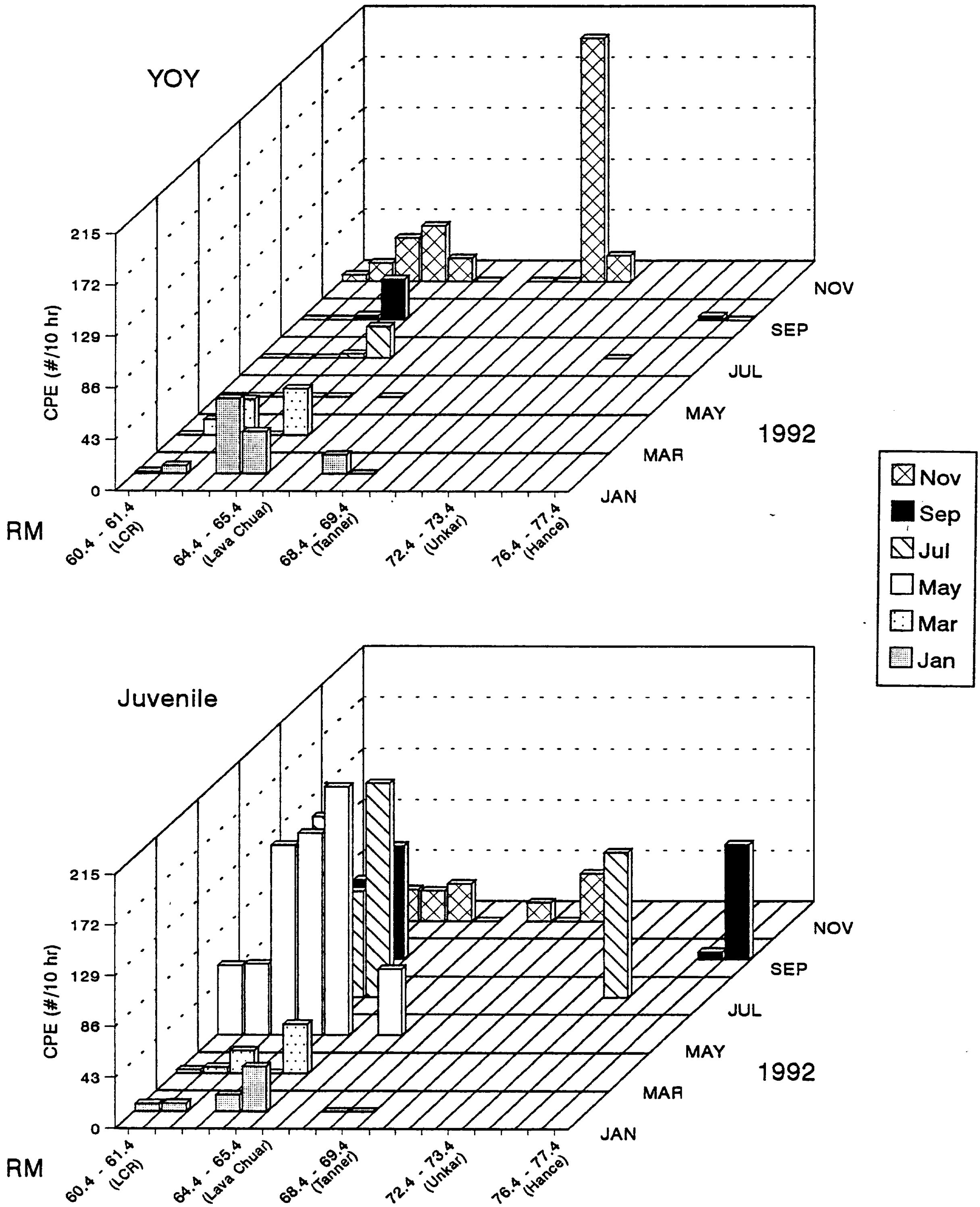


Figure 4-10. Mean monthly electrofishing catch per effort of YOY and juvenile humpback chub in Reach 1, from RM 60.4-77.4 in the Colorado River in Grand Canyon, 1992.

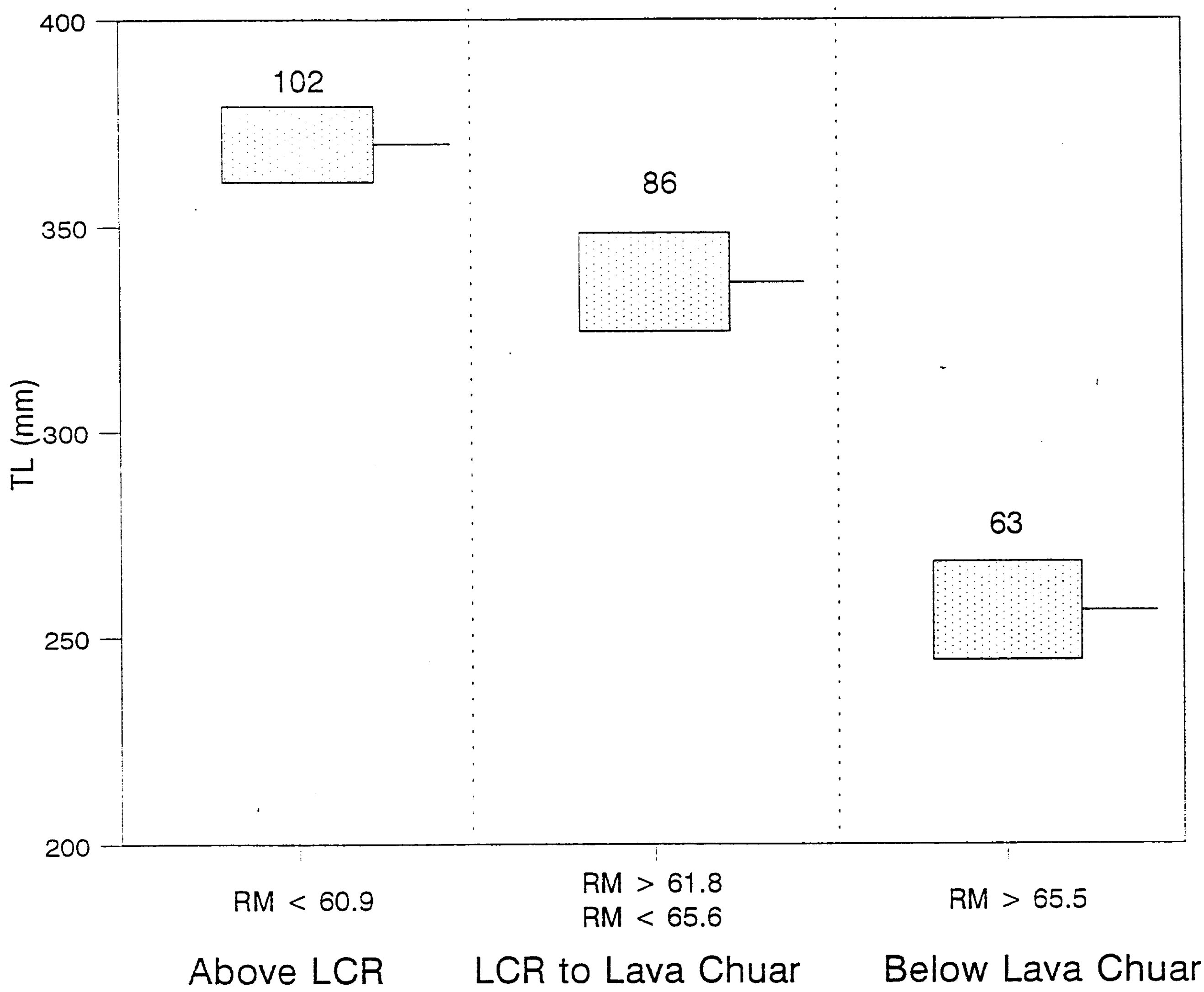


Figure 4-11. Mean TL of adult humpback chub (TL ≥ 200 mm) in three subreaches of the Grand Canyon, 1992. Total sample size is listed above each bar. Error bars represent 95 percent confidence intervals.

Regarding habitat, disjunct growth rates may be related to decreasing habitat suitability for humpback chub downstream. A decrease in productivity or a shift in the composition of available food materials may also account for differential growth rates. This is not, however, supported by comparison of drift samples taken above and below the LCR in 1992 (see Chapter 7). It is also possible that differences in food distribution and abundance are negligible, and humpback chub simply have more difficulty foraging effectively with increased turbidity downstream. Cursory field observations during stomach pumping in 1992 indicated there may be diet differences between chubs sampled above and below the LCR. Increased stomach pumping below the LCR in 1993 will allow further analysis of this phenomenon.

If longitudinal differences in total length of humpback chub are related to age structure of fish within the sub-reaches, then different factors are likely more important. The majority of YOY and juvenile humpback chub migrating (whether actively or passively) from the LCR move downstream of the confluence. In 1992, 95.5 percent of all sub-adult humpback chub were collected below the LCR confluence. It is not known if sub-adults entering the Colorado River mainstem actively select features which exist below the LCR (e.g., habitat, water chemistry, turbidity as cover) or whether the fish simply cannot physically return upstream against the current. If the latter is true, then perhaps some minimum critical size must be reached before the fish are strong enough to migrate upstream; or perhaps some behavioral mechanism is triggered at a certain age or size, inducing active migration. This would tend to longitudinally skew age distribution, resulting in greater numbers of younger, and perhaps smaller, chub below the LCR.

It is likely that no single reason can exclusively explain longitudinal size differences of humpback chub in the mainstem Colorado River. In 1993, B/W intends to modify both field sampling and data analysis to aid in isolating the most important variables. Some aspects that will aid in this investigation will be longitudinal analysis of stomach pumping in conjunction with drift samples, comprehensive analysis of PIT-tag recaptures, and recaptures of fin-punched sub-adults.

Diel Patterns and Effects of Turbidity on Catch Rates of Humpback Chub. The effect of photoperiod and turbidity on catch rates of humpback chub is closely related to movement rather than distribution, and therefore is outside the scope of this chapter. Please refer to Chapter 6 for a detailed discussion of the effects of photoperiod and turbidity on movement of humpback chub.

Other Native Species

Information on catch rates for flannelmouth sucker and bluehead sucker within the three study reaches is presented in Appendix B, Tables B-2 and B-3. A total of 659 flannelmouth suckers were processed in 1992. Adult and juvenile flannelmouth suckers were collected in each study area; YOY were collected in Reaches 1 and 3. A total of 222 bluehead suckers were processed in 1992. As with flannelmouth suckers, adult and juvenile blueheads were collected in each study area, and YOY were collected in Reaches 1 and 3. More detailed analysis on native species distribution will be performed for the final report.

Non-Native Species

Rainbow Trout. Catch rates of rainbow trout within the three study reaches are presented in Appendix B, Table B-1. A total of 2,544 rainbow trout were captured and processed by B/W in 1992. Adult, juvenile, and YOY rainbow were captured from each study reach. Relative condition factor of rainbow trout is presented in Chapter 5.

Striped Bass. A total of three striped bass were captured in the mainstem Colorado River in 1992. All striped bass were captured in Reach 3 between May and July, presumably during upstream spawning migration from Lake Mead. Two striped bass were captured in nets; one at RM 219.5 in May, and one at RM 184.4 in July. One striped bass was captured electrofishing in May at RM 217.5. Total length of bass collected ranged from 388-555 mm, and weight ranged from 457 g (1 lb 0 oz) to 1,486 g (3 lb 4 oz). Water temperature corresponding to all striped bass collections was 14.5° C. In 1991, a total of 15 striped bass were collected in the mainstem. All bass were captured between May and July and the furthest upstream capture was at RM 156.4. The apparent reduction in abundance and upstream migration of striped bass in the mainstem Colorado River from 1991 to 1992 may be due to the reduction of water levels in Lake Mead. However, apparent differences may also be the result of lower sampling efficiency during 1992 or inherent variability in the relatively small sample size.

Fathead Minnow. In 1990-91, a total of nine fathead minnows were collected electrofishing (CPE = 0.033 fish/hr) and only one (0.00004 fish/m^2) collected seining, in all study reaches. In 1992, 144 fathead minnows were collected electrofishing (0.53 fish/hr), and 438 were captured with seines (0.012 fish/m^2). This increased catch of fathead minnows is partially attributable to an increase in seining effort in Reach 1 in 1992, and an increase in electrofishing efficiency (e.g., increased use of "blind sweeping" techniques to collect fish in turbid water). However, stabilization of low velocity habitats, induced by the implementation of interim flows in August 1991, may have created more usable habitat for non-natives such as fathead minnows. It is also possible that large numbers of fathead minnows were transported from the LCR or other tributaries during high spring flows.

CHAPTER 5 - DEMOGRAPHICS OF HUMPBACK CHUB

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INTRODUCTION

The objectives of this study include determining the life history schedule for humpback chub; developing a population model; and determining reproductive capacity, survivorship, and abundance of humpback chub. To this end, the demographics of humpback chub in the Grand Canyon consist of an estimate of the size of the population as well as descriptions of sex, age, and growth characteristics. Using this information, at the conclusion of this study we hope to characterize the dynamics of the humpback chub population in the Colorado River in Grand Canyon.

METHODS

Population Estimate

The population of adult and juvenile humpback chub (N) in the mainstem Colorado River from RM 50.0 to 77.4 (Reach 1) was estimated using Schnabel's Method of maximum likelihood estimate from multiple censuses (Ricker 1975) as expressed by the formula:

(Equation 5-1)

$$N=\frac{\sum(C_tM_t)}{\sum R_t}=\frac{\sum(C_tM_t)}{R}$$

where: N = Population estimate
C_t = Total number of fish captured on day t
M_t = Total marked fish at large at the start of day t
R_t = Number of recaptures in the sample C_t and
R = $\sum R_t$ = Total number of recaptures during the experiment

The distribution of this estimate is asymmetrical. Limits of confidence can therefore be computed by treating small numbers of recaptures ($R \leq 50$) as Poisson variables. For larger R values, limits of confidence can be calculated by the formula:

(Equation 5-2)

$$R+1.92\pm1.960\sqrt{R+1.0}$$

To estimate a natural population using a mathematical model some assumptions must be made relative to the dynamics and catchability of the population. The Schnabel Method assumes (1) no recruitment to the sample population; (2) mortality of marked fish is equal to mortality of unmarked fish;

(3) either marked fish become randomly distributed throughout the population, or sampling is conducted randomly so likelihood of capture is equal for marked and unmarked fish; and (4) migration to and from the population is minimal or equal (Ricker 1958).

Humpback chub equal to or larger than 175 mm TL were consistently marked with uniquely numbered PIT tags injected interperitoneally. The initial mark and release of fish was in October 1990, followed by monthly samples during which previously marked fish were recaptured and additional fish were captured and marked. Individuals that were known to have died were removed from the calculations. Sampling was conducted monthly for 20 months through November 1992. Sampling was not conducted during August, October, and December 1991, or October 1992 and these months were not included in calculations. Fish PIT-tagged by other researchers were not used in estimate calculation at this time.

Length-Frequency

One technique used for estimating age composition and growth of humpback chub is comparison of length-frequency distributions. Since cohorts (fish of one age) tend to form a normal distribution pattern of common lengths, age and growth rate may be determined (Pauly 1984).

Cohorts can be classified in two ways, by age group and by year class. Age groups are designated as 0, I, II, III, etc., where age 0 represents the time from when the fish was hatched to one full calendar year of age. Year class describes a group of fish hatched in the same year (e.g., 1990, 1991). There has not been an age group break-off for humpback chub yet; therefore, the cohorts shown are not divided into groups, nor has the year class been differentiated.

The number, size, and sex of fish sampled was influenced by different sampling objectives. In April and June of 1992, sample methods were size selective for larger fish for radiotelemetry implants, while in August and October of 1992 sampling efforts concentrated on smaller size classes. Changes in sampling procedures and protocols also influenced the size and age classes caught in 1992. Increased sampling efforts using seining and electrofishing produced more humpback chub from the younger age groups in 1992. As a result, the histograms from the earlier stages of the project may reflect gear selectivity more than presence/absence of certain year classes, and these may not be comparable to 1992.

Length-Weight Relationship and Condition Factor

A length-weight relationship was determined for humpback chub based on fish captured in 1991. The following power function was used
(Anderson and Gutreuter 1983):

$$W = aL^b \qquad \text{(Equation 5-3)}$$

where: W = weight in grams,
L = total length in millimeters,
a = a constant, and
b = an exponent.

The parameters a and b were estimated by taking the logarithms (base 10) of both sides of the equation such that:

$$\log W = \log a + b \log L \qquad \text{(Equation 5-4)}$$

and then performing a linear regression using the least squares technique.

Generally, slope 'b' of less than 3.0 describes fish that become less rotund as length increases, and 'b' greater than 3.0 describes fish that become more rotund as length increases. A slope 'b' of 3.0 describes fish that do not change shape as length increases (isometric growth).

An index of well-being or condition factor (Kn) that compensates for allometric growth (i.e., shape changes as fish grow [LeCren 1951]) was calculated for humpback chub caught in 1992 according to the following relationship:

$$Kn = \frac{W}{(aL^b)} \qquad \text{(Equation 5-5)}$$

where: W = weight in grams,
L = total length in millimeters,
a and b = constant and exponent from the length-weight relationship estimated using the least squares regression technique.

This type of condition factor is known as a "relative" condition factor. With this method, an average fish of any given length has a condition factor of 1.0. Fish with Kn greater than 1.0 are more robust than the average fish of that length, while fish with Kn less than 1.0 are less robust. Thus, relative condition factors are a measure of the condition of fish relative to an average fish in that particular population. An average fish, however, may not be in good condition.

A relative condition factor was computed for humpback chub greater than 150 mm TL using the same constant 'a' and exponent 'b' derived from a least squares regression using the pool of chub handled in 1990 and 1991 over 150 mm TL. This pool of fish (550) included all individuals handled with accurate lengths and weights, excluding those recaptured fish carrying either Carlin fingerling tags or Floy tags. These recaptured fish were not included in the analysis because of possible effects of these tags on growth and condition, based on observations of other species (Scheirer and Coble 1991).

Condition factors were compared between months using Fisher's least-significant-difference test (Sokal and Rohlf 1987). Sample values were first tested for normality to confirm the appropriateness of parametric statistics.

RESULTS AND DISCUSSION

Population Estimate

Estimates of the population of adult and juvenile humpback chub (≥ 175 mm TL) in Reach 1 of the mainstem Colorado River were calculated after each sampling trip during which chub were captured (Table 5-1). The last estimate of juvenile and adult humpback chub in Reach 1 of the mainstem Colorado River was 3,449 individuals (95% C.I. = 3,104 to 3,737). Estimates for the first six months of the study were all below 2,000 (1,463 to 1,871) individuals. Estimates for months 7 through 14 were between 2,000 and 3,000 (2,099 to 2,994), and for months 15 to 20 ranged from 3,110 to 3,449 (Fig. 5-1). The variance around these estimates was initially very large, 322 to 18,060, but decreased quickly with the increasing numbers of recaptures. After recaptures totaled 50 or more individuals, R was no longer considered a Poisson variable and confidence limits were calculated.

Recruitment to a population or differential mortality can inflate a population estimate. One of these factors may be affecting population estimates from this study. Substantial increases to the population estimate occur between June and July of 1991 (Fig. 5-1), a period when taggable fish may be emigrating from the LCR. The increased estimate in 1992 was more gradual but may still have been influenced by recruitment of smaller fish to the mainstem population. During 1992, 15 percent of newly marked fish were juveniles (Table 4-8). We assume non-differential mortality of marked and unmarked fish since we successfully recaptured marked fish after many months or even years.

Fish marked during this study may or may not be distributed randomly, but the occurrence of unmarked and marked fish within samples indicates approximately equal catchability. Individual PIT tag recaptures and radiotelemetry data indicate that a component of the humpback chub population migrates up the LCR to spawn during the months of February through May. A reduction in captures during any one sample effort should reduce the population estimate for that period, unless the proportion of marked and unmarked fish available for capture is similar to that of the emigrated group. Since our population estimates did not change significantly during this period, we assume the ratio of marked to unmarked fish did not change, despite migration into the LCR.

Table 5-1. Population estimate of adult and juvenile humpback chub in Reach 1 of the Colorado River in Grand Canyon.

Trip #	Ct	Rt	% Recap	Sum Rt	No. at Large - Recaps	Mt	Ct*Mt	Sum Ct*Mt	Nt	Poisson R-high	N-upper	Poisson R-low	N-lower
90-01	43	0	0	0	43	0	0	0	0.0	0.0	0.0	3.7	0.0
90-02	42	1	2	1	41	43	1806	1806	1806.0	0.1	18060.0	5.6	322.5
91-01	80	4	5	5	76	84	6720	8526	1705.2	1.6	5328.8	11.7	728.7
91-02	3	1	33	6	2	160	480	9006	1501.0	2.2	4093.6	13.1	687.5
91-03	125	14	11	20	111	162	20250	29256	1462.8	12.2	2398.0	30.8	949.9
91-04	7	0	0	20	7	273	1911	31167	1558.4	12.2	2554.7	30.8	1011.9
91-05	29	1	3	21	28	280	8120	39287	1870.8	13.0	3022.1	32.0	1227.7
91-06	36	3	8	24	33	308	11088	50375	2099.0	15.4	3271.1	35.6	1415.0
91-07	77	5	6	29	72	341	26257	76632	2642.5	19.4	3950.1	41.6	1842.1
91-09	95	16	17	45	79	413	39235	115867	2574.8	32.8	3532.5	60.2	1924.7
91-11	45	9	2	54	36	492	22140	138007	2555.7	48.5	2845.5	63.3	2178.8
92-01	27	8	30	62	19	528	14256	152263	2455.9	56.0	2720.0	71.9	2118.9
92-02	6	0	0	62	6	547	3282	155545	2508.8	56.0	2778.6	71.9	2164.6
92-03	44	4	9	66	40	553	24332	179877	2725.4	59.7	3011.5	76.1	2363.4
92-04	40	2	5	68	38	593	23720	203597	2994.1	61.6	3304.6	78.2	2602.5
92-05	47	7	15	75	40	631	29657	233254	3110.1	68.2	3420.1	85.6	2723.7
92-06	36	2	6	77	34	671	24156	257410	3343.0	70.1	3672.6	87.8	2933.4
92-07	72	15	21	92	57	705	50760	308170	3349.7	84.3	3656.5	103.6	2975.8
92-08	9	0	0	92	9	762	6858	315028	3424.2	84.3	3737.9	103.6	3042.0
92-09	41	10	24	102	31	771	31611	346639	3398.4	93.8	3696.7	114.1	3038.9
92-11	58	12	21	114		802	46516	393155	3448.7	105.2	3737.2	126.6	3104.4
Totals	962	114			802	9119	393155		3449				

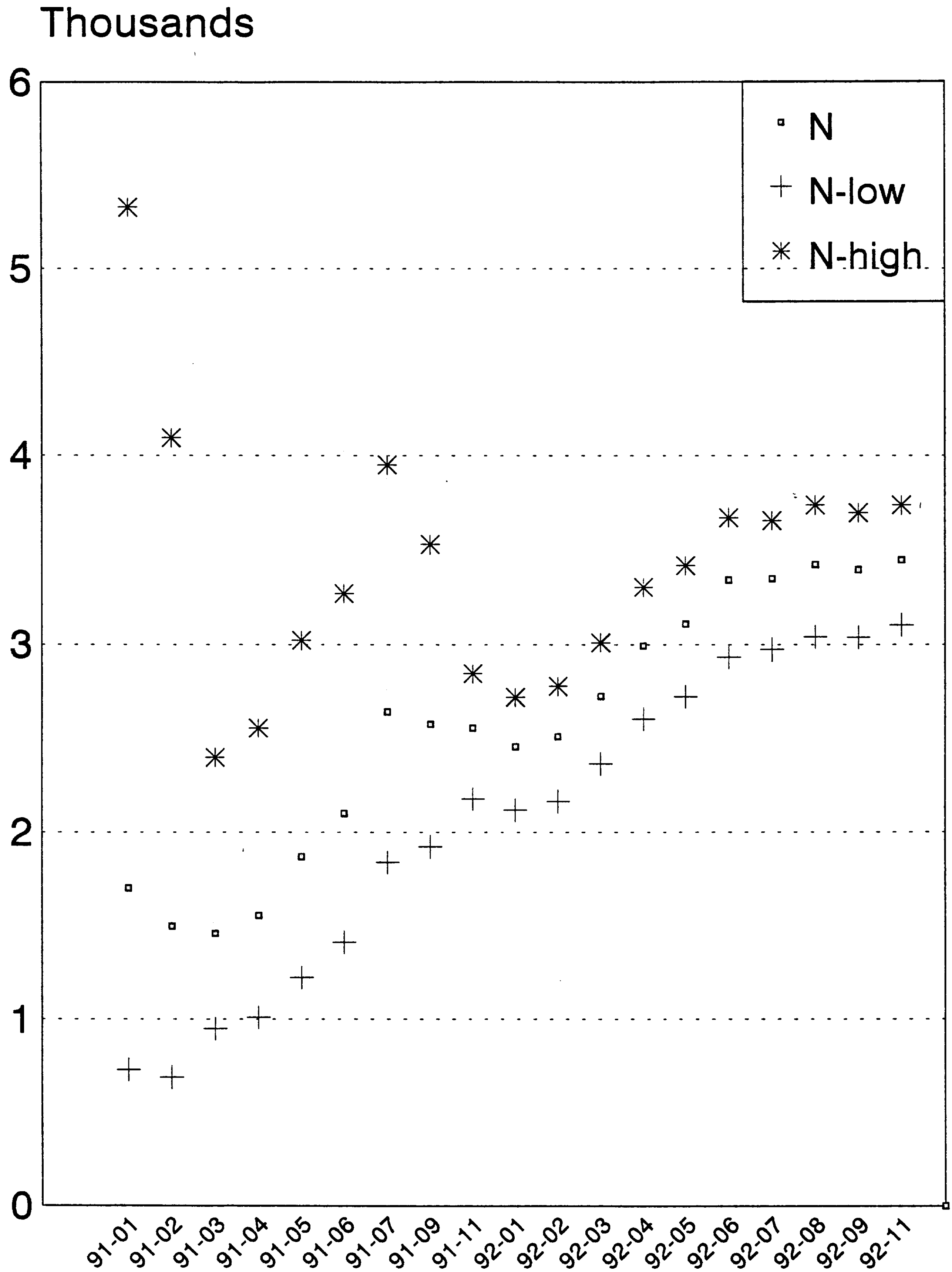


Figure 5-1. **Population estimates for adult and juvenile humpback chub (TL ≥175mm), from January 1991 - November 1992, in Reach 1 of the Colorado River in Grand Canyon, with upper and lower 95 percent confidence limits.**

Sex Ratio

Sex was determined for 367 of 420 adult humpback chub captured in 1992 (Table 5-2). Male to female sex ratio was 45.5:54.5. Males averaged 333 mm TL, with a range of 202 to 455 mm TL. Females averaged 346 mm TL, and ranged from 200 to 451 mm TL. The average weight of males was 362 g with a range of 64 to 908 g. Females averaged 419 g and ranged from 85 to 959 g. Table ** gives an indication of the size of error in length and weight measurements and sex determination by field personnel.

Length-Frequency

Humpback chub of the 1991 year class were first captured in the mainstem in May, 1991 (Fig. 5-2). These young fish most likely originated in the LCR and may have entered the mainstem as early as April, when electrofishing and minnow traps were not used. Humpback chub of the 1992 year class were also first captured in the mainstem in May. Modes representing young fish probably contained chub from the 1991 (1 year olds) and 1992 (YOY) year classes. Separation of age groups was difficult from these length-frequency analyses because of expanded spawning time and variable growth of fish in the LCR (20°C) and the mainstem Colorado River (10°C). Kaeding and Zimmerman (1983) reported that chub remaining in the LCR reached a length of about 100 mm TL in 1 year and 250 to 300 mm after 3 years. They did not report these lengths from fish in the mainstem because some fish in the Colorado River formed an annulus near the end of their first year and others did not. They attribute poor early growth of small Colorado River humpback chub to low water temperatures.

Although nearly all YOY and age 1 fish were captured below the confluence of the LCR, four fish, ranging in size from 74 to 88 mm TL, were captured up to 0.25 miles above the LCR from January through November. Kaeding and Zimmerman (1983) failed to collect chub smaller than 145 mm TL in the mainstem upstream of the LCR in October and November of 1980 and 1981, and April and May of 1981. They hypothesized that, although year-round low temperatures in the Colorado River did not inhibit gonadal maturation, spawning in the mainstem would not produce viable offspring and recruitment of young chub to the population. These young fish most likely migrated upstream following emergence from the LCR, although it is possible that they hatched in the mainstem or in an upstream tributary.

Table 5-2. Number of males and females, sex ratio, and length and weight by month for adult humpback chub collected from the Colorado River in Grand Canyon, 1992. Only fish that were identified as to sex in the field are used in this analysis.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Summary
Males	(M)	8	2	17	17	14	20	37	3	22	27	167
Females	(F)	15	4	20	15	31	15	55	1	19	25	200
	M+F	23	6	37	32	45	35	92	4	41	52	367
Sex Ratio (%)	(M)	41.2	0	45.9	53.1	31.1	57.1	40	75	53.7	51.9	45.5
	(F)	58.8	100	54.1	46.9	68.9	42.9	59	25	46.3	48.1	54.5
	M+F	100	100	100	100	100	100	100	100	100	100	100
TL Mean (mm)	(M)	371	345	339	289	284	341	332	364	349	351	333
	(F)	381	372	356	278	346	371	330	399	360	357	346
	M+F	378	363	348	284	326	354	331	373	354	354	340
TL Minimum (mm)	(M)	324	340	276	213	215	234	202	336	202	203	202
	(F)	237	360	230	200	224	242	207	399	215	231	200
	M+F	237	340	230	200	215	234	202	336	202	203	200
TL Maximum (mm)	(M)	420	350	405	414	409	402	418	396	425	455	455
	(F)	451	385	440	367	423	427	435	399	423	433	451
	M+F	451	385	440	414	423	427	435	399	425	455	455
WT Mean (g)	(M)	477	*	401	277	247	313	349	448	420	411	362
	(F)	572	*	476	237	353	440	377	702	509	472	419
	M+F	539	*	442	258	319	371	365	512	461	440	393

Table 5-2 continued

WT Minimum (g)	(M)	338	*	231	98	102	80	92	387	86	64	64
	(F)	146	*	117	85	95	110	100	702	92	95	85
	M+F	146	*	117	85	95	80	92	387	86	64	64
WT Maximum (g)	(M)	665	*	633	843	666	455	634	562	671	908	908
	(F)	959	*	739	547	600	668	848	702	919	878	959
	M+F	959	*	739	843	666	668	848	702	919	908	959

* Humpback chubs collected in February were weighed in pounds and ounces - the accuary of these measurements is not considered adequate for this anaysis

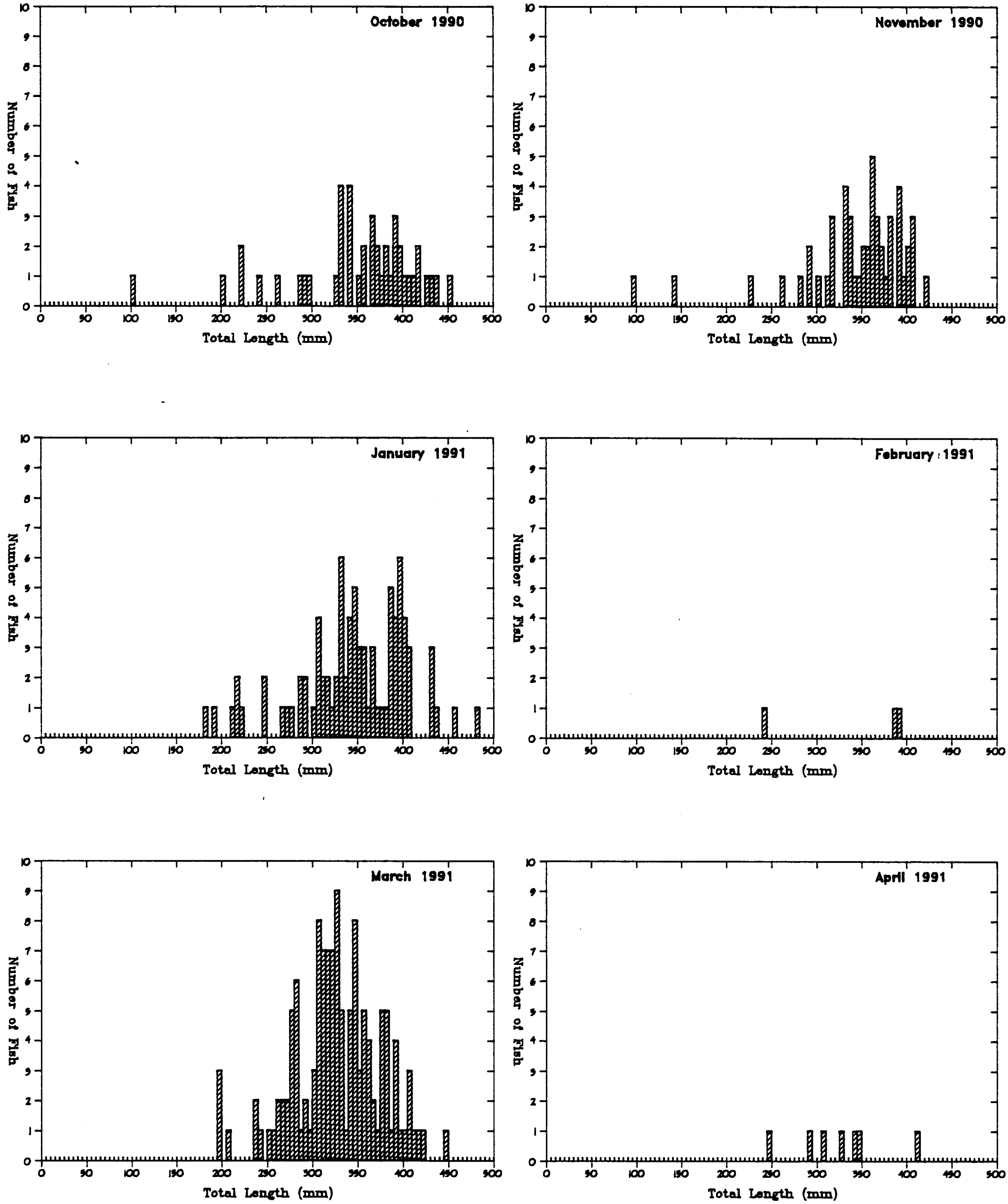


Figure 5-2. **Length-frequency histograms of humpback chub captured in the Colorado River in Grand Canyon, October 1990 through November 1992.**

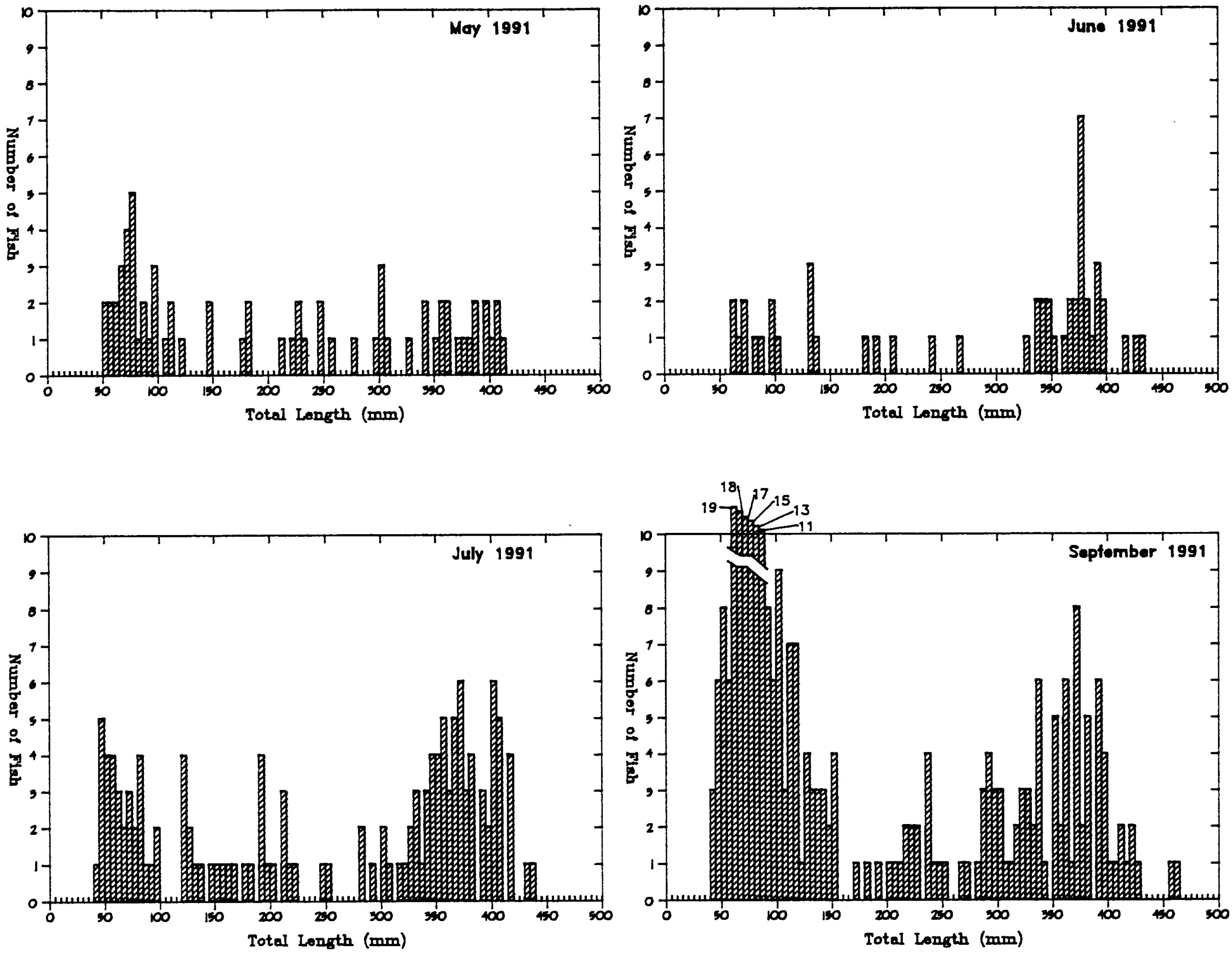
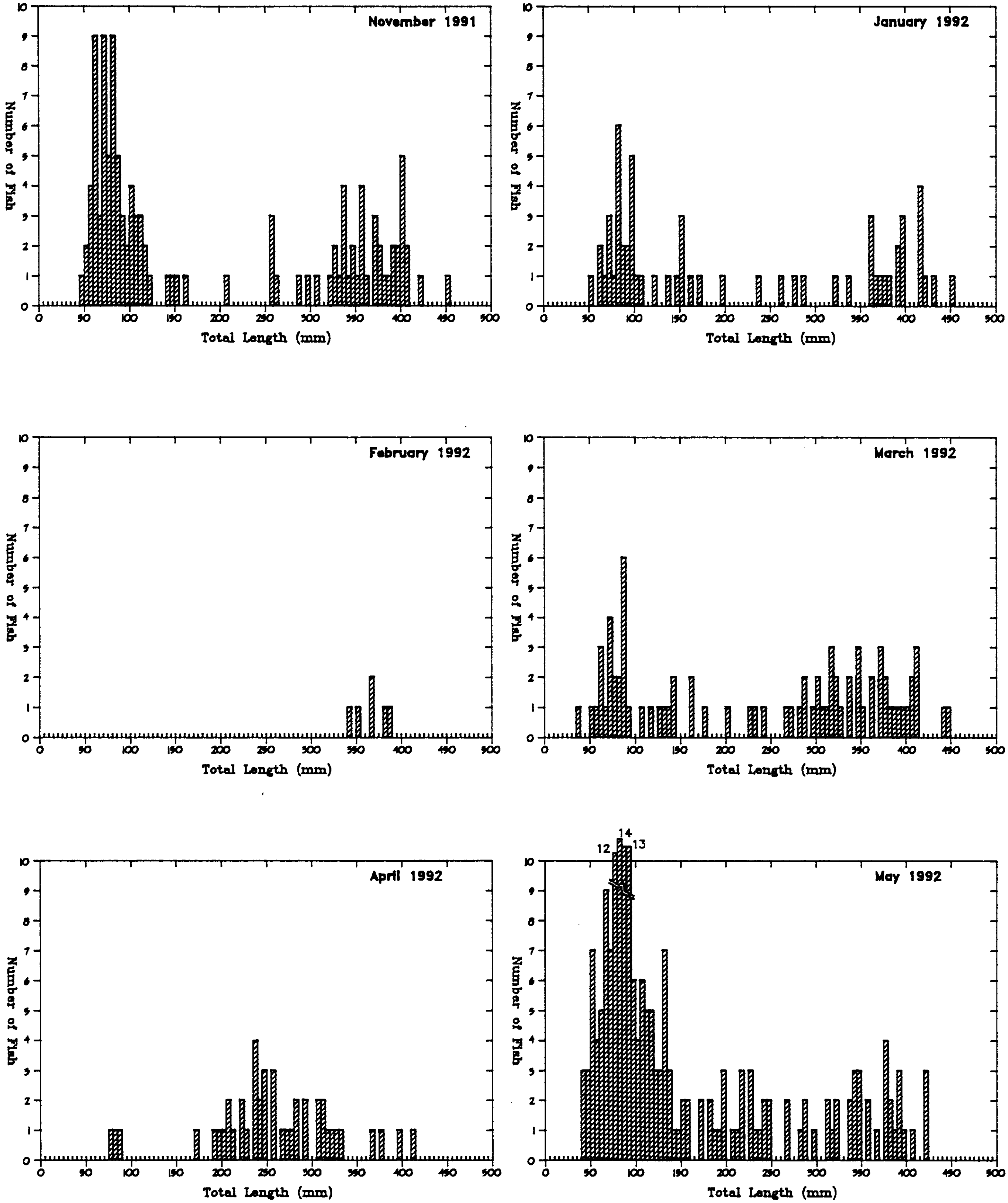


Figure 5-2. Continued.



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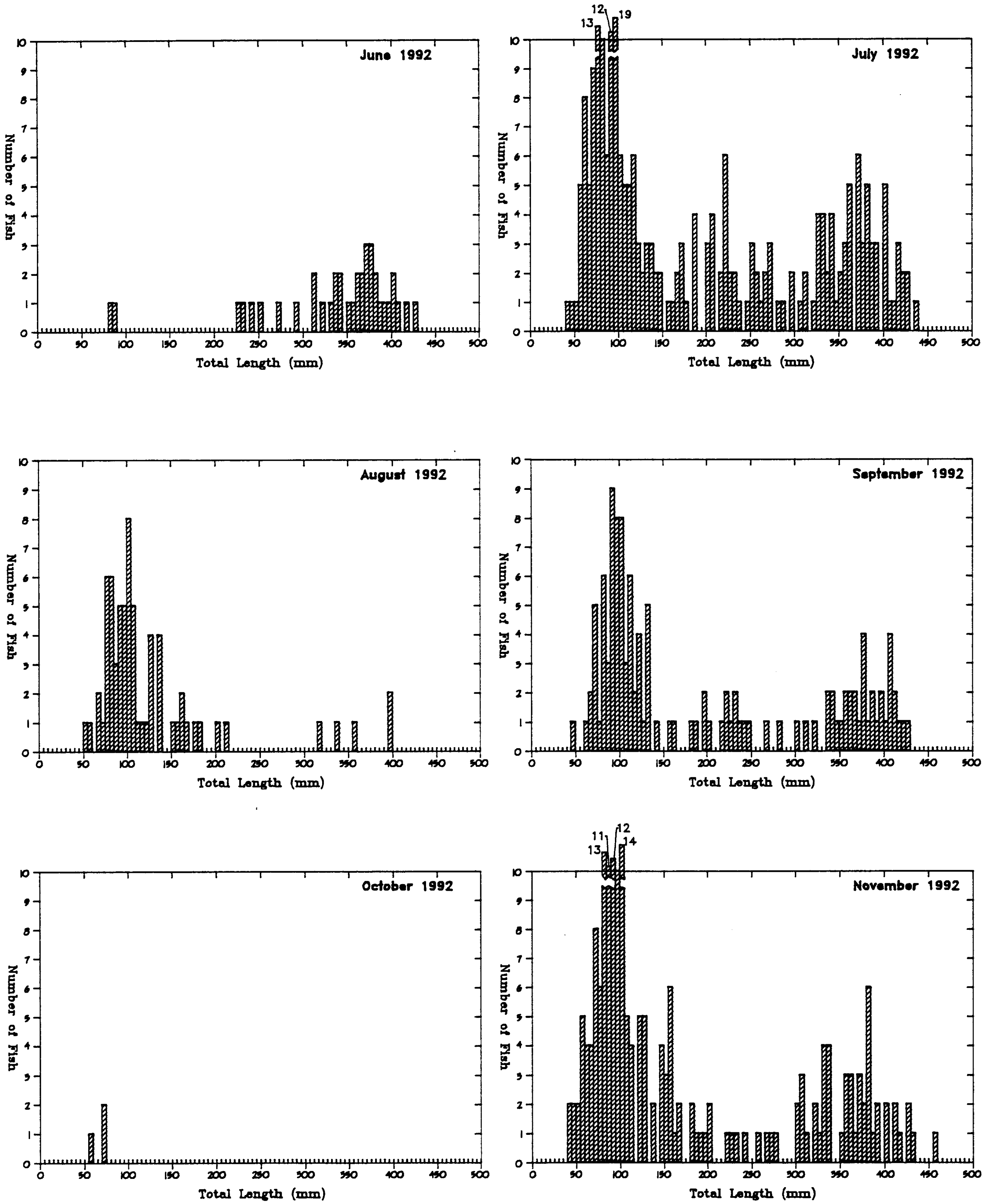

Figure 5-2. Continued.

