Report No. TR-250-04
BIO/WEST, Inc.

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

ANNUAL REPORT - 1991
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Bureau of Reclamation
Upper Colorado River Region
Salt Lake City, Utah 84147

Submitted By

BIO/WEST, Inc.
1063 West 1400 North
Logan, Utah 84321

Richard A. Valdez, Ph.D.
Principal Investigator

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DISCLAIMER

KEY PERSONNEL

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

Richard Valdez - Principal Investigator
Bill Masslich - Project Leader
Bill Leibfried - Project Leader
Tony Wasowicz - Senior Biologist
Randy VanHaverbeke - Senior Biologist
Bryan Cowdell - Senior Biologist
Helen Yard - Biologist
Erika Prats - Biologist
Lydia 'Penny' Trinca - Database Manager
Leslie Brown - Data Analyst
Peter Weiss - Equipment Coordinator

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SUMMARY

FISH SPECIES COMPOSITION

Fifteen species of fish, including five natives and ten non-natives, were captured by BIO/WEST in the Colorado River in Grand Canyon from October 1990 through November 1991. The five native species included humpback chub (Gila cypha), razorback sucker (Xyrauchen texanus), flannelmouth sucker (Catostomus latipinnis), bluehead sucker (Catostomus discobolus), and speckled dace (Rhinichthys osculus). The most common non-native species included rainbow trout (Oncorhynchus mykiss), common carp (Cyprinus carpio), brown trout (Salmo trutta), and channel catfish (Ictalurus punctatus). Fifteen striped bass (Morone saxatilis) were captured in May, June, and July as far upstream as RM 159.5.

HUMPBACK CHUB HANDLED

A total of 964 humpback chub were handled during this investigation, including 281 young-of-the-year (YOY), 77 juveniles, and 606 adults. PIT (Passive Integrated Transponder) tags were injected in 619 adults and juveniles, including 53 adults which were also radiotagged. A total of 194 chub were recaptured, including 61 with BIO/WEST PIT tags (9.9% recapture rate), 47 with PIT tags from other researchers, and 80 with Carlin or Floy tags, fin clips, fin punches, or marking scars; 6 were multiple recaptures. Thus, 20.1 percent (194) of 964 humpback chub captured by BIO/WEST had been previously handled.

SEX RATIOS AND SIZES

Male:female sex ratio for 535 adult humpback chub was 45:55. Adult males averaged 346 mm total length (TL) (220-451 mm), and females averaged 359 mm (181-480 mm). Average weight of males was 392 gm (106-870 gm) and average weight of females was 472 gm (46-999 gm).

LONGITUDINAL DISTRIBUTION OF CHUB

Of 606 adult humpback chub captured, 569 (94%) were in a 13.5-km area between Malagosa Crest (River Mile, RM 57.0) and Lava-Chuar (RM 65.4). These fish were distributed approximately evenly upstream (6.9 km) and downstream (6.6 km) of the LCR (RM 61.3). Of 77 juveniles, 76 (99%) were captured within the same area. Of 281 YOY chub, 274 (98%) were captured in Reach 1 (RM 56.0 - 77.4), primarily downstream of the Little Colorado River (LCR).

CATCH RATES

Catch rates of juvenile and adult humpback chub were highest near the LCR inflow and decreased upstream and downstream in a bell-shaped distribution. In February, 1991, catch rates increased locally indicating local aggregations in eddies and deep return channels. Catch rates in the LCR inflow in March increased to four times higher than in February as a result of a pre-spawning aggregation. Catch rates in the mainstem were lowest in April and May, when the majority of adults were spawning in the LCR, but catch rates resumed pre-March levels in July when the fish returned to redisperse in the main channel.

PHOTOSENSITIVITY OF CHUB

Nighttime catch rates exceeded daytime catch rates for humpback chub in every month except March and September 1991. Pre-spawning aggregations and increased activity in March apparently made the fish more susceptible to daytime netting, and high turbidity in September allowed more daytime near-surface activity. These findings indicated that humpback chub were photosensitive except during pre-spawning aggregations and when turbidity reduced light penetration.

INFLUENCE OF TURBIDITY ON CHUB ACTIVITY

Near-surface activity of adult humpback chub was significantly higher (56% average percentage of radiotagged fish located, APFL) at high turbidity than at low turbidity (22% APFL). This was supported by net catch rates of adults and juveniles, and by average percentage of radio-contacts by remote telemetry stations. These findings supported the hypothesis that humpback chub were photosensitive and that turbidity was used as cover.

DESCENT OF YOUNG CHUB FROM LCR

Large numbers of young humpback chub were captured in the main channel downstream of the LCR from May through November 1991. Local fluctuations in numbers and size variation suggest that these fish descended from the LCR from May through September, with largest numbers in August and September. These fish ranged from 50-90 mm TL in May, 60-100 mm in June, 40-100 mm in July, 40-120 mm in August, and 40-125 mm in November, 1991. Most belonged to the 1991 year class (age-0), although some could have belonged to the 1990 year class (age-I).

CONDITION FACTOR

Relative condition factor (relationship between length and weight for the population) for humpback chub (TL $\geq$ 150 mm) was above 1.00 (population norm) from October 1990 to March 1991, and decreased to below 1.00 from March to June 1991. Relative condition factor remained low the rest of 1991 and was significantly less in November 1991 than in October 1990. The reason for this loss of condition is unknown and could be related to cyclic population phenomena, interim flows, or an invasion of the parasitic tapeworm, Bothriocephalus acheilognathi. This loss in condition was not attributed to handling since the majority of the fish used in this analysis were captured for the first time, and a comparison between first time captures and recaptured fish showed no significant difference in condition.

POPULATION ESTIMATES

A multiple mark-recapture population estimate in the main channel (RM 57.0 - 65.4) for humpback chub over 175 mm TL for March 1991 was 1,395 fish (95% C.I. = 916-2254), and an estimate for September was 2,407 fish (95% C.I. = 1,102-6,564). While we recognize that the March estimate was bound by 66 percent and 162 percent of the estimator, and the September estimate by 46 percent and 273 percent of the estimator, these population estimates provide a perspective of the size of the adult portion of the population in the mainstem near the LCR inflow.

FIDELITY OF HUMPBACK CHUB

Adult and juvenile humpback chub in the Colorado River in Grand Canyon exhibited a high degree of fidelity for specific river locales. Mean net displacement (direct horizontal distance from release point to last contact) for 48 radiotagged adult humpback chub observed an average of 86 days (5-178 days) was 1.34 km (0-5.55 km), and mean gross displacement (sum of horizontal movements) was 4.23 km (0-16.33 km). Of these 48 fish, 83.3 percent exhibited net displacement of less than 2 km. Similar movement was seen with 61 recaptured PIT-tagged fish at large for 99.3 days (0-297 days); mean net displacement was 0.83 km (0-5.79 km). One fish was found 99.0 km downstream of the release site and was excluded from this movement analysis. Of these 61 fish, 88.1 percent were recaptured within 2 km of their release point.

NEAR-SURFACE ACTIVITY OF ADULT HUMPBACK CHUB

Near-surface horizontal activity of radiotagged adult humpback chub appeared to be influenced by time of day, changes in flow stage (ramping), flow magnitude, and turbidity. The fish were more active at night than in the day, with increase activity in the presence of high turbidity. The effect of ramping on near-surface activity could not be identified since times of greatest flow change often occurred during crepuscular periods, when fish activity was usually greatest.

DRIFT MATERIALS

A total of 137 drift samples were analyzed. The three dominant taxa were Simuliidae, Chironomidae, and the amphipod, Gammarus lacustris. The filamentous green algae Cladophora glomerata was present in most samples, and terrestrial invertebrates were found occasionally.

FOOD HABITS

Stomachs of 82 fish were examined. Rainbow trout contained primarily Cladophora glomerata and aquatic invertebrates, primarily Gammarus lacustris and chironomids, but no fish remains were found. Brown trout contained primarily aquatic insects, but no fish. Fifteen striped bass stomachs were examined and most were empty. One 5.45-kg striper contained one 210 mm trout. Of 20 channel catfish captured from the LCR inflow, one contained a 150 mm flannelmouth sucker and a 170 mm bluehead sucker. One walleye contained one unidentified 50 mm fish. Stomachs of eight humpback chub were evacuated using a non-lethal stomach pump. Stomach contents included primarily Gammarus lacustris, aquatic invertebrates, and some Cladophora glomerata.

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INTRODUCTION

This Annual Report was submitted to Bureau of Reclamation (Reclamation) 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 report summarizes the results of this investigation for the calendar years 1990 and 1991. It integrates the findings of three field trips conducted in October, November, and December 1990, together with eleven field trips from January through November 1991. Trip Reports that detail all activities were submitted following each trip. This investigation was initiated by BIO/WEST, Inc. (B/W) on September 1, 1990, and is scheduled for completion on October 15, 1994 (due date for Final Report).

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 impact of Glen Canyon Dam operations on the life history and ecology of the 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.

Objectives

This mainstem investigation is being conducted by B/W concurrently with Arizona Game and Fish Department (AGF), and with tributary studies by the U.S. Fish and Wildlife Service (Service), AGF, and Arizona State University (ASU), all in cooperation with the Navajo Nation and the Hopi Tribe. These agencies 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.

B/W's field research was partitioned into two efforts. The first focused on the collection of life history information and habitat use of humpback chub in Reach 1 near the Little Colorado River (LCR). The second was a distributional survey and habitat data collection in Granite Gorge (Reach 2) and near Havasu Creek (Reach 3). Data collection was coordinated, where possible, with scheduled "research flows" (predetermined releases from Glen Canyon Dam) to determine the impact of dam operations on habitat conditions and fish populations in Grand Canyon. Radiotelemetry was used in Reach 1 in 1990 and 1991 to determine habitat use and movement of humpback chub. Use of radiotelemetry in areas other than Reach 1 may be implemented in 1993, pending a full evaluation of radiotelemetry and a more definitive description of downstream fish distribution.

STUDY AREA

This investigation was conducted in a 170-mile (275-km) region of the Colorado River in the Grand Canyon from Kwagunt Rapid (River Mile, RM 56) to Diamond Creek (RM 226) (Figure 1). This region was divided into three sampling reaches including: (1) Reach 1 from Kwagunt Rapid (RM 56.0) to below Red Canyon (RM 77.4), also known as the Upper Reach, (2) Reach 2 from RM 77.4 to Havasu Creek (RM 160.0), also known as the Middle Reach, and (3) Reach 3 from RM 160.0 to Diamond Creek (RM 226.0), also known as the Lower Reach. All sites were located by river mile (RM), or the distance in miles downstream from Lees Ferry. Lees Ferry is 15.1 miles downstream from Glen Canyon Dam.

Reach 1 (The Upper Reach)

Reach 1 was the uppermost reach of the study area. It extended 21.45 miles (35 km) from Kwagunt Rapid (RM 56.0) downstream to below Red Canyon or Hance Rapid (RM 77.4). The reach was characterized by two geomorphic strata (Table 1), Lower Marble Canyon and Furnace Flats (Howard and Dolan 1981, Schmidt and Graf 1990). Shoreline features 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 create talus shorelines with emergent boulders which enhance fish habitat. Tapeats Sandstone also creates characteristic ledge habitat that provides lateral and overhead cover for fish.

The precambrian sedimentary series first appears as the Nankoweap Formation as an angular uncomformity at RM 63, and from this point to RM 65.5, the shoreline is characterized by steep vertical walls, short talus slopes and large angular blocks. The Cardenas Basalt and Dox Sandstone of the Unkar Group have been angularly juxtaposed downstream of the Palisades Fault. The topographic features of the shoreline are derived from these formations which are present from Lava Canyon (RM 65.5) downstream to Escalante Creek (RM 75), in which the channel is open with boulder and cobble shorelines alternating with talus slopes and occasional vertical walls.

The LCR, the only perennial tributary in this reach, converges with the mainstem at RM 61.3. Several local drainages flow intermittently during rain spates in late July and August, introducing large amounts of sediment into the river. Large alluvial boulder fans at these inflows constrict the river channel forming numerous rapids. Five major rapids (60-Mile, Lava Canyon, Tanner, Unkar, Nevills) occurred in this sampling reach, together with nine minor rapids.

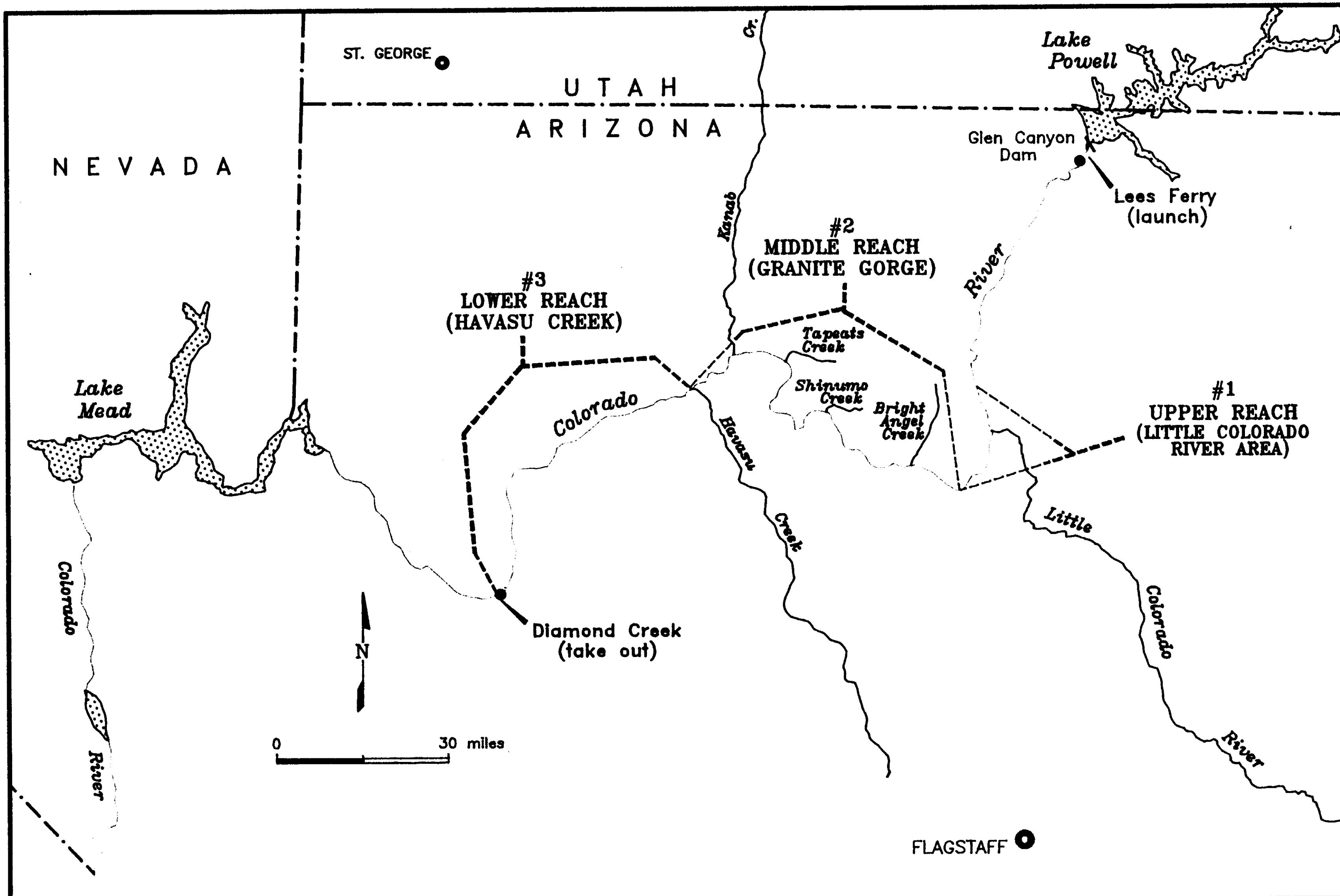

Figure 1. BIO/WEST study area in Grand Canyon and three study reaches.

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

Sample 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 Groge, Muav Gorge, Lower Canyon, and Lower Granite Gorge.

Water quantity and quality in this reach were influenced by releases from Glen Canyon Dam (76.5 miles upstream of the LCR), the Paria River (RM 1.0), Nankoweap Creek (RM 52.2), and the LCR (RM 61.3). Ephemeral drainages also added water volume, chemicals, and sediment to the reach at various times of year.

Fish habitat in this reach was dominated by runs, eddies, pools, and riffles. Eddy return channels, which created ephemeral backwaters at certain flows, occurred at a rate of about one per mile, based on 1:2400 scale aerial photographs of the area. Substrate was composed of 30 to 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. The river channel in the Lower Marble Canyon and Furnace Flats strata averaged 350 (107 m) and 390 feet (119 m) in width, respectively (Table 1).

The majority of humpback chub captured in the mainstem Colorado River in Grand Canyon have been found in this reach. Previous investigations (Kaeding and Zimmerman 1983, Maddux et al. 1987) showed that humpback chub seasonally entered the LCR in spring during spawning activity. It is suspected that many of these fish reside in the mainstem within this reach for the remainder of the year. Determining the extent of use of this river reach by humpback chub and impacts of dam operations on habitat are primary objectives of this investigation.

Fish populations in Reach 1 were sampled within each of four sample substrata (Table 2) with electrofishing gear, gill nets, experimental gill nets, trammel nets, minnow traps and hoop nets. All available habitats were sampled including runs, riffles, eddies, pools, eddy return channels, side channels, and slackwaters. General habitat parameters were documented to characterize fish capture locations including river mile, surrounding geology, and macrohabitat type. Sample locations were pinpointed on acetate sheets overlaid on 1:1200 scale aerial photographs. Radiotelemetry was used to document macro and microhabitat used by humpback chub as well as movement relative to season, time of day, river stage, and turbidity. Riverine habitat was mapped in detail starting in 1991 to characterize occupied, as well as unoccupied habitats. Chemical parameters were measured to further characterize habitat used by humpback chub and impacts of Glen Canyon Dam operations on water quality. Since the LCR empties into the upper 5 miles of this reach (RM 61.3), a concerted effort was made to coordinate with AGF and the Service to assess movement of fish between the LCR and mainstem Colorado River.

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

Sample 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

Reach 2 (The Middle Reach)

Reach 2 was 82.6 miles (133 km) long. It extended from below Red Canyon or Hance Rapid (RM 77.4) downstream to below Havasu Creek (RM 160.0). This reach was composed of four major geomorphic strata, including Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge (Table 1). Upper Granite Gorge, which extended from RM 77.4 to 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 the geomorphic strata of Grand Canyon. The river in Upper Granite Gorge flows primarily through Vishnu Schist (black), Zoroaster Granite (pink), and Hotautu Conglomerate, hard Precambrian formations about 1.8 billion years old which form steep canyon walls and smooth, scoured shoreline with little talus. This geomorphic stratum resembles 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.

The Aisles extend from RM 117.8 to RM 125.5 and include Stephen Aisle and Conquistador Aisle. This geomorphic strata is characterized by reappearance of Tapeats Sandstone in which the shoreline resembles that of the Reach 1 (RM 58 to RM 63). 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 was similar to that upstream of the LCR confluence.

Middle Granite Gorge extends from RM 125.5 to RM 140.0. The river in this geomorphic stratum flows through a combination of precambrian sedimentary, volcanic and metamorphic rock consisting of amphibolitic schist, limestones, diabase intrusives, and granitic plutons. These relatively hard materials have constricted the river to its narrowest point in the Grand Canyon of 76 feet (23 m). 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.

Muav Gorge extends from RM 140.0 to 160.0, where the river also flows through Vishnu Schist and Zoroaster Granite. This geomorphic stratum contains the river to its narrowest average channel width of 180 feet (55 m). Channel bed in this stratum had the highest percentage of bedrock and boulders (78%) of any geomorphic strata.

Eight perennial tributaries flow into the Colorado River within The Middle Reach (Clear, Bright Angel, Crystal, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks). These streams typically have low base flow with little impact on mainstem flows and local impact on water chemistry and biology. The majority of humpback chub found in this reach have been in close proximity to these perennial tributary inflows (Maddux et al. 1986), although the reach contains 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). This reach contains a short section of exposed Tapeats Sandstone (RM 120-130) with habitat similar to that found in Reach 1.

This 82.6-mile reach 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.

A detailed sampling program was developed for this reach to insure complete and thorough sampling. This is important when defining distribution of humpback chub because their affinity to specific river locales (Valdez and Clemmer 1982, Kaeding et al. 1990). The four geomorphic strata were subdivided into 13 sample substrata (Table 2). These were randomly selected 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. Tributary inflows identified for sampling were Bright Angel, Shinumu, Tapeats, Kanab, and Havasu creeks. This reach was sampled primarily with gill and trammel nets, and electrofishing. Radiotelemetry may be implemented in this reach in 1993 following further fish surveys and evaluation of radiotelemetry in 1992.

Reach 3 (The Lower Reach)

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). Lower Canyon extends from RM 160.0 to RM 213.9 with an average channel width of 310 feet (94 m) and a bed of only 32 percent bedrock and boulders. The river in this stratum was wide and continued to flow primarily through sedimentary strata consisting primarily of the Bright Angel Shale Formation, with shoreline characteristic of talus slopes with intermittent alluvial boulder fans. Tertiary lava flows extend downstream of RM 180 shaping much of the shoreline and fish habitat with emergent boulders and cliff features formed by columnar basalt. Lower Granite Gorge extends from RM 213.9 to RM 225.0. This geomorphic stratum had an average channel width of 240 feet (73 m) and a bed of 58 percent bedrock and boulders. This stratum consists of metamorphic and sedimentary features similar to the lower portion of Upper Granite Gorge. The formations consist primarily of granitic and granodioritic rock of the Zoroaster Granite complex intermixed with Tapeats Sandstone of the paleozoic strata.

This reach contained eleven 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, most formed by alluvial tributary fans. There are no significant perennial tributaries in Reach 3.

Sampling in this 66-mile (106 km) reach was conducted in the same manner as in Reach 2, with the primary objectives of surveying fish occurrence and distribution. Radiotelemetry will be used in this reach only if sufficient numbers of adult humpback chub are captured, and B/W and the ACT decide jointly to extend use of this monitoring tool. Sampling in this reach was conducted to collect information on distribution of native species, abundance by age group, habitat use, and changes in habitat availability with change in flows or discharge.

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.

EVALUATION OF METHODS

The methodologies used in this investigation were described in a **DATA COLLECTION PLAN** issued by B/W January 1, 1991, and revised in May 1992. This plan contains detailed information on field sampling and database management, and includes a **Fish Sampling Protocol, Fish Handling Protocol,** and **Database Management Protocol.** We refer the reader to this plan and the protocols for detailed information on sampling methods.

This section describes methods used in 1990 and 1991, and includes an evaluation of each to provide a perspective of advantages and short-comings. It includes a description and evaluation of sample schedules, fish sampling methods, fish handling methods, demography, radiotelemetry, habitat assessment, river flow/stage monitoring, drift studies, food habits and water quality.

Sample Schedules

Monthly and seasonal life history information on humpback chub in the mainstem Colorado River are vital to understanding possible seasonal patterns that may be impacted by operation of Glen Canyon Dam. Field trips were conducted monthly from October 1990 through November 1991 (Table 3). Research activities from October 1990 through June 1991 were designed to monitor fish activity and habitat changes in response to scheduled research flows from Glen Canyon Dam. Time spent on the river during each trip alternated monthly between 10 and 20 days such that seven 10-day trips (October and December of 1990; February, April, June, August, and October of 1991) and seven 20-day trips (November 1990; January, March, May, July, September, November of 1991) were conducted. Trip schedules planned for 1992 and 1993 are the same as conducted in 1991 (i.e., alternating 10 and 20-day trips with no December trip). Changes may be made to this sample schedule in a bilateral agreement between B/W and the ACT if it is determined that a particular season or area is critical and requires different sample effort. Our sample schedules were coordinated with AGF to provide concurrent sampling and comparable data. Following is a brief description of each type of field trip and an outline of daily activities.

Ten-Day Trips

Seven 10-day trips were conducted in 1990 and 1991, with the primary purpose to recontact previously radiotagged adult humpback chub and monitor movement and habitat use in the Reach 1. Fish were initially radiotagged in October 1990 (10-day trip), and initially tracked in November 1990 (20-day trip). Fish were also implanted in November before the routine was established of implanting fish on 20-day trips and tracking on 10 and 20-day trips (Figure 2).

Table 3. Planned BIO/WEST field trips on the Colorado River in Grand Canyon, 1990-1993.

	1990		1991		1992		1993	
Month	**10-D**	**20-D**	**10-D**	**20-D**	**10-D**	**20-D**	**10-D**	**20-D**
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	5	6
B/W People per Trip	6	10	6	10	6	10	6	10

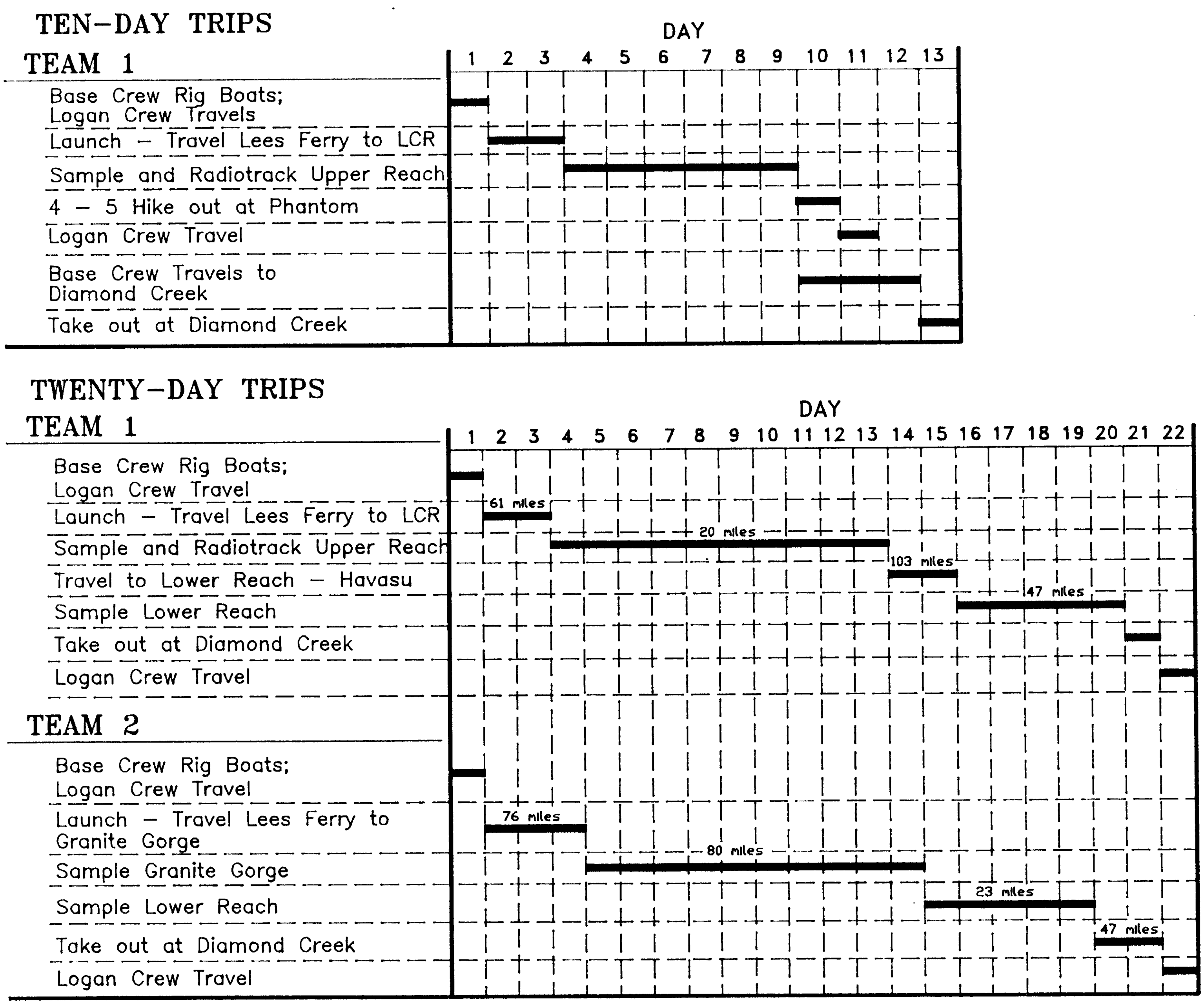

Figure 2. BIO/WEST's travel and sample schedules for 10-day and 20-day trips.