Humpback chub >150 mm TL are difficult to identify by age group because there is no clear distinction of cohorts from length-frequency analysis. Fish older than 4 years of age also become difficult to distinguish by age group because of overlaps resulting from increased dispersion and the smaller distance between frequency modes (Everhart and Young 1981). Variable growth rates between male and female chub, reduced growth rates in older fish, and interruption of growth upon reaching maturity also affect length-frequency analysis. An effort to collect scales from fish <200 mm TL was made in 1992. These will be interpreted and reported in the final report.

Length-Weight Relationship and Condition Factor

Humpback Chub

The length-weight relationship for humpback chub (Fig. 5-3) is described by the equation:

$$W = (1.341 \times 10^{-5})L^{2.938} \quad \text{(Equation 5-6)}$$

where: W = weight in grams
L = total length in millimeters

The exponent of 2.938 indicates that humpback chub growth patterns closely resemble isometric growth (i.e., an exponent equal to 3.0 indicates that the relationship between fish length and weight remains constant).

Humpback chub, unlike rainbow trout, lack pyloric caeca for storing fat reserves. As a result, they are a short-term maintenance species, and condition factor may reflect a more immediate physiological response to the environment, acting as an index of short-term feeding activity or food availability.

Average relative condition factor was calculated for humpback chub (TL>150 mm) for each month in which sampling produced substantial numbers of chub (Table 5-3). We expected to see certain patterns or trends in relative condition based on seasonal spawning activity and possibly food availability. High condition prior to spawning (spawning in March, April, May) was expected as the fish became robust with sex products. Decline in condition after spawning was normal as fish lost substantial amounts of weight from release of sex products and energy expenditure during spawning. Recovery from low post-spawning condition to near or above average condition in late summer-early fall was also expected, as food production was likely to be good. A slight drop in condition may occur as winter approaches and food production decreases.

Relative condition was below 1.00 in January 1992, then increased to above 1.00 in March and April (Fig. 5-4). Relative condition then dropped dramatically in May and June, followed by an increasing trend through September to values above 1.00 and then dropping off to slightly below 1.00 in November.

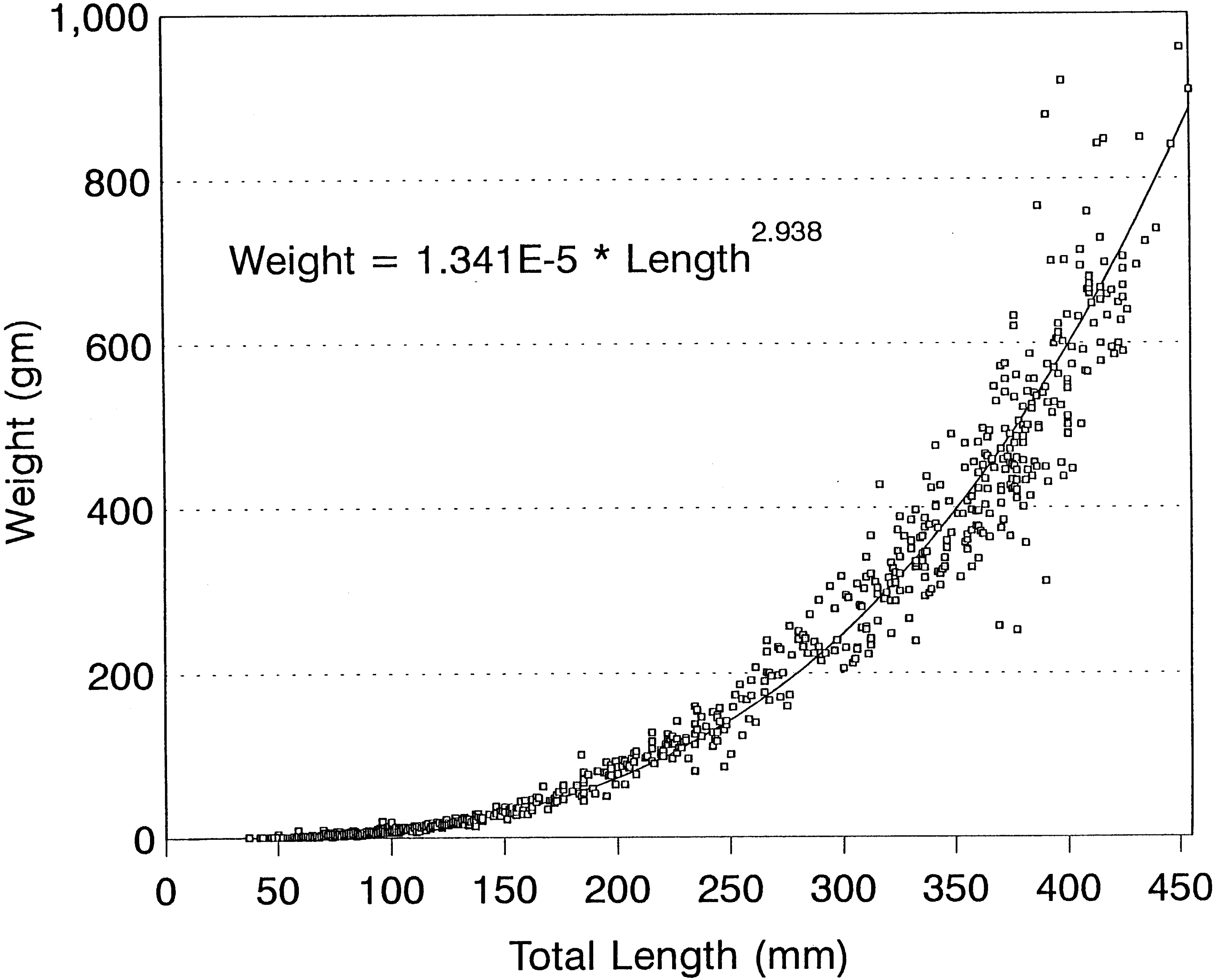

Figure 5-3. **Length-weight relationship for humpback chub from the Colorado River in Grand Canyon, 1992.**

Table 5-3. Monthly relative condition (Kn) of 453 humpback chub (>150 mm TL) from the Colorado River in Grand Canyon, 1992.

Month	Sample Size	Mean Relative Condition	Standard Error
January	31	0.982	0.025
March	45	1.052	0.020
April	40	1.063	0.015
May	62	0.971	0.023
June	34	0.824	0.018
July	110	1.012	0.013
August	12	0.996	0.057
September	51	1.053	0.020
November	68	0.982	0.017

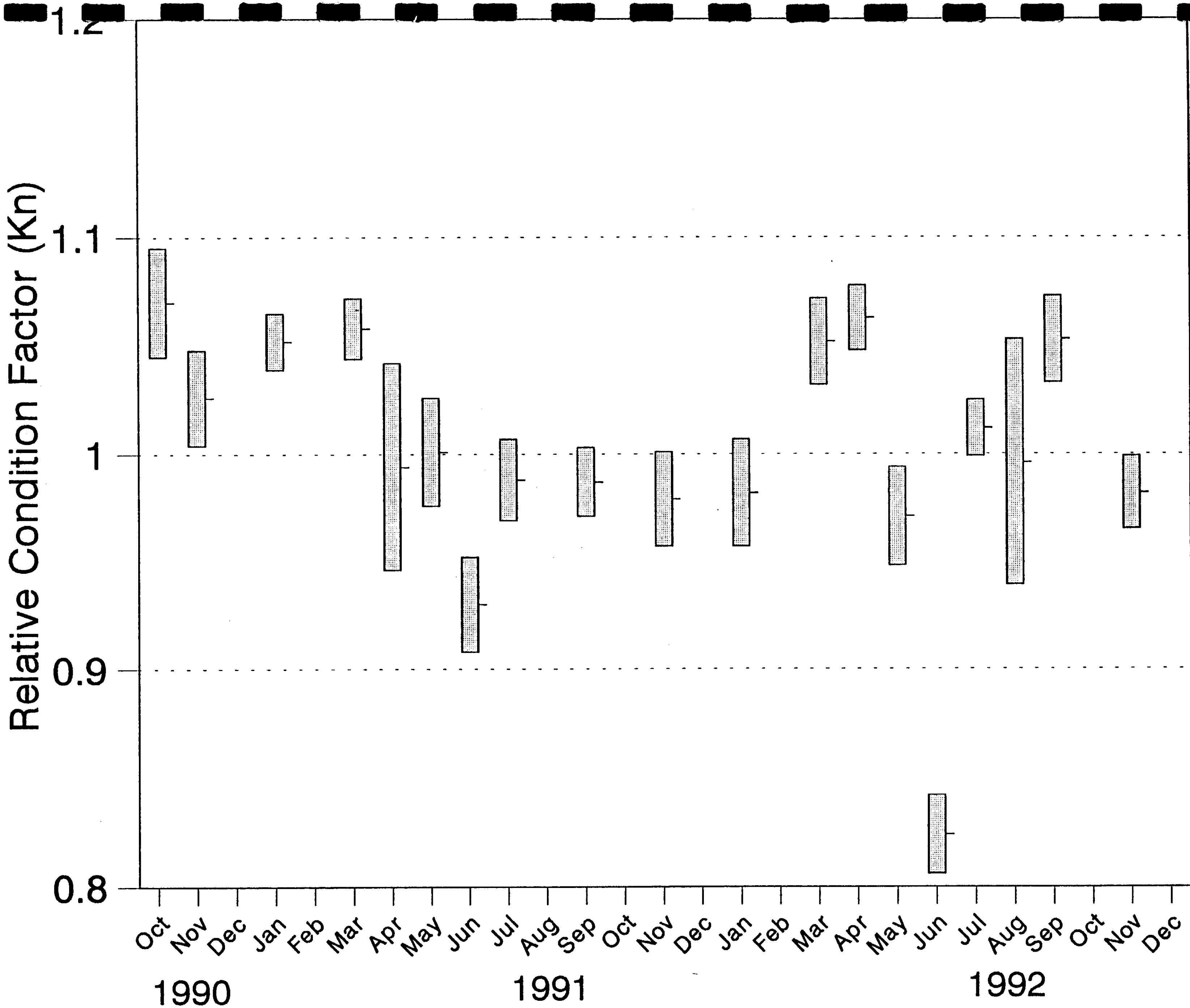

Figure 5-4. **Relative condition factor (Kn) of humpback chub (> 150 mm TL) from the Colorado River in Grand Canyon, 1990-1992. Values represent means ± one standard error.**

These trends in condition are mostly consistent with spawning activity and possibly food availability. Table 5-4 shows the results of statistical comparison of mean monthly relative condition factors for humpback chub in 1992.

Table 5-4. A statistical comparison of mean monthly relative condition factors for humpback chub (>150 mm TL) from the Colorado River in Grand Canyon, 1992. See Table 5-3 for Kn values.

Fisher's Least-Significant-Difference Test. Matrix of Pairwise comparison probabilities.

	Jan.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Nov.
Jan.	1.000							
Mar.	0.032*	1.000						
Apr.	0.016*	0.715	1.000					
May	0.732	0.003*	0.001*	1.000				
Jun.	0.000*	0.000*	0.000*	0.000*	1.000			
Jul.	0.289	0.108	0.049*	0.067	0.000*	1.000		
Sep.	0.026*	0.969	0.735	0.002*	0.000*	0.084	1.000	
Nov.	0.997	0.010*	0.004*	0.642	0.000*	0.175	0.007*	1.000

*significant at 0.05

T-tests indicated that relative condition in January 1992 was significantly lower than in January 1991 (p=0.007), and lower than expected for that pre-spawning period. Although a drop in condition was expected around June, June 1992 condition was also significantly lower than June 1991 (p=0.000). Condition was significantly higher, however, in September 1992 than in September 1991 (p=0.016). Conditions in November 1991 and November 1992 did not differ significantly (p=0.871), but each was significantly lower than that seen in November 1990 (p=0.041 and p=0.038, respectively). This may mean that lower condition in late fall is more the norm for humpback chub than the high condition seen in November 1990, and that the research flows at that time affected their condition differently than interim flows, starting August, 1991.

We also saw a significant difference in condition between male and female humpback chub when pooling the fish throughout the year (p=0.009), with an average condition factor of 1.022 for females and 0.980 for males. An analysis of individual trips showed that differences in condition between the sexes were significant in June, July, and November of 1992, with the females having higher condition factors than the males in each of those months (Table 5-5). This analysis was done to test the hypothesis that the high Kn seen in

Table 5-5. A statisitcal comparison (T-test) of mean monthly relative condition factor for male and female humpback chub (>150 mm TL) from the Colorado River in Grand Canyon, 1992.

Month	Males		Females		P
	N	Kn	N	Kn	
January	9	0.996	14	1.050	0.280
March	17	1.080	19	1.069	0.813
April	17	1.070	14	1.063	0.853
May	14	1.023	32	0.939	0.108
June	18	0.783	15	0.883	0.003*
July	38	0.969	55	1.031	0.024*
September	22	1.017	22	1.092	0.096
November	25	0.960	25	1.050	0.014*

*significant at 0.05

the pre-spawning period was attributed mainly to the increased gonadal weight of the female fish. The analysis showed no significant differences in Kn for this period of time, so the hypothesis was rejected, although the sample size was relatively small. Because Kn did not seem to differ between males and females at this time of year, it appeared that energetics were important to both sexes during this critical winter period as each increased in weight at that time.

Spatial difference in condition was found upon comparing humpback chub caught above versus below the confluence of the Colorado River and the LCR. Fish caught in the staging area (RM 60.9 to 61.9) were excluded from the analysis, as fish tended to aggregate in this area during spawning events and could have biased the analysis. The analysis showed that fish caught below the confluence (RM > 61.9) had significantly higher condition (p=0.003) than those caught above (RM < 60.9). The results suggested that there may be greater availability of food downstream of the LCR confluence, but further analysis is necessary to fully test this hypothesis.

Rainbow Trout

We expected to see similar trends in condition of rainbow trout relative to spawning activity. Because rainbow trout have an earlier spawning period, we expected the cycle of increasing and decreasing condition to be shifted a few months earlier than that for humpback chub. Rainbow trout spawning occurs in January, February, and March; therefore, we expected Kn to increase in November, December, January. Another factor influencing rainbow trout condition is that rainbow trout do possess pyloric caeca. This enables them to store fat more easily than humpback chub, so Kn values may reflect a more delayed response to food availability and other conditions.

Average monthly Kn was calculated for rainbow trout (>200 mm total length) in 1992 as shown in Table 5-6. Condition was below 1.00 in January, then increased to values above 1.00 in March and May (Fig. 5-5). Condition then dropped to near 1.00 for June through September except for an apparent anomalous rise to a value above 1.20 in August. Condition then increased from September to November. Table 5-7 is a comparison of mean monthly relative condition factor for rainbow trout in 1992.

Table 5-6. Monthly relative condition (Kn) of 2,122 rainbow trout (>200 mm TL) from the Colorado River in Grand Canyon, 1992.

Month	Sample Size	Relative Condition	Standard Error
January	479	0.941	0.011
March	405	1.063	0.011
May	252	1.090	0.014
June	14	0.998	0.031
July	279	1.040	0.014
August	118	1.230	0.020
September	189	1.026	0.016
November	400	1.087	0.009

Table 5-7. A statistical comparison of mean monthly relative condition factors for rainbow trout (>200 mm TL) from the Colorado River in Grand Canyon, 1992. See Table 5-6 Kn values.

Fisher's Least-Significant-Difference Test. Matrix of Pairwise comparison probabilities.

	Jan.	Mar.	May	Jul.	Aug.	Sep.	Nov.
Jan.	1.000						
Mar.	0.000*	1.000					
May	0.000*	0.118	1.000				
Jul.	0.000*	0.186	0.009*	1.000			
Aug.	0.000*	0.000*	0.000*	0.000*	1.000		
Sep.	0.000*	0.056	0.002*	0.488	0.000*	1.000	
Nov.	0.000*	0.125	0.831	0.007*	0.000*	0.002*	1.000

*significant at 0.05

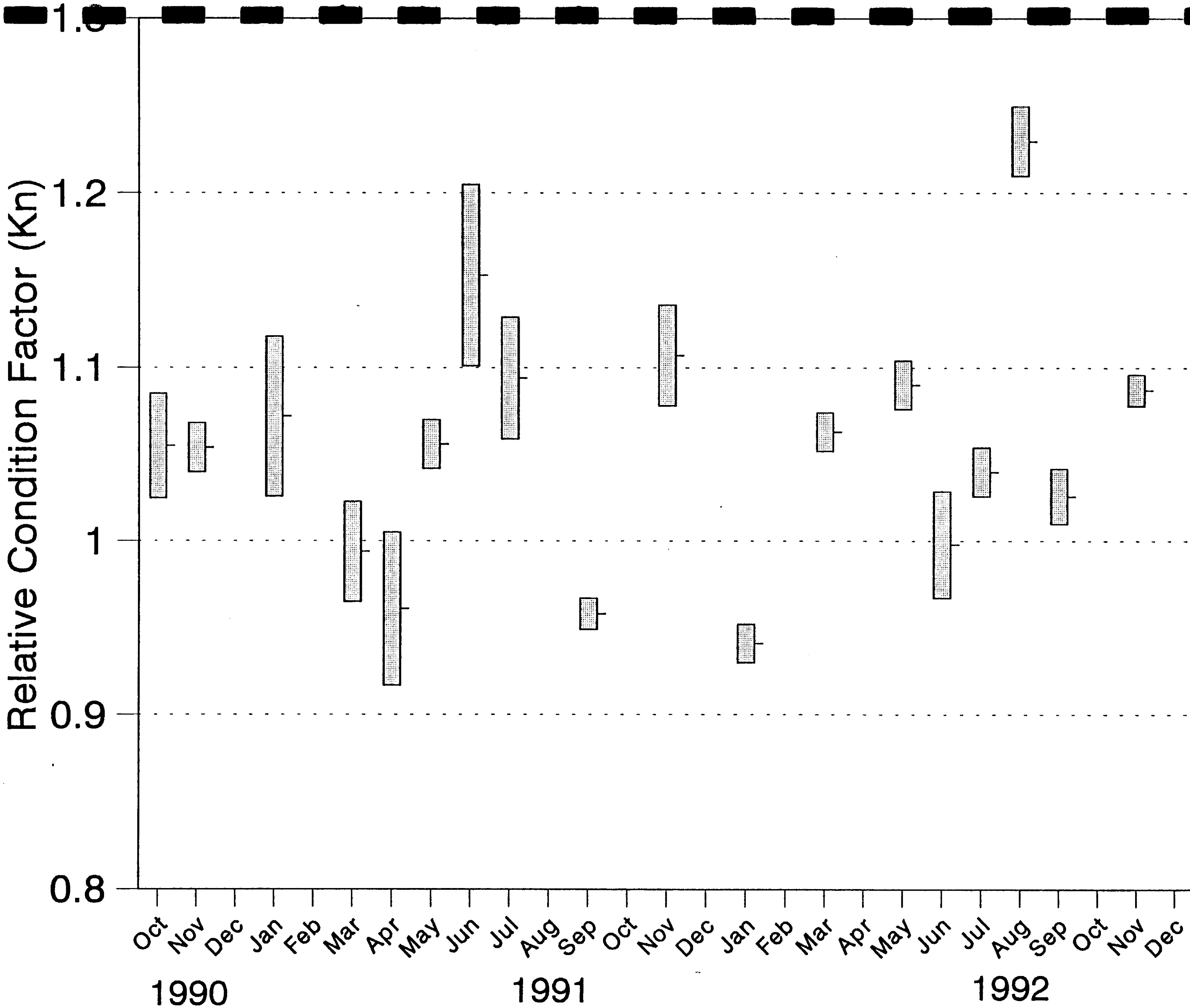

Figure 5-5. **Relative condition factor (Kn) of rainbow trout (> 200 mm TL) from the Colorado River in Grand Canyon, 1990-1992. Values represent means ± one standard error.**

These trends are quite different from those seen in 1990-1991 and different from what would be expected in relation to spawning activity. The drop in condition from November 1991 to January 1992 could be an indication of early spawning by rainbow trout. The rather erratic changes in condition in 1992 are difficult to explain, but it is possible that they are related to the interim flows initiated August 1, 1991. The pattern of relative condition appears to be as expected during the research flows, which were in effect at the start of the study and until interim flows went into effect, but does not appear as expected during interim flows, possibly because of changes in food transport. Further analysis with another year of study should clarify the relationship between dam operations and energetics.

Evaluation of PIT-tagged Recaptures

During the 1992 field season a total of 155 humpback chub captured by B/W had been previously tagged or marked by other researchers (Table 4-8). More complete information on movement and growth of these fish will be assimilated pending acquisition and analysis of initial capture data from participating agencies. Analyses in this report were restricted to fish PIT-tagged by B/W and 71 fish originally PIT-tagged by Arizona State University. A total of 74 chub were captured by B/W, PIT-tagged, and subsequently recaptured. Fifty-four PIT-tagged fish lost weight in the interim and 101 gained weight. Average weight change of PIT-tagged recaptures 1990-1992 at large at least 30 days was +34.7 g (Table 5-8). Average weight change per 30 days was +1.16 g.

Table 5-8. Weight change and net displacement of recaptured PIT-tagged and radiotagged humpback chub in the Colorado River in Grand Canyon, 1992.

	Average		SD		Range	
	PIT	RAD	PIT	RAD	PIT	RAD
Number[a]	155	16	-	-	-	-
No. lost weight	54	13	-	-	-	-
No. gained weight	101	3	-	-	-	-
Ave. Weight change (gm)	34.7	-36.9	115.3	56.0	-494/+489	-215/+43
Ave. Days at large	241	120.6	150.3	87.5	31/699	33/357
Weight change/30 days (gm)[b]	1.16	-10.0	3.8	12.1	-16.5/+16.3	-28.2/+3.0

[a]Only fish at large >30 days were included.
[b]Average weight change computed from individual fish.

Error in weight measurement was estimated from four humpback chub recaptured within one day of initial capture. Average difference in weight of the same fish (sample size of four) was ± 12.5 g (Table 27 *in* Valdez et al. 1992). Based on the relatively large error in weighing fish, the slight weight loss of PIT-tagged recaptures was probably insignificant. Several factors may have contributed to weighing error. There may be inherent error in the scale itself. Since July 1991, nearly all chub were processed on the boat, wind and vibrations often made the scale difficult to "tare", and the digital display did not completely stabilize. Moisture accumulated in the holding boxes and may have affected scale sensitivity. Periodic removal of the scales from the boxes to air-dry helped to alleviate this problem. The amount of water a biologist allowed to drip from a fish prior to weighing probably varied. This was minimized by standardizing the weighing procedure as follows: (1) the boat was tied to shore and stabilized, (2) the scale was tared each time before measuring a fish, (3) the fish was carefully lifted from the live well and excess water allowed to drip for several seconds, and (4) the fish was gently placed in the center of the scale dish, until the fish was still, and the display had stabilized to insure accuracy. The fish sometimes regurgitated during capture and handling, and could have contributed to fish weight variation. There was no way to prevent regurgitation, but extra care was taken to minimize handling time and expedite total processing.

Relative condition factor (Kn) was compared between recaptured PIT-tagged chub (n=126) and adult chub captured for the first time (n=684) to evaluate the effect of PIT-tagging. There was no significant difference in Kn between PIT-tagged recaptures and initial captures, supporting the evidence that PIT-tagging had no measurable, detrimental effect on adult humpback chub.

CHAPTER 6 - MOVEMENT AND ACTIVITY OF HUMPBACK CHUB

Primary Authors: Bill Masslich and Bryan Cowdell

INTRODUCTION

This chapter presents the methods, results and discussion on movement and activity of humpback chub in Grand Canyon. Information in this chapter focuses on data collected during 1992, with some synthesizes of data collected from previous years (1990-91). This chapter addresses project Objectives 1A: Determine resource availability and use of humpback chub in the mainstem Colorado River, 1B: Determine reproductive capacity and success of humpback chub in the mainstem Colorado River, and 1D: Determine distribution, abundance and movement of humpback chub in the mainstem Colorado River, effects of dam operation on the movement and distribution of humpback chub.

Results presented in this chapter are divided into two sections. The first section, describing observations of long range movements of radiotagged and PIT tagged fish, addresses Objective 1D. Data collected on movements to and from the LCR and use of the confluence area during spawning season by radiotagged fish are also presented to address Objectives 1A and 1D. The second section presents information on local movement and activity of humpback chub relative to physical factors, including season, time of day, turbidity, river flow and ramping rates. Results presented in this section address the effects of dam operation on movement of humpback chub, as outlined in Objective 1D. Information presented on near surface activity of humpback chub relative to season, time of day and turbidity describes use of habitat by humpback chub as outlined in Objective 1A. Movement information from radiotelemetry was also used to identify spawning aggregations and movements, as part of Objective 1B.

METHODS

Movement and activity of humpback chub in Grand Canyon were evaluated with radiotelemetry, recaptured PIT-tagged fish, and diel patterns in netting catch rates. Radiotelemetry studies of humpback chub, on going since October 1990, were continued throughout 1992 to identify seasonal and diel patterns in local movement, long-range movement, habitat use, and response by individual fish to changing flows from Glen Canyon Dam operations. Recapture information from previously tagged fish (PIT tagged) was used to assess long-rang movement of humpback chub in the mainstem Colorado River. Netting catch rates were used to assess relationships between patterns of local movement and effects of season, time of day, and turbidity.

Radiotelemetry

Radiotransmitters were implanted in humpback chub at least every other month, during the 20-day trips, and monitored during subsequent 12 and 20-day trips. An effort was made to maintain six to eight active transmitters in fish at all times. Only fish in Reach 1 were implanted with transmitters. Daily monitoring was conducted by boat within an 8-mile reach of the mainstem Colorado River, extending up and downstream of the LCR confluence (RM 57-65). Routine monitoring was extended 2-6 km upstream in the LCR during spawning season. One aerial surveillance was conducted during June to aid in locating radiotagged fish that had migrated up the LCR to spawn.

Telemetry equipment and methods used in 1992 were similar to those described for research conducted in 1990 and 1991 (Valdez et al. 1992). Extensive evaluation of telemetry equipment and techniques were performed and documented for 1990 and 1991. A brief description of equipment and methods used to assess movement and activity of humpback chub is presented in this chapter with emphasis on modifications made during 1992. The reader is referred to the 1991 Annual Report (Valdez et al. 1992) for a comprehensive description and evaluation of equipment and methods.

Radio used in 1992 included Advanced Telemetry Systems (ATS) Model R2000 and Smith-Root (SR) Model SR-40. Data loggers included the ATS DCC-II Model R5042. Data loggers were sent to the manufacturer for data collection software upgrading during 1992. ATS Model 2 BEI 10-35 transmitters, operating in the 40 MHz band, were used exclusively in 1992. Omni-directional Larsen-Kulrod whip antennas were used with ATS R2000 and SR-40 receivers for searching radio signals. Smith-Root loop antennas were used for locating signals by triangulation. Remote stations were each equipped with a directional Proline low band Yagi antenna (30 to 75 MHz).

Telemetry studies in 1992 comprised of three elements, including surveillance, observations, and remote telemetry. A database useful in ascertaining specific information on the life history of humpback chub in Reach 1 was developed for each element. Effort expended on telemetry surveillance and observations is presented in Table 6-1.

Surveillance data were used primarily to determine horizontal long-range movement and diel patterns in near-surface activity. Long-range movement is defined as displacement between gross habitat features or large habitat complexes, and is distinct from localized movement or activity within habitats or small habitat complexes. Near-surface activity was assessed by presence or absence of radiotagged fish above the radio signal extinction depth of approximately 4.5 m (Yard et al. 1990).

Table 6-1. Effort expended for telemetry surveillance and observation of radiotagged adult humpback chub in Reach 1 of the Colorado River in Grand Canyon, October 1990-November 1992.

	Number of Observations	
Telemetry Surveillance	**Day**	**Night**
Boat Surveillance (mainstem)	285	175
Foot Surveillance (LCR)	73	6
Aerial Surveillance (helicopter)	6	0
Total number of surveillance runs	364	181
Telemetry Observations	**Number of Observations**	
Implant	75	
Locate	58	
2-hour observation	33	
24-hour observation	73	
Test flow observation	21	
Total number of observations	260	

Telemetry surveillance was conducted twice daily in all or part of the section between RM 56 and 65. Fish locations were mapped on 1:2400-scale aerial photographs. A confidence level of 1 (high), 2 (medium) or 3 (low) was assigned to each location, as an index of observer confidence for location accuracy. Only locations with a high observer confidence of '1' and '2' were used for the long-range movement database. Corresponding information on light conditions, weather, and water clarity were recorded for each surveillance, and habitat parameters were recorded at each location.

Surveillance locations with confidence levels of 1 or 2 were used to assess the effect of season, time of day, and turbidity on near-surface activity of adult radiotagged humpback chub. Season was divided into a spawning period (February through May) and a nonspawning period (June through January). Spawning times were based on observations of movement of radiotagged fish into the LCR and concurrent increases in netting catch rates in the mainstem Colorado River near the confluence of the LCR during this period. This definition of spawning period is consistent with that reported by Kaeding and Zimmerman (1981) for humpback chub in the Grand Canyon. Time of day was divided into two categories, day (after sunrise and before sunset) and night (after sunset and before sunrise). Sunrise and sunset were calculated on the basis of longitude, latitude, and elevation for a date in the middle of the corresponding field trip. These values were used for all days in that trip. Water clarity was measured using Secchi disc readings. Secchi depths $\geq$ 0.5 m were classified as low turbidity and Secchi depths < 0.5 m were classified as high. Beginning in March 1992, turbidity was also measured as Nephelometric Turbidity Units (NTUs) above and below the LCR confluence during each surveillance run, using a Hach Model 2100P turbidimeter. A relationship between Secchi depth and turbidity in NTUs is presented in Figure 6-1.

Telemetry observations were conducted to evaluate habitat use and local movement in response to time of day, river stage, ramping, and turbidity. Local movement is defined as movement or activity within a macrohabitat or small habitat complex, and was evaluated using radiotagged adult humpback chub monitored by remote telemetry and telemetry surveillance. Individual radiotagged fish were monitored for periods up to 48 hours when fish were within about 4.5 m of the surface and their radio signal was audible. When a fish was first contacted from a tracking boat, its approximate location was determined with an ATS Model 2000 receiver and a directional loop antenna. The tracking boat was then taken to the shore nearest the fish, and care was taken to not disturb the fish. The position of the fish was determined by triangulation with an ATS Model 2000 receiver and directional loop antenna.

Fish were carefully monitored for habitat use and movement particularly during changes in flow stage. Movement and location at each observation time were mapped on a mylar overlay using a 1:1200 or 1:2400-scale aerial photograph. River stage was monitored using temporary staff gages and recorded with each observation. Stage change was measured as river surface elevation change in centimeters per hour (cm/hr). Fish position and river stage were checked and recorded every 30 minutes, or more frequently if river stage changed rapidly. Staff gage readings were connected to known elevations by measuring the vertical distance from the water surface to a temporary benchmark. All temporary benchmarks used for this study were surveyed into known USGS elevations during 1992.

At the conclusion of monitoring, habitat measurements were recorded where, physically possible and when the fish was stationary for at least 30 minutes. Habitat measurements taken at each point included depth, velocity, substrate, temperature, overhead cover, and lateral structure.

Remote telemetry data were collected from three stations, two directional and one omni-directional. Directional remote telemetry stations were re-established at the same sites used during 1991, just upstream of the mouth of the LCR (station KLCR), on river left (RM 61.3), and downstream of the LCR confluence (station KRSH) on river right (RM 62.1). Data collected from the directional stations were used in determining movement within the mainstem and between the mainstem and the LCR. Since only one directional antenna was used at each remote site, the direction in which a fish was traveling had to be

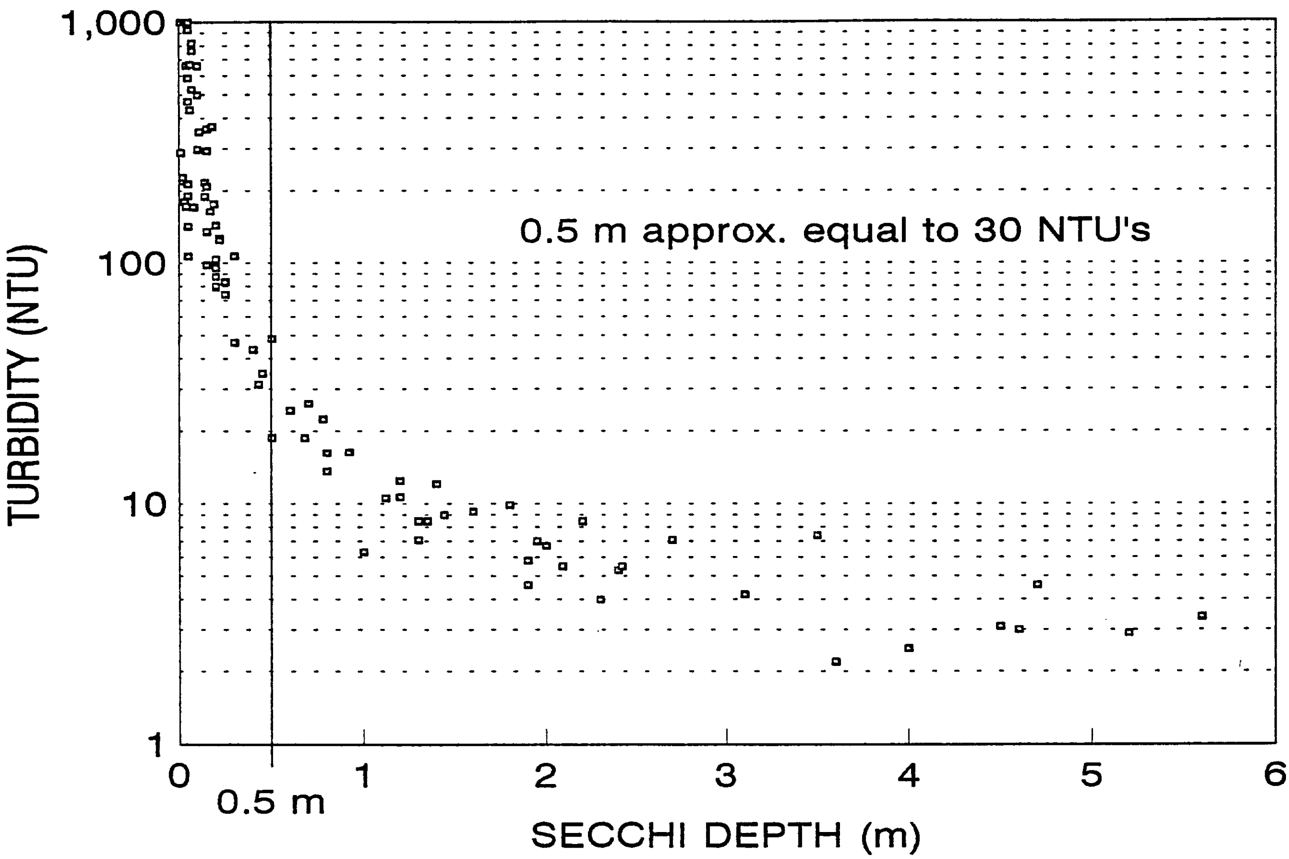

Figure 6-1. Relationship between Secchi depth and turbidity (NTUs) measured in the Colorado River Reach 1, Grand Canyon, March 1992 through January 1993.

determined by locating the fish through surveillance. The directional remote stations were operational from mid-February to mid-August (Fig. 6-2).

The omni-directional station (KILR) was re-established at RM 60.5, and provided useful data on diel near-surface activity and activity relative to turbidity. Information collected from KILR was also used in identifying fish signatures (frequency/pulse combinations) in the area, which expedited locating fish during field trips. KILR was re-established in mid-August of 1992.

PIT Tag Recaptures

Recaptures of PIT-tagged fish by electrofishing, netting, and seining were used to evaluate long-distance movement of humpback chub in Reach 1. All fish recaptured with PIT tags originally implanted by B/W in the mainstem were used in assessing movement. Movement was calculated as the distance between original capture location and recapture locations, with downstream movements presented as negative values and upstream movements as positive values. For multiple recaptures of the same fish, each recapture was treated independently and distance moved based on the original capture location. Elapsed time between original capture and recapture was based on the time between the corresponding dates. Recapture data from other investigators will be incorporated into our database at a later date.

Netting

Netting catch rates were used to assess local movement and activity relative to time of day and turbidity. A complete description of netting methods and calculation of catch rates is presented in Chapter 4.

RESULTS

Long-Range Movement

Long-range movements of humpback chub in the Grand Canyon are hypothesized to be associated with spawning migrations to and from the LCR, response to habitat changes associated with changes in flow, response to food availability, juvenile dispersal, or possibly random movements. These movements were evaluated using radiotelemetry and recapture of PIT-tagged fish. Because telemetry observations or recaptures of tagged fish do not represent continuous data, fish displacement was used as an index to movement. "Net displacement" was defined as horizontal distance from release site to last contact or recapture point for an individual fish. "Gross displacement" was defined as cumulative distance between successive contact points for an individual fish (Valdez et al. 1992).

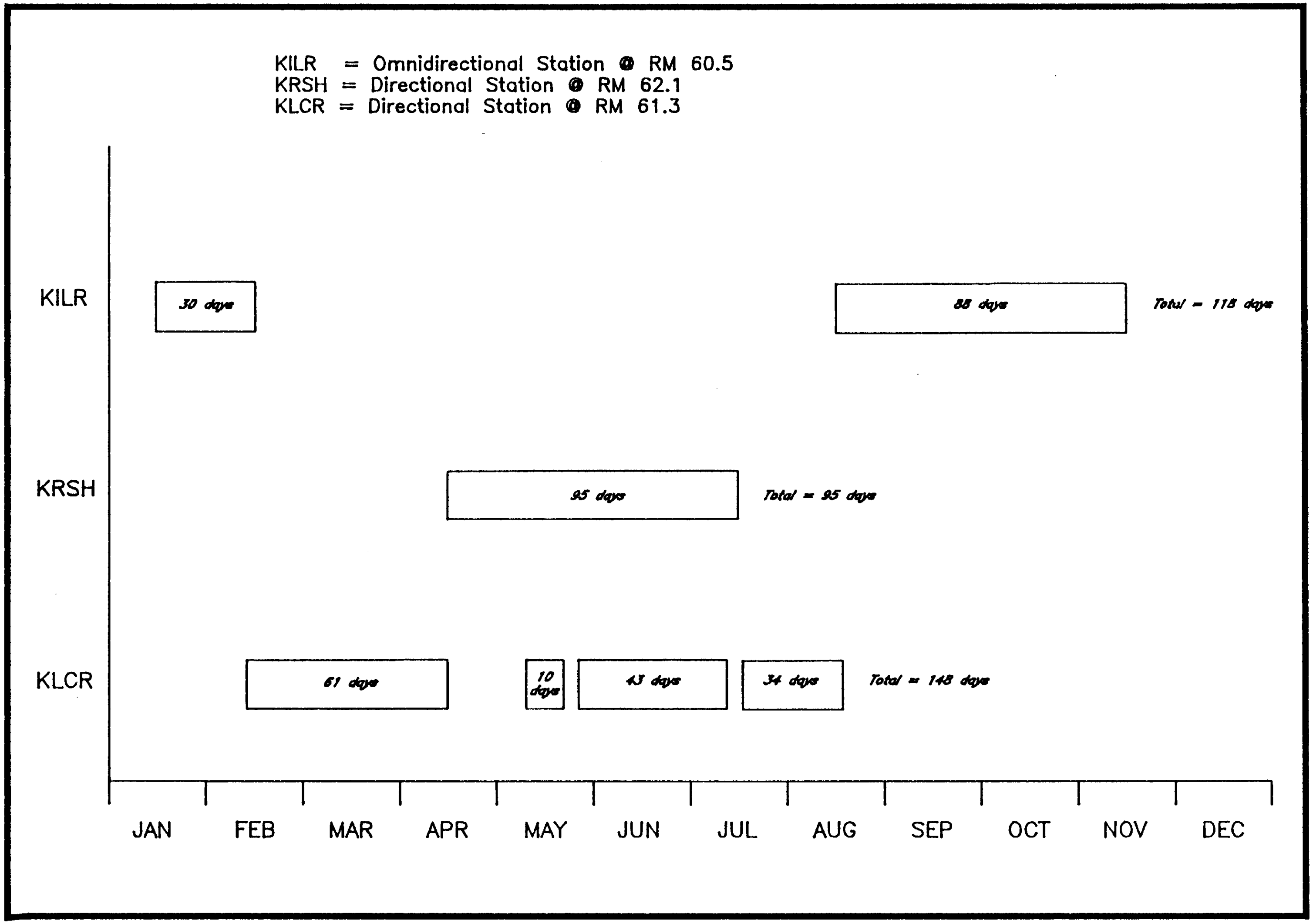

Figure 6-2. Summary of active logging periods for three remote telemetry stations on the Colorado River in Grand Canyon, 1992.

Long-Range Movement of Radiotagged Fish

A total of 27 radiotagged adult humpback chub, implanted between November 1991 and September 1992, were used to evaluate long-range movement or displacement in 1992 (Appendix C, Table C-1). Five fish, implanted in November 1991, were included in the analysis along with fish implanted in 1992. These fish were not evaluated previously because the 2-week, post-surgical acclimation period had not expired prior to earlier analysis. The average length of time for the 27 subject fish between release date and last contact was 87 days, with a range of 1 to 163 days. During this time the fish exhibited a mean "net displacement" of 2.32 km, with a range of 0.08 to 21.4 km (Table 6-2). Mean "gross displacement" during the same period was 5.13 km, with a range of 0.16 to 24.5 km.

Table 6-2. Long-range movements, including mean net and gross movement of radiotagged humpback chub observed by BIO/WEST in the Colorado River in Grand Canyon, 1990-1992.

	Movement (km)				Adjusted Movement (km)[1]			
Date	No. Fish	x Net	x Gross	No. Days	No. Fish	x Net	x Gross	No. Days
1990-1991	48	1.34	4.23	86.1	48	1.34	4.23	86.1
1992	27	2.32	5.13	87.3	26	1.58	4.34	85.0
1990-1992	75	1.68	4.56	86.5	74	1.42	4.29	85.0

[1] Movements of one fish (PIT tag #7F7F1E514C) omitted from analysis (see text for explanation).

Mean net and mean gross displacement for radiotagged fish in 1990-91 were 1.34 km and 4.23 km, respectively. Higher values in 1992 were attributed to movements of one fish (PIT tag # 7F7F1E514C) that was tracked 15 km up the LCR during April of 1992. This fish was located using aerial telemetry, a technique that was not applied to LCR tracking efforts in 1991. Excluding movements of this fish, mean net displacement in 1992 averaged 1.58 km, with a range of 0.08 to 4.40 km, and mean gross displacement averaged 4.34 km, with a range of 0.16 to 11.18 km. These adjusted values were very similar to movements observed by 48 radiotagged humpback chub in 1990-91. Mean net displacement and mean gross displacement were 1.68 km and 4.56 km, respectively when data from both years were combined. Mean net displacement of 1.68 km by humpback chub in the Grand Canyon compares to an "average movement" of 0.8 km reported by Valdez and Clemmer (1982) and a "mean displacement" of 0.8 km reported by Kaeding et al. (1990) for radiotagged adult humpback chub in Black Rocks.