Each 10-day trip involved one field team with six B/W and two ACT biologists. Following sampling, three or four B/W people hiked out at the Bright Angel Trail (Phantom Ranch), while the remaining two or three proceeded to the Diamond Creek takeout to disassemble gear and return to Flagstaff. The team used two 17-foot B/W 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 10-day trips to capture additional fish for radioimplant, if needed. The research boats were usually rolled and loaded on the support boats for transport to and from Reach 1.

Twenty-Day Trips

Seven 20-day trips were conducted in 1990 and 1991. The purpose of the 20-day trips was to capture humpback chub for implanting radiotransmitters, monitor habitat use and changes with flow, assess limiting factors, determine important biotic interactions between humpback chub and other fish species, and survey composition and distribution of fish in the Grand Canyon.

The 20-day trips involved two independent field teams (Figure 2) each with a designated Project Leader with extensive river fisheries experience. The sample schedule for 20-day trips was designed to allocate approximately equal time to each of the three sample reaches. Team 1 had 6 B/W and 1 ACT biologists and worked in Reach 1, while Team 2 with 4 B/W and 1 ACT biologists worked concurrently in Reach 2. The two teams jointly sampled Reach 3 during the last 5 days of the trip. Thus, each of the three reaches was sampled for approximately 10 days.

Team 1 used two 17-foot B/W research boats (Achilles SH-170) for radiotracking and netting, and one SU-16 Achilles research boat for electrofishing. 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 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 the Grand Canyon.

Fish Sampling Methods

Electrofishing

Two electrofishing boats were designed and assembled by B/W and Reclamation biologists with similar systems. The two systems were tested in the area of Lees Ferry with the assistance of Mr.

Norm Sharber of Coffelt Manufacturing. Electrofishing was not used as extensively as anticipated in the first 3 months of the project because of time required to check and clean gill and trammel nets. Increased efficiency with setting and cleaning nets and additional personnel allowed for greater use of electrofishing starting in January 1991.

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 catch-per-unit effort (CPU), expressed as number of fish per 10 hours.

Electrofishing was conducted from SU-16 Achilles research boats with the capability to ascend and navigate 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 require 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, 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. Each fish was visually examined for evidence of injury associated with electrofishing. Fish showing signs of injury (e.g., bruise marks, spinal deformity, failure to recover) were noted, and the injury described in the database. Nontarget fish were released immediately after processing, generally within 0.1 to 0.2 mile of the point of capture. Humpback chub were transported to a central processing station near camp and returned to their capture location for release. This practice was changed 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 return fish to a central processing station.

Output settings on the CPS initially ranged from 15 to 20 amperes and 300 to 350 volts, as recommended by Coffelt Manufacturing for electrofishing in the Colorado River below Glen Canyon Dam (Personal Communication with Norm Scharber, October 9, 1990). The output setting was reduced to 8 to 10 amperes and 200 to 250 volts 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).

Ninety of 5,643 fish (1.6%) captured electrofishing exhibited some external effect (Table 4). This included 81 rainbow trout (75 adult, 6 juvenile), 6 adult brown trout, and 6 humpback chub (4 adult, 2 juvenile). Of 3,653 individuals of these three species, the most common effect (1.1%, n=64) was "bruise marks". Adult rainbow trout had the highest incidence of "bruise marks" and spinal deformity.

Humpback chub showed no evidence of bruise marks from electrofishing, possibly because priority was given to removing stunned chub from the water as quickly as possible. Three chub captured electrofishing in 1990-91 showed extended narcosis but quickly recovered and were released. In September 1991, a juvenile chub exhibited spinal deformity posterior to the dorsal fin. The fish was released after 8 hours when it regained equilibrium and was swimming normally. In November 1991, one juvenile and one adult, captured in the same electrofishing run, showed signs of stress including loss of equilibrium and lethargy. The juvenile was held and observed for about 10 hours and released following apparent recovery. The adult was held for 30 minutes and released. It was recaptured 3 days later by electrofishing 6.7 km downstream. The fish appeared sluggish, never regained equilibrium, and expired after 19 hours. The carcass was X-rayed, but examination was inconclusive. YOY and small juvenile chub (~50-150 mm TL) did not show signs of stress following electrofishing. Small fish are less affected by electrofishing because, at a given voltage gradient, total body voltage increases with length, resulting in greater electroshock to larger fish (Reynolds 1983).

Table 4. External morphological field observations of fish captured by electrofishing in the Colorado River in Grand Canyon, 1990-1991.

			Effect of Electrofishing					
Species[a]	Age Group	Total Captured	Bruise Mark	Spinal Injury	Equilibrium Loss	Extended Narcosis	Unspecified	Total
RB	ADU	3013	62	9	0	0	10	81
BR	ADU	601	2	0	0	0	4	6
HB	ADU	39	0	1	1	1	0	3
		3653	64	10	1	1	14	90

[a]RB=rainbow trout
BR=brown trout
HB=humpback chub

Table 5. Summary of radioimplant procedures on humpback chub in the Colorado River in Grand Canyon, 1990-1991.

	1990		1991							
Procedure[a]	**Oct.**	**Nov.**	**Jan.**	**Mar.**	**May**	**Jun.**	**Jul.**	**Sep.**	**Nov.**	**Total**
MGN	10(4)	7	7	7(2)	0	0	0	0	0	31
MXN	0	0	0	0	3	4	0	0	0	7
MXS	0	0	0	0	0	0	4	0	3	7
LXS	0	0	0	0	0	0	0	6	2	8
TOTALS	**10**	**7**	**7**	**7**	**3**	**4**	**4**	**6**	**5**	**53**

[a]MGN = midline incision, CV3 Gortex nonabsorbable sutures, no needle guide.
MXN = midline incision, 3-0 Maxon absorbable sutures, no needle guide.
MXS = midline incision, 3-0 Maxon absorbable sutures, with SNAG needle guide.
LXS = lateral incision, 3-0 Maxon absorbable sutures, with SNAG needle guide.

Nets

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, struggle very little following entanglement, sustain little external damage, and are quickly and easily removed from nets. Occasionally, a chub may swallow air when removed from the water and have 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 to expel the air.

Gill Nets. Gill nets were used extensively as primary sampling gear to characterize fish assemblages of shallow to deep shoreline habitats. This gear type was used to compare fish distribution and abundance by area and time, as well as to categorize general fish habitat use. 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 CPE expressed as number of fish per 100 feet of net per 10 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 nets were 100 feet long, 6 feet deep, and constructed of double knotted #139 nylon multifilament twine. Float lines 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 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 Cladophora glomerata or debris were replaced and cleaned regularly.

Trammel Nets. Trammel nets were also used to characterize fish assemblages and to document changes in fish distribution and abundance by area and time. Trammel nets consisted of three panels of netting, two outer walls of large mesh and one inner panel of a small mesh, all made 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.

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 shallow habitats. For each seine haul, length and width of habitat sampled was measured as well as maximum water depth. Length and width of the haul was also 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. These measurements allowed researchers to express CPE as numbers of fish per 10 square meters. Seines were not used extensively in 1990 and 1991.

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. Specimens that could not be identified afield and incidental mortalities were preserved in 3 to 5 percent formalin and placed in an appropriately labeled sample jar. All preserved fish were returned to the B/W laboratories for further identification and processing. Specimens were transferred annually to the Service or AGF as required by scientific collecting permits.

Three sizes of seines were used for this study including 30'x6'x1/4", 15'x6'x1/4" and 10'x4'x1/8" (length in feet x height in feet x square mesh in inches). 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.

Fish Traps

Minnow traps and hoop nets are generally considered low-impact capture techniques, although sample sizes in this study were too small to substantiate this. Only one humpback chub (51 mm TL) was found dead in a minnow trap. The trap was set in low velocity and cause of death was undetermined.

Minnow Traps. Unbaited minnow traps were used in 1991 to sample small fish in a variety of habitats including small embayments, rocky shorelines, 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.

Hoop Nets and Frame Nets. Hoop nets were used in various low velocity habitats such as slow runs, pools, and side channels. Three sizes of hoop nets were used, including 2'x 10'x ½", 3'x 12'x ½", and 4'x 16'x ½" (diameter in feet x length in feet x square mesh in inches). 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 the mouth was oriented in a downstream direction to capture fish moving upstream. Nets were checked at least every 8 hours to minimize stress and mortality.

Frame nets (similar to hoop nets except for frame shape and wing configuration) were set and used in the same manner as hoop nets. Fish captured in hoop and frame nets were placed in live wells for processing and released immediately near the point of capture.

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). The most effective baits included native grasshoppers, cheese balls, salmon eggs, artificial flies, and Mormon crickets. No live baits (e.g., Mormon crickets or grasshoppers) will be used on this project to avoid introduction of exotic insect species into the Grand Canyon ecosystem.

Although angling was not used extensively in 1990 and 1991, we plan to use it to capture humpback chub in deep pools that are inaccessible with other sampling gears. Angling for this species is also successful along vertical shoreline cliffs. This gear may also prove effective for capturing fish to determine feeding periodicity through stomach analysis. Fish captured by angling will be processed immediately and released. Angling effort will be recorded as time spent with line in the water.

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 (flannelmouth suckers, bluehead suckers, rainbow trout, brown trout, brook trout, carp, channel catfish, speckled dace, and plains killifish) were measured, weighed, and released immediately at the point of capture. Beginning in August 1991 (decided at ACT Meeting, July 19, 1991), all native fish (humpback chub, razorback suckers, flannelmouth suckers, bluehead suckers) over 150 mm TL were PIT-tagged (PIT = Passive Integrated Transponder), and B/W discontinued video footage of each humpback chub captured.

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 returned to a central processing station at base camp. Each chub was measured as total (TL), standard (SL), and forked length (FL); weighed in grams; PIT-tagged if over 150 mm TL; and photographed on a centimeter grid board. 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. Humpback chub large enough to radiotag (550 gm for 11-gm tags and 450 gm for 9-gm tags) were isolated in a live well and taken to the surgery tent (See Section on Radiotelemetry).

Demography

Population Estimates

The population of adult and juvenile humpback chub (fish longer than 175 mm TL) was estimated using Schnabel's Method of maximum likelihood estimate of N from multiple censuses (Ricker 1975) as expressed by the formula:

$$N = \frac{\Sigma(C_t M_t)}{\Sigma R_t} = \frac{\Sigma(C_t M_t)}{R}$$

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
$R = \Sigma R_t$ total recaptures during the experiment.

Limits of confidence were computed by treating R as a Poisson variable and 1/N distributed normally with a variance estimated by the formula:

$$V(1/N) = \frac{R}{(\Sigma C_t M_t)^2}$$

The square root of V(1/N) yielded an estimate of standard error and limits of confidence were calculated for 1/N using t-values for the normal curve. These limits were then inverted to give a confidence range for N.

This method assumes (1) no recruitment to the sample population, (2) mortality of marked fish equals mortality of unmarked fish, (3) marked fish become randomly distributed through the population so likelihood of capture is equal for marked and unmarked fish, and (4) migration to and from the population is minimal.

All humpback chub were marked with uniquely numbered PIT tags injected interperitoneally. The initial mark and release of fish was in October 1990, followed by monthly samples where previously marked fish were recaptured and additional fish were captured and marked. Sampling was conducted monthly for 14 months through November 1991, although sampling was most intensive on alternating months following the initial sample (i.e., November, January, March, May, July, etc).

The population of adult and juvenile humpback chub in the mainstem was estimated prior to spawning (based on marks and recaptures from October 1990 through March 1991), and after spawning (based on marks and recaptures from July through November 1991). No estimate was based on marks and recaptures from April through June since a large portion of the adult population moved from the mainstem into the LCR to spawn during that time.

Length-Weight Relationship and Condition Factor

Length-weight relationships were determined for each sample of humpback chub captured by monthly trip. The following power function was used (Anderson and Gutreuter 1983):

$$W = aL^b$$

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 logarithms (base 10) of both sides of the function using the GM method (Ricker 1975) such that:

$$\log W = \log a + b \log L$$

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

$$Kn = \frac{W}{aL^b}$$

where: W = weight in grams,
L = total length in millimeters,
a and b = constant and exponent from the length-weight relationship estimated from the GM method.

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 relative condition factor was computed for each monthly sample of humpback chub greater than 150 mm TL, except for February 1991, when the sample was only three chub. These condition factors were computed for all monthly samples using the same constant 'a' and exponent 'b' derived from a GM method regression using the pool of chub handled over 150 mm TL. This pool of fish (800) 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 (Kn) 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 testing.

Radiotelemetry

Fifty-three adult humpback chub were radiotagged in 1990 and 1991 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. Fish were implanted with transmitters every other month during the 20-day trips and monitored during subsequent 10 and 20-day trips. An effort was made to maintain 8 to 10 active transmitters in fish at all times.

Only fish in Reach 1 were implanted and most monitoring was conducted within an 8-mile area around the LCR confluence (RM 57-65). Three aerial surveillances were conducted, one each at the beginning of trips in December 1990, and February and March of 1991. This tracking mode was abandoned when it was determined that crepuscular and nocturnal near-surface activity by radiotagged humpback chub reduced our ability to locate fish during daytime flights. We also determined that these fish had a high affinity for the LCR confluence where tracking could be conducted by boat. Aerial and boat tracking were also conducted in Reaches 2 and 3 but no radiosignals were contacted outside of the 8-mile LCR reach. Similar fidelity has been reported in the only other radiotelemetry studies with this species in Black Rocks, Colorado (Valdez and Clemmer 1982, Kaeding et al. 1990).

Receivers, Antennas, and Transmitters

Receivers manufactured by Advanced Telemetry Systems (ATS) and Smith-Root (SR) were used to monitor humpback chub in the Grand Canyon. One research boat was equipped with a complete set of radiotracking equipment, and surveillances and observations were a scheduled task of the daily sampling routine of Team 1 working in Reach 1.