Data collected in 1990-91 led us to hypothesize that greater average net displacement for radiotagged humpback chub in Grand Canyon than in Black Rocks was associated with spawning migrations of the former from the mainstem into the LCR. Significant differences were found between gross movements of fish that were classified as migratory when compared to non-migratory individuals (Valdez et al. 1992). The same test was performed on movement data collect from 27 radiotagged humpback chub in 1992.

Migratory adults were defined as those fish that were located in the LCR or LCR inflow (RM 61.3-61.4) at least once during the period of contact, indicating that the fish had moved to the area for spawning. Non-migratory fish were never located in this area. Of the 27 radiotagged fish monitored in 1992, 44 percent (12) were classified as migratory and 56 percent (15) were non-migratory (Table 6-3). Differences in both mean gross ($t = 2.024$, $p = 0.063$) and mean net displacement ($t = 1.816$, $p = 0.094$) between migratory and non-migratory fish were not significant at the 5 percent level, when data from all fish were used in the analysis. Excluding the one fish (PIT tag # 7F7F1E514C) that was observed moving 15 km up the LCR we found significant differences between migratory and non-migratory fish in both mean gross ($t = 2.024$, $p = 0.049$) and mean net ($t = 3.082$, $p = 0.005$) movement.

Data collected from radiotagged humpback chub in both 1991 and 1992 support the hypothesis that a significant proportion of long-range movement by humpback chub in Grand Canyon was associated with migration to and from the LCR. We note that analysis of data collected in 1992 indicated that there were also significant differences in net movement between migratory and non-migratory adults. Although net movement of migratory adults was greater than non-migratory adults in 1991, the differences were not significant (Valdez et al. 1992). We speculate that significant differences in net movement in 1992 were associated with more effective radiotracking in the LCR that year. Consistently high flows and lower conductivities in the LCR allowed for radiotracking further upstream in 1991. Since we were generally able to observe the fish on only one leg of the migration before transmitter expiration, the resulting mean net movement for migratory adults was higher in 1992 as in 1991.

Of 27 radiotagged adults in 1992, 21 (77.8%), had a net displacement of less than 2 km (Fig. 6-3). In 1991, 88 percent of 48 radiotagged adults exhibited a net displacement of less than 2 km.

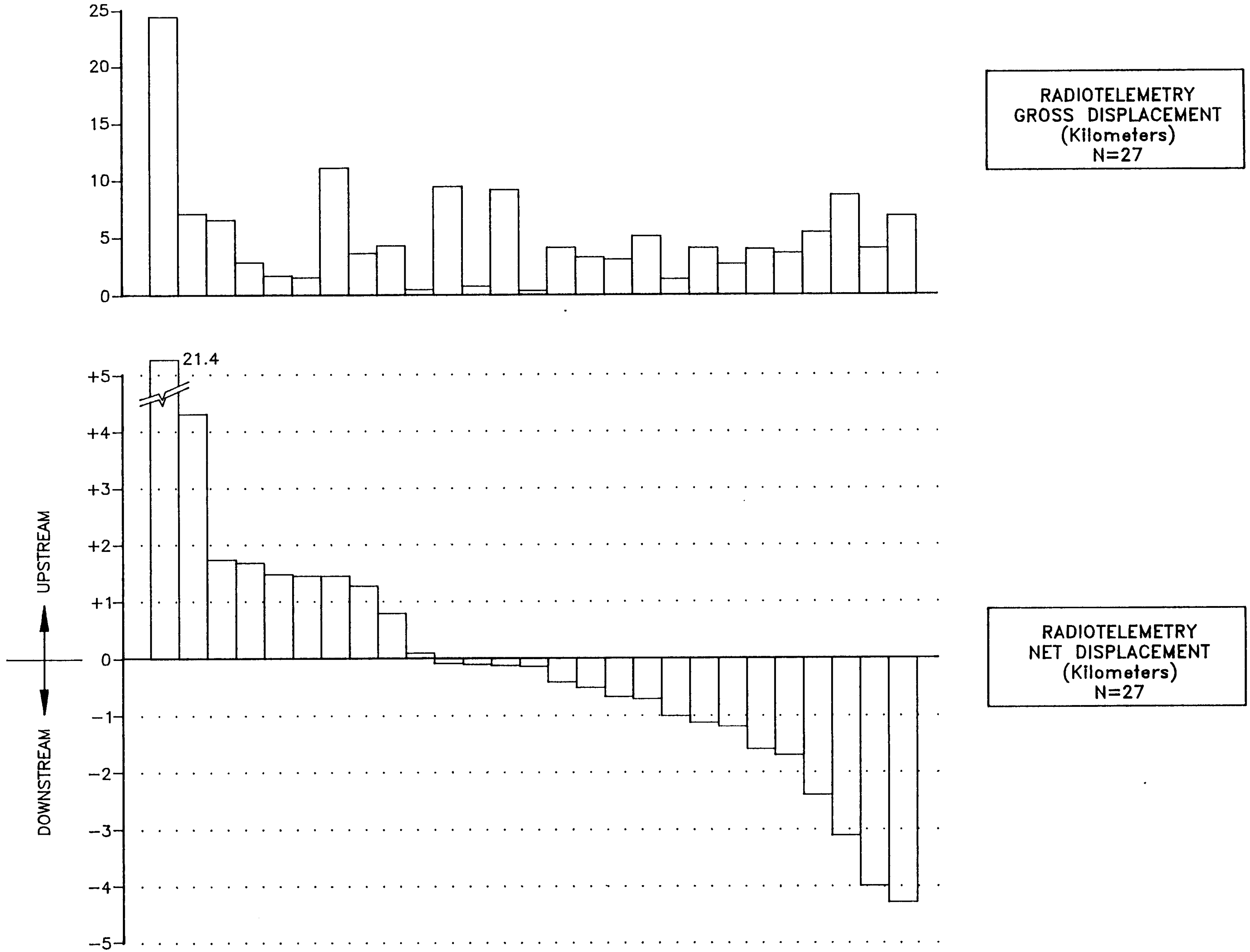

Figure 6-3. Gross and net displacement of radiotagged adult humpback chub in the Colorado River in Grand Canyon, 1992.

Table 6-3. Gross and net displacement of migratory and non-migratory radiotagged adult humpback chub in the Colorado River in Grand Canyon, 1991-1992.

	Migratory				Non-Migratory		
PIT Tag No.	Gross (km)	Net (km)	No. of Contacts	PIT Tag No.	Gross (km)	Net (km)	No. of Contacts
7F7E431037	6.95	-2.45	34	7F7F3E3542	0.1	-0.1	2
7F7E432514	2.36	-1.5	23	7F7F21747D	2.0	-0.3	30
7F7F095814	4.44	2.7	22	7F7F21741B	0.94	0.9	10
7F7F1F6A79	5.49	-1.93	37	7F7F475E72	4.2	1.1	28
7F7D140108	1.72	-0.8	19	7F7F217E36	2.6	-2.5	7
7F7E430D1E	2.30	-1.08	46	7F7D080024	0.5	-0.2	11
7F7F1E514C	15.2	13.27	32	7F7F3E6117	2.7	0.5	9
7F7E432641	4.27	-2.67	14	7F7F3E5B39	2.55	-0.25	19
7F7F271C57	2.5	-1.0	26	7F7E431B2C	3.15	-0.45	26
7F7F1E7A65	5.65	-0.45	23	7F7F3E506C	5.95	-0.05	28
7F7F321C62	2.3	0.8	15	7F7F3E5133	2.5	-0.7	24
7F7F333715	1.05	0.95	18	7F7D085A33	1.85	1.05	21
				7F7F206B7B	0.85	-0.65	15
				7F7F477F56	0.35	0.05	21
				7F7E430660	1.9	-0.4	34
Mean	**4.52**	**2.47**	**25.8**		**2.14**	**0.61**	**19**
STD DEV.	**3.82**	**3.49**	**15**		**1.56**	**0.63**	**2**
MIN	**1.05**	**0.8**	**46**		**0.1**	**0.05**	**34**
MAX	**15.2**	**13.27**			**5.95**	**2.5**	
N	**12**	**12**			**15**	**15**	

Corresponding gross displacement of the 27 fish observed in 1992 varied widely between fish with a mean ratio of net to gross movement of 1:2.2 and a range of 1:1 to 1:119. These data suggest that although the majority of the fish show fidelity to specific locales some exhibit substantial movement up and downstream of these locations.

Spatial fidelity of radiotagged humpback chub was further evaluated by identifying fish that returned to specific locales (the same river mile) after moving distances up to 1 km up or downstream of the location (Table 6-4). Fifty-eight percent of radiotagged fish reoccupied the same locale after

Table 6-4. A summary of radiotagged adult humpback chub which reoccupied a locale following movement of either 1.0, 0.5 or 0.1 km in the Colorado River, Grand Canyon AZ, 1992.

	Distance moved			Failed to Relocate	Failed to Move	Total
	>1 km	>0.5 km	>0.1 km			
No fish	5	1	10	10	1	27
% of Total	18%	4%	37%	37%	4%	100%

moving distances of at least 0.1 km. This compares to an 80 percent reoccupation rate for radiotagged fish in 1990 and 1991. These data suggest that humpback chub show fidelity to specific locations or habitat complexes within a river reach, often moving back and forth between several locations.

Observations of long-range movements of one radiotagged humpback chub (PIT tag # 7F7F3E506C) in 1992 exemplified this fidelity to one or more locales within a given reach of river (Fig. 6-4). Gross movement of this fish was 9.6 km while net movement was less than 0.1 km. All movements occurred within a river reach approximately 1.3 km in length. This fish was observed reoccupying three locales within this reach on numerous occasions during the period of contact. It is hypothesized that movement patterns of this fish and others like it may be associated with one or more factors including shifts in food availability, habitat changes associated with flow changes or random movement among several "favorite" locales.

Long-Range Movement of PIT-Tagged Fish

A total of 124 humpback chub, PIT tagged by B/W, were recaptured one or more times between October 1990 and November 1992, resulting in 139 total captures (Appendix C, Table C-2). Eleven of these fish were recaptured twice and two fish were recaptured three times. Average elapsed time from original capture to recapture was 153.6 days (range = 0-662 days). Average distance from original capture to recapture location was 1.45 km (range = 0-99 km).

Two fish (PIT tag # 7F7F3E2F3A and # 7F7E43193F) were omitted from this database as anomalies or outliers (rationale for omission is presented in the BIO/WEST Annual Summary Report for 1992, Valdez et al. 1992). Excluding these two fish, average elapsed time between capture and recapture was 153.8 days (range = 0-662). Average distance from original capture location, to recapture location for all recaptures from 1990 through 1992 was 0.69 km (range =of 0-6.92), compared to 0.83 km, for 67 recaptures during 1990 and 1991 (Valdez et al. 1992).

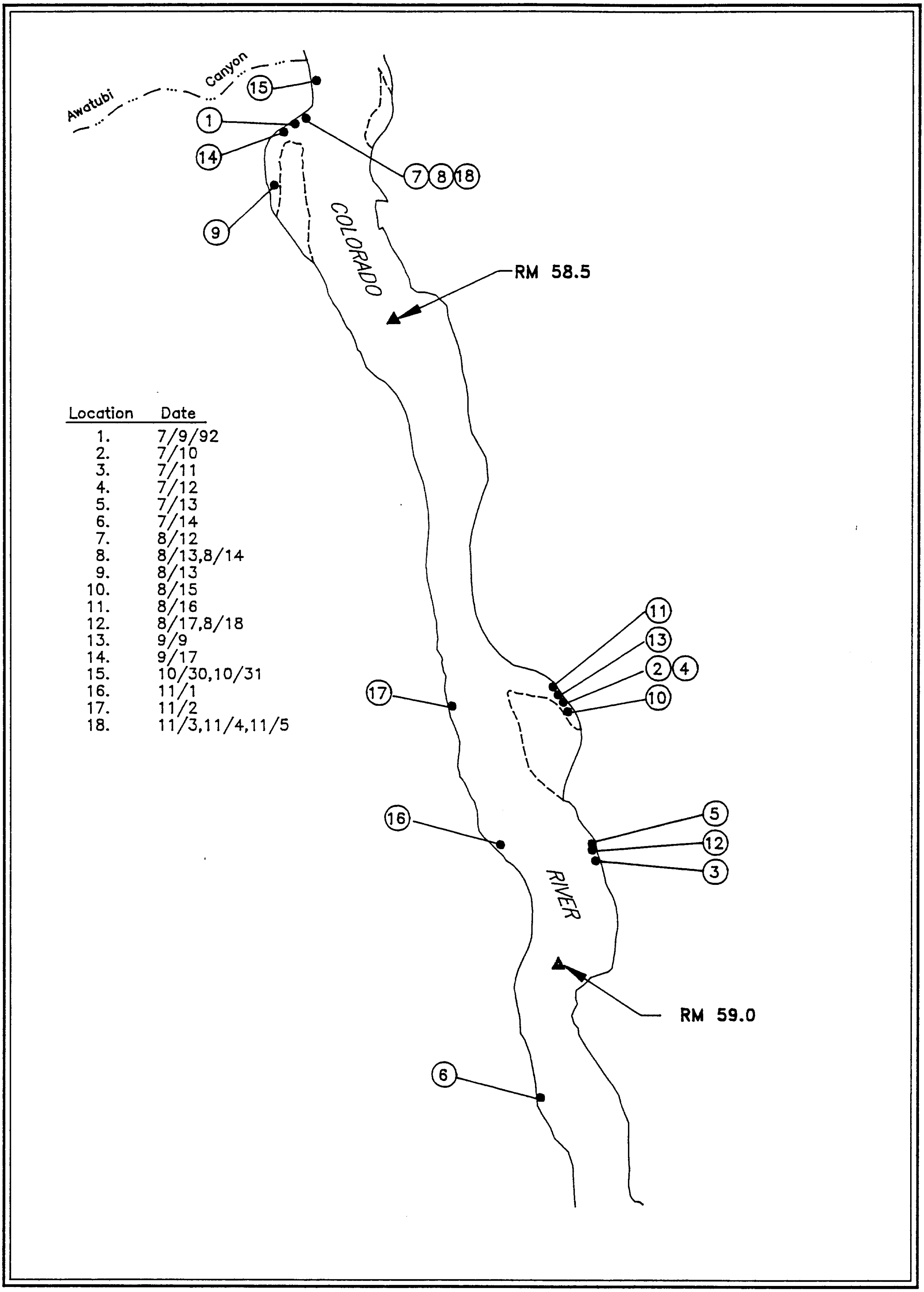

Figure 6-4. Locations of radiotagged adult humpback chub in the main channel Colorado River in Grand Canyon, July 9 through November 5, 1992 (PIT tag # 7F7F3E506C).

Movement of PIT-tagged fish following release was approximately evenly distributed in upstream and downstream directions (Fig. 6-5). Of the 139 recaptures, 55 fish were located upstream and 47 were downstream of the original capture location. The remaining 37 fish were recaptured at the original capture location. Twenty-two of these 37 fish were recaptured within 2 days of release, and 15 were at large for an average of 231 days (range = 33 - 548). These data support the hypothesis that humpback chub exhibit fidelity to specific river reaches.

Movement to and from the Little Colorado River

Two remote stations (KLCR and KRSH) were re-established near the confluence of the LCR in 1992 to monitor movement of radiotagged fish between the two river systems. Data from these two stations, in combination with surveillance and observational data, were used to determine fish used of the confluence area during migration and staging activities, and to determine timing of movements between the two systems.

As in 1991, radiotagged adult began to move into the confluence area in February, with numbers of radiotagged humpback chub peaking in the confluence staging area during March (six fish) (Fig. 6-6). Use of the main channel around the confluence of the LCR continued through May of 1992. Humpback chub were observed moving into the LCR from February through June, with highest numbers of radiotagged fish observed in the LCR in April (five fish). It must be noted that two to three radiotagged fish were consistently observed in the LCR from February through March of 1992. Consistent occupation of the LCR by individual humpback chub in 1991 was not detected until May. Data on timing of fish movement to and from the LCR and spatial use of the confluence area by radiotagged fish were examined in more detail in an attempt to identify relationships between our observations and physical factors that may act as cues. Relationships between movements and flow from the LCR were evaluated in most detail for this report. In general, water temperature in the LCR was inversely related to discharge during the spawning season, especially during short duration flood events.

During 1991, movements of radiotagged fish in the confluence area coincided with flow spikes from the LCR of 2210 cfs on March 5 and 2720 cfs on April 13. During both flow spikes, radiotagged fish utilizing the lower 0.2 miles of the LCR moved back into the main channel. On March 4, two radiotagged fish (PIT tags # 7F7F3E3030 and # 7F7F3E3D23) were observed in the LCR and by March 5 both fish had moved back into the main channel to locations as far as 0.75 miles upstream of the confluence. Mean daily flows in the LCR during this time period increased from 226 cfs on March 3 to 2210 cfs on March 5.

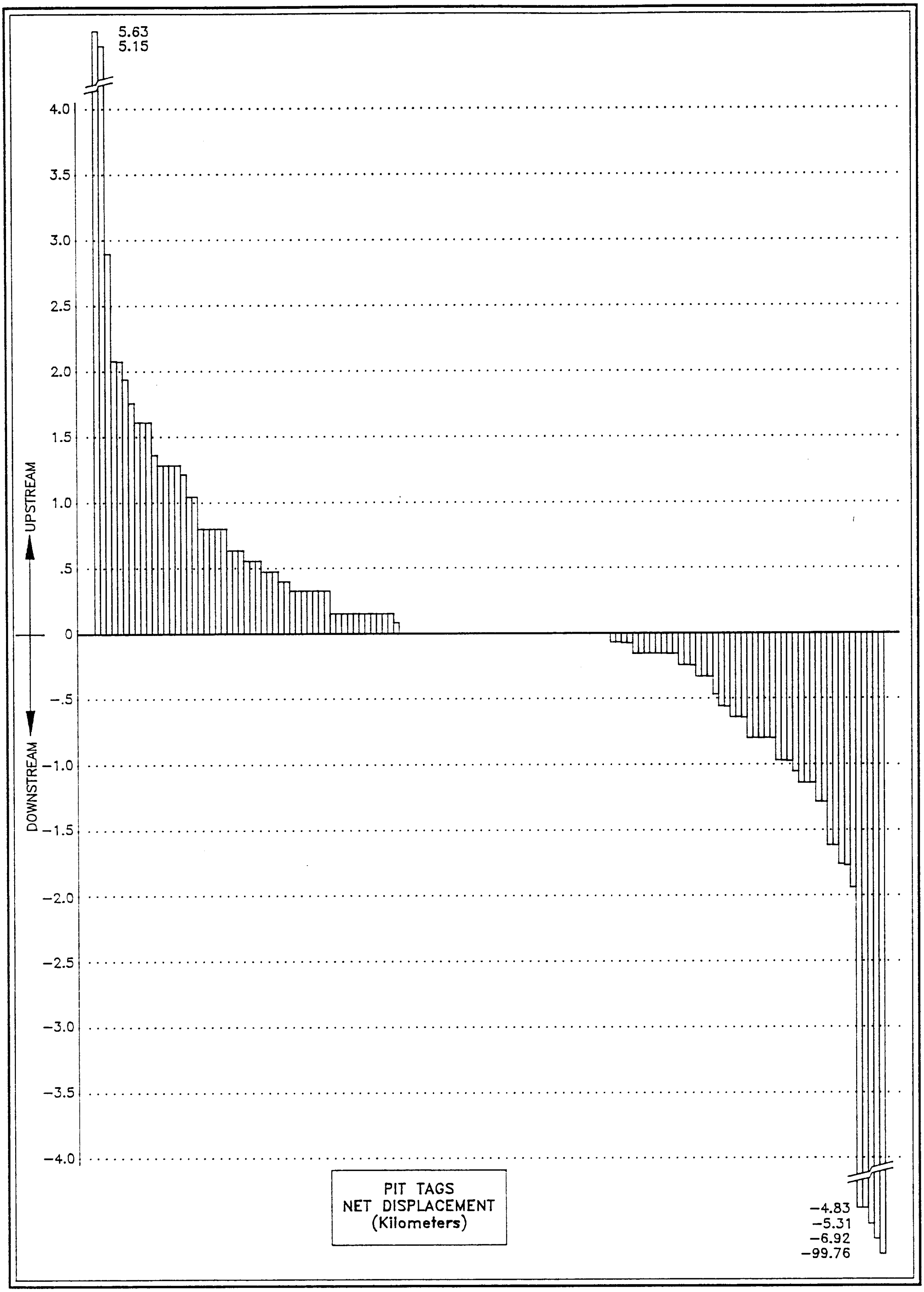

Figure 6-5. Net displacement of PIT-tagged adult and juvenile humpback chub in the Colorado River in Grand Canyon, 1990-1992.

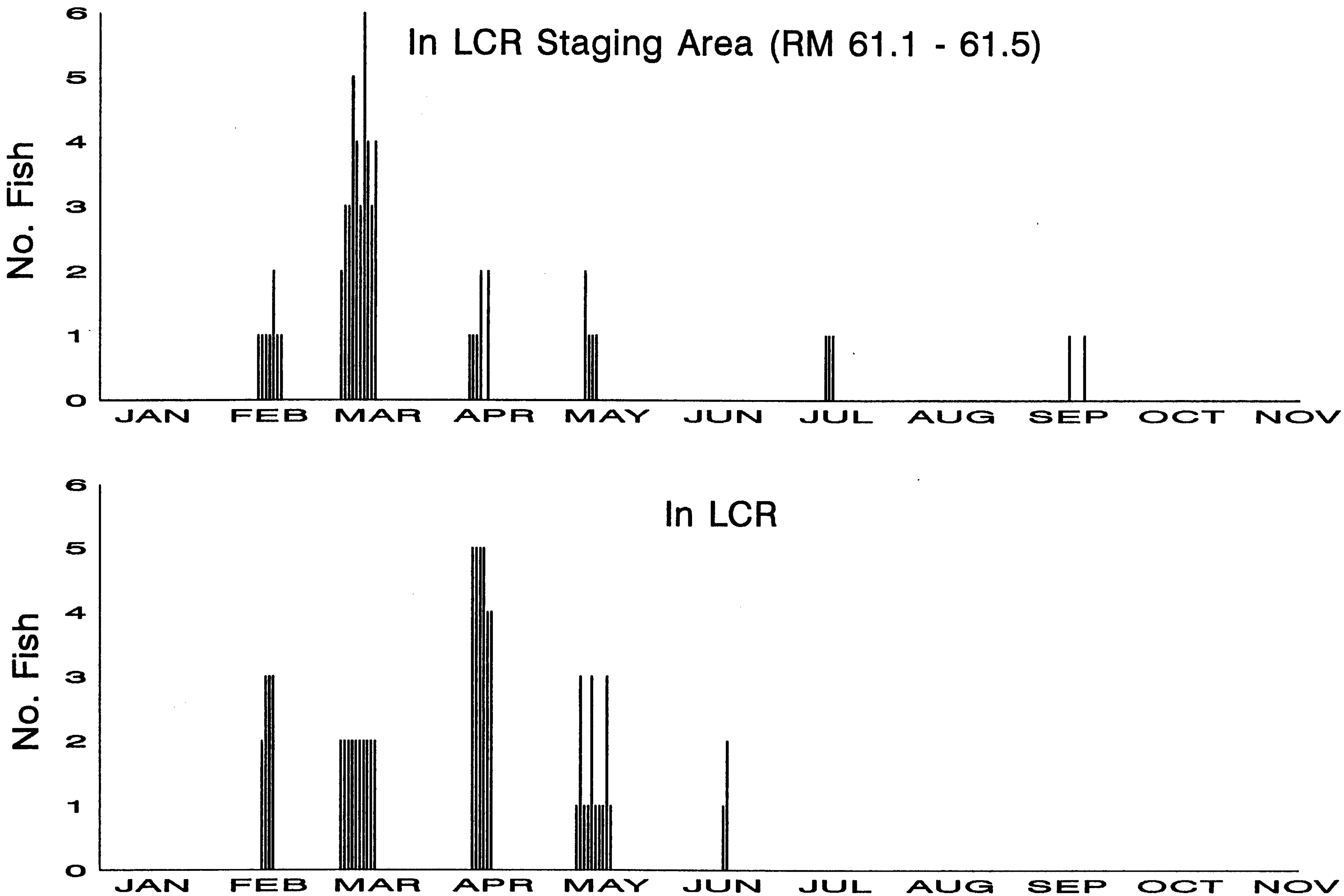

Figure 6-6. Numbers of radiotagged humpback chub contacted daily in the suspected LCR staging area (RM 61.1-61.5) and in the LCR, January through November 1992. Data are from radiotelemetry surveillance and observation.

Both of these fish, in addition to three other radiotagged fish, moved back into the LCR on March 13 and 14 when flows were dropping to 828 cfs and 659 cfs, respectively. Four of these fish were observed moving into the main channel again following a flow spike of 2720 cfs in the LCR on April 13. Two of the four fish moved back into the LCR on April 16, when flows were at 1270 cfs and dropping.

Multiple movements of radiotagged humpback chub between the LCR and main channel were not as extensive in 1992 as in 1991. One radiotagged fish (PIT tag # 7F7E430D1E) was observed moving in and out of the lower 0.1 miles of the LCR three times, twice in February and once in April, before finally moving into the LCR on April 10, where it stayed until contact was lost. The only noticeable relationship between movement of this fish and flow of the LCR was that its final movement into the LCR on April 10 (1530 cfs) coincided with the descending limb of a flow spike of 1750 cfs on April 5. One other radiotagged fish (PIT tag # 7F7E432641) also moved into the LCR during this descending limb on April 9.

Seven other radiotagged humpback chub moved into the LCR during the period from February to May of 1992. Relationships between timing of movements of these fish and hydrological events were not clear. Timing of movements of two radiotagged fish into the LCR were resolved to the day, including one fish (PIT tag # 7F7F1F6A79) which moved in on March 30 and one fish (PIT tag # 7F7F1E514C) that moved in on May 26 (Table 6-5). Flows on March 30 were at 1200 cfs and rising and on May 26 were at 1140 and fluctuating. Movement of one fish from the LCR into the main channel on March 5 roughly corresponded to a small flow spike that peaked at 1270 cfs on March 7. It is estimated that this fish had been in the LCR for a minimum of 20 days prior to returning to the main channel.

Field observations of radiotagged humpback chub using the confluence area during the spawning season indicated that fish utilized different areas of the inflow during the 2 years of observation. It is hypothesized that this difference in use of the confluence area was related to hydrographic differences in both the main channel and LCR in 1991 and 1992. GCES research flows were in place during the spawning season of 1991, while interim flow operations were in effect during spawning in 1992. Hydrographic differences in the LCR were primarily associated with above-normal precipitation in 1992 that resulted in consistently higher discharge throughout the spawning period than in 1991.

Table 6-5. Radiotagged adult humpback chub contacted by the KLCR remote telemetry station in 1992 with estimated dates in and out of the LCR.

Fish No.	PIT Tag No.	Freq/Pulse	Implant Date (ymd)	Initial Contact (ymd)	Last Contact (ymd)	Last Surveillance Contact (ymd)	Days w/in Range	Estimated Date In (ymd)	Estimated Date Out (ymd)
1	7F7E431037	40.650/80	920111	920214	920515	920516	63	-	-
2	7F7E430D1E	40.710/60	920114	920214	920412	920414	58	920410	-
3	7F7F1F6A79	40.620/40	911109	920217	920407	920414	42	920330	-
4	7F7F271C57	40.700/80	920311	920311	920513	920516	30	-	-
5	7F7D140108	40.730/60	920114	920306	920413	920314	29	-	920305
6	7F7F21747D	40.630/60	911109	920319	920329	920314	7	-	-
7	7F7F095814	40.640/80	911108	920412	920413	920413	2	-	920412
8	7F7E432641	40.720/60	920311	920331	920408	920515	9	920409	-
9	7F7F1E514C	40.660/60	920120	920525	920618	920616	3	920526	920618

Differences in spatial use of the LCR confluence area during the spawning season were evaluated for 1991 and 1992 by plotting high confidence locations of all radiotagged fish located in the LCR confluence area during a 4-month period (February through May) for each year (Figs. 6-7 and 6-8). In 1991 (Fig. 6-7), use of the confluence area by radiotagged humpback chub was concentrated in large, deep eddies above the confluence during all months of the spawning period except April. In April, fish were observed utilizing run habitat in the LCR plume along the upstream margin of the large island at the confluence.

It is speculated that fluctuations of main channel flows during February and May of 1991 resulted in significant migration of the plume and flow dynamics that may have been unfavorable for staging or spawning adults. Migration of the plume associated with fluctuating main channel flows results in daily water quality and temperature changes in a substantial portion of the LCR confluence area. Efforts are currently being made to map flow and plume dynamics in the confluence area for future analysis.

Significant discharge from the LCR in March and April of 1991 created conditions which allowed the location of the plume to stabilize to some extent. April field efforts corresponded with a significant flow spike from the LCR, with discharges ranging from 2240 to 971 cfs during the trip. High discharge from the LCR significantly affected flow patterns at the confluence, which resulted in a more stable plume configuration. Although fluctuations in main channel discharge changed flow patterns to some extent, the plume remained stationary on the right side of the large island at the confluence. It is speculated that noticeable differences in spacial use of the plume by radiotagged fish in April were related to this plume stability. It is not clear why similar use patterns were not observed in March under similar flow conditions. Lower temperatures in the LCR flow spike in March (8-11°C) may have been less favorable than the April high flows (9-14°C). Other water quality parameters such as suspended sediment may have also influenced fish behavior.

During the spawning season of 1992, interim flow regimes and consistently high discharge from the LCR created a much more stable plume configuration, which extended significantly farther downstream than in 1991. Spatial use patterns of the confluence area by radiotagged humpback chub in 1992 indicate a more consistent use of the plume than in 1991 (Fig. 6-8). Radiotagged fish were observed utilizing habitat created by the LCR plume during all months of the spawning season (February through March). These observations support the idea that habitats created by stable plume configurations are utilized by humpback chub during the spawning season. To date, it has not been conclusively established that

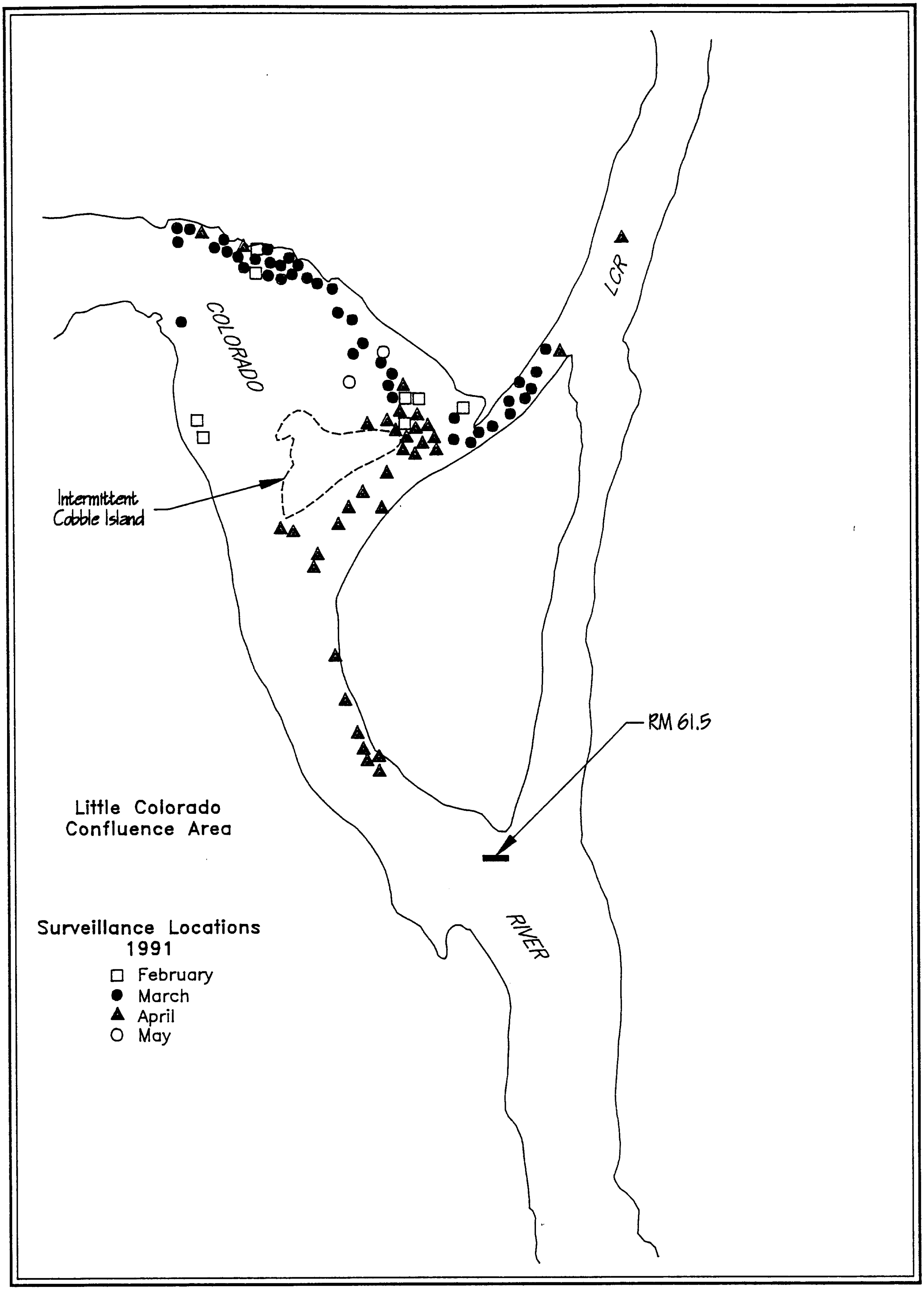

Figure 6-7. Locations of radiotagged fish in the suspected staging area during February through May 1991 in the Colorado River in Grand Canyon.

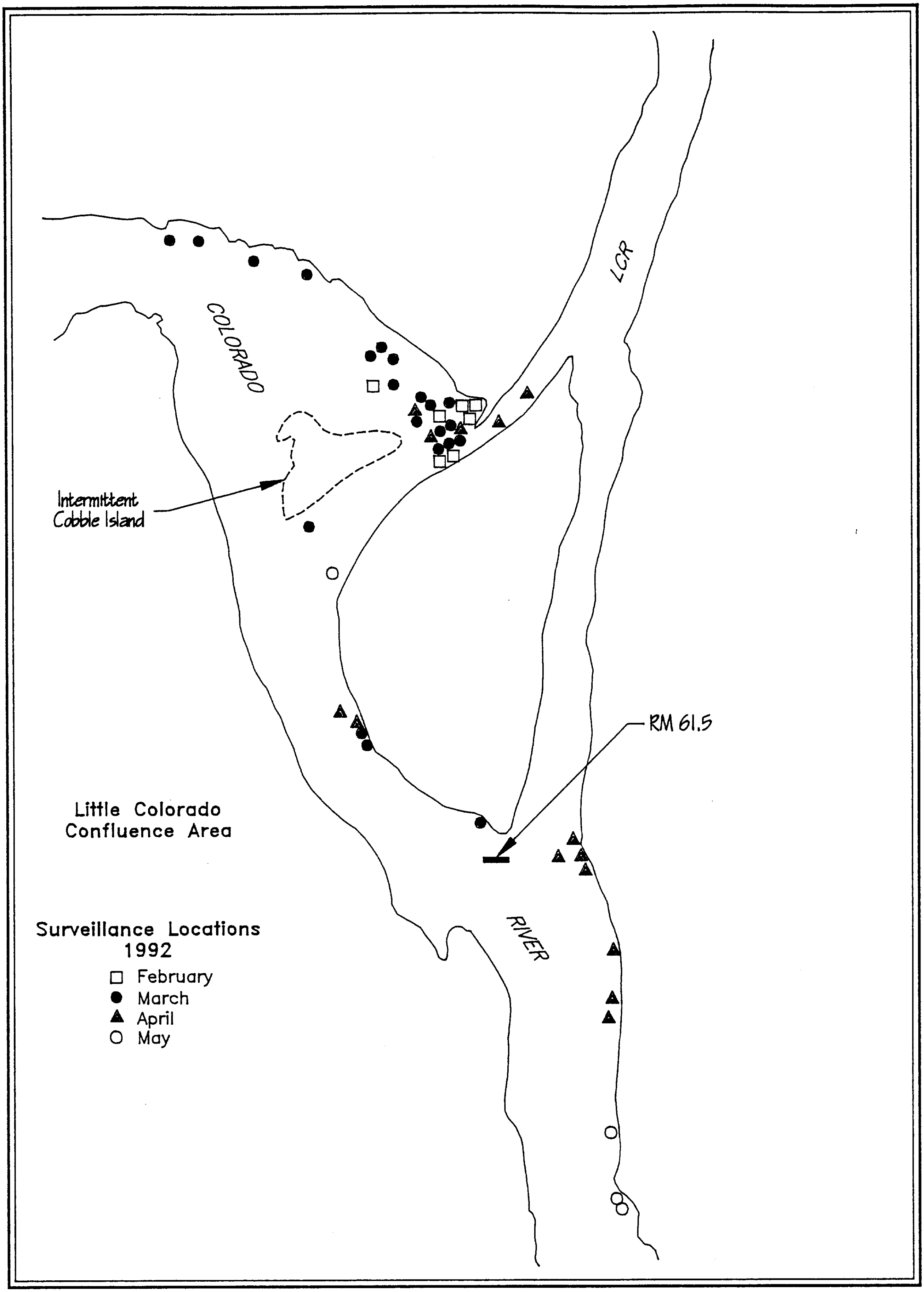

Figure 6-8. Locations of radiotagged fish in the suspected staging area during February through May 1992 in the Colorado River in Grand Canyon.

humpback chub are attempting to spawn in the plume although collection of humpback chub eggs from the in 1991 suggests the possibility.

Local Movement and Activity

Local movement may be affected by behavior (i.e., feeding, resting, spawning, phototaxis), microhabitat change (i.e., depth, velocity), or macrohabitat change (i.e., eddies, runs). Local movements include both horizontal and vertical movements. Local movement and activity were evaluated using radiotelemetry and diel netting catch rates.

Effect of Season, Time of Day, and Turbidity

Near-surface activity, related to season, time of day, and turbidity, was assessed using surveillance and remote telemetry databases. The influence of these three factors on horizontal movement was analyzed using telemetry observation data. Effect of time of day and turbidity was also evaluated using catch rate information from the netting database.

Telemetry Surveillance. Telemetry surveillance data were used to assess near-surface activity of adult humpback chub in the mainstem Colorado River from RM 56 to RM 65 (Reach 1). Based on earlier studies (Yard et al. 1990) and field tests by B/W, extinction depth of radio signals was estimated at 4.5 m at 50 m distance, and it was assumed that fish below this depth were not contacted. By comparing numbers of radio contacts in an area with numbers of contacts expected (known number of fish in the region based on recent releases of radioimplants and cumulative surveillance data), the timing of near-surface activity was evaluated. The ratios between observed and expected contacts were averaged and the resulting average percentage of fish located (APFL) was related to three external factors (season, time of day, and turbidity)

Influence of the three factors on near-surface activity of radiotagged humpback chub was compared using analysis of variance (ANOVA) statistical tests of APFL. Comparisons of 1990-91 versus 1992 data revealed no significant differences ($F = 0.05$, $p = 0.827$) between years. All surveillance data were then pooled and the influence of season, time of day, and turbidity were analyzed.

The mean percentage of fish contacted was significantly higher ($F = 27.54$, $p = 0.000$) during spawning ($n = 148$, mean = 40%, S.D. = 31%) than during the nonspawning season ($n = 295$, mean = 25%, S.D. = 27%). Higher near-surface activity during the spawning season (February through May) suggests that spawning-related activity may differ from "normal" diel activity observed during the remainder of the year.

Turbidity also influenced near-surface activity of radiotagged adult humpback chub. Near-surface activity was significantly greater ($F = 113.07$, $p = 0.000$) during high turbidity (n = 153, mean = 48%, S.D. = 29%) than during low turbidity (n = 288, mean = 20%, S.D. = 25%). This supports the hypothesis that high turbidity provides cover for adult humpback chub allowing utilization of shallow habitats not used during periods of low turbidity.

No significant differences ($F = 2.55$ $p = 0.110$) in APFL were observed between day (n = 280, mean = 28%, S.D. = 29%) and night surveillance (n = 163, mean = 33%, S.D. = 30%). Lack of difference in diel near-surface activity may be due to confounding effects of spawning season and turbidity.

By isolating the influence of each factor, more specific activity patterns were identified (Table 6-6). Near-surface activity increased by 19 to 108 percent during the spawning season when compared to nonspawning season under similar conditions (Fig. 6-9). However, spawning near-surface activity was only significantly higher than nonspawning activity during low turbidity, daytime conditions (Table 6-7). Nonspawning diel activity was usually lowest during the day with a 77 percent increase in APFL during the night. During spawning season, significant diel activity patterns were not observed between day and night under low turbidity. These data support the idea that spawning-related activity may preempt nonspawning, near-surface diel activity patterns.

Table 6-6. Summary of near-surface occurrence of radiotagged adult humpback chub as average percentage of fish located (APFL) at low and high turbidity, during spawning and nonspawning periods and between day and night. Fish were located during telemetry surveillance of the Colorado River in Grand Canyon, November 1990-November 1992.

Turbidity	Season	Time of Day	N	APFL	Standard Deviation[1]
Low	Nonspawning	Day	125	13	20
		Night	81	23	25
	Spawning	Day	49	27	30
		Night	33	30	23
High	Nonspawning	Day	62	43	28
		Night	25	44	28
	Spawning	Day	44	51	25
		Night	22	62	33

[1]Standard Deviation for APFL

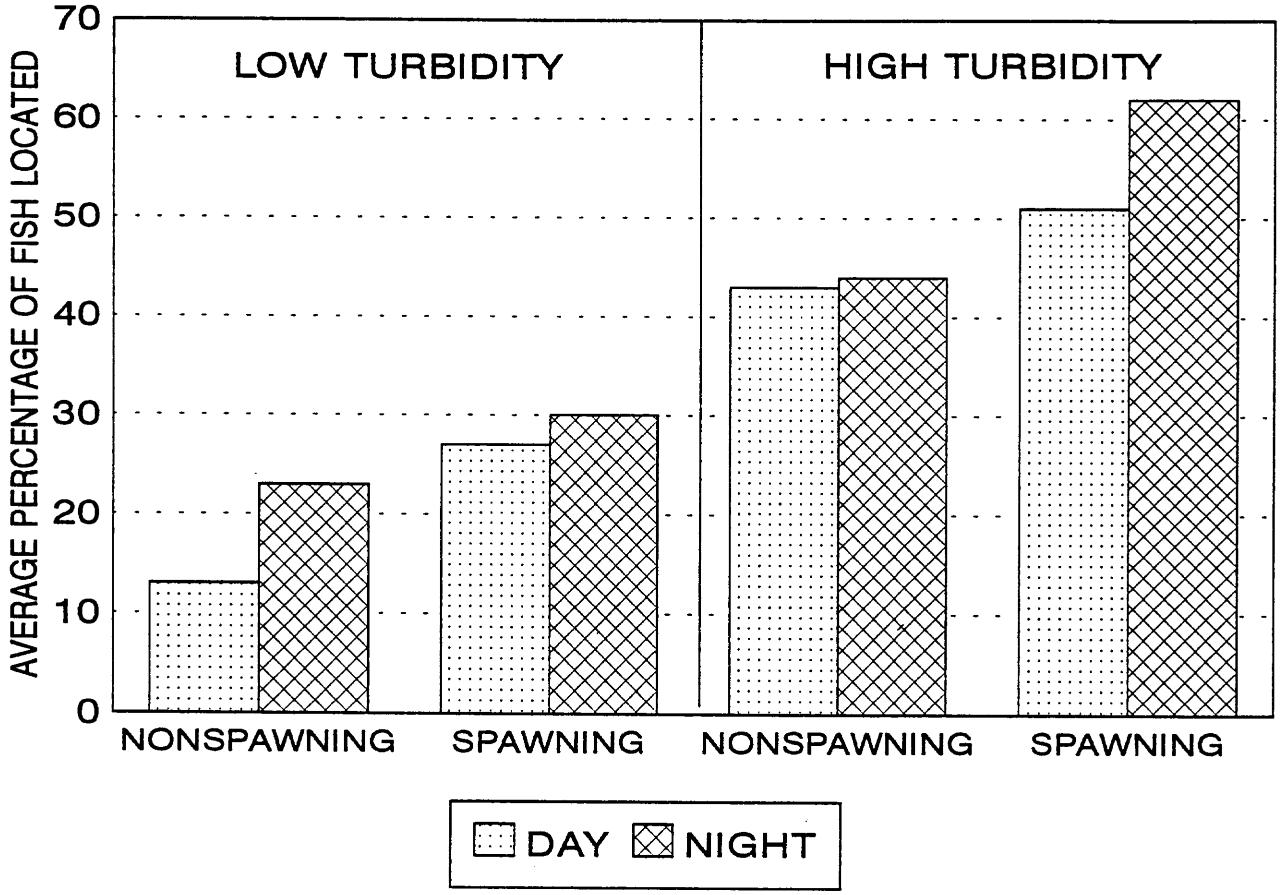

Figure 6-9. **Near-surface occurrence of radiotagged adult humpback chub as average percentage of fish located (APFL) at low and high turbidity during spawning and nonspawning periods and between day and night. Fish were located during monthly telemetry surveillance of the Colorado River in Grand Canyon, November 1990 through November 1992.**

Table 6-7. Statistical[1] comparison on effect of turbidity, season and time of day on average percentage of radiotagged adult humpback chub located (APFL) during telemetry surveillance of the Colorado River in Grand Canyon. November 1990-November 1992. See Table 6-6 for APFL values.

			Low Turbidity				High Turbidity			
			Nonspawning		Spawning		Nonspawning		Spawning	
			Day	Night	Day	Night	Day	Night	Day	Night
Low	Nonspawning	Day	1.000							
		Night	0.004*	1.000						
	Spawning	Day	0.001*	0.416	1.000					
		Night	0.000*	0.159	0.588	1.000				
High	Nonspawning	Day	0.000*	0.000*	0.005*	0.035*	1.000			
		Night	0.000*	0.000*	0.016*	0.050*	0.800	1.000		
	Spawning	Day	0.000*	0.000*	0.000*	0.001*	0.124	0.326	1.000	
		Night	0.000*	0.000*	0.000*	0.000*	0.012*	0.063	0.150	1.000

*Significant at 0.05
[1]Analysis of Variance (ANOVA)

Under high turbidity, no significant differences were observed in APFL between spawning and nonspawning seasons or between day and night. However, significant differences were detected between high and low turbidity during day, night, and across season. High turbidity APFL rates averaged 129 percent higher than comparable low turbidity conditions. This suggests that during high turbidity, near-surface activity increased regardless of season or time of day.

Of the three factors, turbidity had the greatest influence on near- surface activity as indicated by APFL, followed by season and time of day. In general, humpback chub routinely used more shallow habitats under conditions of high turbidity and deeper habitats under low turbidity. The only exception to this occurred during spawning season, when humpback chub were observed using near- surface habitats despite low turbidity.

Remote Telemetry. Near-surface activity of radiotagged adult humpback chub was also monitored by the omni-directional remote telemetry station KILR. Only data collected concurrent with field trips in August through November were analyzed for this report. The analysis was restricted to these data for two reasons: 1) turbidity data were not available for periods between field trips, and 2) using concurrent data facilitated comparison of results with analysis of telemetry surveillance data. Data on near-surface activity from the KILR station were grouped using the same three factors analyzed for the telemetry surveillance data (season, time of day, and turbidity). Since the KILR remote telemetry station was operational during the nonspawning period (August through January), seasonal differences in near-surface activity were not considered. Sunrise/sunset times and turbidity values were consistent with those used for the surveillance analysis.

Fewer implanted fish in 1992 and technical problems associated with excessive noise (invalid contacts) in the database resulted in a lower sample size in 1992. This necessitated the use of a nonparametric, two sample proportion test to analyze patterns in near-surface activity and effects of turbidity. Data collected in 1991 were reanalyzed using the same technique for purposes of comparison. Average percentage of radio contacts (APRC) used in the test were based on the number of contacts with a radiotagged fish within the range of the antenna versus the number of contacts possible within the given time period (Table 6-8).

During 1992, under low turbidity, the APRC was significantly higher ($Z = 5.40$, $p = 0.000$) at night (10.3%) than during the day (6.7%) (Fig. 6-10). Under high turbidity, a significant difference ($Z = 4.90$, $p = 0.000$) in APRC was also found between day (12.6%) and night (7.7%). Analysis of 1991 data indicated a similar pattern for APRC under low turbidity during night (17.3%) and day (7.5%) ($Z = 18.05$, $p = 0.000$)(Fig. 6-11). However, no differences ($Z = 1.52$, $P = 0.129$) were found between day (21.6%) and night (23.0%) under high turbidity in 1991. It is noted that during 1992, APRC were higher during the day than during the night under high turbidity. This relationship is inconsistent with results from remote telemetry analysis in 1991 and analysis of surveillance data for this report. Although these relationships were not statistically significant for 1991 remote telemetry data and surveillance data, results of analysis indicate that APRC was higher during the night than during the day under high turbidity.

The effect of turbidity was also examined for the 1992 data by comparing day and night activity each under low and high turbidity levels. Daytime APRC was significantly higher ($Z = 6.19$, $p = 0.000$) during high turbidity (12.6%) than low turbidity (6.7%). Nighttime APRC was significantly higher during low turbidity (10.3%) than during high turbidity (7.7%) ($Z = 3.20$, $p = 0.001$). When compared to data collected in 1991, results of the daytime APRC were similar; however, results for the night period were inconsistent. During 1991, APRC was significantly higher during the night under high turbidity (19.2%) than low turbidity (15.1%) ($Z = 7.87$, $p = 0.000$). We suspect that differences between 1992 remote telemetry results and previous analysis may be associated with low sample size during 1992 and excessive

Table 6-8. Percentage of radio-contacts for individual adult humpback chub at low and high turbidity levels during the day (D) and at night (N). E = total expected radio-contacts, O/E = observed/expected radio-contact x 100 = percentage of radio contacts. Data are from the KILR remote telemetry station during trips 2-11 (February - November, 1992). APRC = Average percentage of radio contacts.

Freq/Pulse	Low Turbidity				High Turbidity			
	D (E=40)		N (E=56)		D (E=125)		N (E=30)	
Trip 2	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E
40.670/61	0	0	0	0	0	0	0	0
40.630/60	9	22.5	13	23.2	2	16.6	2	6.7
40.620/44	0	0	3	5.4	0	0	0	0
APRC		7.7		9.5		5.5		2.2
Trip 8	D (E=162)		N (E=126)		D (E=57)		N (E=61)	
40.680/44	76	46.9	121	96.0	34	59.6	42	68.9
40.600/84	94	58.0	95	75.3	32	56.1	37	60.7
40.730/83	0	0	0	0	6	10.5	10	16.4
40.650/60	27	16.7	39	31.0	0	0	1	1.6
APRC		30.4		50.6		31.6		36.9
Trip 9	D (E=364)		N (E=329)		D (E=158)		N (E=194)	
40.650/60	15	4.1	47	14.3	2	1.3	4	2.1
40.600/84	0	0	3	0.9	35	22.2	22	11.3
APRC		2.1		7.6		11.8		6.7
Trip 10	D (E=356)		N (E=412)		D (E=05)		N (E=0)	
40.610/59	0	0	1	0.2	-	-	-	-
40.650/60	0	0	2	0.4	-	-	-	-
40.720/83	1	0.2	0	0	-	-	-	-
APRC		0.06		0.2				
Trip 11	D (E=200)		N (E=280)		D (E=240)		N (E=336)	
40.610/60	2	1.0	50	17.9	55	22.9	25	7.4
40.600/80	0	0	4	1.4	28	11.7	16	4.8
40.650/60	0	0	0	0	0	0	0	0
40.720/80	0	0	0	0	0	0	2	0.6
APRC		0.25		4.8		8.7		3.2
Mean APRC		6.7		10.3		12.6		7.7

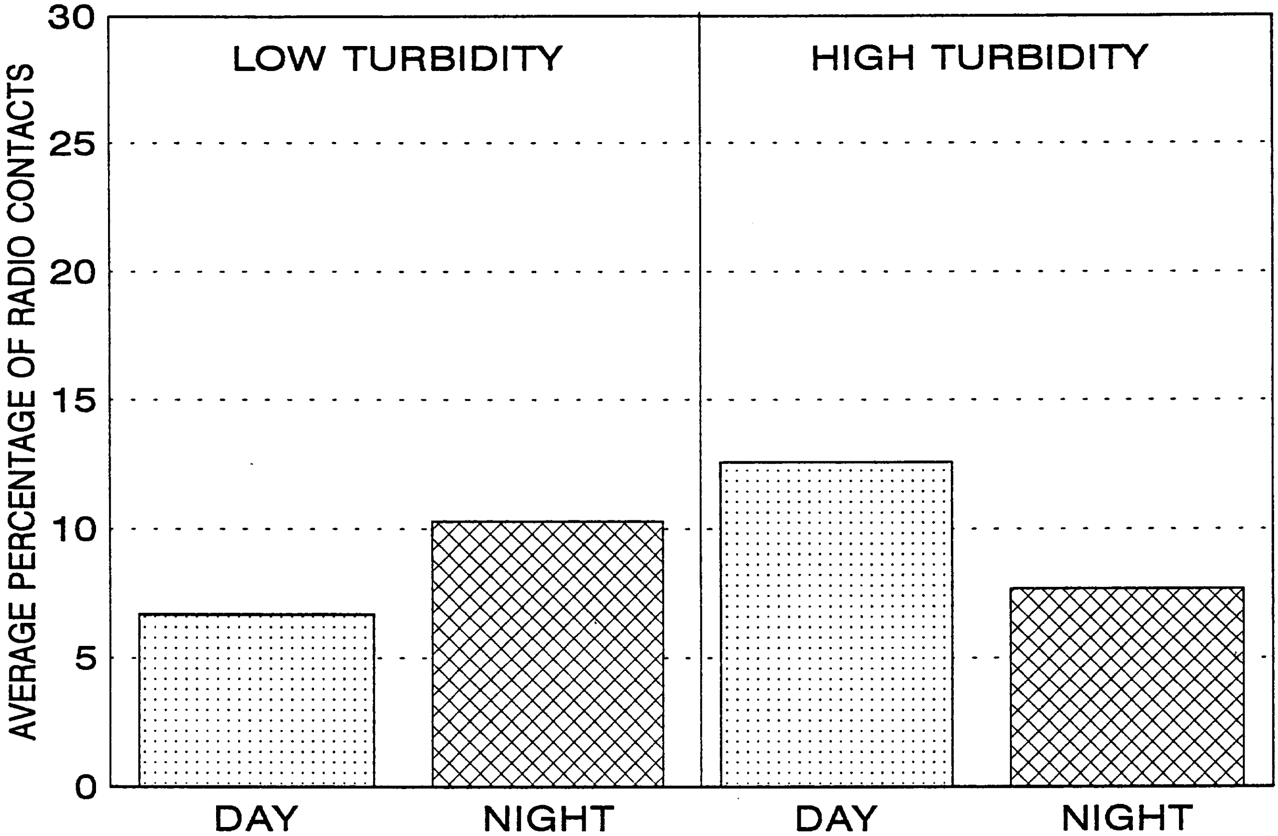

Figure 6-10. Near-surface occurrence of radiotagged adult humpback chub as average percentage of radiocontacts (APRC) at low and high turbidity during day and night. The fish were contacted by the KILR remote telemetry station on the Colorado River in Grand Canyon, 1992.

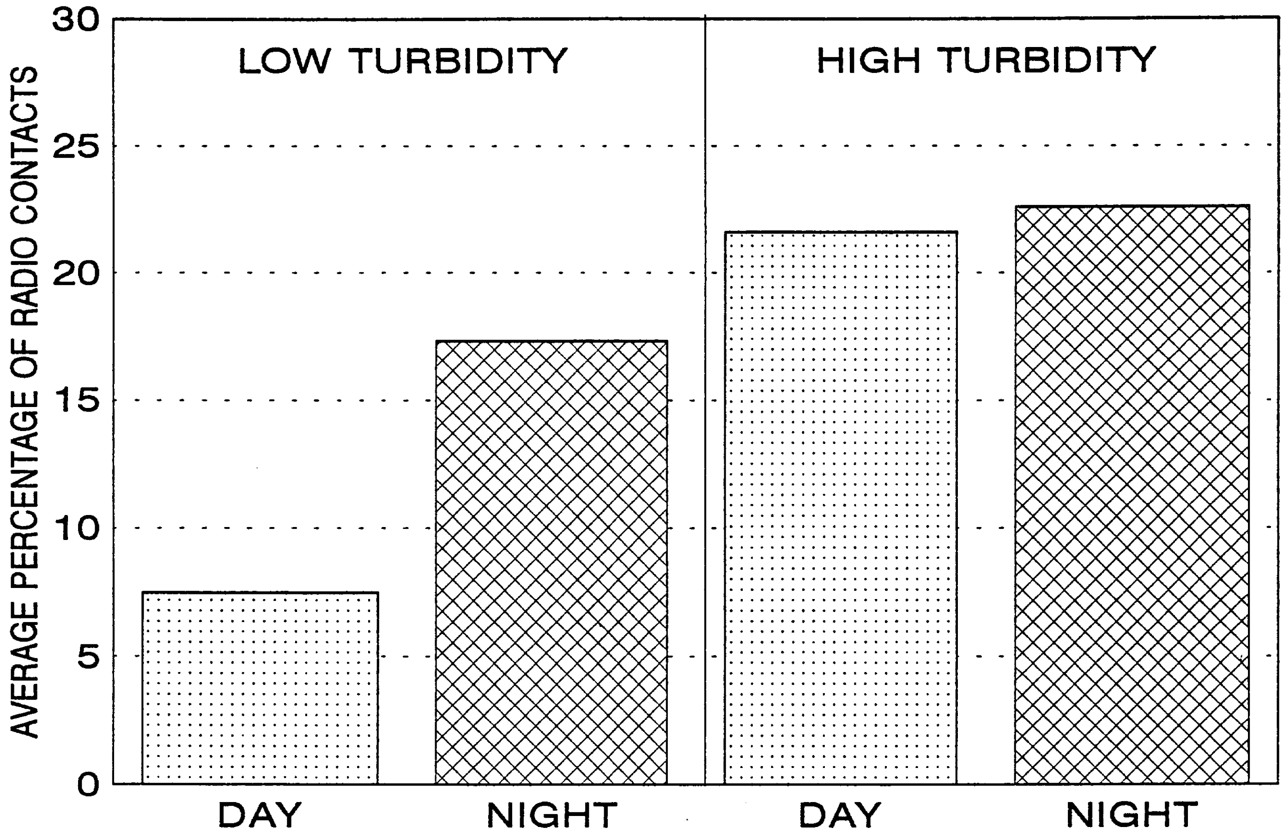

Figure 6-11. Near-surface occurrence of radiotagged adult humpback chub as average percentage of radiocontacts (APRC) at low and high turbidity during day and night. The fish were contacted by the KILR remote telemetry station on the Colorado River in Grand Canyon, October 1990 through November 1991.

noise (errant radio signals) recorded by the remote stations. Further analysis of this database will be necessary for verification of results.

Netting Catch Rates. The effect of season, time of day, and turbidity on local movement of radiotagged humpback chub was also evaluated using netting catch rates in Reach 1. It is assumed that increases in netting catch rates are reflective of increased activity or movement of fish. Breakdowns for season, time of day, and turbidity used to analyze netting data were the same as used for telemetry analysis.

Netting in Reach 1 during the spawning season resulted in a CPE of 20.1 fish/100 feet/100 hours. Catch rates during nonspawning season were 20.2 fish/100 feet/100 hours. Seasonal differences were not detected in netting catch rates within Reach 1 during 1992 ($t = -0.061$, $p = 0.952$). We suspect that a more complete analysis of netting catch rates that evaluates seasonal catch rates for specific subreaches within Reach 1 would show seasonal differences. Time constraints prevent further analysis of these data for this report. Analysis of telemetry data indicated that during spawning season (February through March), radiotagged fish were significantly less responsive to the effects of turbidity and time of day. Taking this into consideration, we pooled seasonal netting data to examine the effects of turbidity and time of day. We suspect that by pooling these data, the effects of turbidity and time of day were diluted to some extent. However, relationships that were detected support the hypothesis that fish activity is significantly affected by turbidity levels and time of day. Relationships between season and netting catch rates will be examined in more detail in the Final Report.

Daytime catch rates of 9.97 fish/100 feet/100 hours were significantly lower than nighttime catch rates of 24.48 fish/100 feet/100 hours ($t = -3.78$, $p = 0.000$) (Fig. 6-12) (Table 6-9). Day versus night catch rates remained significantly different when the effect of turbidity was isolated. Under low turbidity, daytime catch rates of 5.31 fish/100 feet/100 hours were significantly lower than nighttime catch rates of 24.91 fish/100 feet/100 hours ($t = -2.85$, $p = 0.005$). Under high turbidity, day and night catch rates of 11.98 fish/100 feet/100 hours and 24.15 fish/100 feet/100 hours, respectively, were also significantly different ($t = -3.10$, $p = 0.002$).

No significant differences were seen in overall catch rates between high (20.0 fish/100 feet/100 hours) and low turbidities (20.35 fish/100 feet/100 hours)($t = -0.09$, $p = 0.926$). However, when the effect of time of day was isolated, the influence of turbidity became more apparent. During the daytime period, catch rates during high turbidity of 11.98 fish/100 feet/100 hours were significantly higher than catch rates of 5.31 fish/100 feet/100 hours during low turbidity ($t = 1.96$, $p = 0.051$). However, during the night, no significant differences were seen between catch rates of 24.15 fish/100 feet/100 hours during high turbidity and 24.91 fish/100 feet/100 hours during low turbidity ($t = -0.17$, $p = 0.869$).

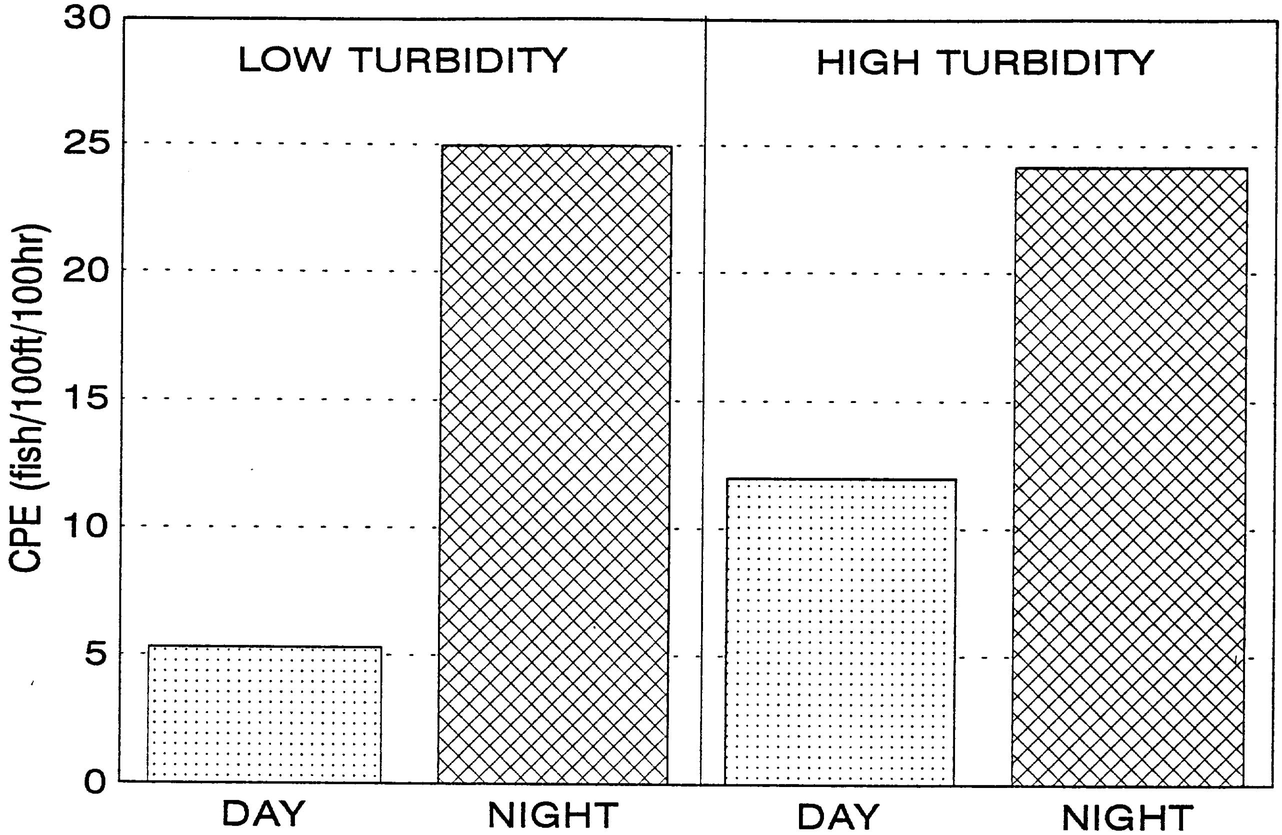

Figure 6-12. Netting catch rates in high and low turbidity during day and night in Reach 1 of the Colorado River in Grand Canyon, 1992.

Table 6-9. Summary of netting CPE of adult humpback chub in Reach 1 of the Colorado River in Grand Canyon, January-November, 1992.

Turbidity	Time of Day	N	CPE[a]	Standard Deviation[b]
High	Day	197	11.98	33.73
	Night	382	24.15	60.65
Low	Day	85	5.31	22.13
	Night	278	24.91	62.29

[a]Fish/100ft/100hrs
[b]Standard deviation for CPE

Telemetry Observation. Telemetry observation data were used to assess horizontal movement patterns of radiotagged adult humpback chub in the mainstem Colorado River RM 56 to RM 65 (Reach 1). Horizontal movement of adult chub was divided into two categories: 1) movements of 5 m or more were considered as movement to a new location, and 2) any movements less than 5 m were considered micro-movements within the same area and classed as zero movement and within the angle of error for locating fish by triangulation. The ratio or proportion of observations of movements to a new location compared to total observations was used as an index of fish activity. The higher the ratio, the greater the horizontal activity of the fish. Proportions were related to season, time of day, and turbidity (Table 6-10).

Table 6-10. Summary of horizontal activity of radiotagged adult humpback chub as proportion of movement ≥ 5 m at low and high turbidity, during spawning and nonspawning periods and between day and night. Fish were monitored in the Colorado River in Grand Canyon, November 1990-November 1992.

Turbidity	Season	Time of Day	N	Number of movements ≥ 5 m	Proportion of movement ≥ 5 m
Low	Nonspawning	Day	284	13	4.6%
		Night	273	34	12.5%
	Spawning	Day	101	24	23.8%
		Night	60	15	25.0%
High	Nonspawning	Day	341	70	20.5%
		Night	343	55	16.0%
	Spawning	Day	297	61	20.5%
		Night	303	63	20.8%

Influence of the three factors on horizontal activity of radiotagged adult humpback chub were compared using a non-parametric two-sample proportion statistical test (Table 6-11). The proportion of horizontal movements was significantly higher in the night versus the day during nonspawning, low turbidity conditions (Fig. 6-13). These results agree with telemetry surveillance analysis under the same conditions. Reduced daytime horizontal activity during low turbidity suggests that in addition to driving fish into deeper habitat, fish that remain in near- surface habitats exhibited less movement during low turbidity. We speculate that these fish may be utilizing microhabitats with lateral or overhead cover.

Table 6-11. Statistical[1] comparison on effect of turbidity, season and time of day on proportion of observed movement of radiotagged adult humpback chub monitored during radiotelemetry observation of the Colorado River in Grand Canyon. November 1990-November 1992. See Table 6-10 for percentage of movement values.

			Low Turbidity				High Turbidity			
			Nonspawning		Spawning		Nonspawning		Spawning	
			Day	Night	Day	Night	Day	Night	Day	Night
Low	Nonspawning	Day	1.000							
		Night	0.001*	1.000						
	Spawning	Day	0.000*	0.007*	1.000					
		Night	0.000*	0.013*	0.859	1.000				
High	Nonspawning	Day	0.000*	0.008*	0.485	0.434	1.000			
		Night	0.000*	0.210	0.074	0.091	0.128	1.000		
	Spawning	Day	0.000*	0.010*	0.495	0.441	0.997	0.140	1.000	
		Night	0.000*	0.008*	0.529	0.468	0.934	0.118	0.939	1.000

*Significant at 0.05
[1]Two sample proportion test.

Patterns of horizontal activity and near-surface activity were also similar in that night/day differences were not observed during the spawning season. This supports the hypothesis that normal diel activities may be preempted by spawning-related activity.

Horizontal activity during the spawning season was an average 185 percent greater than during nonspawning when turbidity was low. This increase in activity during the spawning period was significant during both day and night. No differences in horizontal activity were observed between spawning and nonspawning periods when turbidity was high.

Nonspawning horizontal activity was an average 113 percent higher during high turbidity, when compared to low turbidity during the same time periods. Despite the magnitude of the trend the difference

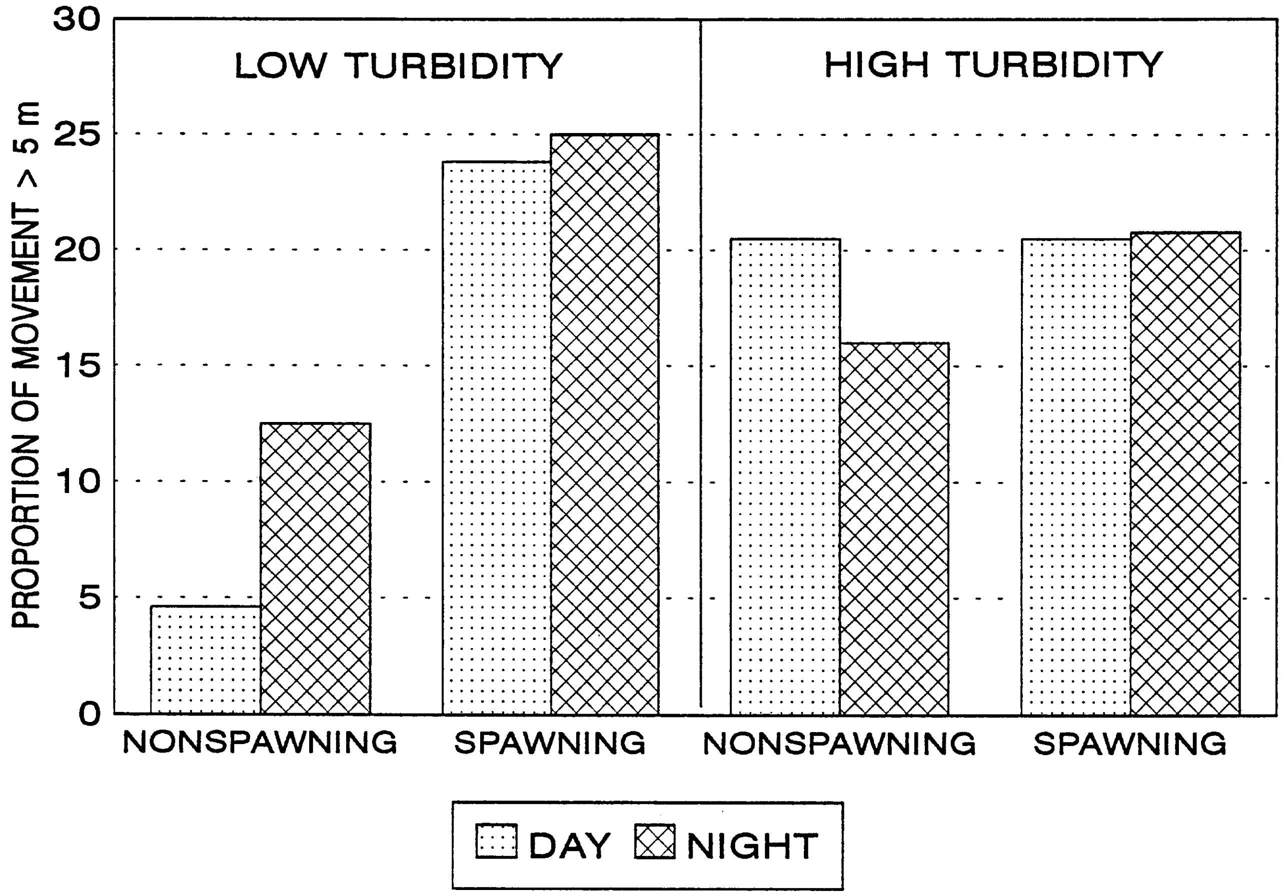

Figure 6-13. **Horizontal activity of radiotagged adult humpback chub as proportion of movement ≥ 5 meters at low and high turbidity, during spawning and nonspawning periods, and between day and night. Fish were monitored during telemetry observation in the Colorado River in Grand Canyon, November 1990 through November 1992.**

was only statistically significant during the day. No differences were observed in horizontal activity between low and high turbidity during the spawning season. These results suggest that while high turbidity significantly influenced nonspawning horizontal activity, it had little or no effect on spawning activity. This differed from the surveillance data, which showed that near-surface activity increased with high turbidity, regardless of season or time of day.

Activity Relative to Flow Level and Stage Change

Telemetry observation data were used to assess activity relative to flow level and stage change. Proportion of movement ≥ 5 m were used as an index of chub activity, and related to different rates of stage change (see Telemetry Observation in the Local Movement section of this chapter for additional explanation of analysis). Absolute value of stage change was used for this analysis. Further analysis will be required to determine possible effects of stage direction (rising or falling) on horizontal activity. Due to significant effects of spawning season on activity of radiotagged fish, only data collected during the nonspawning period were used for this analysis.

Implementation of interim flows in August 1991, resulted in a notable decrease in rates of average absolute stage change during our field observations, from 14.4 cm/hour to 5.4 cm/hour. This decrease in rate of stage change was reflected in horizontal movement patterns of adult radiotagged humpback chub. Proportion of movement before interim flows was 18.0 percent (20/111), and decreased to 13.1 percent (145/1104) with interim flows. Although this difference wa not statistically significant, it suggests possible effects of ramping rates on horizontal activity patterns. Small sample size of pre-interim flow telemetry observations prevented detailed comparisons of humpback chub activity during pre- and post-interim flows regimes.

As reported in the Telemetry Surveillance section of this chapter, turbidity and time of day had a profound influence on activity of adult humpback chub. By isolating each of these factors, specific relationships between interim flow ramping rates and horizontal activity were evaluated. Table 6-12 is a summary of horizontal activity of adult chub related to turbidity, time of day, and absolute stage change.

During low turbidity, horizontal activity increased an average of 230 percent, when absolute stage change was ≥ 5 cm/hr (Fig. 6-14). This increased activity, associated with high rates of stage change, was statistically significant during both day ($z = -2.05$, $p = 0.04$) and night ($z = -2.84$, $p = 0.00$). When turbidity was high, horizontal activity increased only 30 percent under a stage change of ≥ 5 cm/hr. Although this indicates that during high turbidity, ramping rates affect horizontal activity of adult humpback chub, the difference was not statistically significant. No significant diel differences were observed during high turbidity.

Table 6-12. Summary of horizontal activity of radiotagged adult humpback chub as proportion of movement ≥ 5 m at low and high turbidity, during day and night for absolute stage change ≥ 5 cm/hr and between 0-5 cm/hr. Fish were monitored in the Colorado River in Grand Canyon, November 1990-November 1992.

Turbidity	Time of Day	Absolute Stage Change	N	Number of movements ≥ 5 m	Proportion of movement ≥ 5 m
Low	Day	0 - 5	193	3	1.6%
		≥ 5	62	4	6.5%
	Night	0 - 5	147	12	8.2%
		≥ 5	102	21	20.6%
High	Day	0 - 5	127	23	18.1%
		≥ 5	175	38	21.7%
	Night	0 -5	142	17	12.0%
		≥ 5	159	27	17.0%

These results suggest that the rate of stage change, like turbidity and time of day, plays an important role in the activity patterns of adult humpback chub. Similarly, the dramatic difference in high and low turbidity support the idea that turbidity is the primary influence on activity patterns of adult humpback chub in the Grand Canyon.

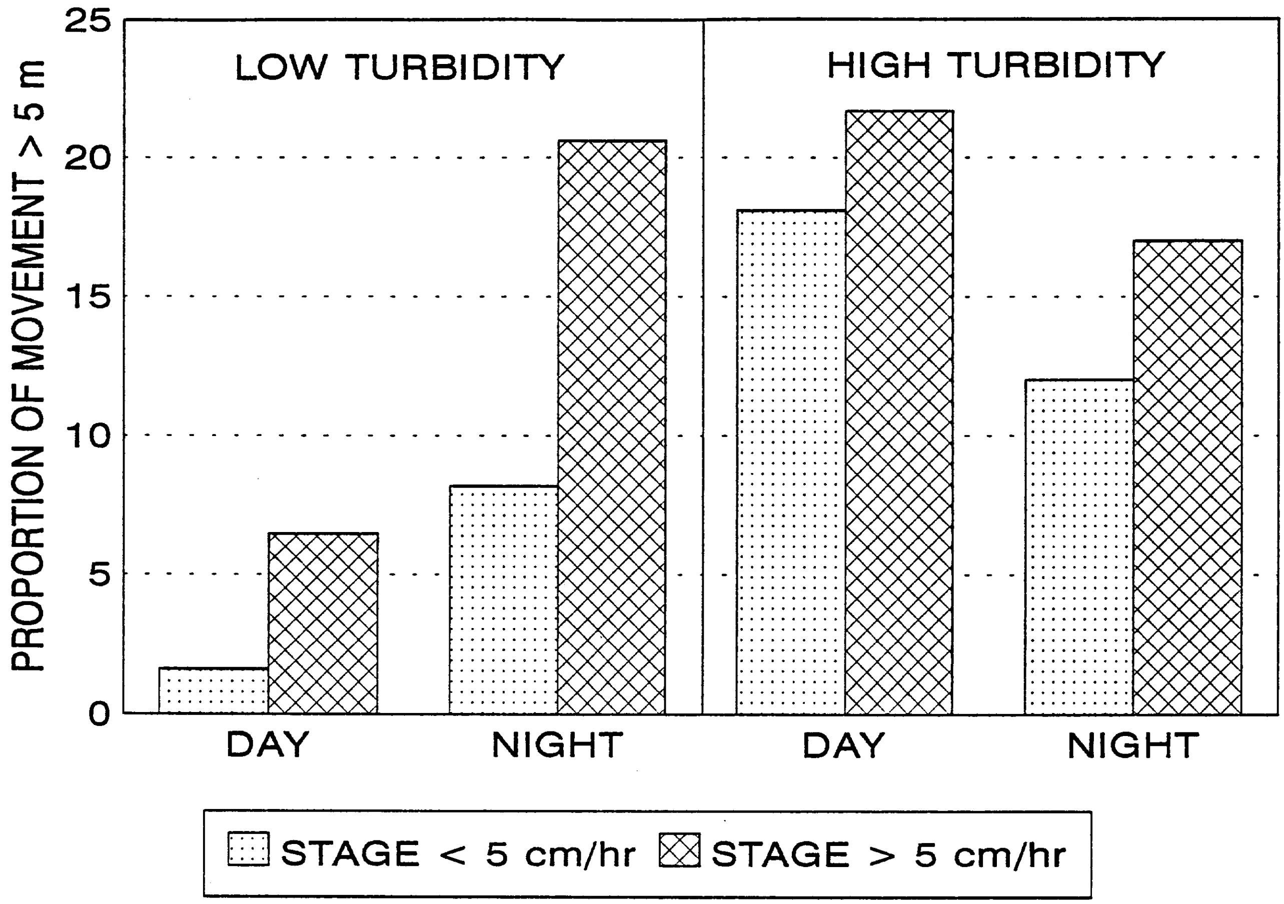

Figure 6-14. **Horizontal activity of radiotagged adult humpback chub as proportion of movement ≥ 5 meters at low and high turbidity, during day and night for absolute stage change ≥ 5 cm/hr and between 0-5 cm/hr. Fish were monitored during telemetry observation in the Colorado River in Grand Canyon, August 1991 through November 1992.**

CHAPTER 7 - ENERGETICS

Primary Author: Bill Leibfried

INTRODUCTION

Drift samples were collected during 1991 and 1992 to determine the availability of food resources utilized by humpback chub in the mainstem Colorado River. Past studies have indicated that fluctuating flow patterns from Glen Canyon Dam may influence the amount of drifting food items (Leibfried and Blinn 1986). These potential foods, including the alga, Cladophora glomerata, and invertebrates, may be an important source of nutrition for humpback chub, complimenting benthic food resources (Kaeding and Zimmerman 1983). The diatoms epiphytic to Cladophora are an important food resource for rainbow trout (Leibfried 1988), and may be important to native fish as well. There may be periods when drifting food resources constitute the majority of available fish food.

Data obtained from drift samples were used in conjunction with other humpback chub food habit studies to improve our understanding of humpback chub biology. In 1992, we successfully used a nonlethal stomach pump to remove gut contents of chub (Valdez and Wasowicz 1992 and Wasowicz et al. 1992). The relative abundances of available foods from drift and benthic sources will be compared to relative abundances of pumped stomach contents of chub in order to estimate food preferences of humpback chub.

Both the drift studies and the food habits analyses will be used to provide data to address Objective 1A: Determine resource availability and resource use by humpback chub, and Objective 1E: Determine important biotic interactions with other species. Addressing these objectives requires studies of food resources and potential predation on chub by non-native fish species.

METHODS

Drift Samples

A minimum of two drift nets (30.48 x 45.72 cm) were employed by each research team. These nets had a mesh size of 570 µm and were 3 m in length. Nets were placed side by side, one collecting surface drift and one collecting subsurface drift. Swoffer current meters and wading rods were used to determine current velocity through each drift net.

A permanent sampling site was established just upstream of the LCR (RM 61.2) to test the effect of discharge, habitat, and time of day on drifting organisms. This site was sampled monthly to provide consistent data and control for additional variables.

All drift samples were preserved in the field with 70 percent ethanol and sealed in either whirl-pacs or zip-lock bags. Each sample container was labeled appropriately. Samples were analyzed in the laboratory under low magnification to assure identification of invertebrates to at least the family level.

Drift data were transformed into sample drift density (Macroinvertebrates per 100 cubic meters of water filtered), as outlined by Allen and Russek (1985):

$$\text{Sample Drift Density} = \frac{\text{number of organisms}}{\text{m3 filtered}} \times 100 \qquad \text{(Equation 7-1)}$$

Organisms per 100 cubic meters of water filtered (orgs/100 m^3 wf) was used in all statistical analysis. Systat version 5.02 (Wilkinson 1990) was used in calculating statistics. Analysis of Variance (ANOVA) and a significance level of $P<0.05$ were used to determine significant differences in the data. Sample size (N), degrees of freedom (DF), and F-test (F) are also presented.

Variables used for analysis included river stage, onset of interim flows, time of day, habitat, depth, and location. River stage was determined to be either rising, falling, or steady at the time of drift sample collection. Sampling prior to August 1, 1991 took place during pre-interim flows while all sampling after August 1 took place during the interim flow period. Time of day was classified as either day or night. For the purposes of determining differential drifting of organisms within riverine habitats, samples were taken in both eddies and runs. Surface and subsurface samples were taken to determine effects of depth. To determine if drift changes with location, samples were analyzed by river mile in relation to the B/W study reaches. Reach 1 was divide into two subreaches; one above and one below the LCR.

Food Habits

Stomach contents of humpback chub and non-native predaceous fish were analyzed by either stomach pumping or by examination of netting or electrofishing mortalities. Non-native fish were sacrificed when necessary to determine the efficiency of stomach pumping methodology to be used on humpback chub. Eight humpback chub were sampled in 1991 and 43 were sampled in 1992 according to the stomach-pumping protocol. This evaluation showed no detrimental effects and proved effective in flushing stomach contents. Pumping of non-native fish was also effective and noninjurious. Stomach samples were preserved in the field with 70 percent ethanol and analyzed in the laboratory. Food times, including fish remains, were counted and sorted by family and species, when possible.

Stomach pumps were designed and constructed for this study based on Gengerke's modification of the original Seaburg design (Gengerke et al. 1973, Seaburg 1957). Flexible plastic tygon tubing was connected to both ends of a clean, hand-held rubber bulb commonly used as an in-line gasoline pump for outboard motors.

The clear outlet tube was inserted into the buccal cavity of the fish and a stream of water pumped through the inlet tube and into the stomach. Food items were subsequently flushed out of the digestive tract through the anal vent of the fish and into a collecting jar. Flexible tubing minimized the chance of damage to the esophagus, and the hand-held rubber pump allowed for precision in dictating water flow and pressure. The use of interchangeable tubes of different sizes allowed for efficient flushing of various sized fish.

RESULTS

Drift Studies

In 1991 and 1992, 398 drift samples were collected and analyzed from the mainstem Colorado River. The three dominant taxa were Simuliidae, Chironomidae, and the amphipod, Gammarus lacustris. The filamentous green alga, Cladophora glomerata, was present in most samples and terrestrial invertebrates were found occasionally.

For the purposes of these analyses, only total numbers of all invertebrate taxon collected (orgs/100 m^3) were used. The quantification of algal biomass is being determined at this time, but is not available for this report.

Four variables were found to significantly affect the drift of invertebrates in the mainstem Colorado River. Two were flow related: river state and onset of interim flows from Glen Canyon Dam. The interim flow releases began August 1, 1991, and continued through 1992. These flows have dampened the extreme high and low discharges released from Glen Canyon Dam prior to August 1991. The other variables that significantly affected drifting organisms were time of day and distance downstream from the dam.

Drifting organism density was greatest (P<.0.5) during falling flows upstream of the LCR in the mainstem (380.6 orgs/100 m^3, n=261, DF=2, F=12.514). Drift declined to 177.2 orgs/100 m^3 wf under rising flows and to 97.9 orgs/100 m^3 wf under steady flow conditions. River stage did not affect drift density in the sites below the LCR. Mean density of drifting organisms were 161.8, 101.7, and 114.1 orgs/100 m^3 wf (n=137) for falling, rising, and steady flows, respectively, below the LCR.

The onset of interim flow regimes from Glen Canyon Dam in August 1991 caused a significant decline in drifting organisms (P<0.05, n=261, DF=1, F=52.132) upstream of the LCR. Drifting organisms declined from 634.8 orgs/100 m^3 wf prior to August to 175.9 orgs/100 m^3 wf after that date. Although post-interim flow drift was decreased, falling lows still created the largest numbers of drifting animals at the LCR site.

Although not statistically significant, interim flow regimes resulted in an increase in drifting organism density downstream of the LCR. Pre-interim flows drift samples (n=8)(averaged 21.8 orgs/100 m^3 wf, while post-interim flow drift averaged 138.2 orgs/100 m^3 wf (n=129).

Sample location had a significant effect on invertebrate drift density (P<0.05, n-398, DF=3, F=4.038). Drift above the LCR averaged 248.0 orgs/100 m^3 wf (n-261). Between the LCR and Hance Rapid drift averaged 190.0 orgs/100 m^3 wf (N=50). Reach 2 drift samples averaged 96.8 orgs/100 m^3 wf (n=59) and Reach 3 drift samples averaged 97.8 orgs/100 m^3 wf (n=28). Average drift density declined from 248.0 above the LCR to 131.4 at all sites below the LCR (n=398, DF=1, F=9.852).

At the LCR site, daytime drift density (299.5 orgs/100 m^3 wf) was significantly greater than night (P<0.05, 156.5 orgs/100 m^3 wf, n=261, DF=1, F=7.548). This was the only location where day versus night comparisons could be made.

Neither habitat nor depth had a significant effect on drifting organisms either upstream of the LCR or below. Drift samples taken in runs versus eddies averaged 222.6 and 168.6 orgs/100 m^3 wf, respectively (n=398). Drift samples taken at the surface averaged 236.2 orgs/100 m^3 wf and below the surface 192.3 orgs/100 m^3 wf.

Food Habits

A total of 236 fish were sampled for stomach contents. Forty-three humpback chub were analyzed for foot habits using a non-lethal stomach pump. Non-native species sampled for food habits were pumped when possible. Some non-natives were sacrificed to obtain gut samples.

Stomachs from 174 non-native fish were examined during 1991 and 1992. Only 11 stomachs examined contained fish remains. Food habits of rainbow trout (n=87) were dominated by Cladophora and aquatic invertebrates, primarily Gammarus, simuliids, and chironomids. No fish were found in any of the rainbow trout sampled. Brown trout (n=23) were feeding mainly on aquatic insects and only six brown trout had fish in their stomachs. Twenty-one striped bass stomachs were examined and most were found empty. One 12-pound (5.45 kg) bass contained one 210 mm trout. Forty-three channel catfish stomachs contained mostly aquatic and terrestrial invertebrates and Cladophora. Three catfish stomachs contained fish remains. One 12-pound (5.45 kg) channel catfish from the LCR area contained one 150 mm flannelmouth sucker and one 170 mm bluehead sucker. One walleye had one unidentified 50 mm fish in its stomach.