ATS Receiver. The ATS Model R2000 is a scanning-programmable receiver. It was used to receive radio frequencies of 40 to 41 MHz in omni-directional searching, directional triangulation, and in remote stations. This receiver was used because of its light weight, compactness, water resistant case, and compatibility with ATS radiotransmitters. It was easy to use with nearly unlimited capacity to quickly and easily add or delete frequencies.

The disadvantage of this unit was that it scans single preprogrammed frequencies instead of multiple frequencies simultaneously. The unit has an optional scan rate setting of 2, 4, 8, 16, or 32 seconds, or 1, 4, 8, or 16 minutes. If the unit has ten preprogrammed frequencies set at 4 second-intervals (time it scans a single frequency), it scans all ten frequencies in 40 seconds and therefore scans a given frequency every 36 seconds. ATS receivers were normally used at the 4-second scanning rate and all radiotelemetry searches and surveillences were conducted in a slow, methodical manner with observers using headsets to reduce the possibility of missing audible signals. The characteristic water-drop sound from radiotransmitters is audible through the ATS R2000, and the unit has a visual signal strength meter.

The ATS R2000 is portable with nickel-cadmium batteries that are rechargeable and replaceable afield. Twelve-volt marine batteries were used as power sources when the battery pack was low, but these became cumbersome when tracking from shore.

Smith-Root Receiver. The Smith-Root SR-40 was also used for omni-directional searching. This model receiver was previously used to successfully aerial and boat-track Colorado squawfish (Ptychocheilus lucius) and razorback sucker (Xyrauchen texanus) in the Green River, Utah (Valdez and Masslich 1992). The SR-40 was preferred for aerial tracking because it simultaneously scans multiple preprogrammed frequencies. This receiver emits audible and visual contact signals. A bank with ten red lights corresponding to preset frequencies, enables trackers to confirm audible with visual signals.

The disadvantage of the SR-40 is that it accommodates only ten preprogrammed frequencies that are set by the manufacturer. Although it receives signals from similar frequencies, it does not register weak signals. Unique frequency/pulse combinations are difficult to distinguish with this unit, particularly when multiple frequencies are contacted (multiple audible and visual signals emit simultaneously), or when two or more fish occupy the same area with transmitters of similar frequency and different pulse rates. Frequencies are also difficult to identify when fewer than five signal contacts occur. The Smith-Root RF-40 programmable receiver has been used as a companion to the SR-40 in past investigations (Valdez and Masslich 1992), but the unit is no longer manufactured. The SR-40 was used as a backup to the ATS R2000, or the two units were used simultaneously to insure complete surveillance coverage. Although the battery pack for the SR-40 was separate from the receiver, keeping these batteries charged was also difficult with different users and various power drains.

Antennas. Omni-directional Larsen-Kulrod whip antennas were used with ATS R2000 and SR-40 receivers for searching radiosignals. Smith-Root loop antennas were used for locating signals by triangulation. Breakage and fraying of the external sheath of the coaxial cable at the handle base of the loop antenna and near the base plate of the whip antenna required frequent checking and periodic maintenance. The ATS loop antenna was found unsatisfactory because exposed components were subject to breakage with field use.

Remote Stations. Remote stations deployed for this investigation were established under the guidance of Grand Canyon National Park. Two remote telemetry stations were established near the mouth of the LCR to monitor movement of radiotagged fish to and from the LCR. One station (KLCR), located immediately upstream of the LCR confluence (RM 61.3) and on the east bank of the Colorado River, had a directional yagi antenna aimed across the river at the upper mouth of the LCR. The second station (KRSH) was located downstream of the LCR confluence (RM 62.1) on the west bank of the Colorado River with a directional yagi antenna aimed across the river in line with the shallowest point in the channel. The antennas were not aimed directly across the LCR because previous tests (Yard et al. 1990) showed signal impedance from high conductance during clear flows. These stations were each equipped with a directional Proline low band yagi antenna (30 to 75 MHz). KLCR was operated continuously from February to mid- August of 1991, and KRSH was operated from mid-May to mid-July of 1991 (Figure 3).

A third remote station (KILR) was deployed in mid-August of 1991, about 1 km upstream of the LCR confluence on the east bank of the Colorado River. This station was equipped with an omni-directional Larsen-Kulrod whip antenna to monitor daily near-surface activity of radiotagged fish from RM 59.9 to RM 61.3.

Each of the three remote stations was equipped with an ATS Model R2000 receiver (data logger compatible) and a DCC-II Model R5041 data logger. Data were downloaded monthly (during field trips) with a portable computer. The receiver and data logger were housed in pad-locked weather-resistant boxes to prevent damage from elements and vandalism. Each station was properly identified in case it was discovered by someone not familiar with the project. The weather-proof boxes and yagi antennas were painted drab brown to camouflage the station and reduce visibility.

Several problems were encountered during installation and maintenance of the remote stations. Data loggers were not received from the manufacturer until May. One data logger was rented from ATS and used at the KLCR station, and the station was activated in February. No other compatible data loggers were available until May when the KRSH station was deployed. Problems with power supply were encountered when the stations were activated, resulting in several inactive logging periods. A solar-powered recharger was incorporated into the KLCR station in April to resolve power problems at that station. Data collected by the KLCR station in late June and early July were lost, because of suspected static power surges associated with electrical storms. Lack of adequate solar radiation in the canyon during winter months resulted in low power supply at the KILR site, and cold winter temperatures also adversely affected battery efficiency.

Transmitters. Two models of ATS radiotransmitters were used in this investigation. The ATS Model 1 BEI 10-18 weighed 9 gm and was 3.8 cm long and 1.3 cm diameter. The Model 2 BEI 10-35 weighed 11 gm and was 6.0 cm long and 1.3 cm diameter. Both models were oblong with an external antenna at one end that measured about 25 cm long and 1.2 mm diameter.

Frequencies of 40.600 to 40.740 MHz were used. These were separated by 10 KHz intervals (i.e., 40.600, 40.610, 40.620, etc.) to distinguish individual transmitters. This 10-KHz separation yielded 15 different frequencies. The combination of 15 different frequencies and 3 pulse rates (40, 60, and 80 pulses per minute) allowed for a total of 45 unique signatures to identify individual fish. The same combination of frequency and pulse was reused following expiration of a transmitter. Transmitter

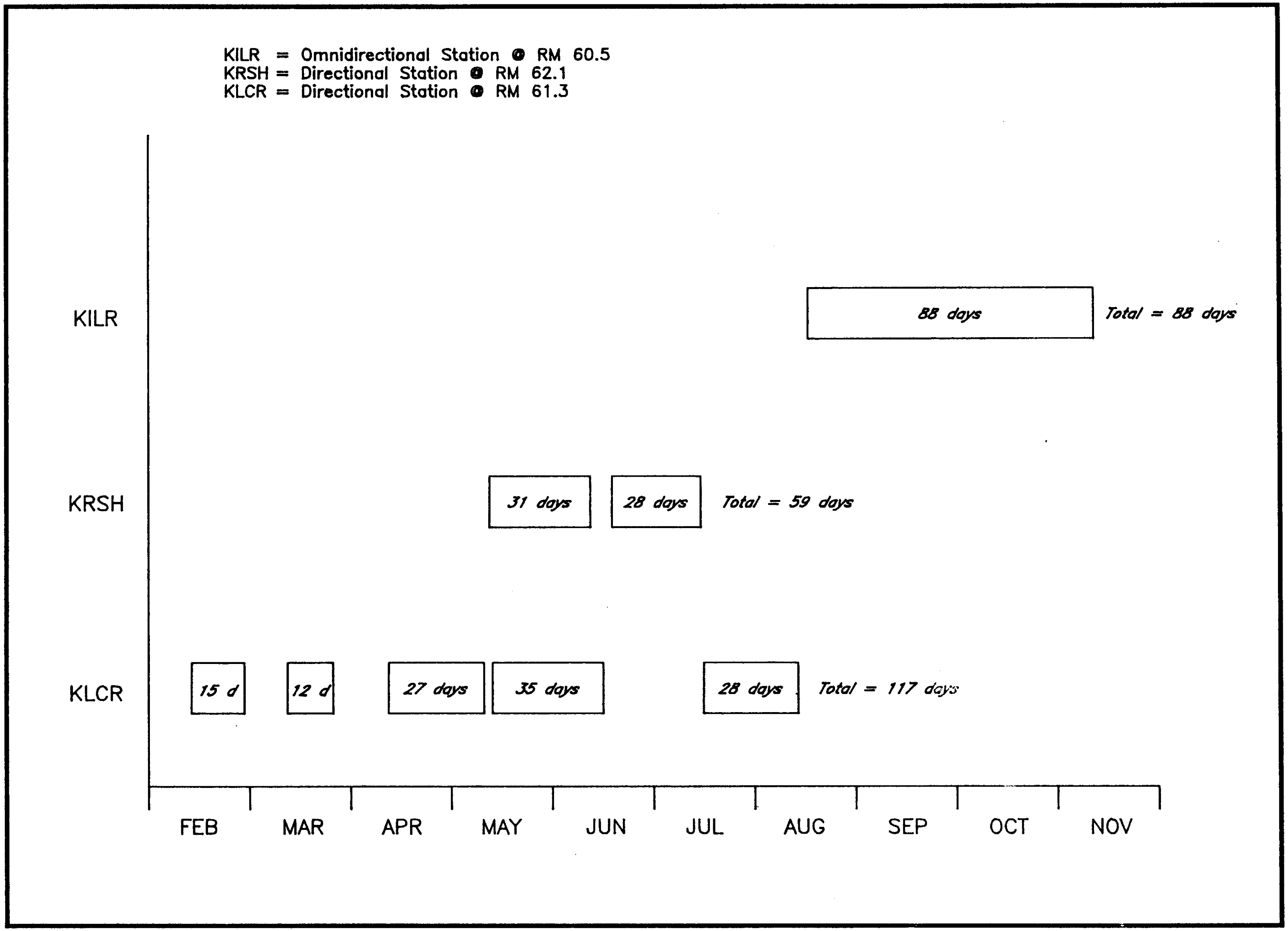

Figure 3. Summary of active logging periods for three remote telemetry stations on the Colorado River in Grand Canyon, 1991.

longevity was a function of battery life. The manufacturer's estimated life for the 9-gm transmitters was 50 days. The 11-gm transmitters with 40 pulses per minute were expected to transmit 120 days, those with 60 pulses per minute were expected to transmit 100 days, and those with 80 pulses per minute were expected to transmit 75 days. All transmitters were checked prior to implanting and immediately after release of the fish to insure that each transmitter was functional and that frequency and pulse rate were accurately recorded.

Yard et al. (1990) determined from field tests that signal reception from 9-gm external-antenna transmitters was effective at a depth of 4.63 m at a horizontal distance of 48 m on the mainstem Colorado River in Grand Canyon. The same transmitter in the LCR was received at a depth of only 0.91 m at a horizontal distance of 48 m. Internal antenna transmitters weighing 13 gm were simultaneously tested with signal reception in the mainstem of 3.96 m depth at 48 m distance, and in the LCR of 0.85 m depth at 48 m distance.

We tested signal reception depth of 11-gm external-antenna transmitters used in this investigation, and found an average depth extinction of 4.5 m at 50 m distance (three field trials of 4.5, 4.5, and 4.6 m). These results were similar to those reported by Yard et al. (1990). A specially developed internal-antenna transmitter (prototype: 13.2 gm, 7.5 cm x 1.3 cm) was simultaneously tested to ascertain if the external antenna could be eliminated while maintaining the same transmisivity and battery life with a transmitter of approximately 13 gm. Average signal depth extinction for the prototype was 3.2 m at 50 m distance (three field trials of 3.2, 3.2, and 3.2 m), or 29 percent less than for the 11-gm external-antenna transmitter.

We also tested signal reception distance, and found that at 1 m depth, the signal from the 11-gm external-antenna transmitter was received at a distance of 1200 m, while that of the prototype was received at only 600 m, or 50 percent of the distance. We concluded from these tests that the internal-antenna prototype was not suitable for our needs in the Grand Canyon, and we continued using the 11-gm external-antenna transmitters.

The transmitters performed as expected. Four of the six fish with 9-gm transmitters were monitored for 30 to 59 days for an average of 50 days, which was the manufacturer's estimated transmitter expectancy. The remaining two fish entered the LCR where high conductivity prevented continued monitoring. The 11-gm transmitters were monitored for 56 to 147 days for an average of 99 days, compared to the manufacturer's estimated transmitter expectancy of 75 to 120 days (weighted average of 93 days).

Although transmitter frequency and duration were consistent with manufacturer standards, considerable variation was seen in pulse rates. Of 29 transmitters with assigned pulse rates of 40, 60, or 80 pulses per minute, fifteen varied by more than 10 percent and two varied by more than 20 percent. This pulse variation could have caused problems with fish signatures, but was alleviated by implanting transmitters with similar frequencies in fish some distance apart. In only one case did fish with transmitters of the same frequency and similar pulse rates occupy the same area (during a spawning aggregation at the mouth of the LCR), but the pulse rates did not vary sufficiently to overlap and fish identity was maintained. A possible cause for pulse variation may be an effect of cold water temperature on the battery or transmitter circuitry.

Radiotransmitters were implanted without a wax coating following cold sterilization with 70 percent ethyl alcohol. Beeswax coatings have been used in earlier studies to provide an inert surface to minimize risk of rejection and expulsion (Tyus 1988). However, the manufacturers of the transmitters contended that the epoxy resin used to encase the electronic components was non-irritating and could be more effectively sterilized than beeswax (Personal communication with Michael Shuster, ATS, October 1990). Beeswax adds undesirable weight and bulk to the transmitter, which is critical with the small size of humpback chub.

Surgical Procedures

Extreme care was taken with surgical procedures to minimize stress to the fish and insure survival and normal behavior. A surgical protocol was established and the primary incision, antenna exit, and suture material evaluated. Each recaptured fish was carefully examined and photographed, and meticulous notes recorded on fish condition. The following is a description and evaluation of each aspect of radiotelemetry used in this investigation.