The only documented predation on humpback chub during 1991 and 1992 was by brown trout. Three brown trout out of 23 samples taken contained identifiable humpback chub remains. One trout had two chub in its gut, while the other two had one chub each. These chub averaged 89 mm SL (range 70-105 mm SL). The trout were collected from the mainstem below the LCR between RM 63.8 and 64.3 during May, September, and November 1992.

Food habits of humpback chub (n=43) from the mainstem Colorado River are summarized in Figure 7-1. The mean number of organisms per chub was greatest for Simuliidae, which comprised 61.7 percent (25.63 orgs) of all invertebrates consumed. The amphipod, Gammarus lacustris, represented 24.1 percent (10.00) orgs) of all food items. Chironomids comprised only 12.6 percent (5.23 orgs). Annelid worms and terrestrial insects were present rarely. The alga, Cladophora glomerata, was present in some chub stomachs but only averaged 0.16 ml per fish.

The three dominant food items: simuliids, Gammarus lacustris, and chironomids, were represented by all life stages. Larval chironomids represented 58.7 percent of all midges eaten, while pupal and adult midges were 28.5 and 12.8 percent, respectively. Most amphipods were adults (97.4%). Only 2.6 percent were immature. Simuliids were dominated by pupae (75.6%), followed by larvae (19.8%) and adults (4.6%).

DISCUSSION

We hypothesize that increased activity by individual fish in response to dam operations causes a bioenergetic deficit unless that activity is associated with increased feeding. We cannot test this hypothesis afield, but can gain a better understanding of this effect by examining movement and diets of the affected fish. At this time we are analyzing the food habits and movement data for humpback chub along with the invertebrate and algal drift data to determine the best methods by which to integrate these data with river flows. As the drift density data show, there is a significant increase in invertebrate drift under the falling hydrograph. This is contrary to data obtained by Leibfried and Blinn (1986) that showed an increase in drift under rising flows. These 1986 data showed that drift rose significantly only when the hydrograph rose quickly after a period of very low discharge (<5000 cfs) that had exposed algal beds for some time.

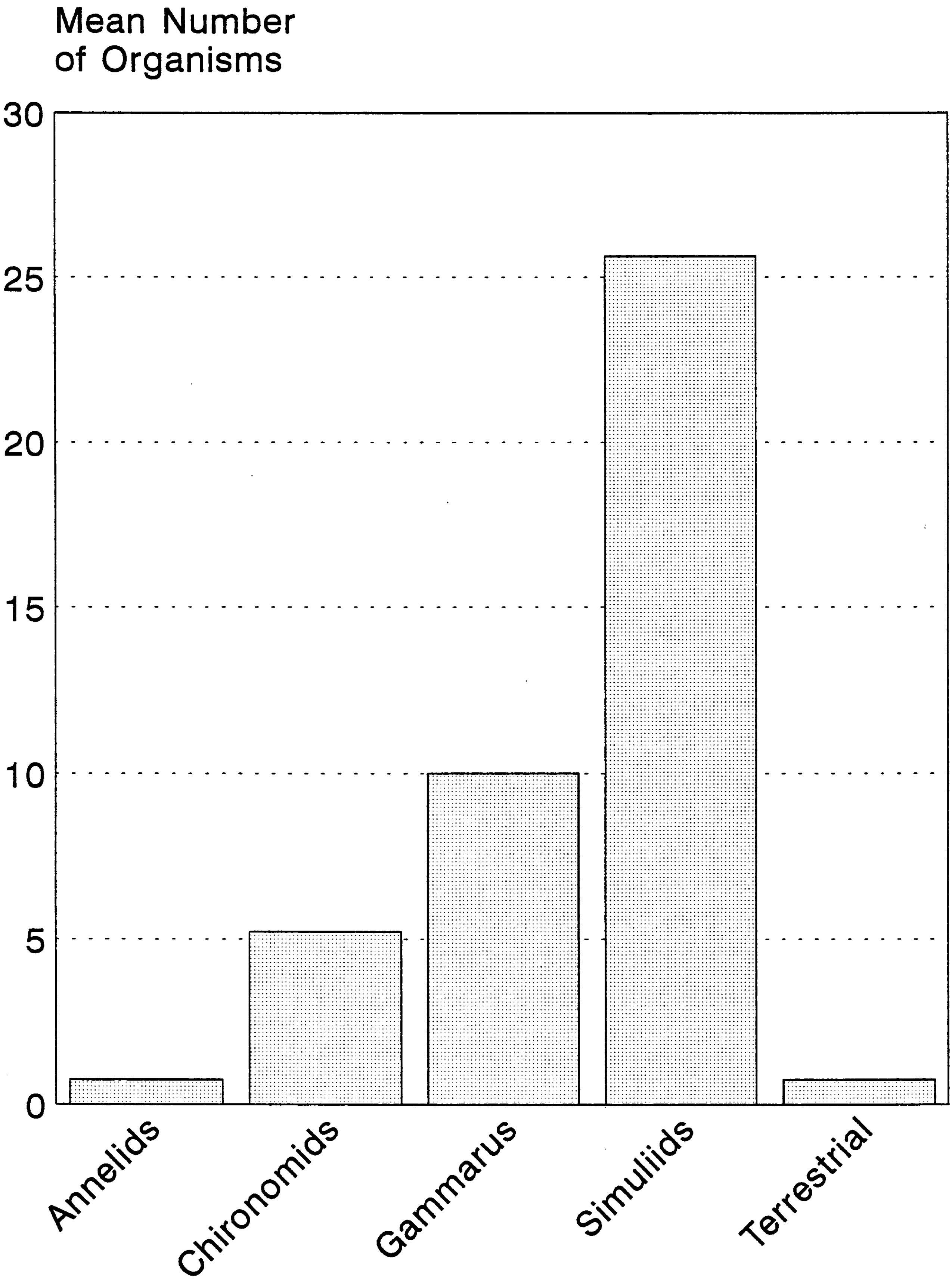

Figure 7-1. **Mean number of organisms per fish from humpback chub collected from the Colorado River in the Grand Canyon, 1991-1992. Stomach contents obtained by non-lethal stomach pump (n=43).**

The decrease in drifting organisms during interim flows may be attributed to the less extreme fluctuation in flow. Leibfried and Blinn (1986) indicate gross fluctuations are required to initiate significant invertebrate drift. At this time it is unknown if drifting food resources are a limiting factor for Colorado River fishes.

We hypothesize that if fish utilize drifting food resources when they become abundant, then a shift in gut contents toward those resources should be evident. If feeding is associated with increased movement, then fish movement patterns should show a concomitant increase with drift.

Stomach pumping has proven an effective and non-injurious method of removing gut contents of humpback chub. Wasowicz et al (1992) documented the efficiency of this method using roundtail chub. In the Grand Canyon, this method is highly efficient in removing invertebrates from humpback chub as well as rainbow trout. Field observations on pumped rainbow trout indicate 100 percent evacuation of all gut contents including Cladophora glomerata. Several chub could not be pumped due to an unknown blockage in the gut that would not allow evacuation of contents using mild flushing pressure. Excessive pressure was not used to avoid injury to the fish. The possibility exists that these blockages may be the result of algae or other vegetation in the gut.

The small volume of Cladophora found in chub guts is in contrast to 77 percent of gut volume reported by Arizona Game and Fish during 1985-1986 (Maddux et al 1987). The observations by C.O. Minckley (Carothers and Minckley 1981), that chub were seen feeding on beds of Cladophora, also indicates that chub may consume algae.

Predation of juvenile humpback chub by brown trout was documented in three individual trout. These fish represented only a small percentage of the 174 non-native fish examined. The area below the LCR has been historically dominated by rainbow trout. Currently brown trout dominate in Reach 2 and the possible invasion of the LCR reach by growing numbers of brown trout may be cause for concern. It is highly likely that regions such as Bright Angel Creek, where piscivorous brown trout are abundant, are difficult places for chub and other native fish to survive.

CHAPTER 8 - WATER QUALITY

Prepared by: Gloria Hardwick

INTRODUCTION

Water quality parameters recorded at each mainstem Colorado River campsite occupied in 1992, the lower LCR, and major tributaries included temperature, conductivity, pH, and dissolved oxygen. Water temperature was also measured in springs discharging into the mainstem river and around gravel fans, and turbidity was measured in the mainstem. Of the parameters measured, water temperature was most easily correlated with fish life histories and emphasized in this chapter. All water quality parameters will be more completely analyzed for the final report.

METHODS

Water quality data were collected using a Hydrolab Surveyor 2 with a Datalogger, or a Hydrolab Datasonde 2. These instruments were maintained and calibrated before and after each trip. Turbidity was measured using a Secchi disk and a Hach Turbidimeter. In addition to water quality data collected by B/W, more complete data were data collected by temperature recorders maintained by GCES or USGS personnel.

RESULTS AND DISCUSSION

Mainstem Colorado River Water Temperature

Water temperatures in the Colorado River showed a warming trend downstream of Glen Canyon Dam. This trend was most pronounced in the summer months, when the sun was high and tributary input was minimal. The greatest longitudinal temperature increase in 1992 was measured in July (Fig. 8-1) The July daily mean temperature increased from 11.1°C at RM 75 to 16°C at RM 214 for a longitudinal increase of about 1°C for every 28 miles. November 1992 water temperature showed no real warming trend downstream, averaging about 10.4°C at RM 30 and RM 214.

Seasonality was also evident for mean daily mainstem water temperature, recorded at RM 61.1. April mean daily temperature at RM 61.1 range from 9.3°C to 9.9°C, while the ranges in mid-July were from 10.3°C to 11.0°C. By mid-October, mean daily water temperature decreased slightly, and ranged from 10.4°C to 10.7°C. Early November temperature, recorded at RM 61.1, were from 9.2°C to 9.8°C.

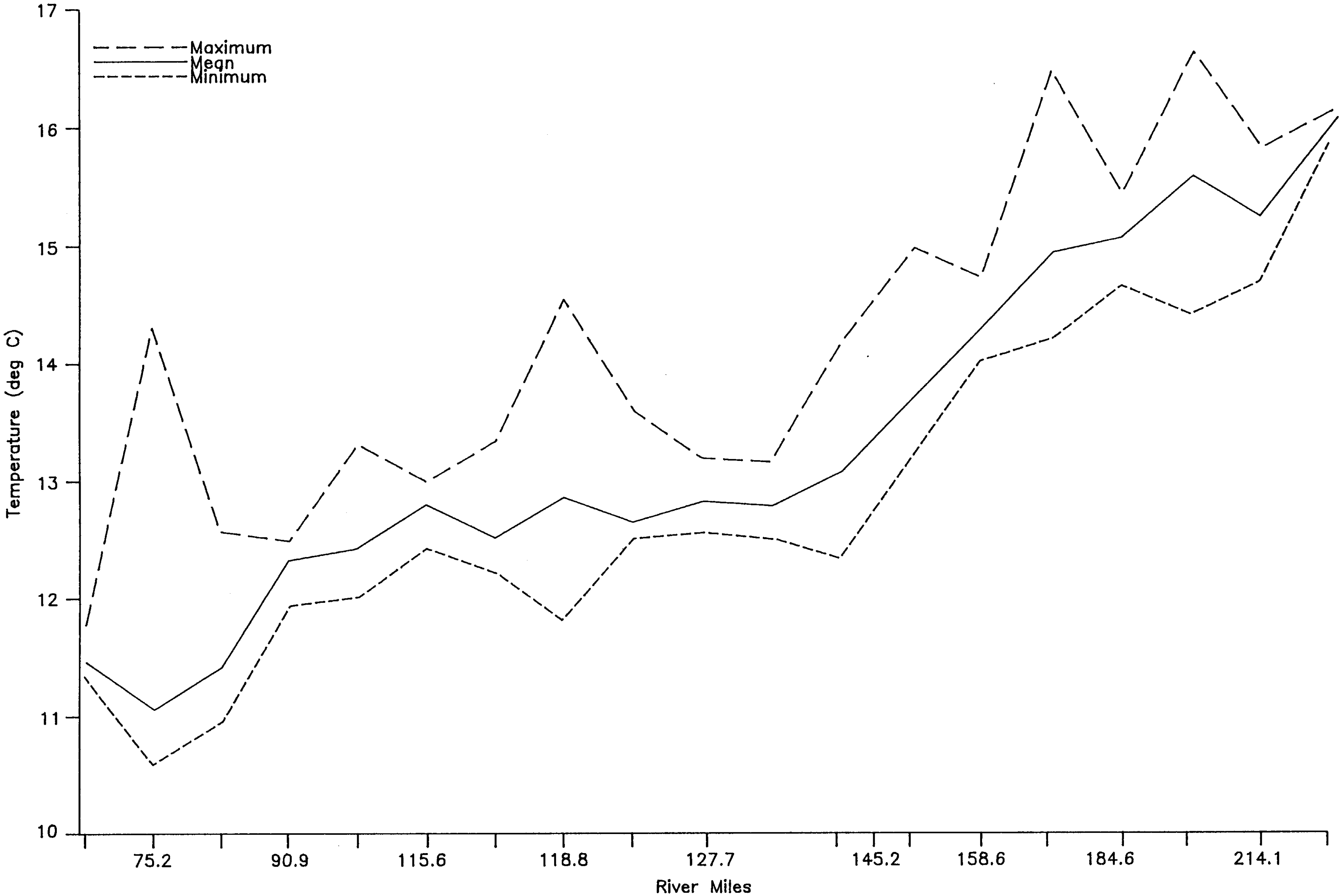

Figure 8-1. Longitudinal mean, minimum, and maximum water temperature of the mainstem Colorado River recorded by BIO/WEST during July 1992. Dates coincide with the following river miles: 9 July - RM 75, 15 July - RM 119, 22 July - RM 159, 26 July - RM 214 (Data points at midpoint of visit at sample site).

Little Colorado River Water Temperature

Mean, minimum, and maximum daily water temperatures for the LCR near the outflow are presented in Figure 8-2. A minimum daily mean temperature of 7°C was recorded in January, and a maximum daily mean of 23°C was recorded in August. By late August water temperature declined to about 18°C. Humpback chub spawning and egg incubation temperatures of 16°C to 22°C (Hamman 1982) were reached in mid April and maintained until August.

Major Tributary Water Temperatures

Major tributaries to the Colorado River in Grand Canyon have small numbers of humpback chub associated with their inflows, and are important spawning sites for native fishes. In addition to water quality parameters recorded by B/W, temperature recording devices were maintained in most tributaries. Figure 8-3 illustrates the daily mean, minimum, and maximum water temperature in Tapeats Creek. BIO/WEST personnel recorded temperatures from the tributaries in March 1992. Temperature ranges of other tributaries in March included Bright Angel Creek, which varied from 9.5°C to 12.2°C over a period of 2 days, Shinumo Creek which varied from 9.6°C to 10.7°C over 2 days and Havasu Creek, which varied from 14.3°C to 16.3° C, Kanab Creek which varied from 15.6°C to 16.8°C (Figure 8-4). The straight line on Figure 8-4 (From September 1991 until April 1992) denotes missing temperature data.

Water Temperature of Special Habitats

Several attempts were made to measure water temperature of unique habitats associated with the mainstem Colorado River. In January, a spring discharging just above river level in the Fence Fault area (RM 30), had a temperature of 21.5°C before reaching the river. It formed a small, warm (17.5°C) pool about 2 m in diameter at the edge of the river. Our Hydrolab ceased to function before we recorded the remaining parameters.

Humpback chub were usually associated with gravel outwash fans in Middle Granite Gorge. We measured water temperature around two of these fans in July, and found that temperature decreased about 0.1°C in 1.5 m. In September, we measured another of these gravel fans, and found a 0.2°C decrease from the surface to a depth of 1.5 m. We found that sampling by wading around these bars was not feasible.

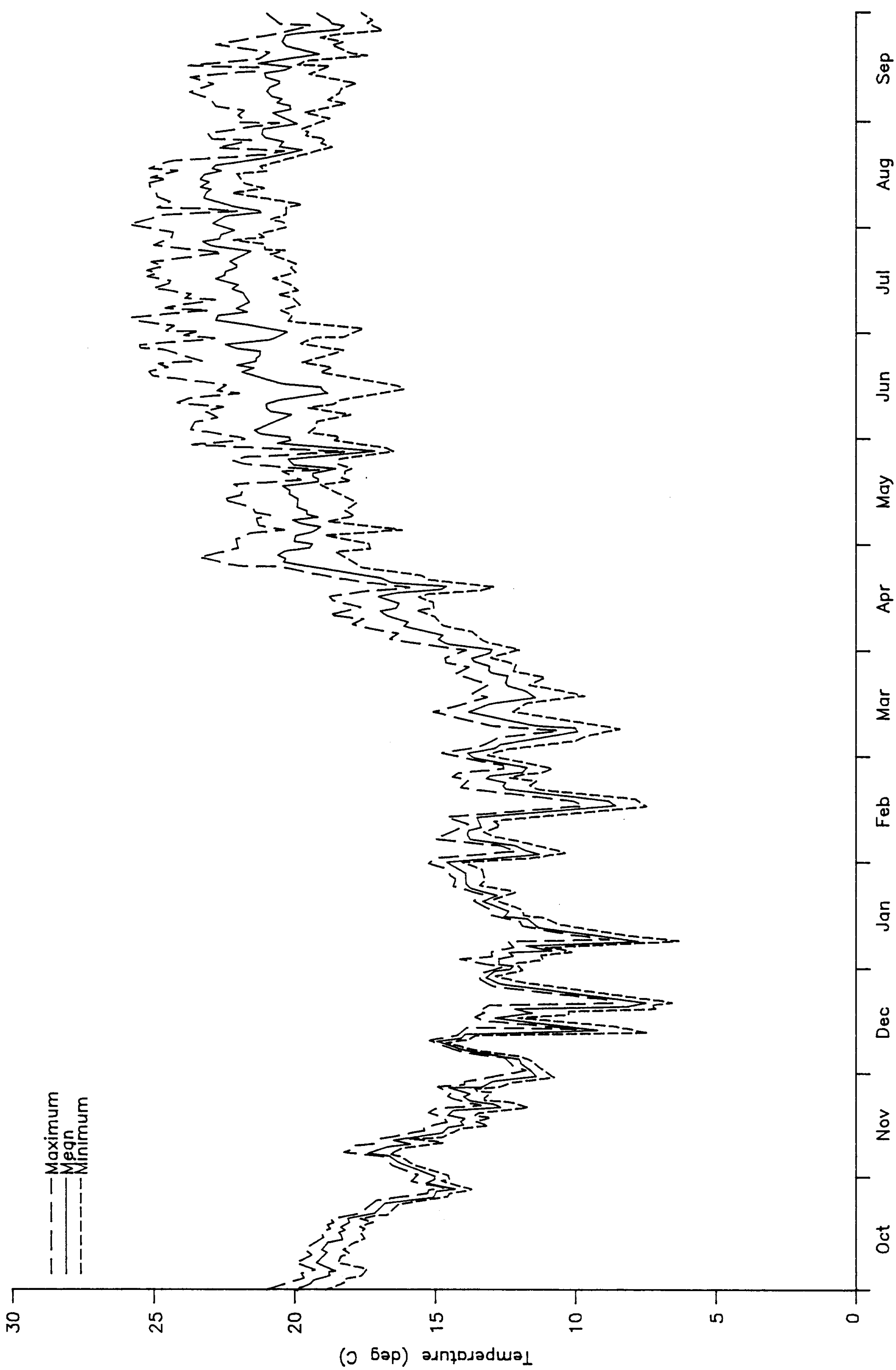

Figure 8-2. **Daily mean, minimum, and maximum water temperatures of the Little Colorado River from October 1991 to October 1992. Data from USGS minimonitors.**

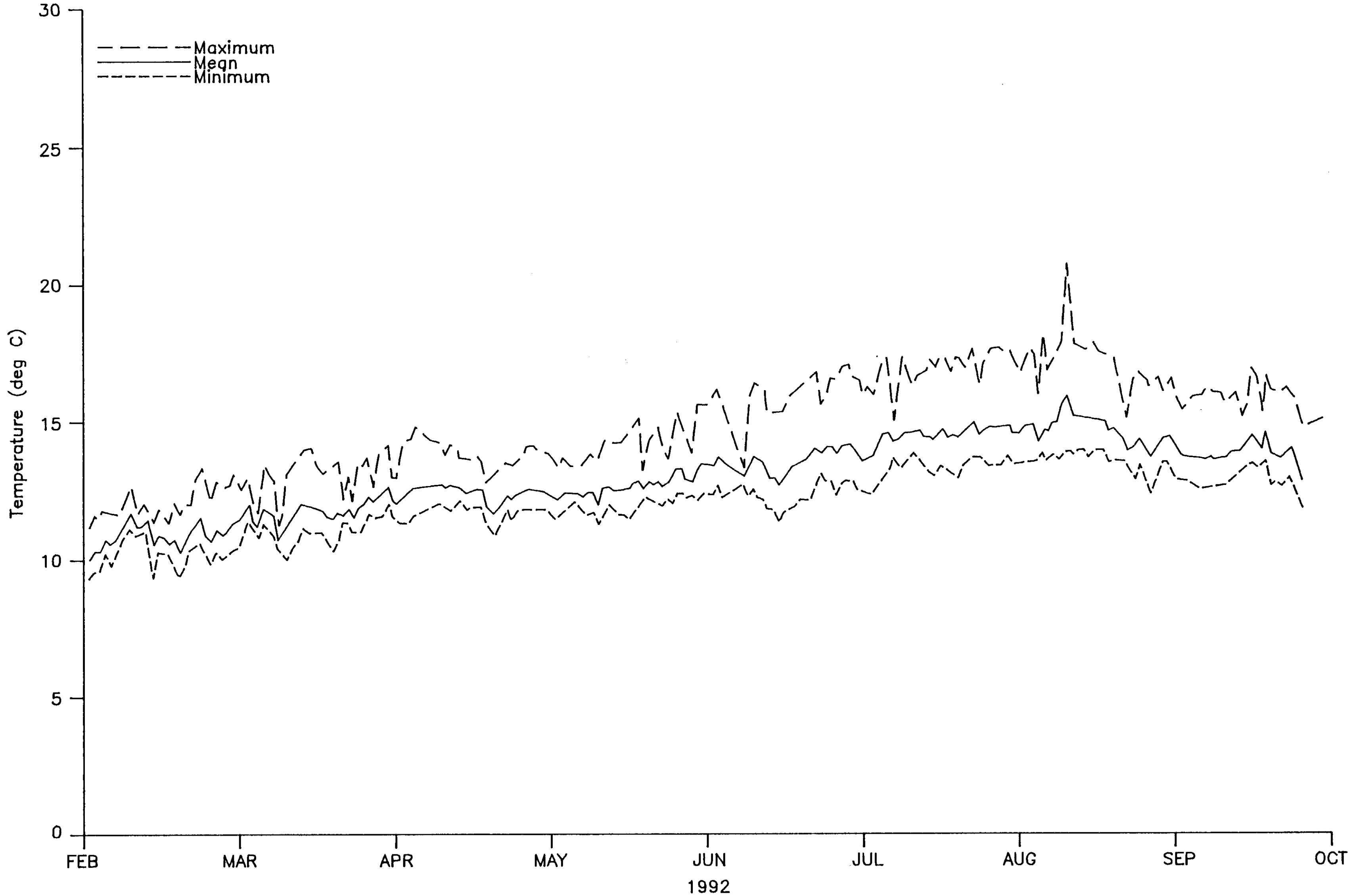

Figure 8-3. Daily mean, minimum, and maximum water temperatures of Tapeats Creek from February 1992 until October 1992. Data recorded on a Ryan tempmentor by Glen Canyon Environmental Studies.

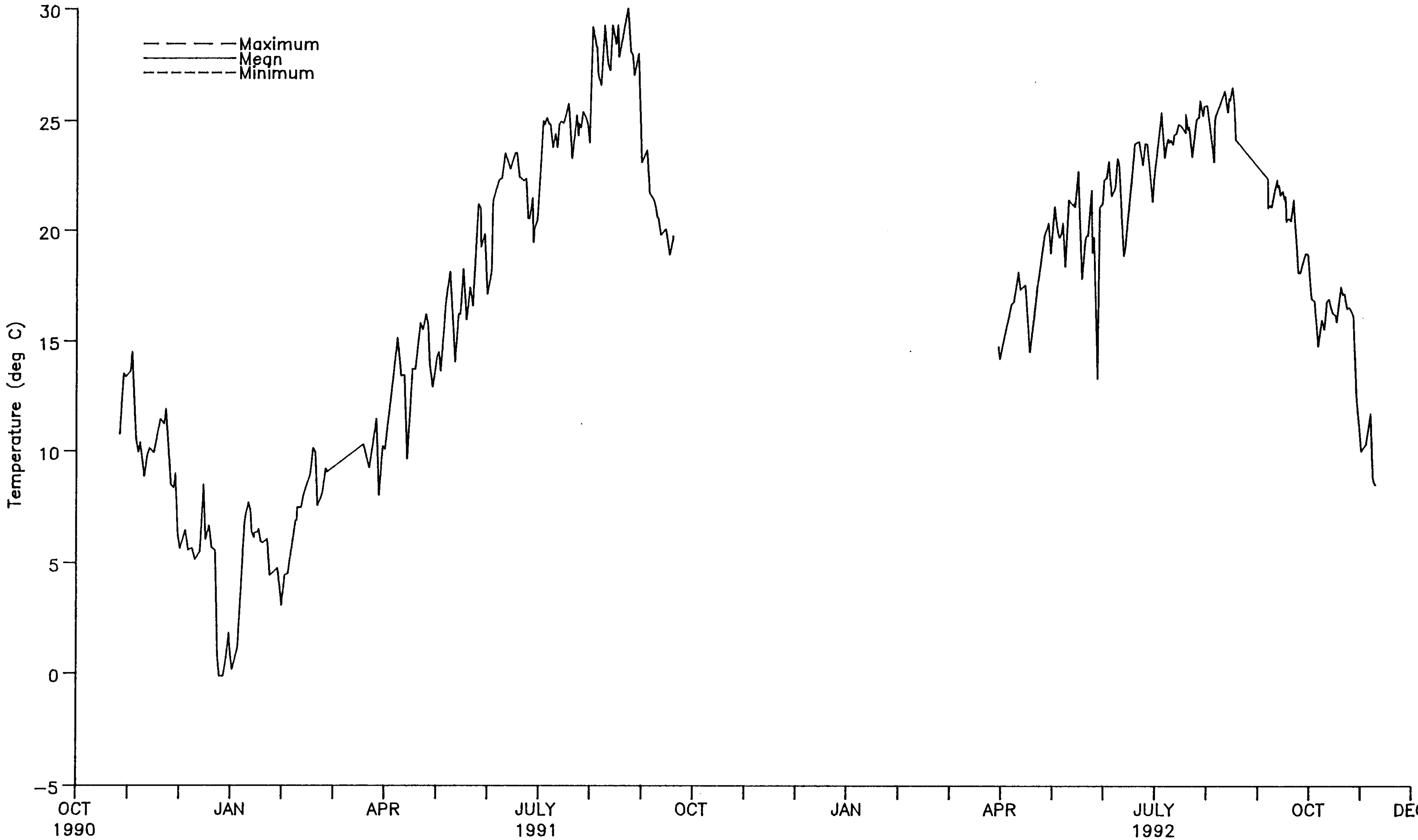

Figure 8-4. Daily mean water temperatures of Kanab Creek from October 1990 to October 1991, and April 1992 to November 1992. No data were available from October 1991 through April 1992. Data recorded on a Ryan tempmentor by Glen Canyon Environmental Studies.

Other Water Quality Parameters

Of the remaining water quality parameters measured, turbidity influenced the near-surface activity depths in an attempt to quantify the relationship. Water temperature was influenced by a number of factors, including, but not limited to, turbidity, discharge, ramping rates, and runoff. In the final report we will examine the relationship of some of these variables to water temperatures. In an attempt to understand the presence of humpback chub in the Middle Granite Gorge area, we will continue to refine our sampling techniques to accurately measure water quality of localized habitats.

CHAPTER 9 - SUMMARY

Primary Author: Richard A. Valdez

BIO/WEST, Inc. initiated fishery investigations of the Colorado River in Grand Canyon in September 1990, as part of Phase II of the Glen Canyon Environmental Studies. A total of 25 monthly field trips were conducted from October 1990 through November 1992 (no trips in December 1991 or 1992). A trip report of preliminary findings was issued following each trip, and an Annual Report was submitted for 1990-91 (Valdez et al. 1992). This is the second Annual Report, and describes findings from 1992. Field work on this investigation is scheduled from October 1990 through November 1993, and the Final Report is due in October 1994.

This Annual Report presents the preliminary findings of 11 monthly field trips conducted in 1992. Data collected during these trips were integrated, where possible, with data collected in 1990 and 1991. Patterns or trends evident from two years in the life cycle of the humpback chub may not persist, and others not detected in this short time period may become evident with more investigation. It is preliminary for us, at this time, to satisfy the objectives of the investigation and accept or reject associated hypotheses. Nevertheless, we offer interpretations relative to each project objective. We caution the reader, however, against deducing or inducing more than these data and our interpretations allow at this time.

The focus of this discussion is on humpback chub, because of its endangered status. Other species are discussed, where possible, but a comprehensive treatise of other native species and the non-native species will not be presented until the Final Report.

Much of this investigation is based on the scientific method of hypothesis development and testing. This approach is being maintained through the investigation, but hypotheses are not presented and discussed in this 1992 Annual Report as in the 1990-91 Annual Report. The following is a summary of our results relative to each of the project objectives.

A literature review was presented in the 1991 Annual Report (Valdez et al. 1992) to identify ecological factors for humpback chub, which may limit the population in the Colorado River in Grand Canyon. These ecological requirements were presented for four life history stages, including (1) spawning/egg incubation, (2) larvae/age-0, (3) juvenile, and (4) adult. In this 1992 Annual Report, these life history stages are incorporated into descriptions and explanations of each of the project objectives.

Objective 1A: Determine resource availability and resource use (habitat, water quality, food, etc.) of humpback chub in the mainstem Colorado River.

Habitat

Humpback chub in Grand Canyon were captured and radiotracked in relatively few habitat types in 1990-91 and 1992. Their occurrence in certain habitat types varied with age of fish, river flow, turbidity, and season. Young humpback chub used shallow, sheltered shorelines (sampling excluded eddy return channels) until the fish were about 180 mm TL, or about 3 years of age. The mode of fish captured in shorelines in 1992 was 90-110. Greater numbers of chub were encountered along shorelines during periods of high river turbidity. Greatest numbers of young humpback chub were found in the mainstem Colorado River in September 1991 and May 1992, indicating descent of young fish, ages 0, I, and II, from the LCR. Greatest numbers of young chub were captured with electrofishing and seines from shorelines with talus, boulders, root wads, and intermittent sand beaches. No young chub were captured from deep, vertical walls, and few were caught from long, expansive sand beaches. Although average depth and velocity along a talus shoreline was greatest at flows of 12,000-14,000 cfs than at 10,000-12,000 cfs, the increase was not significant, indicating that at these flow ranges this habitat was probably stable for the fish. Other habitats remain to be measured at a greater range of flows to identify flows that violate necessary habitat parameters for the fish.

About 94 and 86 percent of adult humpback chub (>200 mm TL) were captured in eddy complexes (active recirculating eddies and eddy return channels) in 1990-91 and 1992, respectively. Similarly, about 83 and 75 percent of radiotagged adults were contacted in eddy complexes. Habitat mapping showed that eddy complexes composed only about 20 percent of the surficial area of Reach 1, near the LCR inflow, while runs were 69 percent and pools were 11 percent of surface area. Bathymetry (depth and velocity isopleths) of the channel in these areas showed that maximum river depth ranged from about 12 to 14 m, but the eddy complexes in which greatest numbers of adult chubs were captured and radiotracked, were usually less than 5 m deep with regions of low velocity.

Water Quality

Water quality parameters, including conductivity, pH, and dissolved oxygen, were within the normal tolerance range of humpback chub in Grand Canyon. Mainstem water temperature, however, was too low for successful reproduction by humpback chub, razorback suckers, flannelmouth suckers, bluehead suckers, and speckled dace, and probably limits survival of young fish descending from warm canyon tributaries, e.g., LCR, Shinumo, Kanab, Bright Angel, Havasu. Mean daily mainstem temperature of 11.1°C was recorded in July at RM 75 and 16.0°C at RM 214, for a downstream longitudinal increase of about 1°C for every 28 river miles. Although 16°C is within the acceptable spawning temperature of all five native fishes, it does not occur until late July, after spawning activity is completed.

Seasonality was evident for mean daily mainstem water temperature. April mean (when humpback chub are spawning in LCR) at RM 61.1 (just above LCR inflow) ranged from 9.3°C to 9.9°C, while ranges in mid-July were 10.3°C to 11.0°C. In mid-October, mean temperature ranged from 10.4°C to 10.7°C, and from 9.2°C to 9.8°C in November.

Minimum daily mean temperature of the LCR was 7°C in January and maximum daily mean was 23°C in August. The optimum range for spawning by humpback chub of 16°C to 22°C was maintained in the LCR from mid-April to mid-August 1992.

Several local warm springs have been located, and measured along the mainstem, including one at Fence Fault (RM 30), with a temperature of 21.5°C in January 1992. This spring formed a 2-m diameter, warm pool of about 17.5 C. Other local warm springs were found in Middle Granite Gorge, in association with small gravel bars. In nearly all cases, humpback chub were captured in the vicinity of these springs, including two ripe males in April 1992. These springs may account for local, limited reproduction by the species in the mainstem. Radiotagged adults remaining near these mainstem springs, during normal spawning time in the LCR, is further evidence of local mainstem spawning.

Turbidity was identified in 1991 as a component of water quality that affected the activity and behavior of humpback chub. Further studies with radiotelemetry and capture information in 1992 confirmed this relationship. In both years, near-surface activity of adult radiotagged humpback chub was significantly greater under high turbidity (Secchi disk <0.5 m, 30 NTUs) than low turbidity. This was true for day, night, and all seasons, except during spawning, when fish were aggregating locally in eddies or at the mouth of the LCR. These activity patterns indicate that humpback chub use turbidity as cover for safety during feeding as well as against predation. The aspect of increased feeding activity with turbidity will be tested with the aid of a non-lethal stomach pump implemented in 1993, and the aspect of predation will be determined by examining large numbers of predators associated with the native species.

Food

The food of 43 adult humpback chub, recovered with a non-lethal stomach pump in 1992, included blackflies (Simuliidae), amphipods (Gammarus lacustris), midges (Chironomidae), annelid worms, terrestrial insects, and algae (Cladophora glomerata). Simulids comprised the greatest number of organisms per chub (25.63), or 61.7 percent of all food items. Amphipods represented 24.1 percent (10.00 organisms per chub), while chironomids comprised only 12.6 percent (5.23 organisms per chub). Annelids and terrestrial insects were rare, and Cladophora was found occasionally. Simulids in the diet were dominated by pupae (75.6%), larvae (19.8%), and adults (4.6%), while chironomids were larvae (58.7%), pupae (28.5%), and adults (12.8%). The amphipods were 97.4 percent adults and only 2.6 percent immature.

The three dominant taxa in 398 river drift samples were Simuliidae, Chironomidae, and amphipods, consistent with the food items found in humpback chub. The filamentous green algae (Cladophora glomerata) was present in most samples, and terrestrial invertebrates were found occasionally. Drifting organism density was greatest (380.6/100 m^3) during falling flows upstream of the LCR, but declined to 177.2 organisms/100 m^3 under rising flows and 97.9 organisms/100 m^3 under steady flow. Mean densities below the LCR were 161.8, 101.7, and 114.1 organisms/100 m^3 for falling, rising, and steady flows, respectively, below the LCR. Drift density decreased upstream of the LCR, from 634.8 to 175.9 organisms/100 m^3, following implentation of interim flows on August 1, 1991. No significant change in drift was seen below the LCR after interim flows. A longitudinal decrease in drift density was seen, from 248.0 above the LCR to 190.0 between the LCR and Hance Rapid, 96.8 in Reach 2, 97.8 in Reach 3. Average drift density declined from 248.0 above the LCR to 131.4 at all sites below the LCR.

Similar composition in chub stomachs as in drift samples indicates that adut humpback chub are either feeding on drift or in pockets of trapped detritus, such as in recirculating eddies. Significantly fewer organisms below the LCR than above--and possibly less available food--could be one reason for reduced numbers of fish downstream of the LCR inflow region.

Objective 1B: Determine the reproductive capacity and success of humpback chub in the mainstem Colorado River.

Mainstem reproduction by humpback chub in Grand Canyon is, at best, extremely limited, or more likely nonexistent as a result of cold water temperatures. Some spawning may occur at tributary inflows and in localized warm springs. No evidence of spawning was found in the mainstem Colorado

River in 1990, 1991, or 1992. Of 48 radiotagged adults monitored in 1990-91 and 27 in 1992, none exhibited mainstem spawning behavior, and all fish monitored from March through June moved into the LCR. Large aggregations of chubs at the LCR inflow in March 1991 and February-March 1992 included many milting males and some females with expressible eggs. Few eggs were found in the inflow, indicating some spawning in small gravel pockets behind large boulders or drift of eggs deposited upstream in the LCR. Daily flow fluctuations and floods from the LCR create variable channels of water through the inflow with different temperaturs. With the water temperature of the LCR at about 20 C, and that of the main channel at about 8 C, any viable eggs deposited in LCR water were likely killed and possibly disintegrated by the cold mainstem flows. Spawning may be occuring at other tributary inflows, but the success of eggs and larvae depend greatly on tributary and mainstem hydrology and thermal regimes during the 5-day incubation period and 7-day larval phase.

Numerous small warm springs have been located along the mainstem Colorado River in Grand Canyon that may be used locally for spawning by humpback chub and other native species. Three of four adult humpback chub, captured between RM 30.5 and 31.3 in April 1993, were taken about 10 m from a warm shoreline spring, with a temperature of 19°C compared to 8°C in the mainstem (water temperature at fish capture location was 12 C). Small aggregations of humpback chub associated with springs were also captured in 1992 and 1993 between RM 126.1 and 128.8, including two milting males in April 1993. Two radiotagged adults in the same area showed only localized movements, at the same time that extensive movement was occurring about 65 miles upstream by pre-spawning fish into the LCR. Small pockets of gravel and alluvial fans associated with these springs should provide appropriate substrate for localized spawning by humpback chub. Local spawning by few individuals at tributary inflows and local warm springs could explain the infrequent occurrence of very young humpback chub in the mainstem upstream of the LCR or further downstream.

Objective 1C: Determine survivorship of early stages of humpback chub in the mainstem Colorado River.

A complete demographic analysis has not been conducted on the young humpback chub captured in 1990-91 and 1992. A total of 281 YOY and 77 juveniles were captured in 1990-91, and 119 YOY and 526 juveniles were captured in 1992. The designation of fish into YOY (age 0) or juveniles (ages I, II) is based on length-frequency analysis, and probably does not accurately reflect the ages of these fish, because of variable times spent by individuals in warm LCR water (20 C) and cold mainstem water (10 C). Large numbers of young humpback chub were captured in the mainstem as early as May in 1991 and 1992, indicating a descent or transport of these fish from the LCR. The large range in sizes of these young fish indicates that more than one year class was included. The numbers of young chub in the mainstem varied by month, indicating that fish continued to emerge from the LCR through most of the summer.

The difficulty in distinguishing cohorts, using length-frequency analysis, will require actual aging of samples of fish to determine unique individual sizes by cohort and cohort strength. B/W is currently examining scales of humpback chub less than 200 mm TL in an attempt to determine age to length relationships, as well as length at transition from the LCR to the mainstem. This will enable us to monitor cohort strength using survival curves or "catch curves".

The demography of the humpback chub population in Grand Canyon is largely determined by survival of the fish in their first 3 years of life and recruitment into the adult portion of the population. Survival of these young fish is determined by temperature regimes, habitat stability, food availability, predation, and parasitism. These young fish may be subject to thermal shock as they emerge from the 20°C LCR water into the 10°C water of the mainstem. Mortality has been reported in age-0 humpback chub subjected to a 6°C change, from 10 to 4°C (U.S. Fish and Wildlife Service 1979). Fish that remain in the mixing zone may survive by acclimating, or the physiological shock may cause erratic swimming and flashing which may induce predator response. Habitat stability is probably one of the most critical factors affecting survival in the mainstem. Instability of shoreline habitats, including eddy return channels (backwaters), appears to affect fish up to about 180 mm TL, and may cause downstream transport of large numbers of young, subjecting them to increased energy expenditure, predation, and decreased habitat availability. The effect of the non-native parasitic Asian tapeworm (Bothriocephalus acheilognathi) and parasitic copepod Lernaea cyprinacea, on humpback chub is not known, but these are likely to stress the fish and possibly contribute to death of individuals.

Objective 1D: Determine the distribution, abundance and movement of humpback chub in the mainstem Colorado River, and effects of dam operations on the movement and distribution of humpback chub.

The distinction is made, for the purpose of this discussion, between effects from the construction and presence of Glen Canyon Dam, and those effects observed from operations. Historic records, although few in number, indicate that the distribution and abundance of humpback chub decreased following the construction of Glen Canyon Dam. Historic records in numerous locations throughout

Grand Canyon, as well as the current distribution of fish in Cataract Canyon--a similar region upstream of Lake Powell--indicate that the species was present in much of Grand Canyon and many of its tributaries. The impoundment of the Colorado River and releases of cold hypolimnetic water, starting in the late 1960's, protracted the distribution of chubs in the canyon and lead to a slow reduction in numbers through failure of mainstem reproduction and perhaps altered food resources, increased predation and competition.

Distribution

Over 90 percent of 2,029 humpback chub captured by B/W in the mainstem Colorado River, from October 1990 through November 1992, were found in a 13.5 km area around the LCR inflow, 6.9 km upstream and 6.6 km downstream. Small aggregations of chub were found upstream of this area near Awatubi Canyon (RM 58) and upstream of South Canyon (four adults were captured in April 1993 between RM 30.5 and 31.3). Small aggregations were also found downstream above Clear Creek (RM 83), near Salt Creek (RM 92), near Shinumo Creek (RM 108), near Garnet Canyon (RM 114), upper end of Middle Granite Gorge (RM 119), below Fossil Canyon (RM 126-129), near Kanab Creek (RM 143), near Havasu Creek (RM 156.7). Many of the fish captured in these areas have been recaptured--some multiple times--indicating little movement from these areas.

Movement

Humpback chub in Grand Canyon have shown fidelity for specific mainstem sites, similar to other populations in the upper basin, including Black Rocks and Westwater Canyon. Average net displacement of 27 radiotagged adults monitored periodically in 1992 for an average of 87 days (1-163) was 1.58 km (0.08-4.40). Average gross displacement was 4.34 km (0.16-11.18). This analysis did not include a fish that was contacted 15 km up the LCR by aerial tracking. Mean net and gross displacement of 48 radiotagged fish in 1990-91 was 1.34 km and 4.23 km, respectively. Slightly greater movement by humpback chub in Grand Canyon than in Black Rocks (0.8 km net displacement) is attributed to spawning movement into the LCR.

Movement of PIT-tagged fish was similar to that of adult radiotagged fish. Of 124 humpback chub (juveniles and adults) PIT-tagged by B/W, at large an average of 153.6 days (0-662), average distance from release to recapture location was 1.45 km (0-99). Average distance from release to recapture for all fish from 1990 through 1992 was 0.69 km (0-6.92), compared to 0.83 km for 67 recaptures in 1990-91.

Radiotelemetry and catch data show little movement by the majority of adults and juveniles, although selected individuals have moved great distances. These long movements are unexplained at this time, but could have been caused by stress from handling, dispersal of young from a population center, or random movement. We also observed that movement by radiotagged adults was typically from one eddy complex to another, with little time spent between complexes.

Different movement patterns were observed for adult humpback chub in the LCR inflow for 1991 and 1992. In spring 1991 (prior to interim flows), movement in the inflow area coincided with flow spikes from the LCR of 2,210 cfs on March 5 and 2,720 cfs on April 13. Fish moved into the mainstem until these high flows subsided, frequently moving between the LCR plume and deep shorelines immediately upstream of the LCR. In spring 1992 (during interim flows), there was less movement between the LCR and mainstem, and the fish occupied a more extensive area of the inflow. The relationship between LCR and mainstem flows and ascent by pre-spawning humpback chub into the LCR is unclear.