Surgical Protocol. A detailed surgical protocol was established to minimize stress to the fish and prevent bacterial contamination. The protocol was developed from procedures established by Tyus (1982) for Colorado squawfish and by Valdez and Nilson (1982) and Kaeding et al. (1990) for humpback chub. Added precautions allowed the fish to recover rapidly and quickly resume normal behavior and activities. This increased the likelihood that information collected on radiotagged fish reflected normal behavior. Surgical procedures were refined and practiced to complete the implant within 6 minutes (time from first incision to last suture). Surgeries were performed inside a large tent to minimize exposure to blowing sand and reduce the risk of infection.

A member of the B/W team was assigned head surgeon, and the responsibility of insuring that all aspects of the surgical procedure were standardized and monitored. That person had considerable experience performing surgeries on small mammals for product testing for a well-known medical products company. Three people were involved with surgery; the head surgeon, a surgical assistant, and an anesthetist to administer anesthesia and monitor respiration of the fish.

Each fish destined for radioimplant was handled with extreme care to minimize stress. This included holding each fish individually in a live well with fresh river water for transport to the surgery tent. Prior to surgery, each fish was measured, weighed, and photographed on a grid board. Meristics (relational measurements of body parts) were not taken on radioimplanted fish to minimize stress.

The standard was used that transmitter weight could not exceed 2 percent of fish weight (Bidgood 1980, Marty and Summerfelt 1990). Care was taken to select fish that were healthy and showed no signs of stress. Nine-gm transmitters were implanted in 6 of 238 fish (22%) weighing 450 gm or more, and 11-gm transmitters were implanted in 47 of 121 fish (39%) weighing 550 gm or more (Figure 4). Females were not implanted from March through May to prevent stress to these gravid fish and eliminate the risk of transmitter expulsion from enlarging egg masses (Bidgood 1980, Marty and Summerfelt 1990).

Primary Incision. Two locations were used for the primary incision; midline and lateral. The midline incision was located on the belly between the pectoral and pelvic girdles along the linea alba. The lateral incision was generally on the left side of the fish, midway between the pectoral and pelvic fins and about 1 cm from the linea alba. Midline incisions were used on 45 humpback chub and lateral incisions were used on eight (Table 5). Of the 12 radiotagged fish recaptured, ten had midline and two had lateral incisions. Each radiotransmitter was introduced through the primary incision and positioned on the pelvic girdle with the antenna protruding through the abdominal wall posterior to the pelvic girdle. The trailing antenna was clipped in line with the end of the hypural plate of the fish to prevent fraying of the tail fin. The incision area was washed with sterile saline before and after the surgical implant.

Incisions along the linea alba have been the standard procedure for most transmitter implants (Hart and Summerfelt 1975, Marty and Summerfelt 1986, Marty and Summerfelt 1990, Bidgood 1980, Personal Communications with G. Klontz, Univ. of Idaho). Midline incisions are conventionally used in abdominal surgeries in veterinarian practices because the linea alba is a fascial plane that is

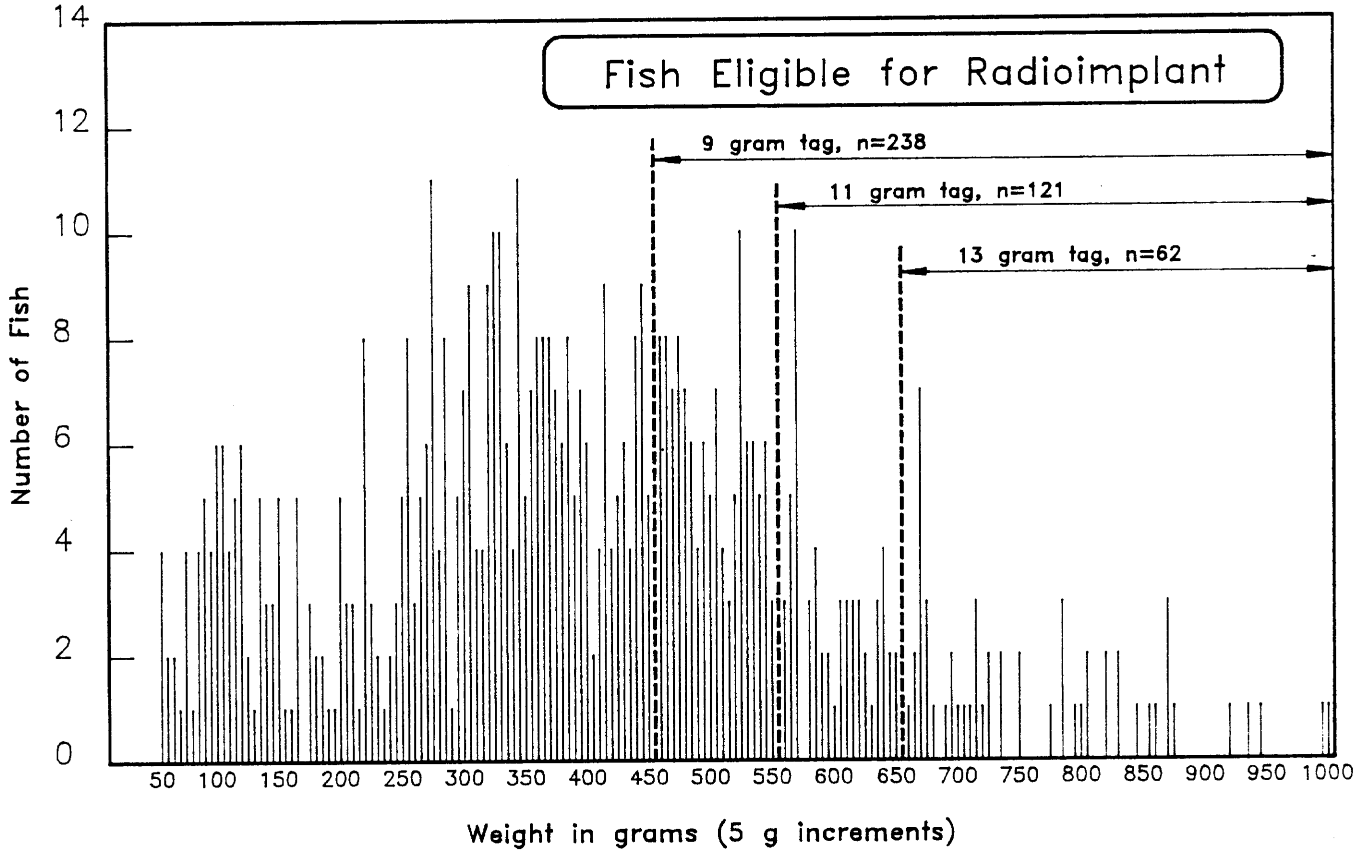

Figure 4. Weight histogram for humpback chub greater than 50 gm captured by BIO/WEST in the Grand Canyon during 1990-1991. Numbers of humpback chub eligible for radio-implant with transmitter weight less than or equal to 2 percent body weight are indicated.

stronger than muscle fibers with little nerve and vascular tissue (Marty 1991, Personal Communications with Von Seggern, W.L. Gore and Assoc., Flagstaff, AZ; and Cosgrove, Univ. of Calif., Davis). Studies show that properly-sutured midline incisions are nearly as strong as those of the lateral wall (Marty and Summerfelt 1990).

Lateral incisions were used in the upper Colorado River basin on humpback chub (Valdez and Clemmer 1982, Kaeding et al. 1990) and Colorado squawfish and razorback suckers (Tyus 1988, Valdez and Masslich 1992). Lateral incisions were preferred in these species to reduce irritation of the suture line from visceral pressure, and lessen the likelihood of abrasion of sutures with the river bottom. Marty and Summerfelt (1986) noted that the ventral body wall thickened rapidly lateral to the midline, making surgery difficult. Incisions of the lateral body wall generally bleed more than incisions of the midline because the body wall is more vascularized. It is important to avoid bleeding because clots lead to the formation of adhesions (Rosin 1985) that are the first step in the process of transintestinal expulsion. Incision location was not mentioned as a factor of transmitter expulsion by Marty and Summerfelt (1990), but Tyus (1988) felt that incision site may have a bearing on transmitter expulsion.

Antenna Exit. A drawback of external-antenna transmitters is the need to expose the antenna to insure proper signal transmission. The point where the antenna protrudes from the body cavity can be an avenue for bacterial invasion. This area is often aggravated by the rotating action at the antenna caused by water currents. Many methods have been used for passing the external antenna through the body cavity. Winter et al. (1978) used a knitting needle to tunnel a cavity under the skin to an exit point. Ross and Kleiner (1982) used an eyed, curved rug needle sleeved with 0.5-cm diameter plastic tubing to pass the antenna the length of the abdomen and through the wall. Chart and Cranney (1991) used the same shielded needle technique to implant 86 hatchery-reared bonytail (Gila elegans) for release into the Green River, Utah. These techniques led to problems with possible damage to the peritoneal cavity and vital organs, as well as possible bacterial contamination.

Two techniques were used in this investigation to pass the transmitter antenna through the abdominal wall. One involved passing the antenna through a small incision with mosquito forceps and suturing anteriorly and posteriorly at the exit point. The second technique used a specially-designed "sleeved needle antenna guide" (SNAG). The SNAG consisted of a gently curved 20-cm long hollow stainless steel needle inside a 15-cm long hollow stainless steel sheath. The inside diameter of the inner needle was 0.06 inches (1.52 mm), which accommodated the antenna, with an outside diameter of 0.05 inches (1.27 mm). The sheathed needle was inserted in the primary incision and guided to a point posterior to the pelvic girdle where the needle was pushed through the abdominal cavity. The sheath was removed and the antenna threaded through the needle. The needle was pulled through the antenna exit leaving the antenna in place.

The mosquito forceps technique was used on 38 fish and the SNAG was used on 15 (Table 5). Of the 12 radiotagged fish recaptured, only two had been treated with the SNAG (Table 6). The condition of the antenna exit on both fish was rated good, whereas nine of the ten fish with the mosquito forceps technique were rated fair or poor.

Suture Material. Two types of suture material were used; CV3 Gortex non-absorbable and 3-0 Maxon absorbable. CV3 Gortex was used on the first 31 fish implanted from October 1990 through March 1991 (Table 5). The 3-0 Maxon absorbable suture was used for the remaining 23 fish implanted from May through November 1991. A PH 26 curved needle was standard with each suture material. Other investigators have used 3-0 prolene sutures (Ethilon™) with Colorado squawfish and razorback suckers (Tyus 1988, Valdez and Masslich 1992), humpback chub (Valdez and Nilson 1982, Kaeding et al. 1990), and bonytail (Chart and Cranney 1991).

The CV3 Gortex suture (developed by W.L. Gore and Associates) was originally selected because of its handling ease, excellent tensile strength, and incorporation by healing tissue. However, at least some inflammation was noted around the sutures of the first six fish recaptured. Possibly, the porosity of the suture that allows tissue integration also allowed bacterial wicking from the unsterile river environment into the peritoneal cavity (Personal Communication, Von Seggern, W.L. Gore and Assoc.).

After further research, we decided to use 3-0 Maxon, a polygluconate monofilament suture that is absorbable over long-term (Personal Communication, G.D. Marty, Univ. of Calif, Davis). Monofilament suture is less likely to wick water and bacteria into the peritoneum. Long-term absorption (90 days) allows the incision ample time to heal before the sutures dissolve, particularly in the 8° to 10°C temperatures of the Colorado River in Grand Canyon.

Evaluation of Surgical Procedures

Twelve of the 53 (23%) radiotagged humpback chub were recaptured by B/W in 1991, including seven males and five females (Table 6). Two additional fish were recaptured by AGF. The fish recaptured by B/W were at large an average of 117.8 days (range 52-357 days), and were displaced an average of 5.7 miles (9.17 km) from their release site. One fish (PIT tag #7F7F3F2F3A) was

Table 6. Data and evaluation of condition fo

PIT Tag No.	Freq/pulse	Sex	In R] (	Surgical Procedure[1]	Condition[2]	
					Primary Incision	Antenna Exit
7F7F3F3626	40.620/78	F	9(	MGN	poor	poor
7F7F456B2C	40.610/58	M	9(	MGN	fair	poor
7F7F3C4162	40.630/62	M	9(	MGN	good	fair
7F7F3F4E77	40.710/80	M	9(	MGN	fair	fair
7F7F3F520D	40.630/86	M	91	MGN	good	fair
7F7F3C243E	40.620/53	M	91	MGN	poor	poor
7F7F3F2F3A	40.660/39	F	91	MGN	good	fair
7F7F3C6F15	40.700/42	M	91	MGN	good	fair
7F7D075B05	40.610/82	F	91	MXN	good	fair
7F7F3E3C5C	40.730/61	F	9(	MGN	good	good
7F7F3F3764	40.600/63	F	91	LXS	good	good
7F7F3E3542	40.680/78	M	91	LXS	good	good
MEANS:						

[1]-MGN = midline incision, CV3 Gortex nonat
MXN = midline incision, 3-0 Maxon absorbat
MXS = midline incision, 3-0 Maxon absorbab
LXS = lateral incision, 3-0 Maxon absorbable

[2]-good - slight or no inflammation - healed/he:
fair - moderate inflammation/mild infection
poor - dehiscent incision or exit - infection p

[3]-average absolute displacement

recaptured 61.5 miles (99.0 km) downstream of the release site. Excluding this fish, average net displacement was 0.65 miles (1.0 km) from release to recapture site. Six fish moved downstream, five moved upstream, and one fish remained near the release site.

The 12 recaptured fish weighed an average of 643.6 gm (range 500-780 gm) at release and 585.3 gm (range 452-713 gm) at recapture for an average weight loss of 58.7 gm (9%). Weight change for individual fish ranged from 1.0 gm gained (0.2% body weight) to 226 gm lost (28.0%), for an average weight loss of 9.0 percent. Average weight loss of radiotagged fish (58.7 gm) was greater than weight loss observed for recaptured PIT-tagged fish (12.3 gm). This weight loss was noted for the entire population in 1991, as indicated by decreased relative condition factor of fish captured for the first time.

Of 12 fish recaptured, 9 were implanted with a surgical technique that included a midline incision, CV3 Gortex non-absorbable sutures, and no needle guide (MGN); one was implanted with a midline incision, 3-0 Maxon absorbable sutures, and no needle guide (MXN); and two were implanted with a lateral incision, 3-0 Maxon absorbable sutures, and the sleeved needle antenna guide, SNAG (LXS). Changes in surgical technique were implemented to enhance closure of the incision in cold water and to reduce the likelihood of inflammation and infection. These changes were made as recaptured fish were evaluated and potential problems identified.