Movement and activity of humpback chub relative to flow magnitude and ramping continue to be analyzed. Implementation of interim flows in August 1991 resulted in a decrease in average rate of stage change, from 14.4 cm/hour to 5.4 cm/hour. A 27 percent decrease in local movement or activity of fish during ramping was also seen following the implementation of interim flows. Although this decrease was not statistically significant, it suggests relationships between ramping rates and fish activity. Additional analyses are needed to isolate influencing variables such as turbidity, time of day, season, etc.

Objective 1E: Determine important biotic interactions with other species for all life stages of humpback chub.

Fifteen species of fish were captured in the mainstem Colorado River in Grand Canyon in 1991, and 14 species were captured in 1992. Ten species of non-native were captured each year. The ratios of native to non-native species captured by electrofishing in Reaches 1, 2, and 3 were 96.2:3.8, 96.8:3.2, and 93.6:6.4, respectively. Rainbow trout comprised 83.4 percent of the electrofishing catch in Reach 1, while humpback chub were only 2.7 percent. Rainbow trout and brown trout comprised 36.9 and 32.8 percent of the electrofishing catch in Reach 2, while humpback chub were only 0.3 percent of the catch. Common carp dominated the catch in Reach 3 with 67.0 percent, and humpback chub were only 0.3 percent of the catch. In all but a few samples taken near the LCR, humpback chub were always accompanied by non-native species, including rainbow trout, brown trout, channel catfish, carp, and fathead minnows. Only three striped bass were captured in the mainstem in 1992. These were captured in May and July, two at RM 219.5 and one at RM 184.4. Size range was 388-555 mm TL and 457-1,486 g. In 1991, 15 striped bass were captured in the mainstem in May and July, with the furthest upstream capture at RM 156.4.

Of 174 stomachs of non-native fish examined in 1991 and 1992, only 11 contained fish remains, including 6 brown trout, 1 striped bass, 3 channel catfish, and 1 walleye. Humpback chub (size range of 70-105 mm TL) were found only in brown trout stomachs, while one 5.45-kg channel catfish contained one 150 mm flannelmouth sucker and one 170 mm bluehead sucker. While this incidence of native fish in stomachs of non-native species does not appear to be high, it may be significant to populations of native species because of the large numbers of non-natives present and the difficulty of capturing predators during feeding.

Besides sympatry and predation, competition for food between native and non-native species also seems apparent. The three dominant taxa found in stomachs of humpback chub (Simuliidae, Chironomidae, amphipods) were also dominant in rainbow trout and brown trout, although rainbow trout diet volume was dominated by Cladophora. The relatively low densities of drift and benthic macroinvertebrates throughout the Colorado River in Grand Canyon, particularly below the LCR, suggests competition for limited food resources.

Objective 2A: Determine the life history schedule for the Grand Canyon humpback chub population.

A description of the life history schedule for the humpback chub in the Colorado River in Grand Canyon was presented in the 1991 Annual Report (Valdez et al. 1992). This schedule was similar in 1992, with the following exceptions. From October through February, fish were dispersed in the mainstem in eddies, eddy return channels, slow runs, and pools. Local aggregations in eddies and deep pools were noted in February, close to and away from the LCR. In March 1991, the fish aggregated as large numbers of adults at the mouth of the LCR. This aggregation was not as distinct in 1992, perhaps because of LCR flow regimes. Adults ascended the LCR to spawn from April through mid-July, and descended in July and August. The adults redispersed in the mainstem by August. From May through September, large numbers of young chub descended from the LCR with peak numbers in August and September.

Objective 2A. Develop or modify an existing population model from empirical data collected during the study for use in analyses of reproductive success, recruitment and survivorship.

A feasibility evaluation for developing a population model for humpback chub in Grand Canyon was written in March 1993 (Ryel and Valdez 1993), and is included as Appendix D of this Annual Report. This report was submitted to GCES and the Senior Scientist and Advisors for evaluation and comment. The document is included with this report, and we encourage comments from reviewers.

RECOMMENDATIONS

1. Change trip length from 20 and 10-day monthly schedule to 16 days every month, except for 20-day trips in May, July, and September.

2. Continue fish sampling with same gear types including electrofishing, gill nets, trammel nets, hoop nets, and seines. Expand effort at sampling habitats used by younger fish with seines, small-mesh hoop nets and minnow traps. Closely monitor electrofishing efforts and try to work at low amperage levels (<12 amps).

3. Continue to randomly sample geomorphic substrata in Reaches 2 and 3 to sample as much of the lower reaches as possible.

4. Expand sampling upstream to the Paria River, as Reach 0, and continue to define extent of LCR population in the mainstem, upstream and downstream bounds.

5. Redirect radiotelemetry from Reach 1 to Reaches 2 and 3 to help locate concentrations of humpback chub and spawning areas.

6. Examine stomach contents of predators captured at LCR inflow by angling with artificial lures.

7. Continue volunteer program to satisfy personnel needs during both 20-day trips (to clean nets) and 16-day trips (to help sample fish and radiotrack).

8. Continue to map macrohabitat and develop concurrent bathymetry and velocity zonations to evaluate habitat dynamics with flow; work cooperatively with geomorphologists.

9. Conduct non-lethal stomach pumping of adult humpback chub (>250 mm TL) to evaluate use of food resources.

10. Evaluate mainstem spawning during April and May 1991 trips.

11. Coordinate modeling efforts early with other investigators to meet data collection needs for demographic model.

12. Initiate GIS digitization of all data.

13. Develop standardized base maps for the Colorado River, Grand Canyon with river miles on center line 1:2400 scale.

14. Survey temporary bench marks to permanent bench marks as soon as possible before temporary bench marks become indistinguishable.

15. Make data available from ongoing studies in a reasonable time for use by all investigators.

16. Continue to conduct meristic measurements to 1 of every 10 chubs, but continue to photograph all fish. Discontinue video of each fish.

17. Use existing USGS stations to collect ongoing water quality. Use Hydrolabs to collect point location information such as at tributary inflows, springs, and during spates.

18. Continue specific turbidity measurements to correlate with near-surface fish activity.

19. Modify sampling reaches to reflect geomorphic strata and realistic sampling areas. Reach 1 would extend from RM 56 to RM 77.4 (was 76.5), Reach 2 would extend from RM 77.5 to RM 159.9 (was 156), and Reach 3 would extend from RM 160.0 to RM 226.

20. Discontinue use of radiotransmitters with frequency of 40.690 to avoid interference from errant signals caused by Hydrolab in USGS station at the LCR.

21. PIT tag native fish as small as 150 mm TL.

22. Fin punch humpback chub to small to PIT tag with a standard protocol.

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APPENDIX A - DISCHARGE HYDROGRAPHS

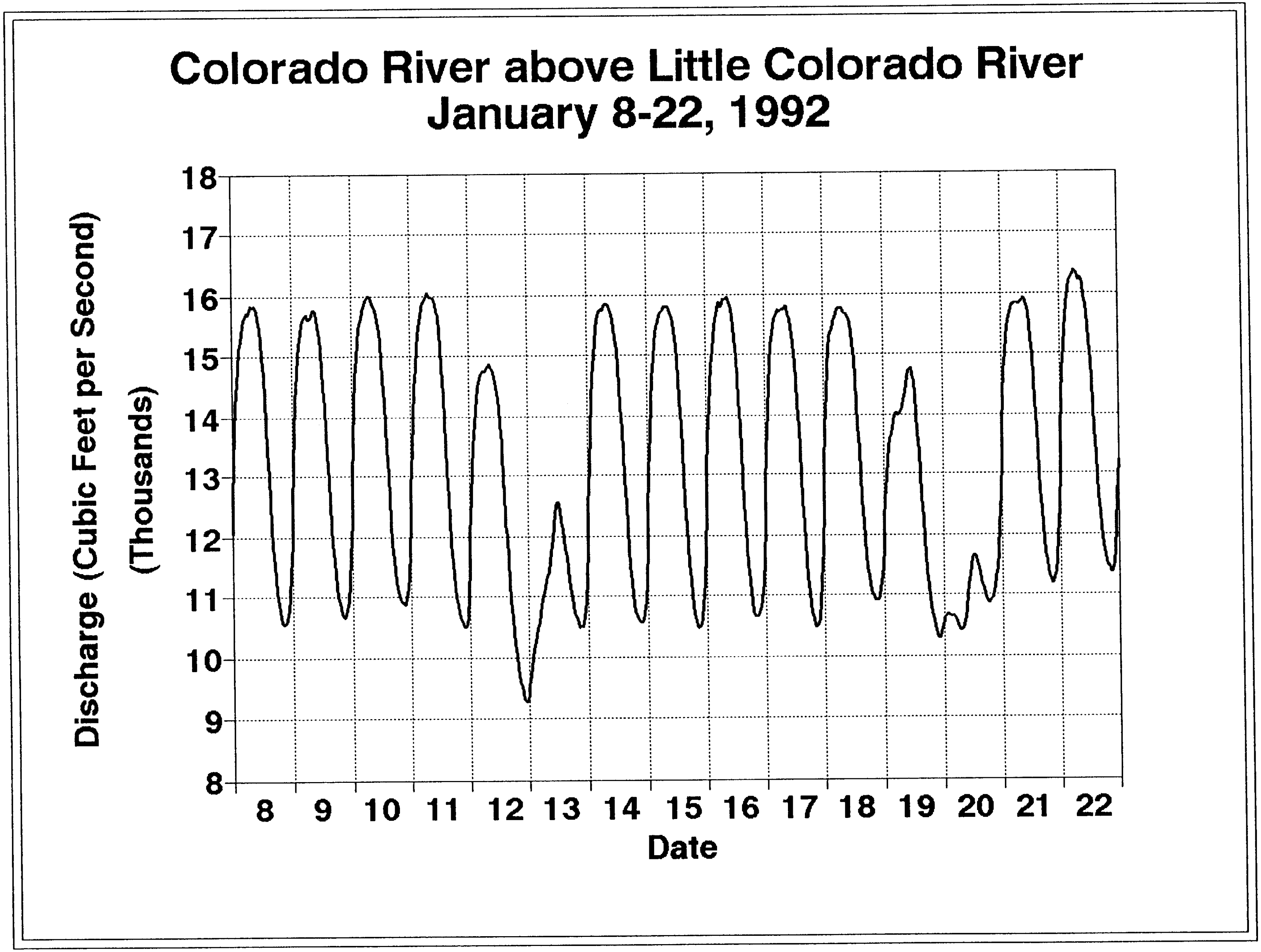

Figure A-1. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 1—January 8-22, 1992.

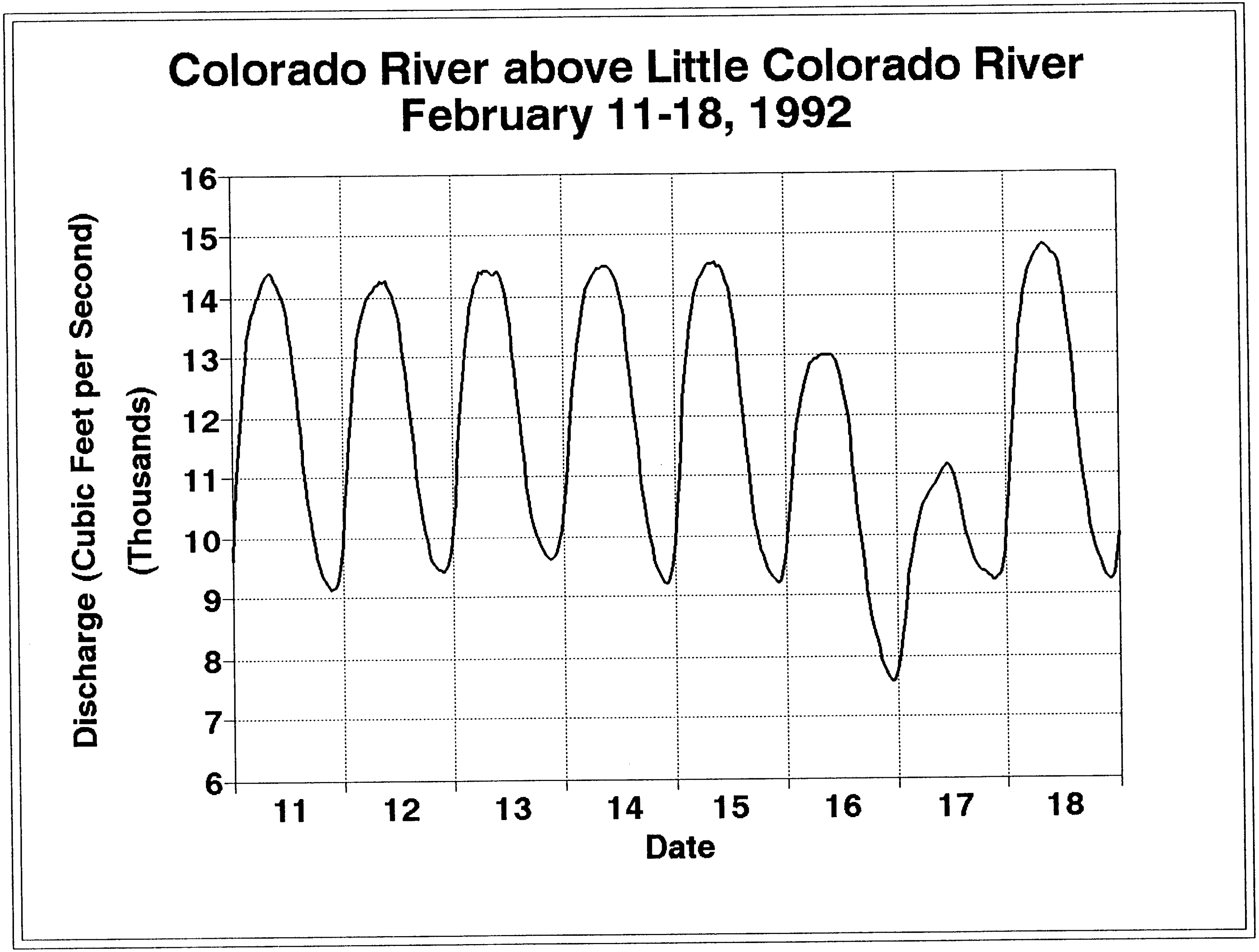

Figure A-2. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 2—February 11-18, 1992.

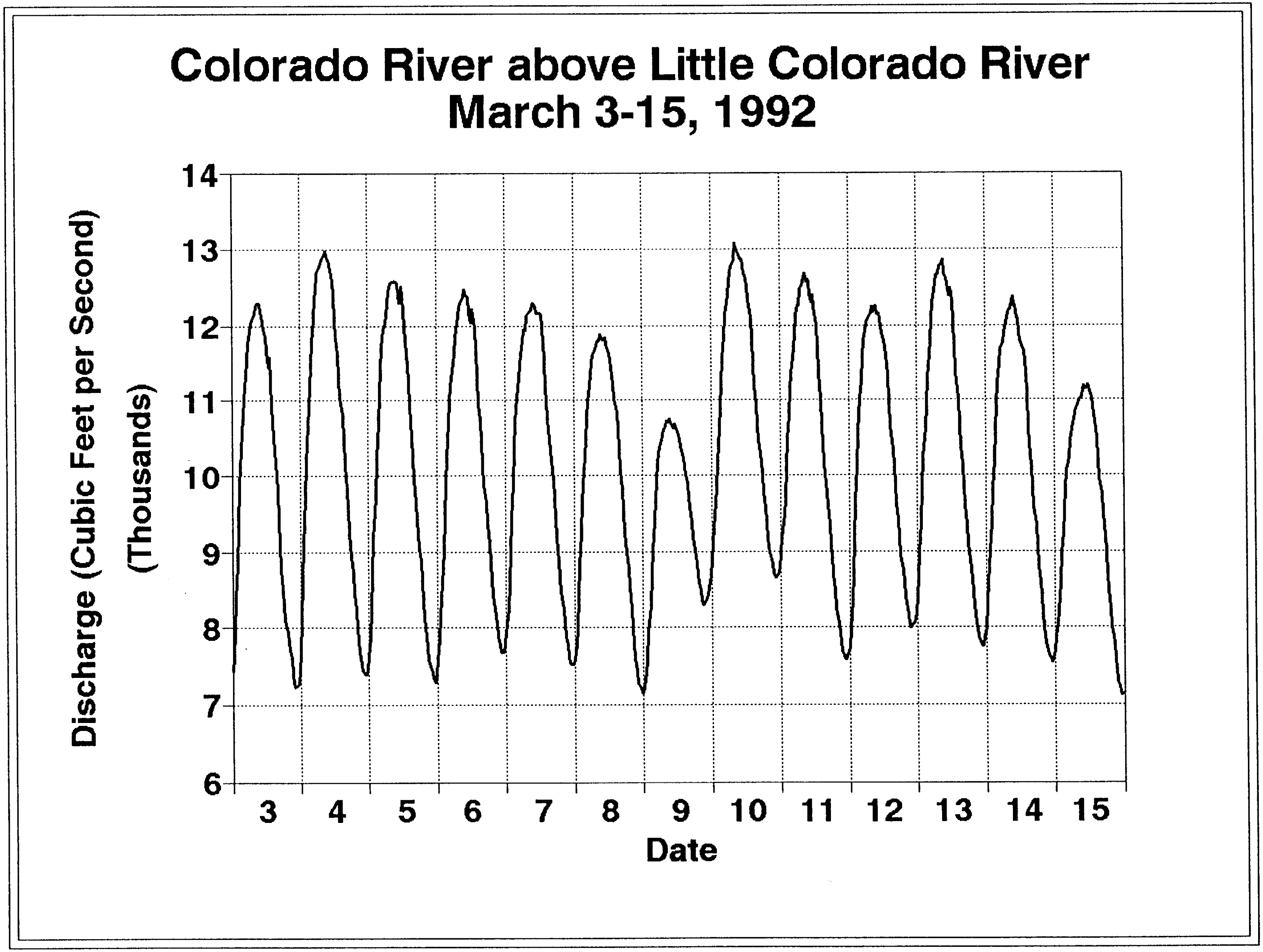

Figure A-3. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 3—March 3-15, 1992.

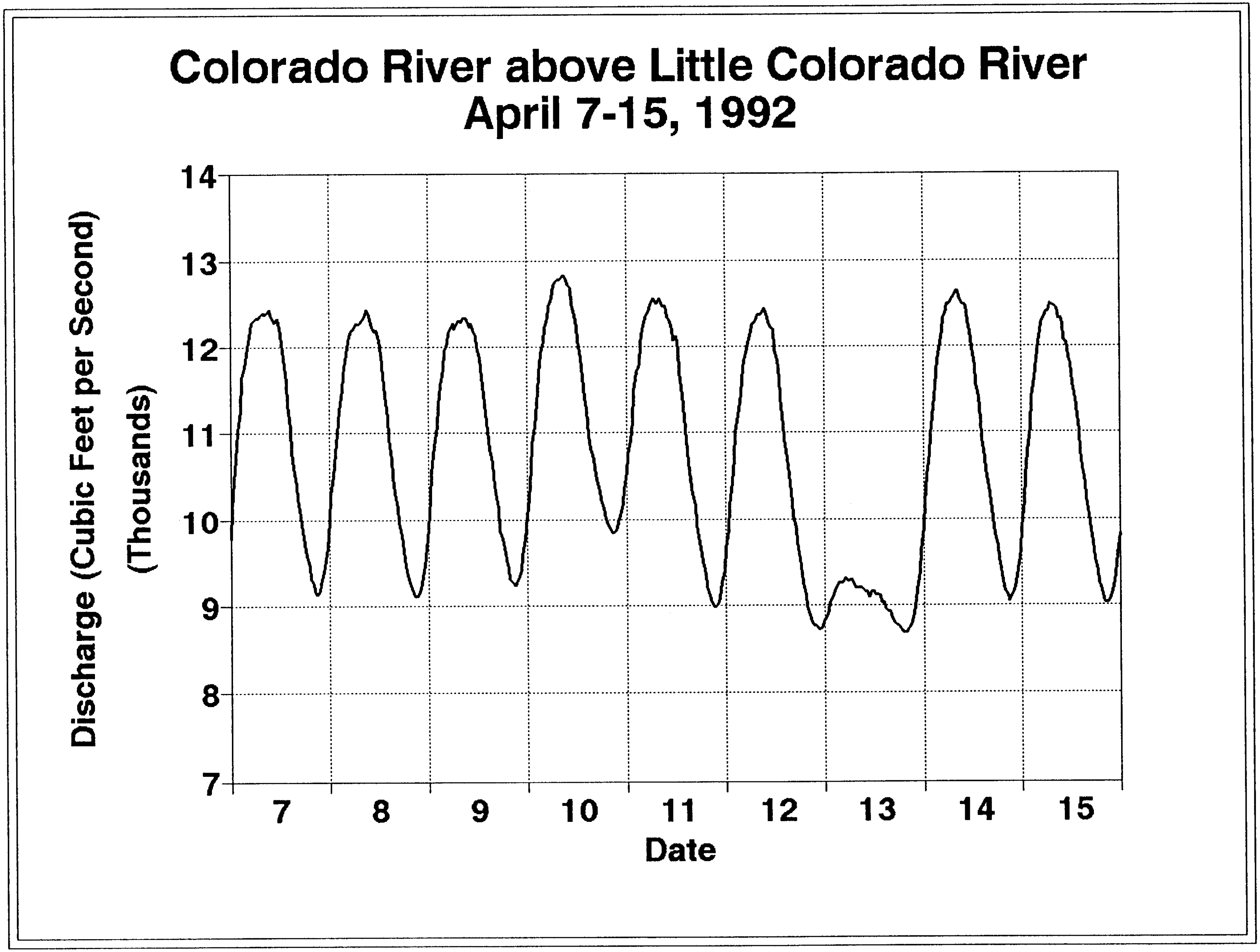

Figure A-4. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 4—April 7-15, 1992.

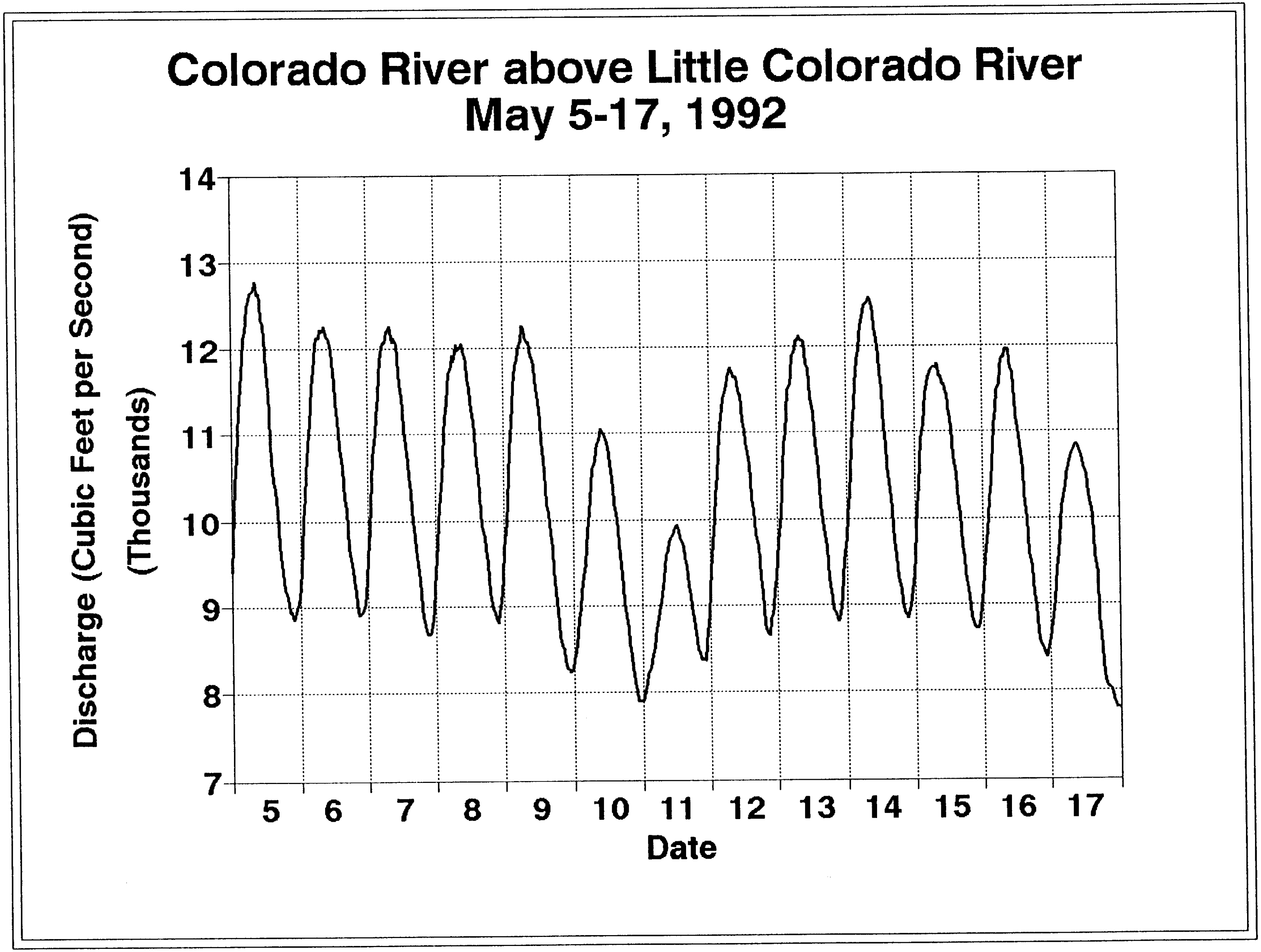

Figure A-5. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 5—May 5-17, 1992.

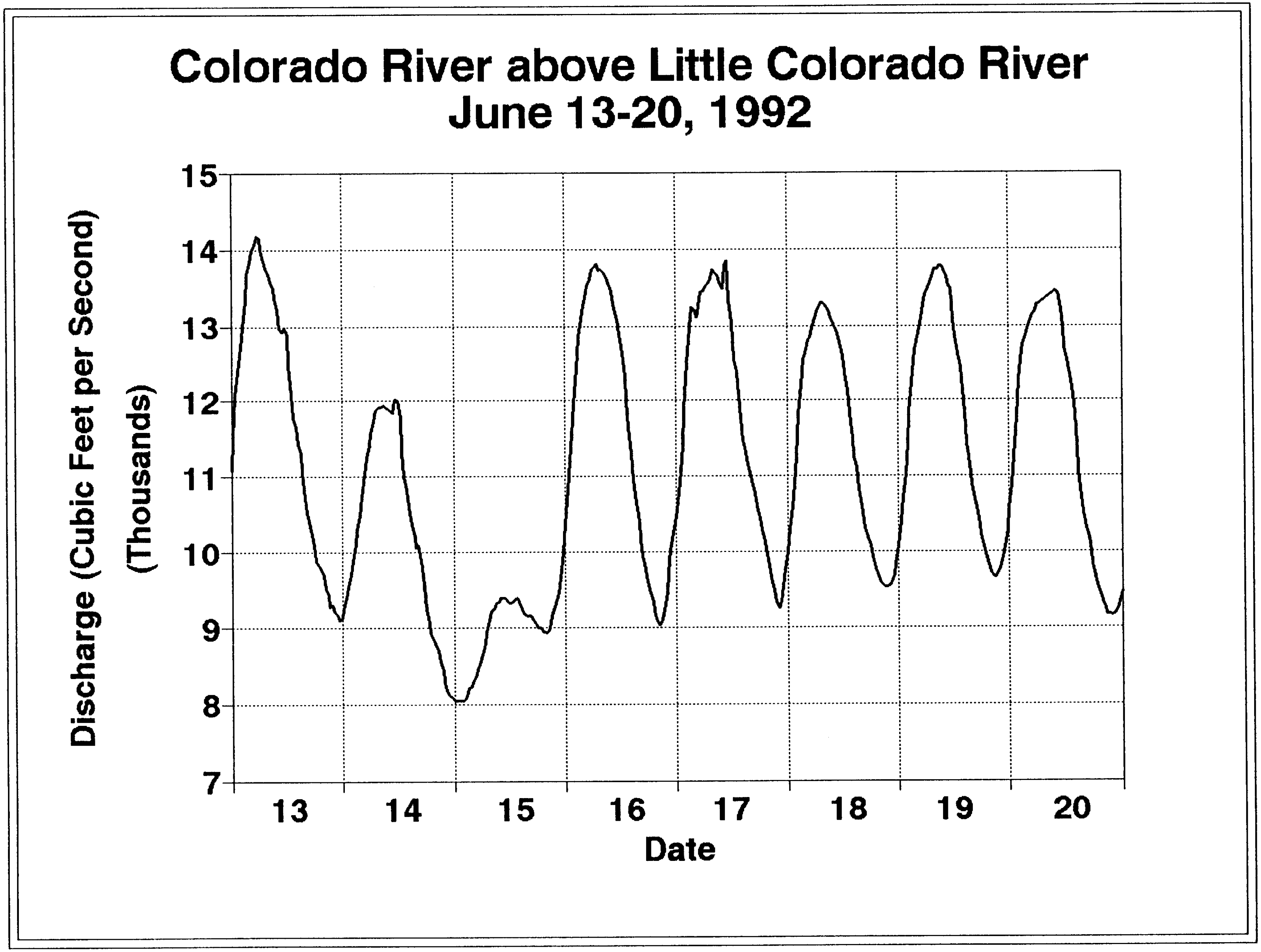

Figure A-6. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 6—June 13-20, 1992.

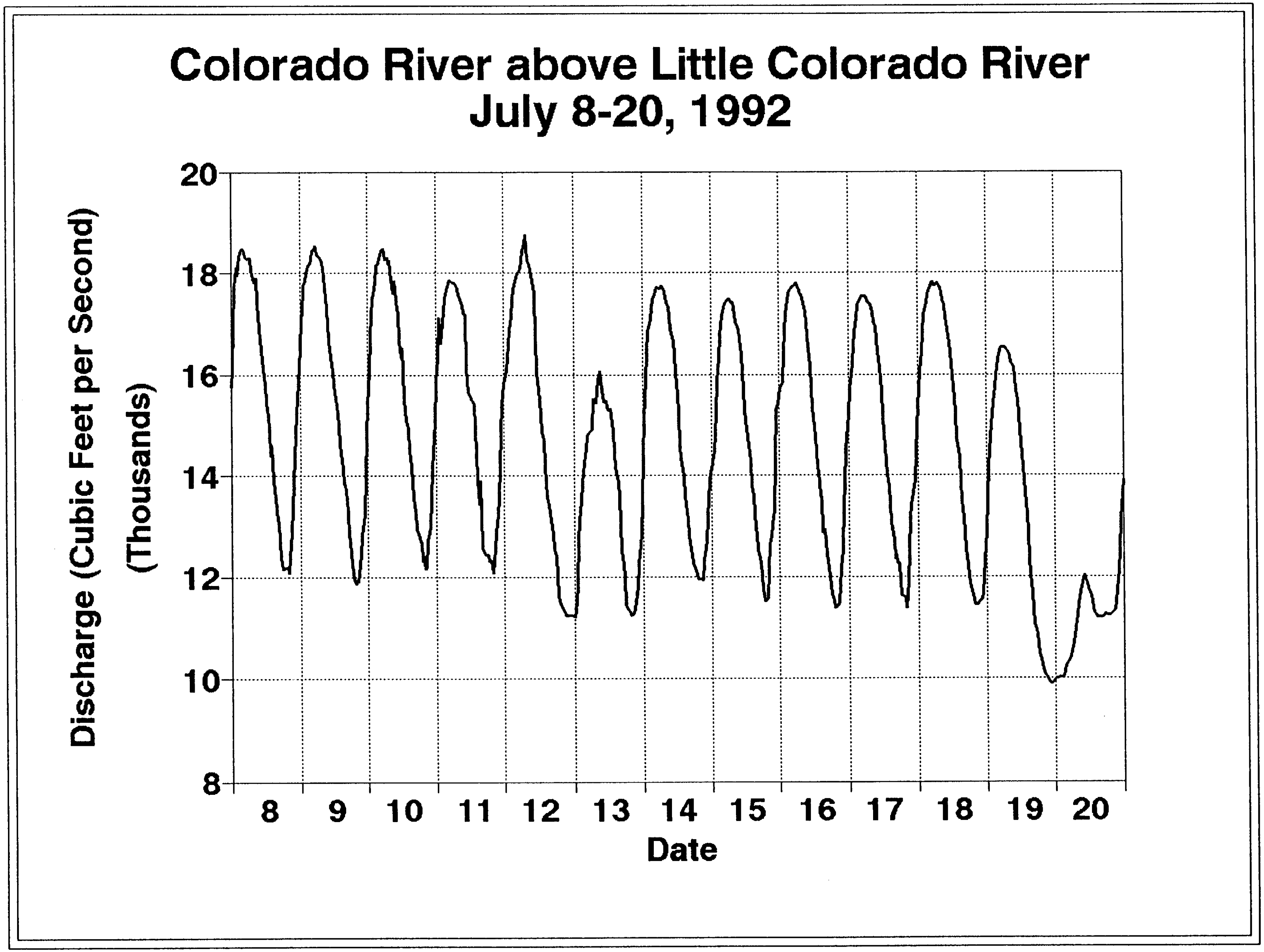

Figure A-7. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 7—July 8-20, 1992.

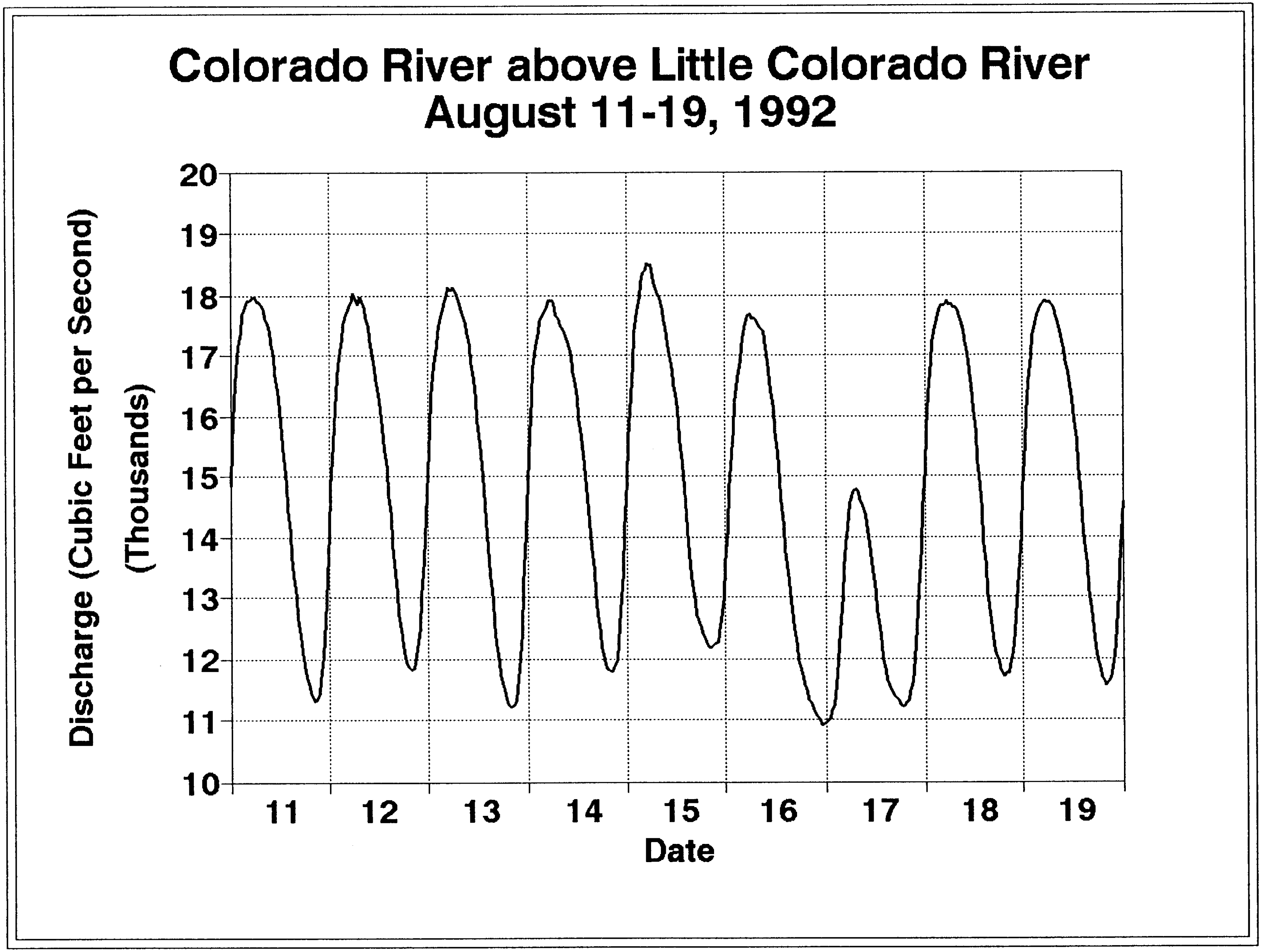

Figure A-8. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 8—August 11-19, 1992.

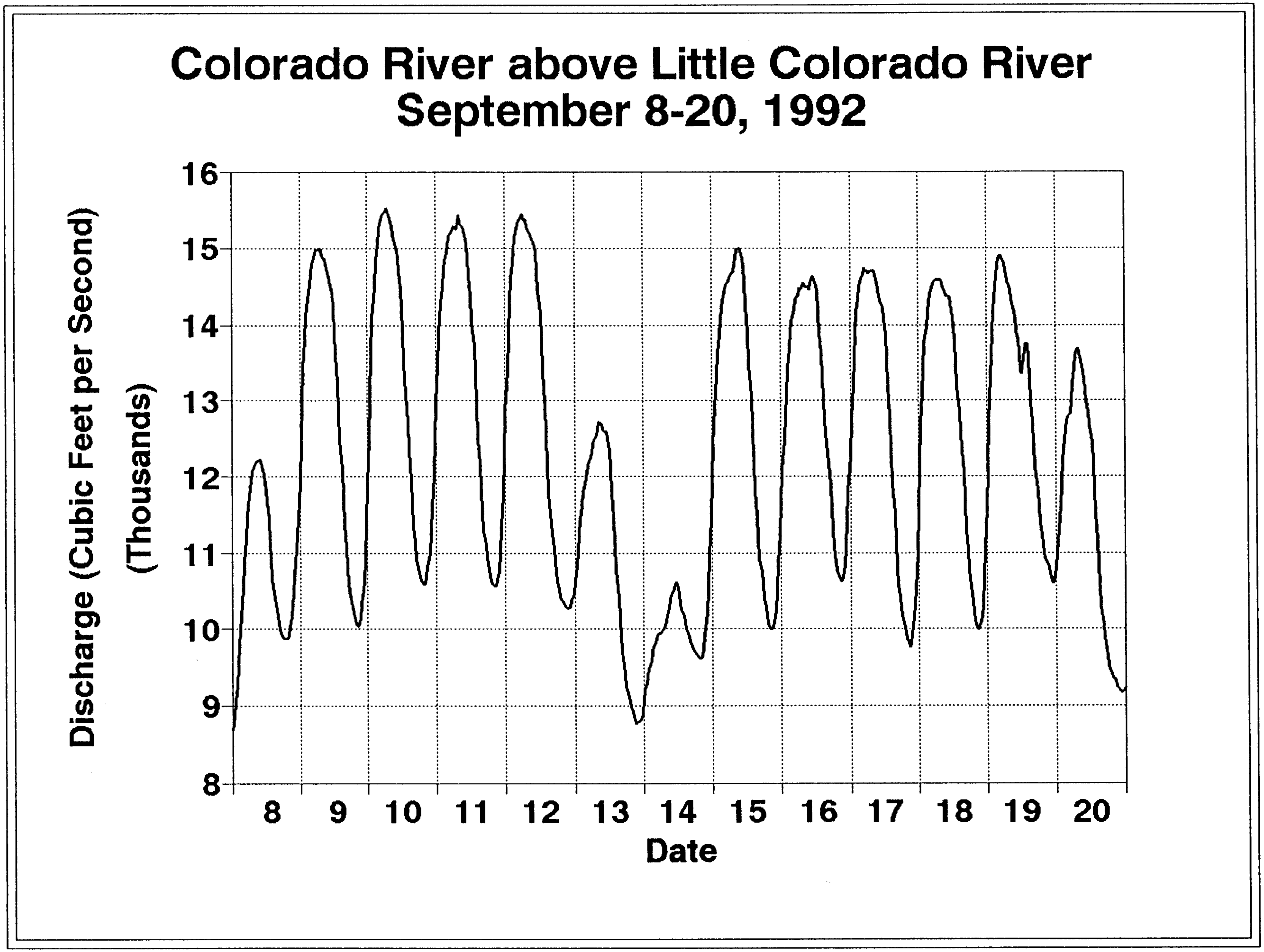

Figure A-9. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 9—September 8-20, 1992.

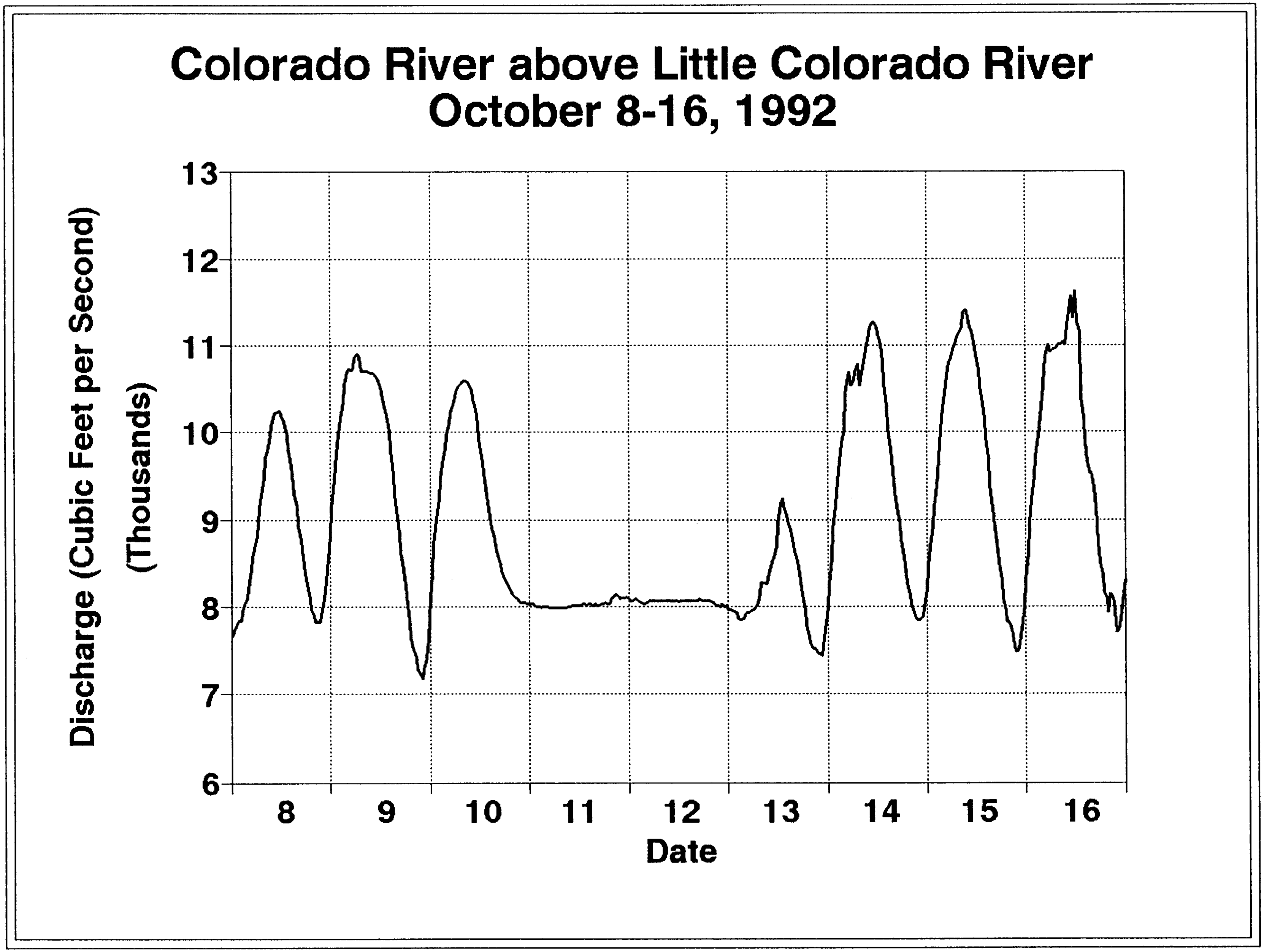

Figure A-10. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 10—October 8-16, 1992.

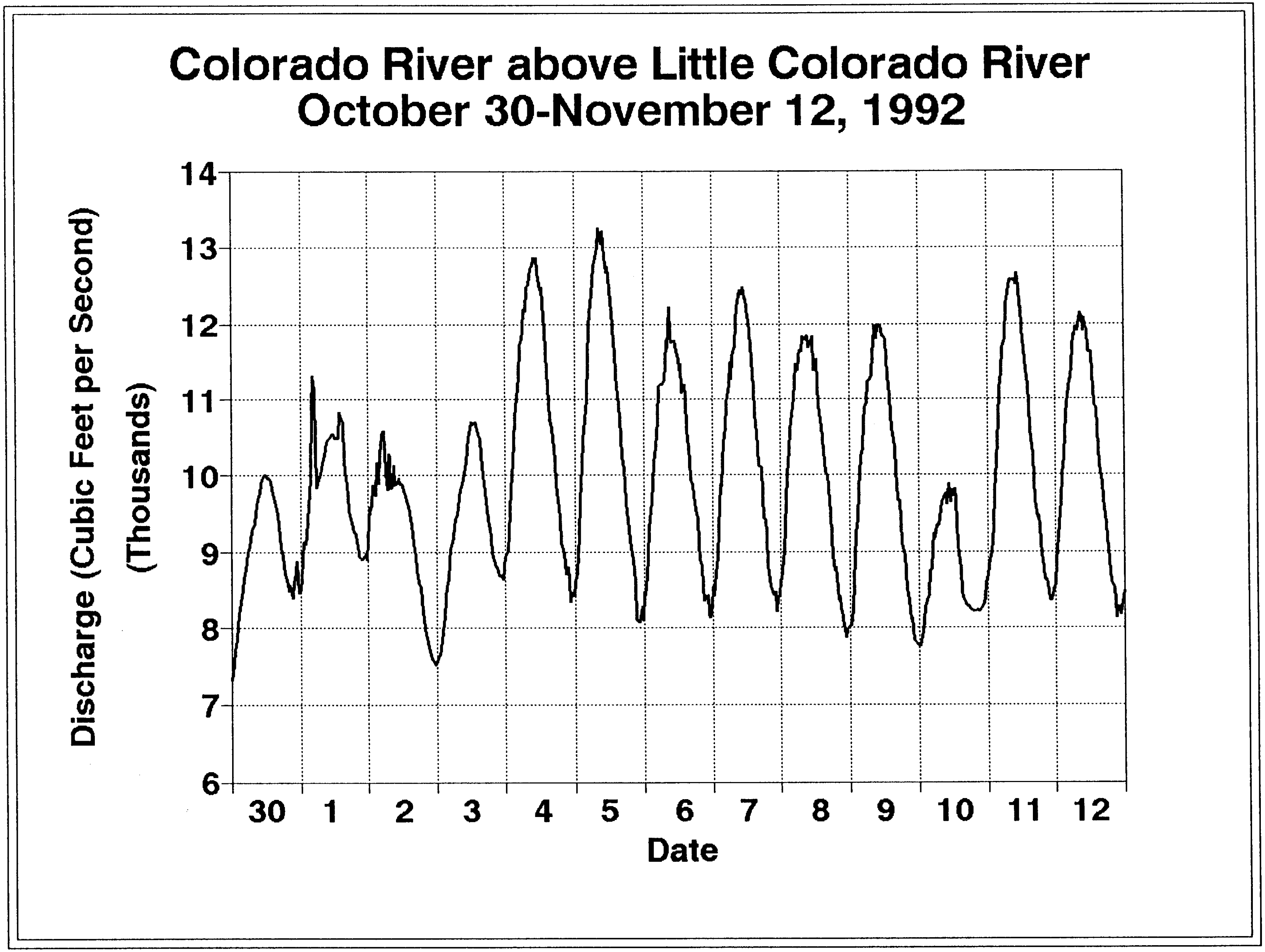

Figure A-11. Flow of the Colorado River immediately above the Little Colorado River during BIO/WEST field trip 11—October 30 - November 12, 1992.

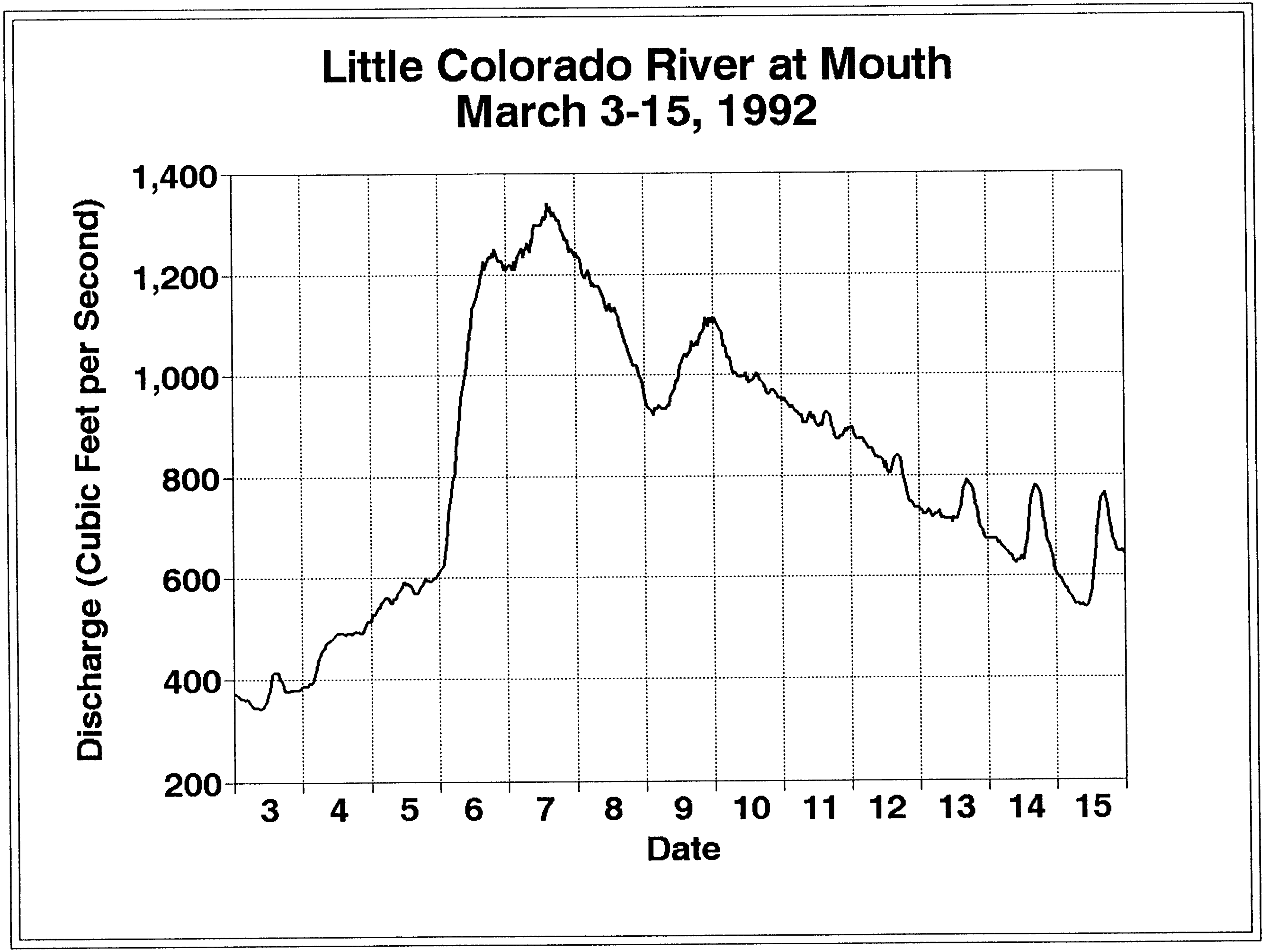

Figure A-12. Flow of the Little Colorado River at the mouth during BIO/WEST field trip 3—March 3-15, 1992.

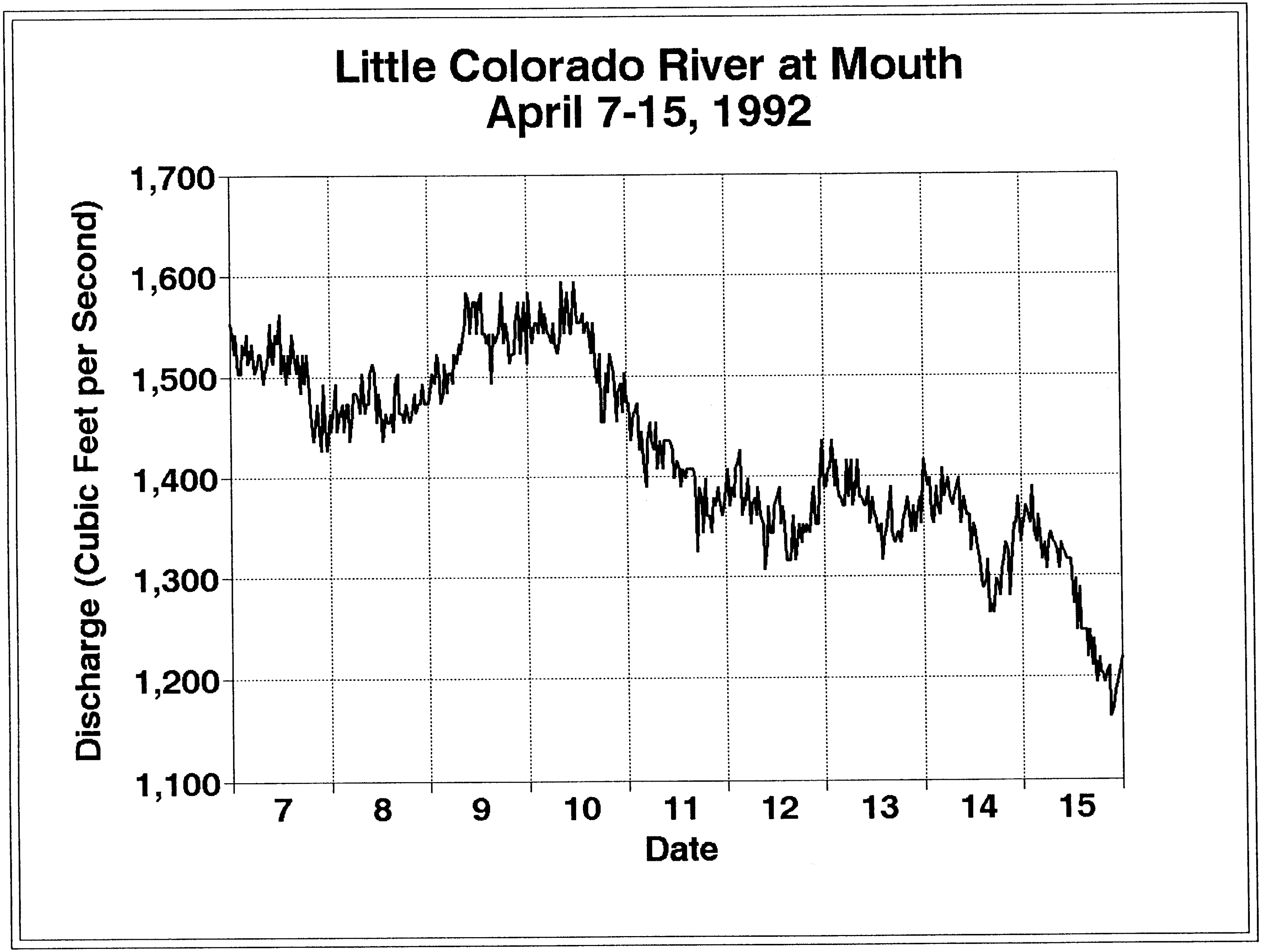

Figure A-13. Flow of the Little Colorado River at the mouth during BIO/WEST field trip 4—April 7-15, 1992.

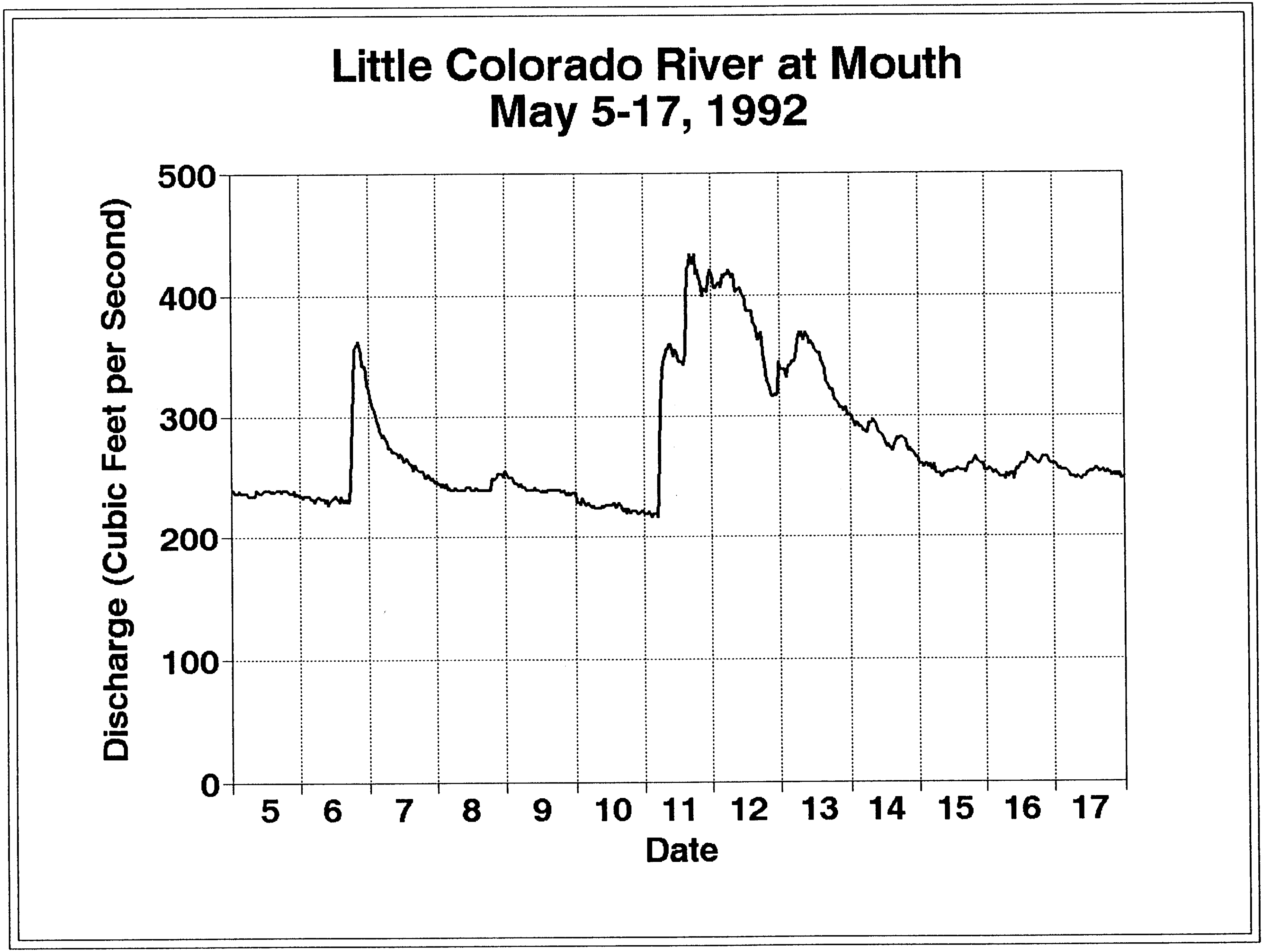

Figure A-14. Flow of the Little Colorado River at the mouth during BIO/WEST field trip 5—May 5-17, 1992.

APPENDIX B - SPECIES COMPOSITION, DISTRIBUTION, ABUNDANCE

Appendix B-1. Catch rate (CPE) of adult, juvenile and YOY rainbow trout by gear in the Colorado River in Grand Canyon, 1992.

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult RB			Juvenile RB			YOY RB		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
							NETS[b]								
GM	140	66	42	301.83	136.93	92.60	4.49 (13)	0	0	0	0	0	0	0	0
GP	165	160	106	353.44	327.05	216.60	30.36 (111)	0.54 (2)	0	0	0	0	0	0	0
GX	47	55	55	101.61	114.67	115.97	4.14 (4)	0.50 (1)	0	0	0	0	0	0	0
TK	246	315	201	537.03	636.01	422.34	16.79 (66)	8.09 (37)	0.51 (2)	0	0	0	0	0	0
TL	250	361	210	533.25	735.74	466.03	45.61 (153)	0.93 (6)	0	0	0	0	0	0	0
TM	35	192	101	75.08	385.77	208.19	88.37 (36)	21.49 (37)	2.00 (2)	0	0	0	0	0	0
TN	55	159	124	121.94	320.35	253.37	54.32 (34)	10.82 (19)	0	0	0	0	0	0	0
TW	0	10	0	0	19.03	0	-	0	-	-	0	-	-	0	-
Totals	**938**	**1318**	**839**	**2024.18**	**2675.55**	**1775.10**									

Appendix B-1 continued

GEAR[a]	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult RB			Juvenile RB			YOY RB		
	REACH			REACH			REACH			REACH			REACH		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
TRAPS[c]															
HL	0	11	4	0	209.14	105.28	-	3.03 (6)	1.05 (1)	-	0.98 (2)	0	-	0	0
HS	0	16	3	0	308.04	39.76	-	1.90 (7)	0	-	1.57 (5)	0	-	0	0
MT	702	91	20	17712.89	2199.57	569.15	0	0	0	0	0.09 (2)	0	0.01 (1)	2.38 (8)	0
Totals	**702**	**118**	**27**	**17712.89**	**2716.75**	**714.19**									
ELECTROFISHING[d]															
EL	432	293	207	102.36	103.35	64.45	1-21.38 (1128)	68.37 (548)	1.32 (10)	7.96 (88)	15.33 (138)	2.19 (17)	0.24 (5)	2.18 (23)	0.39 (4)
SEINES[e]															
				Total Area (m^2)											
SA	23	13 (11)	4 (10)	6345.5	3644	318	0.04 (1)	0.01 (2)	0	0	0.21 (3)	0	0	0.18 (1)	0
SB	22	0	0	3159	0	0	0.10 (2)	-	-	-	-	-	-	-	-
GF	5	0	0	1035	0	0	0.7 (1)	-	-	-	-	-	-	-	-
SG	53	0	0	11975.5	0	0	0.09 (10)	-	-	-	-	-	-	-	-

Appendix B-1 continued

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult RB			Juvenile RB			YOY RB		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Totals	103	13	4	22515.0	3644	318									
ANGLING															
AN	6	0	0	34.8	0	0		-	-	0	-	-	0	-	-

[a]See Table 4-1 for identification of gear codes.

Appendix B-2. Catch rate (CPE) of adult, juvenile and YOY flannelmouth sucker by gear in the Colorado River in Grand Canyon, 1992.

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult FM			Juvenile FM			YOY FM		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
NETS[b]															
GM	140	66	42	301.83	136.93	92.60	9.93 (32)	0	0	0	0	0	0	0	0
GP	165	160	106	353.44	327.05	216.60	7.15 (27)	1.05 (3)	0.40 (1)	0	0	0	0	0	0
GX	47	55	55	101.61	114.67	115.97	1.11 (1)	0	0.76 (1)	0	0	0	0	0	0
TK	246	315	201	537.03	636.01	422.34	17.75 (72)	5.09 (24)	1.23 (5)	0	0.24 (1)	0	0	0	0
TL	250	361	210	533.25	735.74	466.03	20.05 (82)	6.86 (36)	2.38 (8)	0	0	0	0	0	0
TM	35	192	101	75.08	385.77	208.19	13.33 (5)	15.90 (35)	34.81 (37)	0	0	0	0	0	0
TN	55	159	124	121.94	320.35	253.37	34.24 (21)	13.80 (23)	33.85 (47)	0	0	0	0	0	0
TW	0	10	0	0	19.03	0	-	0	-	-	0	-	-	0	-
Totals	**938**	**1318**	**839**	**2024.18**	**2675.55**	**1775.10**									

Appendix B-2 continued

GEAR[a]	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult FM			Juvenile FM			YOY FM		
	REACH			REACH			REACH			REACH			REACH		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
TRAPS[c]															
HL	0	11	4	0	209.14	105.28	-	0	2.67 (3)	-	1.87 (4)	3.15 (3)	-	0	0
HS	0	16	3	0	308.04	39.76	-	0.26 (1)	0	-	0.81 (3)	0	-	0	0
MT	702	91	20	17712.89	2199.57	569.15	0	0	0	0	0.50 (11)	0.22 (1)	0	0	0
Totals	**702**	**118**	**27**	**17712.89**	**2716.75**	**714.19**									
ELECTROFISHING[d]															
EL	432	293	207	102.36	103.35	64.45	1.83 (4)	4.07 (32)	3.14 (12)	1.38 (12)	2.49 (28)	3.59 (23)	0.57 (5)	0	0.72 (2)
SEINES[e]															
				Total Area (m^2)											
SA	23	13 (11)	4 (10)	6345.5	3644	318	0	0.77 (6)	0	0.53 (3)	1.08 (9)	2.23 (2)	0.43 (3)	0	0
SB	22	0	0	3159	0	0	0	-	-	0.27 (5)	-	-	0	-	-
GF	5	0	0	1035	0	0	0.3 (4)	-	-	0	-	-	0	-	-
SG	53	0	0	11975.5	0	0	0.09 (3)	-	-	0.17 (9)	-	-	0	-	-
Totals	**103**	**13**	**4**	**22515.0**	**3644**	**318**									

Appendix B-2 continued

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult FM			Juvenile FM			YOY FM		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
ANGLING															
AN	6	0	0	34.8	0	0	261	160	114	29	56	29	8	0	2

[a]See Table 4-1 for identification of gear codes.

Appendix B-3. Catch rate (CPE) of adult, juvenile and YOY bluehead sucker by gear in the Colorado River in Grand Canyon, 1992.

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult BH			Juvenile BH			YOY BH		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
NETS[b]															
GM	140	66	42	301.83	136.93	92.60	0	0	0	0	0	0	0	0	0
GP	165	160	106	353.44	327.05	216.60	0.81 (3)	0	0.39 (1)	0	0	0	0	0	0
GX	47	55	55	101.61	114.67	115.97	0	0	0	0	0	0	0	0	0
TK	246	315	201	537.03	636.01	422.34	6.10 (21)	1.80 (8)	1.37 (4)	0	0	0	0	0	0
TL	250	361	210	533.25	735.74	466.03	0.33 (2)	1.21 (7)	1.61 (5)	0	0	0	0	0	0
TM	35	192	101	75.08	385.77	208.19	0	3.99 (8)	0.96 (1)	0	0	0	0	0	0
TN	55	159	124	121.94	320.35	253.37	1.88 (1)	1.99 (4)	9.66 (13)	0	0	0	0	0	0
TW	0	10	0	0	19.03	0	-	0	-	-	0	-	-	0	-
Totals	**938**	**1318**	**839**	**2024.18**	**2675.55**	**1775.10**									

Appendix B-3 continued

GEAR[a]	Total samples REACH 1	Total samples REACH 2	Total samples REACH 3	Total time (hr) REACH 1	Total time (hr) REACH 2	Total time (hr) REACH 3	Catch Per Effort (number of fish) Adult BH REACH 1	Adult BH REACH 2	Adult BH REACH 3	Juvenile BH REACH 1	Juvenile BH REACH 2	Juvenile BH REACH 3	YOY BH REACH 1	YOY BH REACH 2	YOY BH REACH 3
TRAPS[c]															
HL	0	11	4	0	209.14	105.28	-	3.67 (7)	56.17 (53)	-	1.33 (3)	1.14 (2)	-	0	0
HS	0	16	3	0	308.04	39.76	-	3.29 (10)	0	-	2.78 (8)	0	-	0	0
MT	702	91	20	17712.89	2199.57	569.15	0	0	0	0	1.54 (4)	0	0	0	0
Totals	**702**	**118**	**27**	**17712.89**	**2716.75**	**714.19**									
ELECTROFISHING[d]															
EL	432	293	207	102.36	103.35	64.45	0.42 (1)	1.29 (11)	1.54 (9)	0.38 (4)	0.38 (5)	1.11 (7)	0	0	0
SEINES[e]															
				Total Area (m^2)											
SA	23	13 (11)	4 (10)	6345.5	3644	318	0	0.26 (3)	0	0	0.16 (1)	0	0.26 (5)	0	1.04 (1)
SB	22	0	0	3159	0	0	0.05 (1)	-	-	0	-	-	0	-	-
GF	5	0	0	1035	0	0	0	-	-	0	-	-	0	-	-
SG	53	0	0	11975.5	0	0	0.02 (3)	-	-	0.03 (6)	-	-	0	-	-
Totals	**103**	**13**	**4**	**22515.0**	**3644**	**318**									

Appendix B-3 continued

	Total samples			Total time (hr)			Catch Per Effort (number of fish)								
							Adult BH			Juvenile BH			YOY BH		
	REACH			REACH			REACH			REACH			REACH		
GEAR[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
ANGLING															
AN	6	0	0	34.8	0	0									

[a]See Table 4-1 for identification of gear codes.

Appendix B-4. Number (percentage) of adult fish captured in gill and trammel nets by trip in all study reaches of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CC	CP	FM	FR	FV	HB	RB	SB
92-01	150/475	4 (2.9)	3 (2.2)	2 (1.5)	12 (8.8)	12 (8.8)			23 (16.8)	81 (59.1)	
92-02	16/4	1 (6.3)				7 (43.8)			6 (37.5)	2 (12.5)	
92-03	371/529	32 (8.6)	15 (4.0)	4 (1.1)	25 (6.7)	100 (27.0)		5 (1.3)	40 (10.8)	150 (40.4)	
92-04	74/36	10 (13.5)				23 (31.1)		1 (1.4)	38 (51.4)	2 (2.7)	
92-05	347/600	17 (4.9)	24 (6.9)	7 (2.0)	34 (9.8)	136 (39.2)	1 (0.3)		49 (14.1)	78 (22.5)	1 (0.3)
92-06	67/36	2 (3.0)		1 (1.5)		19 (28.4)			37 (55.2)	8 (11.9)	
92-07	235/495	3 (1.3)	17 (7.2)	1 (0.4)	42 (17.9)	45 (19.1)			80 (34.0)	46 (19.6)	1 (0.4)
92-09	213/508	6 (2.8)	14 (6.6)	2 (0.9)	17 (8.0)	67 (31.5)			47 (22.1)	60 (28.2)	
92-11	225/420	4 (1.8)	2 (0.9)	1 (0.4)	25 (11.1)	43 (19.1)	1 (0.4)	1 (0.4)	53 (23.6)	95 (42.2)	
Total	**1698/ 3,103**	**79 (4.7)**	**74 (4.4)**	**20 (1.2)**	**155 (9.1)**	**464 (27.3)**	**2 (0.1)**	**7 (0.4)**	**373 (22.0)**	**522 (30.7)**	**2 (0.1)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-5. Number (percentage) of adult fish captured in gill and trammel nets by trip in Reach 1, of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CC	CP	FM	FR	FV	HB	RB
92-01	116/162	2 (1.7)		1 (0.9)	1 (0.9)	17 (14.7)			23 (19.8)	72 (62.1)
92-02	16/4	1 (6.3)				7 (43.8)			6 (37.5)	2 (12.5)
92-03	209/147	5 (2.4)	1 (0.5)		3 (1.4)	40 (19.1)			40 (19.1)	120 (57.4)
92-04	74/36	10 (13.5)				23 (31.1)		1 (1.4)	38 (51.4)	2 (2.7)
92-05	141/147	4 (2.8)	1 (0.7)	1 (0.7)	2 (1.4)	44 (31.2)			39 (27.7)	50 (35.5)
92-06	67/36	2 (3.0)		1 (1.5)		19 (28.4)			37 (55.2)	8 (11.9)
92-07	99/123	1 (1.0)	1 (1.0)			25 (25.3)			50 (50.5)	22 (22.2)
92-09	133/131	2 (1.5)	2 (1.5)	1 (0.8)		43 (32.3)			38 (28.6)	47 (35.3)
92-11	172/155	1 (0.6)	1 (0.6)			26 (15.1)	1 (0.6)		49 (28.5)	93 (54.1)
TOTAL	**1,027/941**	**28** **(2.7)**	**6** **(0.6)**	**5** **(0.5)**	**6** **(0.6)**	**244** **(23.8)**	**1** **(0.1)**	**1** **(0.1)**	**320** **(31.2)**	**416** **(40.5)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-6. Number (percentage) of adult fish captured in gill and trammel nets by trip in Reach 2 of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CP	FM	FR	FV	HB	RB
92-01	16/156		2 (12.5)	3 (18.8)	2 (12.5)				9 (56.3)
92-03	68/164	7 (10.3)	13 (19.1)	8 (11.8)	11 (16.2)				29 (42.6)
92-05	146/309	13 (8.9)	23 (15.8)	12 (8.2)	61 (41.8)	1 (0.7)		8 (5.5)	28 (19.2)
92-07	86/231	1 (1.2)	16 (18.6)	11 (12.8)	7 (8.1)			30 (34.9)	21 (24.4)
92-09	70/223	3 (4.3)	12 (17.1)	10 (14.3)	23 (32.9)			9 (12.9)	13 (18.6)
92-11	46/235	3 (6.5)	1 (2.2)	18 (39.1)	17 (37.0)		1 (2.2)	4 (8.7)	2 (4.3)
TOTAL	**432/1,318**	**27 (6.3)**	**67 (15.5)**	**62 (14.4)**	**121 (28.0)**	**1 (0.2)**	**1 (0.2)**	**51 (11.8)**	**102 (23.6)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-7. Number (percentage) of adult fish captured in gill and trammel nets by trip in Reach 3 of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CC	CP	FM	FV	HB	RB	SB
92-01	18/157	2 (11.1)		3 (16.7)	8 (44.4)	5 (27.8)				
92-03	94/218	20 (21.3)	1 (1.1)	4 (4.3)	14 (14.9)	49 (52.1)	5 (5.3)		1 (1.1)	
92-05	60/143			6 (10.0)	20 (33.3)	31 (51.7)		2 (3.3)		1 (1.7)
92-07	50/141	1 (2.0)		1 (2.0)	31 (62.0)	13 (26.0)			3 (6.0)	1 (2.0)
92-09	10/154	1 (10.0)		1 (10.0)	7 (70.0)	1 (10.0)				
92-11	7/30				7 (100)					
TOTAL	**239/843**	**24 (10.0)**	**1 (0.4)**	**15 (6.3)**	**87 (36.4)**	**99 (41.4)**	**5 (2.1)**	**2 (0.8)**	**4 (1.7)**	**2 (0.8)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes

Appendix B-8. Number (percentage) of adult fish captured by electrofishing by trip in all study reaches of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BK	BR	CC	CP	FH	FM	FV	HB	RB	PK	SB	SD
92-01	643/121			72 (11.2)		131 (20.4)	8 (1.2)	6 (0.9)	1 (0.2)	4 (0.6)	409 (11.3)			12 (1.9)
92-03	551/191	7 (1.3)	1 (0.2)	55 (10.0)	1 (0.2)	155 (28.1)	5 (0.9)	9 (1.6)		4 (0.7)	277 (50.3)			37 (6.7)
92-05	414/97	1 (0.2)		149 (36.0)		51 (12.3)	18 (4.3)	6 (1.4)		3 (0.7)	179 (43.2)		1 (0.2)	6 (1.4)
92-07	564/158	5 (0.9)		59 (10.5)	3 (0.5)	167 (29.6)	21 (3.7)	11 (2.0)		20 (3.5)	261 (46.3)			17 (3.0)
92-08	149/40			2 (1.3)		3 (2.0)	6 (4.0)	4 (2.7)		5 (3.4)	123 (82.6)			6 (4.0)
92-09	352/162	5 (1.4)		6 (27.3)		46 (13.1)	33 (9.4)	13 (3.7)		1 (0.3)	134 (38.1)			23 (6.5)
92-11	499/163	1 (0.2)		70 (14.0)		54 (10.8)	51 (10.2)	9 (1.8)		5 (1.0)	304 (60.9)	1 (0.3)		5 (1.0)
TOTAL	**3,172/932**	**19** (0.6)	**1** (>0.01)	**503** (15.9)	**4** (0.1)	**607** (19.1)	**142** (4.5)	**58** (1.8)	**1** (>0.01)	**42** (1.3)	**1,687** (53.2)	**1** (>0.01)	**1** (>0.01)	**106** (3.3)

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-9. Number (percentage) of adult fish captured by electrofishing by trip in Reach 1 of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH	BK	BR	CP	FH	FM	HB	RB	SD
92-01	241/59			3 (1.2)	9 (3.7)	7 (2.9)		4 (1.7)	209 (86.7)	9 (3.7)
92-03	217/73		1 (0.5)		4 (1.8)	3 (1.4)	2 (0.9)	3 (1.4)	197 (90.8)	7 (3.2)
92-05	138/32			1 (0.7)	5 (3.6)	16 (11.6)	2 (1.4)	2 (1.4)	107 (77.5)	5 (3.6)
92-07	204/68			2 (1.0)	4 (2.0)	15 (7.4)	5 (2.5)	16 (7.8)	161 (78.9)	1 (0.5)
92-08	149/40			2 (1.3)	3 (2.0)	6 (4.0)	4 (2.7)	5 (3.4)	123 (82.6)	6 (4.0)
92-09	87/74	1 (1.1)		1 (1.1)	9 (10.3)	5 (5.7)		1 (1.1)	66 (75.9)	4 (4.6)
92-11	317/86			1 (0.3)	13 (4.1)	31 (9.8)	1 (0.3)	5 (1.6)		1 (0.3)
TOTAL	**1,353/432**	**1 (0.1)**	**1 (0.1)**	**10 (0.7)**	**47 (3.5)**	**83 (6.1)**	**14 (1.0)**	**36 (2.7)**	**1,128 (83.4)**	**33 (2.4)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-10. Number (percentage) of adult fish captured by electrofishing by trip in Reach 2 of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CC	CP	FM	FH	HB	RB	SD
92-01	336/36		67		67	4			198	
			(19.9)		(19.9)	(1.2)			(58.9)	
92-03	248/59	1	55		101	5			78	8
		(0.4)	(22.2)		(40.7)	(2.0)			(31.5)	(3.2)
92-05	258/37	1	148		33	3		1	72	
		(0.4)	(57.4)		(12.8)	(1.2)		(0.4)	(27.9)	
92-07	253/43	5	55	3	73	4	6	4	96	7
		(2.0)	(21.7)	(1.2)	(28.9)	(1.6)	(2.4)	(1.6)	(37.9)	(2.8)
92-09	219/46	2	95		25	8	16		66	7
		(0.9)	(43.4)		(11.4)	(3.7)	(7.3)		(30.1)	(3.2)
92-11	175/72	1	69		40	8	16		39	2
		(0.6)	(39.4)		(22.9)	(4.6)	(9.1)		(22.3)	(1.1)
TOTAL	**1,489/293**	**10**	**489**	**3**	**339**	**32**	**38**	**5**	**549**	**24**
		(0.7)	**(32.8)**	**(0.2)**	**(22.8)**	**(2.1)**	**(2.6)**	**(0.3)**	**(36.9)**	**(1.6)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

Appendix B-11. Number (percentage) of adults captured by electrofishing by trip in Reach 3 of the Colorado River in Grand Canyon, 1992.

Trip	F/S[a]	BH[b]	BR	CC	CP	FH	FM	FV	HB	RB	PK	SB	SD
92-01	66/26		2 (3.0)		55 (83.3)	1 (1.5)	2 (3.0)	1 (1.5)		2 (3.0)			3 (4.5)
92-03	86/59	6 (7.0)		1 (1.2)	50 (58.1)	2 (2.3)	2 (2.3)		1 (1.2)	2 (2.3)			22 (25.6)
92-05	18/28				13 (72.2)	2 (11.1)	1 (5.6)					1 (5.6)	1 (5.6)
92-07	107/47		2 (1.9)		90 (84.1)		2 (1.9)			4 (3.7)			9 (8.4)
92-09	46/42	2 (4.3)			12 (26.1)	12 (26.1)	5 (10.9)			2 (4.3)	1 (2.2)		12 (26.1)
92-11	7/5				1 (14.3)	4 (57.1)							2 (28.6)
TOTAL	**330/207**	**8 (2.4)**	**4 (1.2)**	**1 (0.3)**	**221 (67.0)**	**21 (6.4)**	**12 (3.6)**	**1 (0.3)**	**1 (0.3)**	**10 (3.0)**	**1 (0.3)**	**1 (0.3)**	**49 (14.8)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 4-5 for fish codes.

APPENDIX C - MOVEMENT AND ACTIVITY OF HUMPBACK CHUB

Table C-1. Length of contact and long-range displacement of 48 radiotagged adult humpback chub in the Colorado River, Grand Canyon, 1990-1991.

Fish No.	PIT Tag No.	Freq/Pulse	Implanted Date	Last Contact Date	Days Between Contact	Capture Location (RM)	Final[a] Location (RM)	Displacement Gross (miles)	Displacement Net (miles)	No. Contacts	Movement to/from LCR
1	7F7F456D61	40.740/80	911107	911108	1	58.8	58.9	0.1	-0.1	2	N
2	7F7F095814	40.640/82	911108	920413	157	58.8	61.5	4.44	2.7	22	Y
3	7F7F21747D	40.630/62	911109	920314	126	60.1	60.4	2.0	-0.3	30	N
4	7F7F1F6A79	40.621/44	911109	920414	157	60.1	0.7LCR	5.49	-1.93	37	Y
5	7F7F21741B	40.610/83	911112	920305	124	64.8	63.9	0.94	0.9	10	N
6	7F7E431037	40.650/82	920111	920516	126	58.3	60.75	6.95	-2.45	34	N
7	7F7E432514	40.601/61	920113	920414	92	60.45	0.6LCR	2.36	-1.5	23	Y
8	7F7D140108	40.730/62	920114	920314	60	60.7	61.5	1.72	-0.8	19	Y
9	7F7E430D1E	40.710/60	920114	920414	91	60.8	0.53LCR	2.30	-1.08	46	Y
10	7F7F1E514C	40.660/62	920120	920616	148	65.3	9.3LCR	15.20	13.27	32	Y
11	7F7F475E72	40.680/44	920308	920818	163	61.5	60.4	4.2	1.1	28	N
12	7F7E432641	40.720/62	920311	920515	65	61.1	2.4LCR	4.27	-2.67	14	Y
13	7F7F271C57	40.700/83	920311	920516	66	61.3	62.3	2.5	-1.0	26	N
14	7F7F1E7A65	40.630/84	920418	920818	122	61.75	62.2	5.65	-0.45	23	Y
15	7F7F217E36	40.610/42	920508	920515	7	61.9	64.4	2.6	-2.5	7	N
16	7F7D080024	40.730/83	920509	920516	7	61.5	61.7	0.5	-0.2	11	N
17	7F7F3E6117	40.670/80	920614	920910	88	62.7	62.2	2.70	0.5	9	N
18	7F7F3E5B39	40.640/40	920615	920718	33	62.7	62.95	2.55	-0.25	19	N
19	7F7E431B2C	40.740/42	920616	920911	87	61.4	61.85	3.15	-0.45	26	N
20	7F7F3E506C	40.620/62	920709	921105	119	58.3	58.35	5.95	-0.05	28	N
21	7F7F3E5133	40.710/41	920709	921103	117	58.3	59.0	2.5	-0.7	24	N

Table C-1 continued

Fish No.	PIT Tag No.	Freq/Pulse	Implanted Date	Last Contact Date	Days Between Contact	Capture Location (RM)	Final[a] Location (RM)	Displacement Gross (miles)	Displacement Net (miles)	No. Contacts	Movement to/from LCR
22	7F7D085A33	40.600/84	920713	921105	115	61.2	60.15	1.85	1.05	21	N
23	7F7F321C62	40.650/60	920713	920912	61	61.2	60.4	2.3	0.8	15	N
24	7F7F206B7B	40.680/60	920909	921104	56	58.2	58.85	0.85	-0.65	15	N
25	7F7F477F56	40.740/60	920909	921109	61	58.3	58.25	0.35	0.05	21	N
26	7F7E430660	40.610/59	920912	921109	58	60.4	60.80	1.9	-0.4	34	N
27	7F7F333715	40.720/83	920915	921105	51	61.3	60.35	1.05	0.95	18	N
			Mean		87.3			3.2	1.44	22	
			Standard Deviation		1			0.1	0.05	2	
			Minimum		163			15.2	13.27	46	
			Maximum								

[a]0.30LC = 0.30 km upstream into LCR

Table C-2. Elapsed time and distance displaced for 61 juvenile and adult humpback chub PIT-tagged and recaptured by BIO/WEST, October 1990 - November 1992.