The condition of the primary incision and antenna exit were evaluated for each of the 12 fish according to the criteria: good (slight or no inflammation - healed or healing), fair (moderate inflammation - mild infection), or poor (incision dehiscent - infection present). The primary incision of eight fish (67%) was good, including six fish with midline incisions and two with lateral incisions. Of the remaining four fish, the primary incision was fair on two (17%) and poor on two (17%). The antenna exit of three fish (25%) was good, while that of six fish (50%) was fair, and three fish (25%) rated poor.

Two of the 12 fish recaptured (PIT tag #7F7F3F3626 and #7F7F3C243E) showed signs of dehiscence (opening of the incision) that could lead to transmitter expulsion. This could be caused by a number of reasons including pressure on the incision from expansion of the abdomen during normal activity or feeding. Bidgood (1980) and Marty and Summerfelt (1990) cautioned that implanting gravid females could lead to internal injury and increase the likelihood of transmitter expulsion. Another possible cause of dehiscence is inflammation associated with infection which can occur with improper closure of the incision, tissue failure due to infection, or delayed healing from cold water temperatures. Investigators also note that expulsion rate is higher when transmitter weight exceeds 2 percent of fish weight (Bidgood 1980, Marty and Summerfelt 1990).

Because there was evidence of dehiscence that could lead to transmitter expulsion in two recaptured fish, surgical techniques were reevaluated and modified to minimize the likelihood of dehiscence. CV3 Gortex nonabsorbable sutures were replaced by 3-0 Maxon absorbable sutures, the SNAG technique was used instead of a small incision for the antenna exit, and lateral incisions were implemented. Three fish were recaptured with Maxon sutures. The first of these (PIT tag #7F7F075B05) did not have sutures present and the primary incision was mostly healed, but the antenna exit was inflamed. The other two fish (PIT tags #7F7F3F3764 and 7F7F3E3542) showed excellent healing and very little inflammation around at the primary incision site and antenna exit.

We also tried a lateral incision to reduce abrasion of the incision from the river bottom, and possibly enhance healing (the lateral wall has more vascularity than the <u>linea</u> <u>alba</u>). Of ten fish recaptured with midline incisions, six had healed with little or no inflammation, two had moderate inflammation, and two showed signs of expulsion. Of the 12 fish recaptured, the two (PIT tags #7F7F3F3764 and #7F7F3E3542) with the best post-operative response had been implanted using a lateral incision, Maxon sutures, and the SNAG technique. The primary incision of each was healed, each antenna exit was only slightly inflamed, and there was little inflammation at the suture sites. Additional recaptures are needed to more fully evaluate these three factors; incision location, suture type, and antenna-exit technique.

Telemetry Analysis

Three databases were developed from radiotelemetry in 1990 and 1991, including surveillance, observations and remote telemetry. Each database was useful in ascertaining specific information on the life history of humpback chub in Reach 1. Effort expended on telemetry surveillance and observations is presented in Table 7.

Surveillance data were used primarily to determine horizontal long-range movement and diel patterns in near-surface activity. Telemetry surveillance was conducted twice daily in all or part of the section within RM 56-65. 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. Corresponding information on light conditions, water clarity (turbidity as secchi disk reading), and habitat were recorded for each location.

Table 7. Effort expended for telemetry surveillance and observation of radiotagged adult humpback chub in Reach 1 of the Colorado River in Grand Canyon, 1990-1991.

	Number of Observations	
Telemetry Surveillance	**Day**	**Night**
Boat runs (mainstem)	132	103
Foot runs (LCR)	47	0
Aerial runs (helicopter)	5	0
Total number of surveillance runs	184	103
Telemetry Observations	**Number of Observations**	
Implant	53	
Locate	58	
2 hour observation	33	
24 hour observation	44	
Test flow observation	21	
Total number of observations	209	

Table 8. Substrate categories and descriptions applied to the Colorado River in Grand Canyon.

Substrate	**Description**
Silt	fine material <0.062 mm in diameter
Sand	coarse fines 0.062 - 2 mm in diameter
Gravel	particles 2 to 75 mm in diameter
Cobble	particles 75 to 300 mm in diameter
Boulder	particles >300 mm in diameter
Bedrock	substrate a solid rock shelf

Remote telemetry data were collected from three stations, two directional and one omni-directional described earlier in this section. Data collected from the directional stations (KLCR and KRSH) were used in determining movement 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 determined with the aid of surveillance locations. The omni-directional station (KILR) provided useful data on diel near-surface activity and activity relative to turbidity. Information collected from KILR was also used to identify fish signatures (frequency/pulse combinations) in the area.

Telemetry observations were conducted to evaluate habitat use and local movement in response to time of day, river stage, ramping, and turbidity. Individual radiotagged fish were monitored for periods of 2 or 24 hours when fish were within about 4.5 m of the surface and their radiosignal 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 monitored for 2 hours were first observed for 30 minutes to determine if they were moving or stationary. Stationary fish were located by triangulation and monitored for an additional 1.5 hours to determine habitat use. Triangulations were marked for locations where a fish remained stationary for 30 minutes or more during the 1.5-hour monitoring period.

Moving fish were monitored for an undetermined amount of time to ascertain their behavior or movement patterns, or both, relative to various factors including time of day, river stage, ramping, turbidity, local macrohabitats, and other radiotagged fish in the area. If a fish became stationary, it was monitored as described above.

Fish monitored for 24 hours were carefully observed for habitat use and movement particularly during changes in flow stage. Movement and each area occupied for longer than 30 minutes were mapped on a mylar overlay over a 1:1200-scale aerial photograph. River stage, determined from temporary bench marks, was recorded with each observation. Fish position was checked every 1 to 2 hours or more frequently if river stage changed rapidly.

A detailed hand-drawn map or a detailed map using a mylar overlay of an aerial photograph (depending on photo availability) was prepared for each fish monitored. Distance and direction of all movements were recorded on the map and on a telemetry data sheet together with time of day and river stage.

At the conclusion of monitoring, habitat measurements were recorded where possible 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. Procedures for measuring each of these microhabitat parameters are presented in the Microhabitat Quantification Section below.

Habitat Assessment

Microhabitat Quantification

Microhabitat consists of a set of parameters that directly affects and influences a fish in its immediate location. Water depth, velocity, substrate, and instream cover are the most commonly described parameters of microhabitat in streams. These parameters were measured for as many fish as possible at locations in which humpback chub were observed, captured, or located with radiotelemetry (Valdez et al. 1990). In contrast, macrohabitat is described in terms of major habitat units. Backwaters, eddies, pools, runs, riffles, and return channels are the most common macrohabitats of large river systems such as the Colorado River.

Adults. Microhabitat was described for adult humpback chub from radiotelemetry locations and for juveniles from electrofishing capture locations. Water depth, velocity, substrate, and cover were assessed for radiotagged adult humpback chub monitored over periods of 2 to 24 hours. These measurements were taken from a boat or by wading at point locations determined from triangulation of radiosignals. Depth was measured to the nearest tenth of a meter with a telescoping meter rod or a wading rod. In areas where water depth exceeded the length of the measuring rod, depth was taken with a fathometer. Water velocity was measured with a Swoffer current meter to the nearest tenth of a meter per second at the same location as the depth measurement. Velocity of the water column was measured at a point 3 cm from the river bottom, and at two-tenths, six-tenths and eight-tenths of the water depth. Measurements taken in eddies or reverse currents greater than 90 degrees from the main directional flow were recorded as negative velocities.

Substrate was categorized as silt, sand, gravel, cobble, boulder or bedrock by visual observation, probing with a depth rod, or physical examination. Substrate categories are described in Table 8. The two most common substrates were recorded and classified as either dominant or subdominant. Substrate which accounted for the greatest surface area was dominant and the second most common substrate was subdominant.

Lateral, overhead and instream cover were described at each microhabitat sampling location. Overhead cover was characterized as overhanging banks such as rock ledges or streamside vegetation. Lateral cover included vertical rock walls and boulders. Instream cover included boulders, log or debris jams, sand shoals, or rock jetties.

Juveniles. Microhabitat of juveniles was determined from transects located along shorelines where young chub were captured and not captured by electrofishing (Figure 5). Measurements were taken at four sites: (1) CRASH: a boulder/talus slope on river right above Crash Canyon, RM 62.6, (2) SALT: a talus slope on river right upstream of the Hopi Salt Mines, RM 63.1, (3) WEEP: a vertical wall on river left upstream of the Hopi Salt Mines, RM 63.0, and (4) SAND: a sand beach on river right below the Hopi Salt Mines, RM 63.5. Sites 1 and 2 yielded large numbers of juvenile humpback chub during electrofishing in July, September, and November, while areas 3 and 4 yielded no chub. The purpose for selecting these four distinct sites was to measure habitat occupied by large numbers of juveniles as well as adjacent habitats devoid of fish. These sites will be remeasured at various river flows to determine the range of flows needed for suitable juvenile habitat.

A shoreline distance of 100 m was assessed with nine transects extending perpendicular to the shoreline and in the near-shore zone where the young chub were captured. Each transect was 3 m long and measurements were taken at 0.5, 1.5, and 2.5 m from the water's edge. Water velocity was recorded at six-tenths of the distance from the water's surface. Depth and velocity were averaged separately for 0.5, 1.5, and 2.5 m measurements to distinguish near-shore from off-shore habitat. Substrate was also assessed separately.

Macrohabitat Mapping

Macrohabitat and shoreline type were assessed visually at different flow levels in order to relate fish habitat dynamics with dam operations according to the method used by Valdez and Masslich (1992). Twenty-one habitat maps and four substrate maps were developed from seven areas of the mainstem Colorado River in the vicinity of the LCR inflow (Figure 6, Table 9). Humpback chub were captured in each of these areas. Seven areas identified as ESPN, CAMP, LCRI, HOPI, SALT, WHAL, and WEEP were mapped at flows of approximately 4,290 to 16,600 cfs. Flow ranges during the 0.5 to 1.5-hour mapping process were determined from instantaneous discharge readings at the U.S. Geological Survey (USGS) gage on the Colorado River immediately above the LCR. These areas, as well as areas devoid of chub, will continue to be mapped through 1992.

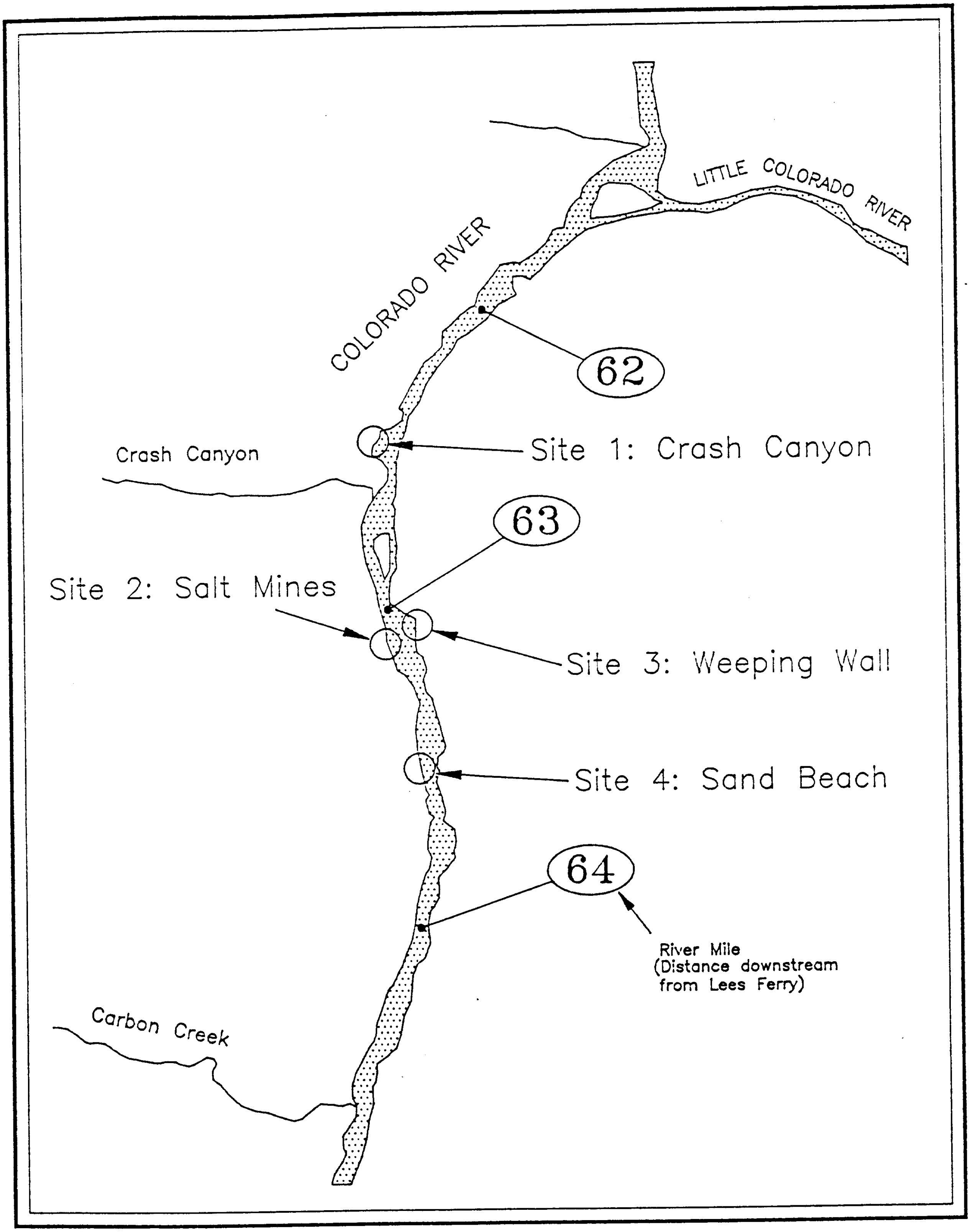

Figure 5. Locations of four microhabitat measurement sites for juvenile humpback chub on the Colorado River in Grand Canyon.