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
1	7F7D025F6F	910512	910908	119	58.80	58.90	-0.1
	"	910512	920507	361	58.80	58.80	0
2	7F7D026D0F	910714	920112	182	58.40	59.50	-1.1
3	7F7D075B05	910612	911110	151	60.20	60.80	-0.60
4	7F7D076C2E	910719	921109	479	64.70	64.65	0.05
5	7F7D08030B	910613	911109	149	60.90	60.15	0.75
6	7F7D080D77	910714	910709	361	58.80	58.30	0.50
7	7F7D085054	910417	910716	90	61.30	60.90	0.40
	"	910417	910717	91	61.30	60.80	0.50
8	7F7D085E2B	910517	910911	117	61.40	60.75	0.65
9	7F7D086032	910613	920113	214	61.10	60.70	0.40
10	7F7D086C43	910518	920115	242	60.70	61.20	-0.50
11	7F7F050F0A	910111	921103	662	60.60	60.40	0.20
12	7F7F3C243E	910311	910612	93	61.20	60.80	0.40
13	7F7F3C277A	901118	910911	297	61.10	60.75	0.35
	"	901118	911110	357	61.10	60.90	0.20
14	7F7F3C2E7A	910112	910311	58	60.50	61.20	-0.70
	"	910112	910311	58	60.50	61.20	-0.70
	"	910112	910717	186	60.50	61.30	-0.80
15	7F7F3C3457	910108	910908	243	58.30	58.80	-0.50
16	7F7F3C3B2D	910111	910912	244	61.10	61.10	0
17	7F7F3C4111	910112	910113	1	108.30	108.30	0
18	7F7F3C4162	901123	910114	152	64.40	64.10	0.30
19	7F7F3C4279	910114	910214	31	64.60	61.40	3.20
20	7F7F3C4341	910108	920709	548	58.80	58.80	0
21	7F7F3C4477	901121	901124	3	64.20	65.40	-1.20
22	7F7F3C4554	901018	910308	140	60.20	60.10	0.10
23	7F7F3C6F15	910518	910914	119	61.40	64.70	-3.3
24	7F7F3E232E	901117	920118	62	61.10	61.05	0.50
25	7F7F3E2640	910108	910713	186	58.20	58.40	-0.20
	"	910108	920710	549	58.20	58.30	-0.10
26	7F7F3E2720	901116	920912	301	60.30	60.40	-0.10

Table C-2 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
27	7F7F3E2772	910717	920508	296	61.40	61.90	-0.50
28	7F7F3E2865	910115	910117	2	64.40	64.50	-0.10
29	7F7F3E2913	910308	910309	1	61.40	61.90	-0.50
30	7F7F3E2A49	901018	920912	330	60.40	60.20	0.20
31	7F7F3E2B48	910309	910311	2	61.90	61.40	0.50
32	7F7F3E2B52	901019	920917	333	64.60	64.35	0.25
33	7F7F3E2E05	910109	920615	523	58.30	61.30	-3.00
34	7F7F3E2F26	901116	910715	241	60.10	60.30	-0.20
35	7F7F3E2F3A	901020	910708	260	65.00	127.00	-62.00
36	7F7F3E3212	901130	901201	1	213.60	213.60	0
	"	901130	901201	1	213.60	212.50	0.80
	"	901130	910320	110	213.60	213.60	0
37	7F7F3E3310	901117	910613	208	61.00	60.90	0.10
38	7F7F3E3370	901017	920307	142	60.40	60.20	0.20
39	7F7F3E3675	910109	910306	56	58.90	58.80	0.10
40	7F7F3E384D	910309	920713	492	60.80	61.15	-0.35
41	7F7F3E3C5C	901118	911110	357	61.10	60.90	0.20
42	7F7F3E3C5F	910312	910914	186	64.80	64.70	0.10
43	7F7F3E3D45	910717	910912	57	61.30	61.20	0.10
44	7F7F3E3D73	910115	910117	2	64.70	64.40	0.30
45	7F7F3E3E15	910109	910306	56	58.90	58.80	0.10
46	7F7F3E4105	901116	911119	3	60.40	61.50	-1.10
47	7F7F3F3425	910116	920312	421	65.00	63.70	1.30
	"	910116	920719	550	65.00	65.30	-0.30
48	7F7F3F3626	901017	910112	87	60.40	60.80	-0.40
49	7F7F3F3A28	910311	910311	0	61.40	61.20	0.20
50	7F7F3F3C2B	910115	920615	517	64.80	61.30	3.50
51	7F7F3F3C2F	910116	910914	241	64.70	64.70	0
52	7F7F3F3D79	910109	910908	242	58.90	58.80	0.10
53	7F7F3F4146	910116	910916	243	65.30	65.20	0.10
54	7F7F3F427E	910108	910908	251	58.80	58.80	0
	"	910108	920910	246	58.80	58.30	0.50

Table C-2 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
55	7F7F3F441C	901017	910715	271	60.40	60.50	-0.10
56	7F7F3F452E	901018	910614	239	60.40	61.40	-1.00
57	7F7F3F4942	910311	910311	0	61.40	61.40	0
58	7F7F3F4B6C	901201	910320	109	213.60	213.60	0
59	7F7F3F4C51	910715	921105	479	60.30	60.40	-0.10
60	7F7F3F4D30	910308	910309	1	60.10	60.80	-0.70
61	7F7F3F4E5B	910712	910712	0	57.00	57.00	0
62	7F7F3F4E77	901117	910311	114	61.00	61.20	-0.20
63	7F7F3F4F0A	910310	910310	0	61.10	61.10	0
	"	910310	910911	185	61.10	61.30	0.80
64	7F7F3F4F13	910314	910314	0	62.50	62.50	0
	"	910314	920717	491	62.50	62.65	-0.15
65	7F7F3F5016	910114	920719	372	64.70	65.30	-0.60
66	7F7F3F5108	910308	910308	0	61.40	61.40	0
67	7F7F3F5144	910112	910113	1	108.30	108.40	-0.10
	"	910112	910307	54	108.30	108.30	0
68	7F7F3F520D	910311	910515	65	61.20	60.90	0.30
69	7F7F431A46	910312	910312	0	64.50	64.50	0
70	7F7F450D11	910308	920113	311	60.10	60.20	-0.10
71	7F7F456B2C	901020	910116	88	64.60	64.70	-0.10
72	7F7F456D7D	910614	911110	149	61.40	61.75	-0.35
73	7F7D027E29	910911	911110	60	60.75	60.90	-0.15
74	7F7D07124A	910913	910914	1	62.70	65.70	-3.00
75	7F7D073D4A	910915	920918	369	126.70	127.70	-1.00
	"	910915	921105	1	126.70	127.10	-0.40
76	7F7F075A72	920719	920919	62	127.10	127.00	0.10
77	7F7D07604C	910916	911112	57	63.90	63.70	0.20
78	7F7D077D5A	920518	920718	61	126.60	127.20	-0.60
79	7F7D08181F	920614	920615	1	61.30	61.30	0
80	7F7D081904	910908	910908	0	58.30	58.30	0
81	7F7D081F7B	910908	920709	305	58.80	58.80	0
82	7F7D084D01	910911	920510	242	108.10	108.10	0

Table C-2 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
83	7F7D085017	910908	921102	421	58.30	58.30	0
84	7F7D085056	920615	920912	89	61.30	60.90	0.40
85	7F7D085367	920719	920918	61	128.30	127.00	1.30
86	7F7D140108	920113	920509	117	60.70	61.50	-0.80
87	7F7D17336C	910913	910913	0	62.00	62.00	0
88	7F7D177318	910913	920408	208	62.70	61.50	1.20
89	7F7D177356	911111	920409	150	61.90	61.50	0.40
90	7F7D180A5A	920815	920815	0	62.60	62.60	0
91	7F7D18100E	921103	921103	0	60.40	60.40	0
92	7F7D181478	920713	921105	115	61.15	60.50	0.65
93	7F7E430660	920308	920912	188	61.25	60.40	0.85
94	7F7E430D1E	920114	920114	0	60.80	60.80	0
95	7F7E43193F	911112	911115	3	63.70	68.00	-4.30
96	7F7E432637	920311	921103	237	61.30	60.50	0.80
97	7F7E432646	911109	920309	121	60.70	61.10	-0.40
98	7F7E432721	920310	920716	128	61.85	62.50	-0.65
99	7F7F041527	920910	920910	0	58.80	58.85	-0.05
100	7F7F050906	920709	920911	64	58.80	58.85	-0.05
101	7F7F1F111E	920713	920713	0	114.90	114.90	0
102	7F7F1F1508	920718	920718	0	127.60	127.60	0
103	7F7F1F6B4F	911109	920307	119	60.40	60.15	0.25
	"	911109	920912	308	60.40	60.40	0
104	7F7F217E36	920508	920509	1	61.90	61.90	0
105	7F7F272652	920111	920709	180	58.90	58.90	0
106	7F7F2D512F	920910	920910	0	76.30	76.30	0
107	7F7F321C62	920713	920912	61	61.30	60.20	1.10
108	7F7F332F28	920709	920710	1	58.80	58.60	1
109	7F7F334240	921104	921104	0	60.90	60.90	0
110	7F7F334466	921103	921103	0	60.35	60.40	-0.05
111	7F7F334836	920816	920816	0	63.00	63.00	0
112	7F7F3E3542	910915	911113	59	64.40	64.40	0
113	7F7F3E485A	920215	921105	264	61.50	60.50	1.00

Table C-2 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
114	7F7F3E594F	920312	920508	57	63.70	61.90	1.80
115	7F7F3E6117	920614	920616	2	62.70	62.70	0
116	7F7F3F3764	910914	911112	59	64.70	64.75	-0.05
117	7F7F3F3A24	910915	910915	0	63.20	63.20	0
118	7F7F3F451B	910912	921105	55	61.20	60.40	0.80
119	7F7F3F4E04	910913	920715	306	62.00	61.80	0.20
120	7F7F450369	910914	920718	308	64.70	65.20	-0.50
121	7F7F450C5C	910913	920115	124	62.00	62.15	-0.15
122	7F7F475E72	920308	920410	33	61.50	61.50	0
123	7F7F477E4F	920718	921108	113	65.20	64.20	1.00
124	7F7F48015B	920718	920718	0	127.60	127.50	0.10
	x			153.87			0.90
	MIN			0.00			0.00
	MAX			662.00			61.50
	N			139.00			139.00

APPENDIX D - DEVELOPMENT OF A POPULATION MODEL FOR HUMPBACK CHUB IN GRAND CANYON

Report No. TR-250-07
BIO/WEST, Inc.

DEVELOPMENT OF A POPULATION MODEL FOR HUMPBACK CHUB (Gila cypha) IN GRAND CANYON
Phase I: A Feasibility Evaluation

Submitted to

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March 8, 1993

SUMMARY

The feasibility of developing and implementing a population model for the endangered humpback chub (Gila cypha) in Grand Canyon was evaluated. We determined that a modelling effort would be a valuable tool to identify and integrate existing data; to identify and quantify important state and rate variables; to estimate reproduction, recruitment, and survivorship; to identify parameters that most effect change; to help interpret monitoring data; and to analyze population viability. A conceptual model diagram is offered for evaluation and refinement by research biologists. We determined that age-structured models would be more useful than simple birth-death models. We recommend a phased approach to the modelling program, and proceeding with Phase II of this modeling effort--refine a conceptual model of humpback chub in Grand Canyon. Results of this modelling effort could facilitate data integration under the Scientific Integrated Management Program, aid the organization of the Integrated Humpback Chub Final Report, help interpret data from the Long-Term Monitoring Program, and aid decision-makers under adaptive management of the Glen Canyon Dam operations.

INTRODUCTION

Background

Comprehensive studies of the life history and ecology of the humpback chub (Gila cypha) in Grand Canyon are being conducted under the auspices of the Grand Canyon Environmental Studies (GCES), Phase II. These investigations are designed to provide input to state and federal agencies charged with the management and protection of this endangered species, and to address two of the seven conservation measures arising from the 1978 biological opinion on Glen Canyon Dam operations. Mainstem investigations are being conducted by BIO/WEST, Inc. (Valdez et al. 1992) and Arizona Game and Fish Department (Angradi et al. 1992a), while studies in the Little Colorado River are by Arizona State University (Douglas and Marsh 1992), Arizona Game and Fish Department (Angradi et al. 1992b), and U.S. Fish and Wildlife Service. The objective of this document is to assess the feasibility of developing and implementing a population model for humpback chub as part of these investigations.

The need for a population model was identified in the development of objectives for these GCES studies of humpback chub. The objectives of the combined investigations are:

Objective 1: To determine the ecological and limiting factors of all life stages of humpback chub in the mainstem Colorado River, Grand Canyon, and the effects of Glen Canyon Dam operations on the humpback chub.

- 1A: Determine the resource availability and resource use (habitat, water quality, food, etc.) of humpback chub in the mainstem Colorado River.
- 1B: Determine the reproductive capacity and success of humpback chub in the mainstem Colorado River.
- 1C: Determine survivorship of early stages of humpback chub in the mainstem Colorado River.
- 1D: Determine distribution, abundance and movement of humpback chub in the mainstem Colorado River, and effects of dam operations on the movement and distribution of humpback chubs.
- 1E: Determine important biotic interactions with other species for all life stages of humpback chub.

Objective 2: Determine the life history schedule for the Grand Canyon humpback chub population.

- 2A: Develop or modify an existing population model from empirical data collected during the study for use in analyses of reproductive success, recruitment and survivorship.

Although only Objective 2A specifically addresses the development of a population model, models could also aid in meeting Objectives 1B, 1C, 1D, and 1E.

Modelling Program Overview

Modelling efforts are often conducted in a phased approach with specific tasks completed before proceeding to the next. The appropriateness and suitability of the modelling effort are evaluated at the end of each major phase. A modelling program for humpback chub in Grand Canyon would be best managed through a phased approach. Phase I is the production of this feasibility evaluation on modelling humpback chub populations in Grand Canyon. For the chub research effort, this evaluation examines the role and use of models, objectives of a modelling program, types and applicability of models, parameter estimation for models, and future tasks that could be accomplished with a modelling program. Each of these is discussed below in detail.

The modelling tasks identified in this evaluation can be placed in four other phases. Phase II would involve the production of a conceptual model for humpback chub in Grand Canyon. Phase III would be the assimilation of data on humpback chubs, initial parameter estimation and model development, and aiding in the production of the "Integrated Humpback Chub Final Report". Phase IV would entail using the modelling program to help design the monitoring program and evaluate these monitoring efforts. A fifth phase would be used to conduct a viability analysis on this population. Each phase would be conducted sequentially, except that Phases IV and V may overlap. The tasks identified in each of these phases are listed below in the section "Tasks of the Modelling Effort".

THE ROLE OF MODELS

It is best at the outset to define the role of models, since research biologists often perceive that modelling efforts can become a major driving force in the research and decision-making process. Models are best used as tools that help researchers and decision-makers define problems and organize thoughts (Starfield and Bleloch 1986), quantify factors that are not easily or directly measurable (Vaughan and Saila 1976), integrate factors to assess their effects on system dynamics (Forrester 1961), and examine the consequences of complexity (Thornley and Johnson 1990). These tools are best utilized along with laboratory and field experimentation in the problem solving/decision-making process (Beyschlag et al. 1993). While models allow for the investigation and integration of system dynamics, their outputs are of minimal value unless they can be supported by findings involving direct measurement. This use of models as a tool, integrated into the consolidated research framework, is proposed as the modelling effort with humpback chub in the Grand Canyon.

Rationale

Population studies are usually approached in one of three ways (Smith and Fowler 1981). The first is a natural history study, which is primarily descriptive in nature. Much of the work on humpback chub, to date, has been of this type. Descriptive information is essential to defining a population, its distribution, and basic ecology, and to formulate concepts on the dynamics of the population. The second approach is the development of conceptual models which are usually flow charts and written narrative. These conceptual models are designed to help interrelate and understand various components of the population and its environment. The third approach is to develop formal mathematical models to describe population components and functions, and their dynamics. All three approaches overlap, to some extent, and a holistic approach to the study of population dynamics involves the integration of all three. This integrated approach is recommended in this modelling effort--to develop conceptual and mathematical model aspects and integrate them with natural history studies of humpback chub of the past and present.

The humpback chub in Grand Canyon lends itself to the development of conceptual and mathematical population models for several reasons. First, the species in readily accessible for study (albeit difficult at times!). Methods have been developed and refined for capturing the fish and for collecting information on several life history parameters. Second, much research has already been conducted on this species, prior to and including the present studies. This sizable database will be useful in identifying parameters and interactions for developing a population model. Third, the chubs occupy a relatively closed system, bounded by barriers (Glen Canyon Dam and waterfalls) or unsuitable habitat (Lake Mead). This minimizes problems with random immigration and emigration, that are often difficult to quantify. Finally, the life history of these fish is similar to many freshwater species, and the results of modelling efforts for other fish species may be useful in understanding humpback chub population dynamics. Of the four mainstem Colorado River endangered fish species (i.e., Colorado squawfish (Ptychocheilus lucius), razorback sucker (Xyrauchen texanus), bonytail (Gila elegans) and humpback chub), the humpback chub in Grand Canyon is the most favorable for a productive modelling effort.

A modelling effort will facilitate data integration, as well as development and interpretation of future monitoring efforts in Grand Canyon (Fig. 1). It can be used as an organizing and integrating tool for the production of the Integrated Humpback Chub Final Report, and could aid decision-makers in the "Adaptive Management" of Glen Canyon Dam. Data needs for the modelling effort should be coordinated through the Principal Investigators Scientific Integration team to ensure that all necessary and pertinent data are available or are being collected.

OBJECTIVES

The first step to any modelling effort is defining clear objectives (Innis 1979). As stated above in Objective 2A of the comprehensive investigation, the modelling effort is "for use in the analysis of reproductive success, recruitment and survivorship" of humpback chub. While certainly useful in this context, a modelling effort could have broader application in the context of the GCES studies. The following are objectives for a comprehensive modelling effort of humpback chub in Grand Canyon. These objectives were selected because of their importance to the GCES investigations, and are considered objectives likely to be met. This list of objectives is not exhaustive, and may grow through the course of the modelling effort. The first objective formulates a conceptual model for humpback chub in Grand Canyon, while the other four objectives use models with mathematical formulations based upon the conceptual model.

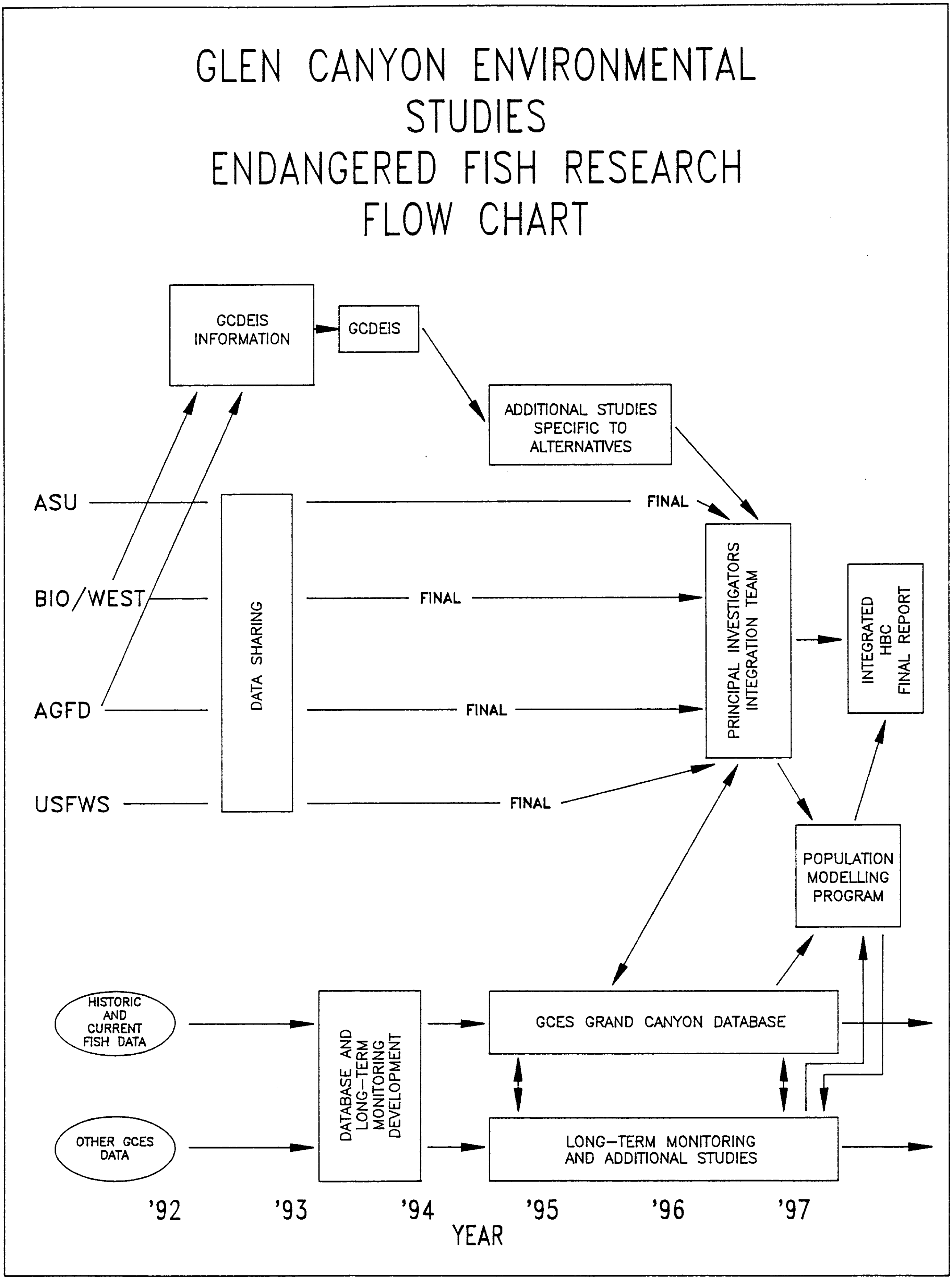

Fig. 1. Flow chart of Glen Canyon Environmental Studies Endangered Fish Research Program illustrating the inclusion of a modelling program.

Objective 1 -- Develop A Conceptual Model

The first objective would be to develop a conceptual model of humpback chub populations in Grand Canyon. This conceptual model would be designed to provide a framework of the present understanding of humpback chub in Grand Canyon. A preliminary diagrammatic scheme of this model is shown in Fig. 2. Important parameters are the estimated numbers of individuals in various age groups (state variables) within defined components of the system, and reproductive, survival, and movement rates (rate variables) between these age groups. The conceptual model does not contain values for the state or rate variables, but simply identifies the parameters and inter-relationships of the population, as well as abiotic and biotic factors affecting each variable.

The conceptual model should be reviewed and refined with input from past and present researchers of humpback chub in Grand Canyon. This model will provide the organizational framework to help assess the current knowledge of the population, where data are missing, and how various management practices may affect the population. The framework may change with new information or needs from managers and decision-makers.

This conceptual framework will be extremely useful in integrating the information collected by the present group of researchers in Grand Canyon. This integration is necessary for the preparation of the integrated humpback chub final report which addresses the overall GCES objectives listed above. The conceptual model will be useful in organizing and assessing the status of data collected for all of the GCES project objectives.

The conceptual model also provides the framework for a quantitative modelling effort used to address the following four objectives. While mathematical formulations rarely include the entire conceptual model structure shown in Fig. 2, this consensus picture of the population is essential in designing any model to meet other objectives.

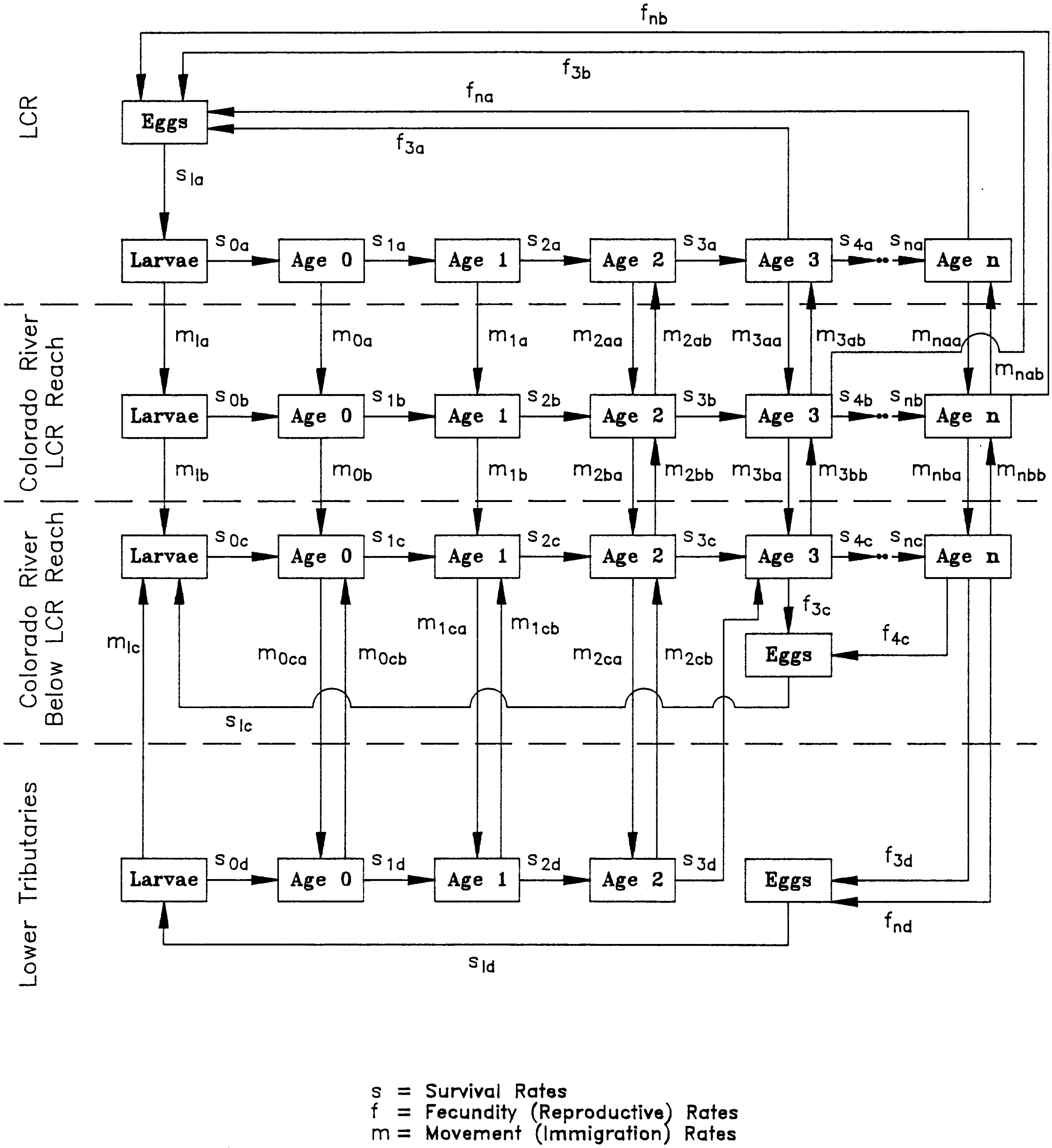

Fig. 2. Conceptual model of humpback chub population in Grand Canyon. Four components--Little Colorado River (LCR), LCR reach of Colorado River, Colorado River below LCR reach, and lower tributaries. Abundance in age groups are shown by boxes while solid lines indicate progression from one age to another, or movement of fish. Rates are indicated as: s = survival, f = fecundity, and m = movement.

Objective 2 -- Estimate Reproductive, Recruitment And Survivorship

The second objective of the modelling effort is to aid in the estimation and analysis of reproductive success, recruitment, and survivorship. This objective is essentially the same as GCES Objective 2A and similar to Objectives 1B and 1C. One aspect of this objective is to estimate life history parameters that are difficult to measure. With information on some life history parameters, others can be estimated using a model with stated assumptions of population trajectory (Vaughan and Saila 1976, Van Winkle et al. 1978, Deangelis et al. 1980, Manly 1990). For example, if estimated adult population size and survival rates are known, the recruitment rate needed to maintain a stable, or increasing, population can be calculated. Such calculated rates can be compared with estimates from field measurements to determine if recruitment is sufficient to maintain the population, and to assess the effect of high variation in recruitment on population dynamics.

In addition, rate parameters affected by density of some aspect of the population (density dependence) may be identified with a model (Van Winkle et al. 1978, Manly 1990). For example, the robust condition of adult chubs in the mainstem Colorado River suggests that factors affecting survival of younger age groups (perhaps density) may be limiting the number of fish that reach maturity as hypothesized for many fish by Gulland (1965).

This objective will also assess the importance of reproductive success and recruitment of various components of the population (e.g., mainstem Colorado River vs. Little Colorado River [LCR]). This analysis may give insights to the significance of chub recruitment in the mainstem relative to that from the LCR. Perhaps there is enough recruitment from the LCR to maintain the population, and contributions from the mainstem component are minimal.

Objective 3 -- Identify Parameters That Effect Changes

The third objective of this modelling effort is to identify the parameters that most effect changes in the population. The relative change in potential population growth rate caused by changes in life history parameters can be effectively assessed with population models (Horst 1977, Caswell 1978, Caswell 1988). This "sensitivity analysis" would help focus the monitoring effort by identifying key monitoring parameters to ascertain the status and trajectory of the population. In addition, it would help identify life history parameters that may have the biggest effect on the population in response to environmental change (see also Objective 5). This may include investigating environmental changes that have detrimental effects (e.g., reducing food supply, increasing predation), or management schemes that may prove beneficial to the population (e.g., temperature and flow modifications, predator reduction).

Objective 4 -- Interpret Monitoring Data

The fourth objective is to aid in the interpretation of monitoring data. Monitoring activities will be limited to parameters that are readily measurable, but not likely to totally portray population trajectory. Population modelling will provide a way to inter-relate monitoring parameters and assess population status.

The combined endeavor of linking the modelling effort with the monitoring program, will provide a better assessment of population status and the means to modify the monitoring program, as well as identify areas needed for further study. This will be particularly useful when monitoring results do not fit expected model outputs, based on the present level of understanding of the population.

Objective 5 -- Viability Analysis

The fifth objective would be to conduct a viability analysis of the humpback chub population in the Grand Canyon. This analysis could include the present population, as well as the effects of a second spawning population.

The analysis of species viability--or vulnerability to extinction--is rooted in the theory of island biography (MacArthur and Wilson 1963,1967). The theory contends that the persistence of plant and animal species is related to island size and became the basis for later work in defining refuge sizes (Diamond 1976, Diamond and May 1981, Soulé 1987). The probability of species persistence has been assessed for whole systems (Forman et al. 1976, Lovejoy 1980), as well as individual populations (Frankel and Soulé 1981, Shaffer 1981). Persistence of whole systems and persistence of individual populations are generally interrelated, and key species are sometimes used to assess the viability of whole systems (Frankel and Soulé 1981, Soulé and Simberloff 1986).

The vulnerability of a population is often expressed as the minimum viable population (Soulé 1987) that would have a high probability of surviving for a long period of time, e.g., a 95% probability that the population survives for 1000 years (Allen et al. 1992). Because of species differences in life history strategy, the minimum viable population size, and number and sizes of refuges is not easily generalized (Simberloff and Abele 1976, Simberloff and Abele 1982, Soulé 1987).

Shaffer (1981) listed four sources of uncertainty that affect population viability: 1) demographic uncertainty, 2) environmental uncertainty, 3) natural catastrophes, and 4) genetic uncertainty. Demographic uncertainty of humpback chubs would result from random changes in survival, recruitment, and population distribution. Environmental uncertainty would result from changes in food supply, populations of competing or predatory fishes, parasite infestation, and water flow regimes from Glen Canyon Dam and the LCR (as flows affect water temperature, turbidity and volume). Catastrophes affecting chub populations may include the release of toxic chemicals into the river system, introduction of a deadly disease or debilitating parasite, and major storm events that cause significant habitat changes. Genetic uncertainties result from changes in gene pool caused by genetic drift, and inbreeding that may affect reproductive or survival rates.

Environmental (Allen et al. 1992, Shaffer 1987) and demographic uncertainties--as related to population distribution and connectivity (Gilpin 1987)--are the most likely factors affecting the persistence of humpback chub in Grand Canyon. Modelling efforts to assess population viability should include investigating the effects of demographic and environmental uncertainties, as well effects of catastrophic events. Genetic uncertainty is unlikely to affect the present humpback chub population in Grand Canyon, because the present size likely exceeds that considered necessary for maintaining genetic diversity (Frankel and Soulé 1981, Franklin 1980).

TYPES OF MODELS

The formalization of conceptual models into mathematical entities generally produces one of two basic types of fish population models: 1) simple birth-death models, or 2) age- and stage-structured models. Both can be structured as deterministic (non-random) or stochastic (random components) models and can include the effects of density on various rates. Each of these model types is evaluated for its applicability in modelling humpback chub population dynamics to meet the above objectives.

Simple Birth-Death Models

These models characterize the rate of change in population size in terms of average population birth and death rates (Renshaw 1990). The population can be characterized by unbounded growth or decline, or its growth rate can be limited by the feedback of density--as in the familiar logistic population growth model. These models are characterized by the lack of any age structure, and assume average rates of reproduction and survival across the entire population. Time lags are often built into these models in an attempt to account lengthy maturation times (Goel et al. 1971, Braddock and Van Den Driessche 1981). These models are most applicable when all life stages of a species are subject to similar ecological pressures.

The uses of this model formulation is varied and widespread ranging from characterizing population growth or decline of many organisms (Goel et al. 1971, Starfield and Bleloch 1986, Renshaw 1990) to calculating persistence times in viability analyses (Leigh 1981, Belovshy 1987, Allen et al. 1992). One significant use of these models in fisheries is the development of catch-based models for harvested fish populations (Gulland 1983, Schnute 1985). Stock-recruitment or surplus-yield models have been significant components of fisheries management based on the assumption of density-limiting population growth (e.g., Ricker 1973, Getz 1980, 1984, Gatto and Rinaldi 1980, Walter 1981, Fowler et al. 1982, Policansky 1986).

The use of simple birth-death models is limited in characterizing humpback chub populations to meet the above objectives. The major drawback is the inability to separate life stages into individual units, that often behave differently and subject to different ecological needs and environmental conditions. In addition the large body of catch-based models, applied to harvested fish populations, has limited value is assessing the humpback chub population. However, these birth-death models may be used to assess the dynamics of specific age groups of chubs, and in a general way, to assess the population persistence.

Age- and Stage-Structured Models

Age- and stage-structured models have their foundations in the work of Bernardelli (1941), Lewis (1942) and Leslie (1945). These models are based upon the division of a population into distinct age, size, or stage classes, and allow for assessment of population dynamics assuming different reproductive and survival rates for each class. They were developed for populations with age- or stage-specific differences between classes.

The simplest form of these models are projection (Leslie) matrices used to calculate population size in each of **m** age groups in time **t+1** from the population in time **t** (Fig. 3). The square projection matrix **A** contains rates of reproduction and survival for each of the **m** age groups. The model structure has been modified slightly to account for stage-based populations-- those whose structure are more readily assessed by size or developmental stage instead of age (Lefkovitch 1965, Caswell 1982, 1988).

These models have been refined substantially since their original formulation (Usher 1972). The application of these models has assumed that the rates in the projection matrix are stochastic in nature (Pollard 1966, Getz and Haight 1989), functions of density (Leslie 1948, 1959, Smith 1973, Pennycuick 1969, Fowler 1987), and functions of environmental factors (Horst 1977, Vaughan 1981). The flexibility

$$\begin{bmatrix} f_1 & f_2 & \cdots & f_m \\ p_1 & 0 & \cdots & 0 \\ \vdots & p_2 & & \vdots \\ \vdots & & \ddots & \vdots \\ 0 & \cdots & p_{m-1} & 0 \end{bmatrix} \begin{bmatrix} n_{1,t} \\ n_{2,t} \\ \vdots \\ n_{m,t} \end{bmatrix} = \begin{bmatrix} n_{1,t+1} \\ n_{2,t+1} \\ \vdots \\ n_{m,t+1} \end{bmatrix}$$

$$\mathbf{A} \qquad N_t \qquad N_{t+1}$$

Fig. 3. Projection matrix model for calculating the population of a species at time **t+1** (**N_{t+1}**) from the population at time **t** (**N_t**) using the projection matrix **A** (from Fowler and Ryel 1978).

of this modelling structure is in the ability to make each element of the projection matrix a function of any factor affecting it.

Age- and stage-based models have been used for a assortment of organisms, including insects (Lefkovich 1965, Horst 1976), large mammals (Fowler and Smith 1973, Ryel 1980, Fowler 1981), and trees and herbaceous species (Hartshorn 1975, Meagher 1982, Law 1983). Fish populations have also been assessed with these models and they have been applied to assess harvest yield (Walters 1969, Jensen 1974, Quinn 1981, Law and Grey 1988), to quantify effects of environmental factors (Horst 1977, Vaughan 1981), to estimate life history parameters (Vaughan and Saila 1976, Van Winkle et al. 1978), and to evaluate the significance of changes in life history on population growth rate (Caswell et al. 1984).

The age-structured model formulation would be the most useful in a modelling effort of humpback chub in Grand Canyon. The model format readily adapts to the conceptual model framework presented in Fig. 2. Past and present studies (see next section) will provide initial estimates of many of the model parameters. Environmental and density-dependent effects on various parameters can readily be incorporated into the model structure. This model structure would allow for addressing Objectives 2-5 of this modelling effort.

A complete model formulation for humpback chub in Grand Canyon--including parameter estimation of all the state and rate variables shown in Fig. 2--is unlikely. Instead, formulations will be based on needs, objectives and to some extent on available data. Thus, a general formulation of the population used in viability or sensitivity analyses, may contain much of the structure in Fig. 2, while a much reduced formulation may be used to estimate parameter values, or assess certain monitoring data where only a segment of the population is of interest.

PARAMETER ESTIMATION

Parameterization of an age-structured model for humpback chub in Grand Canyon should be possible with the volume of data available and being collected. As mentioned above, past and present research has accumulated a sizeable database on life-history parameters of humpback chub in Grand Canyon, as well as from five other populations (Black Rocks, Westwater Canyon, Desolation Canyon, Cataract Canyon, and Yampa Canyon). While this database will not provide estimates for all parameters identified in the conceptual model in Fig. 2, it will likely provide much of the needed information. These data are being assimilated in the Scientific Integrated Management program of GCES.

Parameter needs for an age-structured model fall into four basic categories: 1) age-class population size, 2) age-specific survival rates, 3) age-specific reproductive rates, and 4) age-specific and spatially-determined rates of movement (immigration and emigration). Studies in both the mainstem Colorado River and the LCR should supply information on many of these parameters.

Mainstem tagging studies may provide estimates of population size, as well as survival and fecundity rates of adults and subadults, by age group, living in the mainstem. In addition, sex ratios of these fish can be calculated. Tagging studies in the LCR should provide estimates of population size, sex ratio, and survival and fecundity rates of subadult and adult chubs in the LCR. The combination of data from the LCR and mainstem should provide an estimate of the exchange of fish between the two systems. Movement rates of subadult and adult humpback chub in the mainstem downstream of the LCR component may be assessed, but estimation of population size and survival and reproductive rates may be difficult.

Assessing abundance of younger chubs is likely to be more difficult. However, within the LCR, estimates of population size and survival may be possible through tagging studies--at least for individuals greater than 150mm. In addition, the rate of emigration from the LCR may be possible through coordinated efforts between the LCR and mainstem studies. Estimates of survival and movement in the mainstem may also be possible through tagging studies.

The effects of environmental changes on life-history parameters will be difficult to measure directly in most circumstances. However, such changes in parameter values can be investigated by hypothesizing bounds on the parameter value as affected by environmental change. These exercises are often beneficial to assess relative magnitude of an environmental change or perturbation.

TASKS OF MODELLING EFFORT

The following tasks are proposed to meet the Five objectives outlines above, and to integrate into the overall GCES study objectives. The tasks are ordered by a logical progression of execution, although some tasks would be conducted simultaneously.

Task 1 -- Refine Conceptual Model

The first task is refinement of the initial conceptual model diagrammed in Fig. 2. This refinement would be conducted by present researchers working on humpback chub in Grand Canyon. The object would be to identify all state and rate variables between compartments. Changes to this conceptual model diagram would be part of an ongoing effort as new information is gathered on the species. The conceptual model could then be used in the preparation of the Integrated Humpback Chub Final Report. This task meets the needs of Objective 1 and constitutes the work of Phase II.

Task 2 -- Develop An Age-Structured Model

This task would be to develop an age-structured model for the humpback chub population in Grand Canyon. A general formulation will be necessary to meet Objectives 3 and 5, with the potential that more specific formulations will have to be developed to address the parameter estimation needs and monitoring data evaluation of Objectives 2 and 4, respectively. This task will be conducted throughout the modelling effort and will be closely coordinated with the work performed under the other tasks. The initial model development would be conducted under Phase III with modifications and enhancements made under Phases IV and V.

Task 3 -- Evaluate Present Data

The third task would be to evaluate the present data as assembled by the Scientific Integrated Management program and is included in Phase III. Efforts would be made to estimate population sizes by age group and population sector, and to determine survival, reproductive and movement rates as outlined in the conceptual model. Estimates may be in terms of actual numbers or as relative magnitude. Significant omissions of data on important parameters may result in recommendations for future research efforts. This task would also be ongoing throughout the modelling effort as new data or interpretations became available. The model(s) developed in task 2 would be used to help meet the requirements of Objective 2, and the resulting parameter estimates calculated in task 3 would be used in tasks 4-7 to meet Objectives 3-5. Also this task would aid in the integration of data for the production of the "Integrated Humpback Chub Final Report".

Task 4 -- Conduct A Sensitivity Analysis

This task would be designed to meet Objective 3--that of conducting a sensitivity analysis to determine the life history parameters for which the population is most sensitive. The general model developed in task 2 would be used to help evaluate some of the questions concerning dam operations, as well as help determine monitoring parameters to measure. Results of this task would be used in the preparation of the Integrated Humpback Chub Final Report and in the design of the monitoring program. These efforts are included under Phase IV.

Task 5 -- Use Models To Help Interpret Monitoring Data

This task--also under Phase IV--would use model formations from task 2 to aid the interpretation of monitoring data. It would be done in coordination with the monitoring program. Thus, data on population size and rates of survival, reproduction, recruitment, and migration would be assessed in the framework of the whole population. This task would continue in conjunction with the monitoring program. Changes in the conceptual model and parameter estimates may come from this task. This task meets the needs of Objective 4.

Task 6 -- Viability Analysis

This task would conduct an initial viability analysis for humpback chub in Grand Canyon using the general model formulation from task 2. The probably of persistence of the existing population would be evaluated under various environmental and catastrophic uncertainties. In addition, the effects of establishing a second spawning populations of humpback chub in Grand Canyon would be addressed. This task meets the needs of Objective 5 and comprises the work in Phase V.

Task 7 -- Identify Additional Studies

The work specified in the above tasks may identify the need for additional studies. This task would help to design and integrate special studies to measure additional parameters needed in the assessment of humpback chub population dynamics. This task would be ongoing throughout the modelling effort, as needed. While it does not address a specific objective, this task may be necessary to the successful completion of any of the five modelling objectives. Recommendations for additional studies may come from Phases II through V.

RECOMMENDATIONS

1. Develop a phased modelling program as part of the investigations of humpback chub in Grand Canyon. Evaluate the effectiveness and objectives of the modelling program at the end of each phase. Redirect the modelling effort in response to the needs of the GCES research program.

2. Proceed with Phase II of the modelling program--refining a conceptual model of the humpback chub population in Grand Canyon for use in integrating the humpback chub research program and in producing the "Integrated Humpback Chub Final Report".

3. Use the modelling effort to help integrate data collected on humpback chub in Grand Canyon to aid in producing the "Integrated Humpback Chub Final Report".

3. Use an age- or stage-based population model structure in modelling efforts on humpback chub.

4. Integrate the modelling program with the monitoring effort, both in helping to design the program and in aiding the interpretation of monitoring data.

5. Conduct a viability analysis for humpback chub in Grand Canyon. Include in this analysis, the effects of different environmental changes and perturbations, and the significance of adding a second spawning population.

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APPENDIX D-1: EXPLANATION OF CONCEPTUAL POPULATION MODEL FOR HUMPBACK CHUB IN GRAND CANYON

Introduction

The conceptual population model for humpback chub in Grand Canyon is based on four population components, including 1) the Little Colorado River (LCR) component, 2) the Colorado River component near the LCR inflow, 3) the Colorado River component away from the LCR inflow, and 4) the tributary component. Each component is identified by state variables (i.e., eggs, larvae, age 0, age I, etc.), and rate variables (i.e., survival, reproduction, movement), as shown in Fig. 2.

The LCR Component

For the purpose of this model, all humpback chub in Grand Canyon are considered one population. Past and current research indicate that a large proportion of that population resides in the LCR (LCR component), all or most of the year. The numbers of fish that remain in this tributary year around, as well as the numbers that ascend annually from the mainstem to spawn, are unknown. There is presently no definitive evidence of reproduction by humpback chub in Grand Canyon outside of the LCR, primarily because cold water released from Glen Canyon Dam prevents maturation of eggs and survival of larvae in the mainstem. Some reproduction may be occurring in other tributaries (e.g., Bright Angel, Shinumo, Kanab, Tapeats, Havasu creeks), but evidence--such as gravid fish, incubating eggs, and larvae--has not been found in these streams.

The Colorado River/LCR Inflow Component

Current research shows that about 95 percent of the humpback chub in the mainstem Colorado River in Grand Canyon are found within a 13-km area around the LCR inflow. The relationship between this Colorado River/LCR inflow component and the LCR component is not clear. Radiotelemetry and extensive mark-recapture studies in the mainstem show that the majority of adults of the Colorado River/LCR inflow component annually ascend the LCR to spawn in February-May, and descent in June-July. These fish spawn simultaneously with adults of the LCR component in the lower 13 km of the LCR.

It is not presently known is some adults of the Colorado River/LCR inflow component remain for one or more years in the LCR before returning to the mainstem. Similarly, the numbers of adults of the LCR component moving into the mainstem is unknown.

Large numbers of young humpback chub (age 0 and age I) descend annually from the LCR into the mainstem Colorado River. It is not known if these fish are primarily the progeny of the Colorado River/LCR inflow component, of the LCR component, or a mixture of the two. Large numbers of young (age 0, age I), subadult (age II), and adult (age III+) humpback chub remain in the LCR year around, suggesting that the progeny of the LCR component primarily remains in the LCR. This evidence also supports the hypothesis that there are two distinct population components in the area--the LCR component, and the Colorado River/LCR inflow component.

The Colorado River Component Away From The LCR

About 5 percent of the humpback chub captured in the Colorado River in Grand Canyon, from 1990 through 1992, were found in regions of the Colorado River outside of the 13-km area around the LCR inflow. Little is known about these fish, including their origin, abundance, distribution, movement, reproduction, and survival. These fish have been found primarily in small local aggregations, usually in or near the inflow of Bright Angel Creek, Shinumo Creek, Kanab Creek, or Havasu Creek. Small aggregations have also been found in Stephen Aisle and Conquistador Aisle (RM 116-122), and Pumpkin Spring (RM 213) far below the LCR inflow, as well as Tiger Wash (RM 27), and Malagosa Canyon to Awatubi Canyon (RM 57-58), upstream of the LCR inflow. All sizes of fish are represented in the sum of these aggregations, but there is no conclusive evidence of local reproduction. Many of these fish may be emigrants from the LCR inflow component.

The Tributary Component

Small numbers of humpback chub have been historically and recently captured in a number of tributaries, including Shinumo Creek, Bright Angel Creek, Kanab Creek, and Havasu Creek. Thorough sampling has not been conducted in these tributaries to determine if these fish are tributary residents or emigrants from another component of the Grand Canyon population. Young humpback chub captured in these tributaries indicates either local successful reproduction or ascent by mainstem fish attracted by the warmer tributary temperatures.