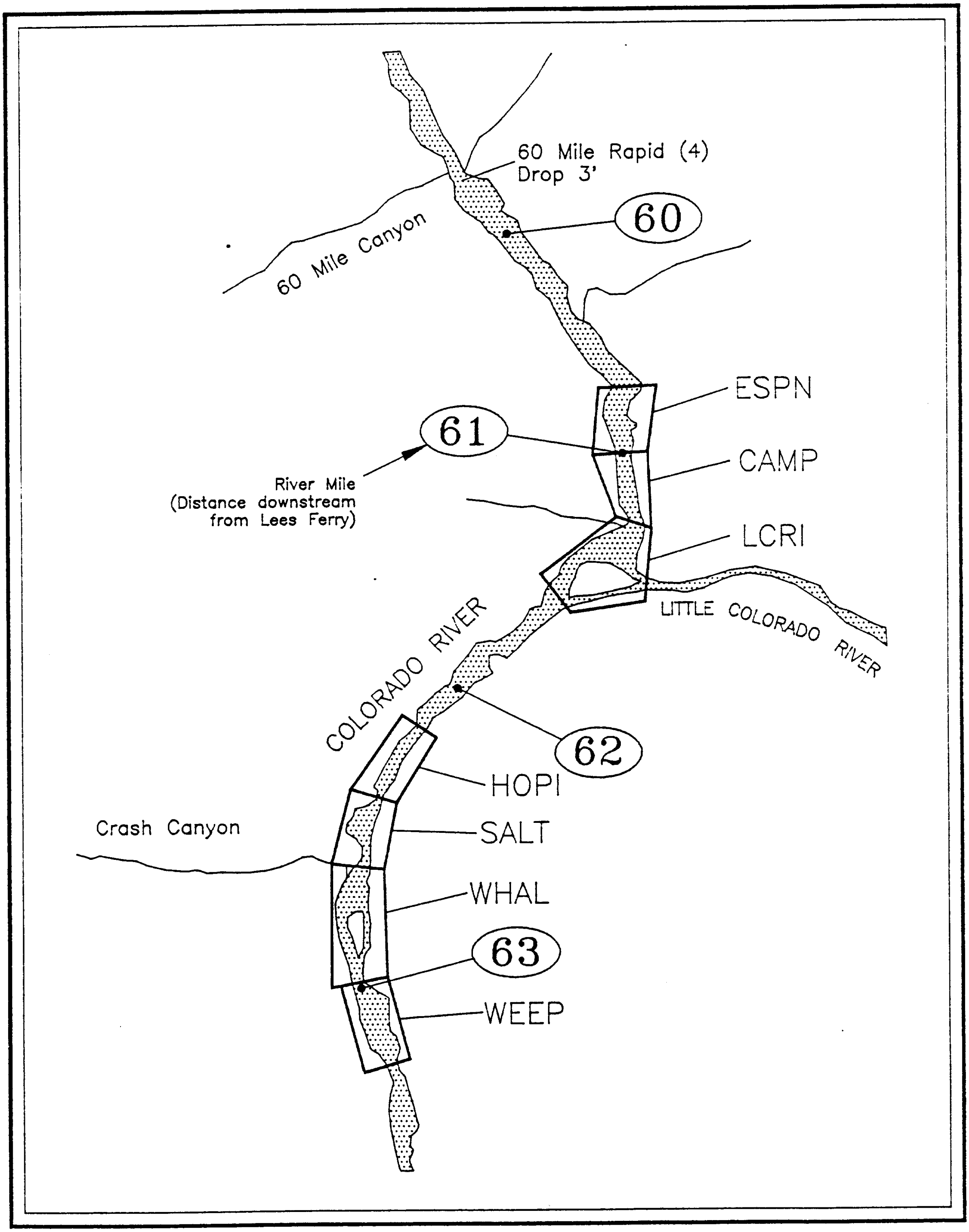

Figure 6. Locations of seven macrohabitat mapping areas on the Colorado River in Grand Canyon.

Table 9. Habitat map areas completed at various flows of the Colorado River in Grand Canyon, 1990-1991.

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)
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)
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)
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

The same observer developed all habitat maps to standardize technique and minimize observer variation. Criteria were established for consistent definition of macrohabitat type. The level of error cannot be assessed for this methodology, i.e., accurate measurement of macrohabitat is not technically possible. However, the method is precise in that it provides a consistent evaluation of relative area of macrohabitat at different flows.

At each flow level, macrohabitat and shoreline type were documented by tracing selected areas on mylar overlays placed atop existing aerial photographs (1:1200 scale). Macrohabitats and shoreline types were traced on the mylar overlays by an observer standing on high vantage points 30 to 50 m above the river surface.

Each area mapped encompassed the reach of river included in one 1:1200 aerial photograph (1 cm = 12 m), which usually included 400 to 450 m of river and 35,000 to 50,000 m^2 of riverine habitat. Each reach was mapped and photographed from two high vantage points located approximately one-third of the distance from each end of the reach. Binoculars were used to aid more definitive demarcation of macrohabitats. All mapping was done under good lighting and calm wind; optimum conditions usually occurred in the morning during summer.

Each habitat map was developed by first establishing a measured baseline between two prominent, easily identifiable points to increase accuracy for transfer to a MIPPS system. The existing water line was traced on a mylar overlay using identifiable landmarks such as rocks, trees, and points of land. Shoreline type was then denoted according to the definitions provided in Table 10, and boundaries identified for linear analysis. All major macrohabitats were traced on the mylar overlay using landmarks and triangulation techniques to outline as closely as possible boundaries of eddies, runs, riffles, pools, slackwaters, return channel/backwaters, and rapids. Each of these macrohabitat types is defined in Table 11. As many landmarks as possible were traced on the mylar overlay to facilitate locating reference points when entering the information into the MIPPS system.

Each habitat map was identified with a unique code name, date, time of day, and estimated flow stage. Each photo point was also located and the film roll and frames indicated on the mylar overlay for later reference.

Habitat maps were transferred to the GCES Office in Flagstaff, Arizona, where they were scanned into the MIPPS system and stored in separate computer files. Surface area of each macrohabitat type (i.e., eddies, runs, riffles, etc.) was assessed and summed in square meters,

Table 10. 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).

Table 11. 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.

and linear distance of each shoreline type was summed in meters. A substrate map was also developed during a low-flow period which consisted of surface area of unique substrate types summed in square meters.

Surface areas of macrohabitats and substrates as well as linear distances of shoreline types were summed for each habitat map and entered into a file such that each file contained data associated with one habitat map for a given flow level. When additional habitat maps are developed, surface area of each macrohabitat type will be regressed against flow to quantify changes in surficial habitat from dam operations. Threshold effects or sharp inflections in regression lines will be noted to identify flow levels where macrohabitat changes are greatest. It is hypothesized that changes in flow lead to increased fish activity because of (1) changes in macrohabitat, or (2) increased volumes of suspended food. Increased activity from changes in habitat suitability may lead to detrimental excessive energy expenditure, while feeding activity may be beneficial. Relationships of flow and macrohabitat will be compared with activity of radiotagged fish to ascertain if this cause-effect relationship exists.

River Flow/Stage Monitoring

Twenty-two temporary bench marks (TBM) were established in 1990 and 1991 in an 8-km area of Reach 1. The primary purpose for these TBM's was for the reoccupation of a point so that stage discharge recorded at one point in time could be related to data collected during alternate periods regardless of actual discharge. Variation in river stage was monitored with temporary staff gages surveyed to these TBMs. These TBMs were established at strategic locations in order to relate fish movement and habitat use to river stage. Each TBM will be surveyed relative to GIS (Geographic Information System) benchmarks. At this time, 11 of 22 TBM's have been surveyed into the longitudinal transect in Reach 5 (LCR RM 60-72) of the GIS benchmark system in Grand Canyon (M. Yard, GCES, Flagstaff, Arizona, personal communication). A series of stage readings will be collected during a changing hydrograph. The process is similar to developing a flow routing model that will provide the degree of accuracy needed to relate movement of radiotagged fish to ramping and flow level.

Drift Studies

Drift samples were collected to determine availability of food resources that may be 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, Cladophora glomerata and invertebrates (including Gamarus lactustris), may be important sources of nutrition for humpback chub, complimenting benthic food resources (Kaeding and Zimmerman 1983). There may be periods when drifting food resources constitute the majority of available fish food.

These data will be used in conjunction with future food habits studies to improve our understanding of humpback chub biology. Relative abundances of available foods from drift and benthic sources will be compared to relative abundances of stomach contents taken nonlethally to determine food habits of chub.

A minimum of two drift nets (30.48 x 45.72 cm) were employed by each research team to trap drifting allochthonous material. These nets had a mesh size of 600 microms and were 3 m long. Nets were placed side by side, with one collecting surface drift and one subsurface drift. Swoffer current meters and wading rods were used to determine current velocity through each drift net.

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 macroinvertebrates to at least the family level. Drift data were transformed into sample drift density (macroinvertebrates/100 m^3), as outlined by Allen and Russek (1985):

$$\text{Sample Drift Density} = \frac{\text{number of macroinvertebrates}}{m^3 \text{ filtered}} \times 100$$

Food Habits

Stomach contents of humpback chub and non-native predaceous species (striped bass, channel catfish, carp, rainbow trout, brown trout) were analyzed. Non-native fish were sacrificed when necessary and to determine the efficiency of non-lethal stomach pumping methodology to be used on humpback chub in 1992. Eight humpback chub were pumped in January 1991, according to a prototype study agreed to by the ACT. This evaluation showed no detrimental effects and proved effective in flushing stomach contents. Pumping of non-native fish was also very effective and noninjurious. Stomach samples were preserved in the field and analyzed in the laboratory. Food items were counted and sorted by family and species when possible. Fish in stomachs were measured and identified to species if possible.

Water Quality

Water quality data were collected during each monthly field trip using a Hydrolab Surveyor 3. Temperature, dissolved oxygen, pH, conductivity, and redox potential were recorded daily at each camp site. Constant-recording Datasondes were also deployed on some trips to monitor these chemical parameters continuously through the trip. These instruments generated a large volume of water quality data that are to be analyzed concurrently by B/W and GCES. We intend to corroborate these data with water quality data collected at the USGS gages in the canyon.

In 1991, 365 Hydrolab single point readings were taken for the mainstem Colorado River. Forty-one readings were taken in tributary streams near outflows. Tributaries in Reaches 2 and 3 were sampled 28 times and the LCR was sampled 13 times. Hydrolab readings were taken 140 times in Reach 1, 137 times in Reach 2, and 88 times in Reach 3. All Hydrolab readings were in addition to Reclamation Datasonde recorders used on all BIO/WEST trips.

HISTORICAL BACKGROUND

The purpose of this section is to provide a summary of historical records of humpback chub in the Colorado River from Glen Canyon Dam to Lake Mead. Fish captured in or near tributaries were included, and collections from the LCR were omitted. A list of collection dates, localities, and references from 1942 to present is presented in Appendix A, Table A-1 (Minckley 1992). Historic capture locations of humpback chub from 1942 to 1987 are shown in Figure 7, and capture locations from this B/W study from October 1990, to November 1991, are shown in Figure 8 for comparison. A more complete discussion of B/W capture locations is presented in the section on Species Composition, Distribution, and Abundance.

Archeological Finds

The oldest known remains of humpback chub in the Grand Canyon are estimated to be about 4,000 years old and were found in Stanton's Cave (RM 31.8), (Euler 1978, Miller and Smith 1984). The fish were identified as Gila cypha based on prominent supra-occipital processes for muscle attachment, the angle of neural and hemal spines to the centrum of caudal vertebrae, and the anterior arm of the pectoral girdle. Also found in the cave were remains of bonytail (Gila elegans), Colorado squawfish, flannelmouth suckers (Catostomus latipinnis), and bluehead suckers (Catostomus dicobolus). No razorback sucker remains were found, and all bones were non-fossilized. Fish bones of Gila were also found in an archeological site at RM 136 (Jones 1985). Additionally, bones of humpback chub were taken from Catclaw Cave, now a inundated archeological site below Hoover Dam (Miller 1955).

Pre-Dam Records

In May of 1908, the Kolb brothers hiked to the LCR and gave the following account (Kolb and Kolb 1914):

> "Then Emery discovered what it was. On the opposite side of the pool the fins and tails of numerous fish could be seen above the water. The striking of their tails had caused the noise we had heard. The 'bonytail' were spawning. We had hooks and lines in our packs, and caught all we cared to use that evening. They are otherwise known as Gila Elegans, or Gila Trout, but 'bonytail' describes them very well. The Colorado is full of them; so are many other muddy streams of the Southwest. They seldom exceed 16 inches in length, and are silvery white in color. With a small flat head somewhat like a pike, the body swells behind it to a large hump...".

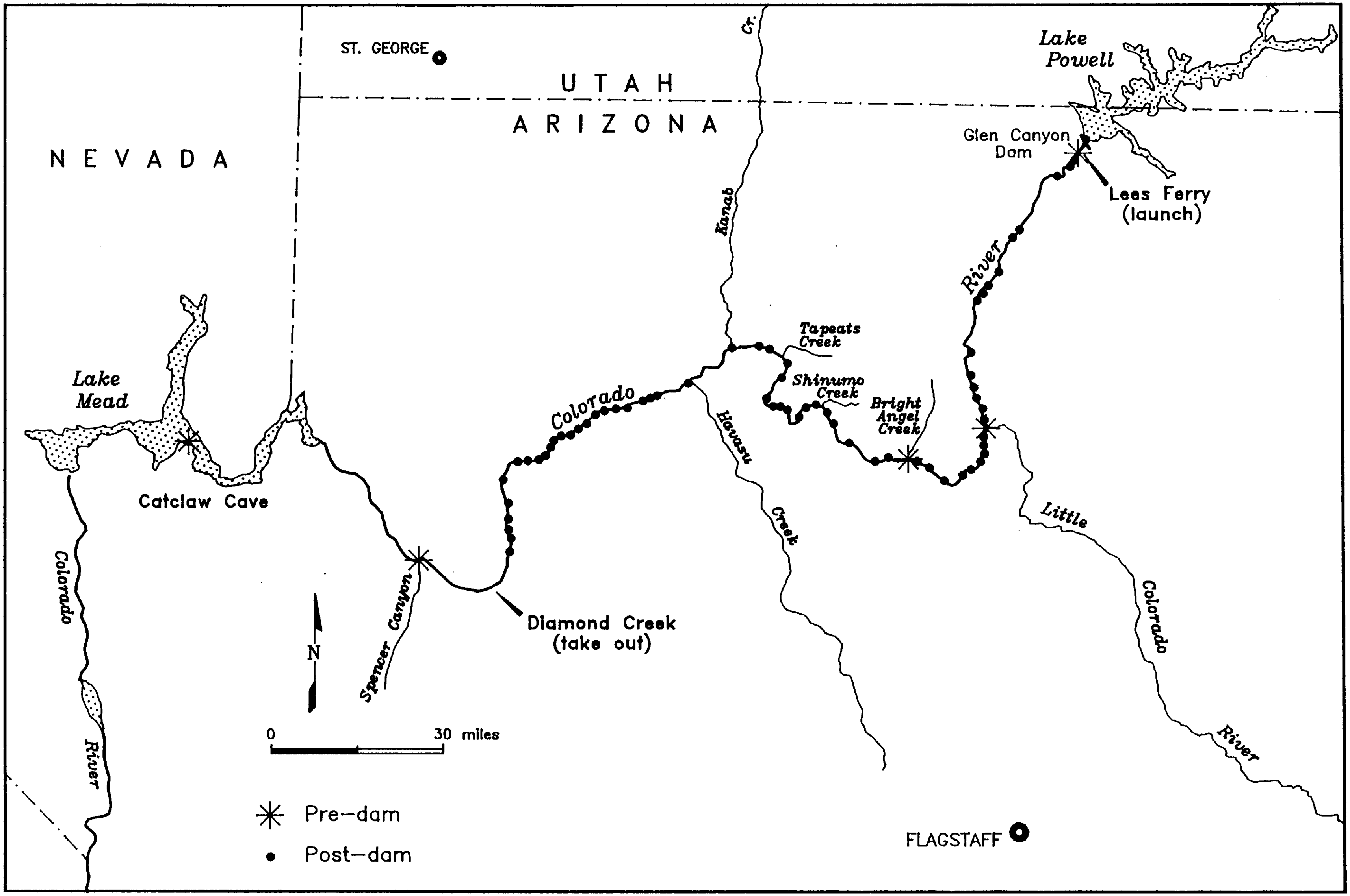

Figure 7. Historic capture locations of humpback chub in the Colorado River in Grand Canyon, 1942-1987.

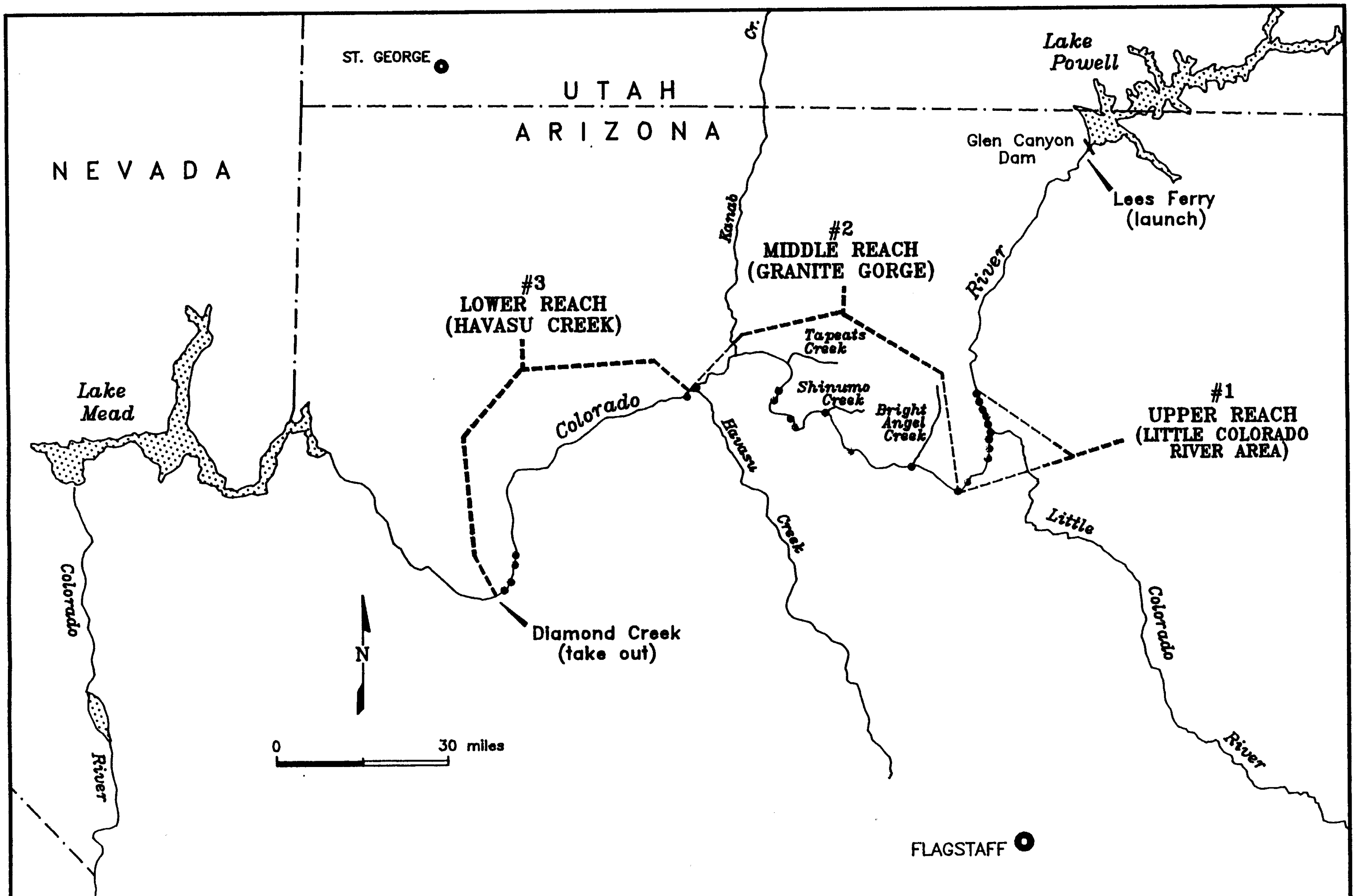

Figure 8. Locations of humpback chub captured by BIO/WEST in the Colorado River in Grand Canyon, 1990-1991.

This article further describes that the LCR was ponded by high flows from the main Colorado River. The Kolb brothers were probably a few hundred meters upstream from the LCR mouth when they observed the spawning activity. Photographs taken at the time clearly show that the Kolbs caught humpback chub (USDI 1988).

No written records of humpback chub exist after the Kolb brothers' account until 1946, when the species was described by R.R. Miller (1946). This specific description was based on one fish taken by angling at Bright Angel Creek in 1942 and two fish donated to Grand Canyon National Park in 1944. The capture localities of these fish are unknown. The next record was eight juveniles captured from Spencer Creek (RM 246) in October 1955 by O.L. Wallis (Kubly 1990).

Post-Dam Records

Post-dam records are far more numerous than pre-dam records because of the advent of research activities since construction of Glen Canyon Dam in 1963. The first post-dam records of G. cypha were between Glen Canyon Dam and Lees Ferry. One adult was captured at Lees Ferry in 1963 and is preserved at Arizona State University (ASU). Humpback chub were mentioned in AGF creel census reports between 1964 and 1968 (Stone 1964, 1966; Stone and Queenan 1967; Stone and Rathbun 1968). Data on individual fish were not included in these reports. In addition, fifteen humpback chub were captured in July 1967, and one was caught in August 1970, within a few hundred meters downstream of Glen Canyon Dam (Holden 1973). Humpback chub have not been reported from this reach since 1970.

Fifteen major scientific collecting trips were conducted through Grand Canyon from 1970 to 1976 in which humpback chub were captured. Only young or juveniles (SL< 165 mm) were captured, except for four adults caught from the mouth of the LCR in June 1976. Based on comparisons with G. elegans and G. robusta from elsewhere, collectors concluded that all chub specimens taken from Grand Canyon were G. cypha. It is important to note that young or juveniles were caught at RM 44 (just below President Harding Rapid), RM 69 and 71 (between Tanner and Cardenas), and at RM 108.7 (Shinumo Creek) (Suttkus et al. 1976; Suttkus and Clemmer 1977).

The Museum of Northern Arizona conducted six river trips between November 1978, and November 1979. All humpback chub captured during these trips from the main Colorado River were adults, except for one young fish (< 100 mm) captured at RM 93.5 (in a small backwater just above Granite Rapid). Fish were also caught at RM 19.5, 27.5 (below Tiger Wash), RM 33 (Redwall Cavern), RM 55 (above Kwagunt Creek), RM 72 (above Unkar Creek), RM 108.5 (near mouth of

Shinumo Creek), RM 132 (near mouth of Stone Creek), RM 156.6 (Havasu Creek), and RM 194 (below Boulder Wash)(Carothers and Minckley 1981). Ripe males were caught near Tiger Wash and Unkar Creek (Minckley 1978).

Three semi-annual river trips were made by the Service beginning in October 1980. Sampling conducted between Nankoweap and Unkar rapids yielded 504 adult humpback chub (>200 mm TL). The abundance of these fish followed a bell-shaped distribution about the mouth of the LCR. No fish smaller than 145 mm TL was collected from the Colorado River above the LCR confluence, although mature fish were present. Many small fish were caught in spring and fall below the LCR confluence (Kaeding and Zimmerman 1981, 1983).

As part of GCES, AGF has sampled the Colorado River since April 1984 (Maddux et al. 1987; Kubly 1990) (Tables 12 and 13). Humpback chub were caught from RM 32 to RM 217. The majority of fish captured below the LCR were small (TL<200 mm) since seines were the primary sampling gear and trammel nets were used only in 1984. Some of these fish were larvae, suggesting that occasionally successful reproduction occurred in the mainstem Colorado River (Kubly 1990). Humpback chub were also caught at Bright Angel, Shinumo, Kanab, and Havasu creeks. Ripe adults were caught in Shinumo, and concentrations of adults were photographed at the mouth of Havasu Creek (Maddux et al. 1987).

Summary

Pre-dam records are too few to characterize distribution or abundance of humpback chub in Grand Canyon. The four locations cited (Lees Ferry, LCR, Bright Angel Creek, Spencer Canyon) and pre-dam river conditions suggest that the species was distributed throughout the region. Post-dam capture locations ranged from the base of Glen Canyon Dam downstream for 256 miles to below Separation Rapid (RM 241). Maddux et al. (1987) found young humpback chub as far downstream as RM 217 in 1985 and 1986, years of record high flows. These high flows probably transported these young fish further downstream than might be expected during low flows. Few humpback chub were found downstream of Reach 1 by B/W researchers in 1990 and 1991, possibly because of the lack of high flows.

Table 12. Summary of humpback chub captured April 1984 - June 1986 in the mainstem Colorado River from Glen Canyon Dam to Lake Mead[a].

Reach	BS	LSDN	EF	TN
Reach 10 (Glen Canyon Dam-Lee's Ferry)	0	0	0	0
Reach 20 (Lee's Ferry-LCR)	0	0	8	0
Reach 30 (LCR-B.A. Creek)	336	0	31	2
Reach 40 (Bright Angel-National)	8	2	10	4
Reach 50 (National-Diamond)	53	2	2	0

[a](Maddux et al. 1987, condensed from Kubly 1990). BS = bag seine, LSDN = larval seine and dip net, EF = electrofishing, TN = trammel net.

Table 13. Summary of humpback chub captured April 1987 - September 1989 in the mainstem Colorado River from Glen Canyon Dam to Lake Mead[a].

Reach	BS	LSDN	EF	TN
Reach 10	0	0	0	0
Reach 20	0	0	0	0
Reach 30	196	1	0	0
Reach 40	2	1	0	0
Reach 50	16	0	0	0

[a](condensed from Kubly 1990)

HABITAT AVAILABILITY AND USE

Microhabitat Use

Juvenile Humpback Chub

Juvenile humpback chub were captured in distinct shoreline habitats of the mainstem Colorado River in May, June, July, August, September, and November 1991 (sampling was not conducted in August, October, and December 1991). Length-frequency analysis (See section on Age and Growth) indicates that the majority of these young fish were from the 1991 year class (YOY) and probably originated from the LCR. Distinct shoreline habitats from the mouth of the LCR (RM 61.3) to Lava Canyon (RM 65.2), except for backwaters, were sampled with electrofishing (backwaters were sampled by AGF). Shoreline types included talus slopes, vertical cliffs, sand beaches, earthen banks, earthen banks with root wads, and large standing boulders. Juvenile humpback chub were captured along talus slopes, earthen banks with root wads, and from large standing boulders. These habitat types frequently contained small sand pockets. Few or no young chub were captured along shorelines with vertical cliffs, sand beaches, or barren earthen banks. Adult humpback chub were captured from inundated talus slopes and between large standing boulders. Rainbow trout of all sizes were common in shorelines with young chub.

Depth, velocity, and substrate were distinctly different between the two sites where juvenile humpback chub were captured and where no chub were found (Figure 9, Table A-2). Average depth and velocity (Table 14) of one site with no fish (WEEP) was significantly greater (Fisher's least-significant-difference test, LSD<0.05) than that of sites with fish (CRASH and SALT). However, depth and velocity at the SAND site was less than (not significant LSD>0.05) that of the two sites with fish (Figure 10). This comparison points to the importance of the combination of parameters that constitute microhabitat (i.e., depth, velocity, substrate, cover). In this case, excessive depth and velocity alone might explain the absence of chub from the vertical cliff WEEP site, although the absence of cover and broken substrate also influenced the value of this site. In the case of the SAND site, the absence of fish is probably best explained by the absence of cover and broken substrate, since depth and velocity were within the range used by young chub at the CRASH and SALT sites.

The dynamics of these shoreline habitats during different flow levels and ramping rates needs further examination. Talus shorelines may be used by YOY humpback chub (following 1-3 months in the LCR) in lieu of other habitats not available under existing conditions. Perhaps talus shorelines

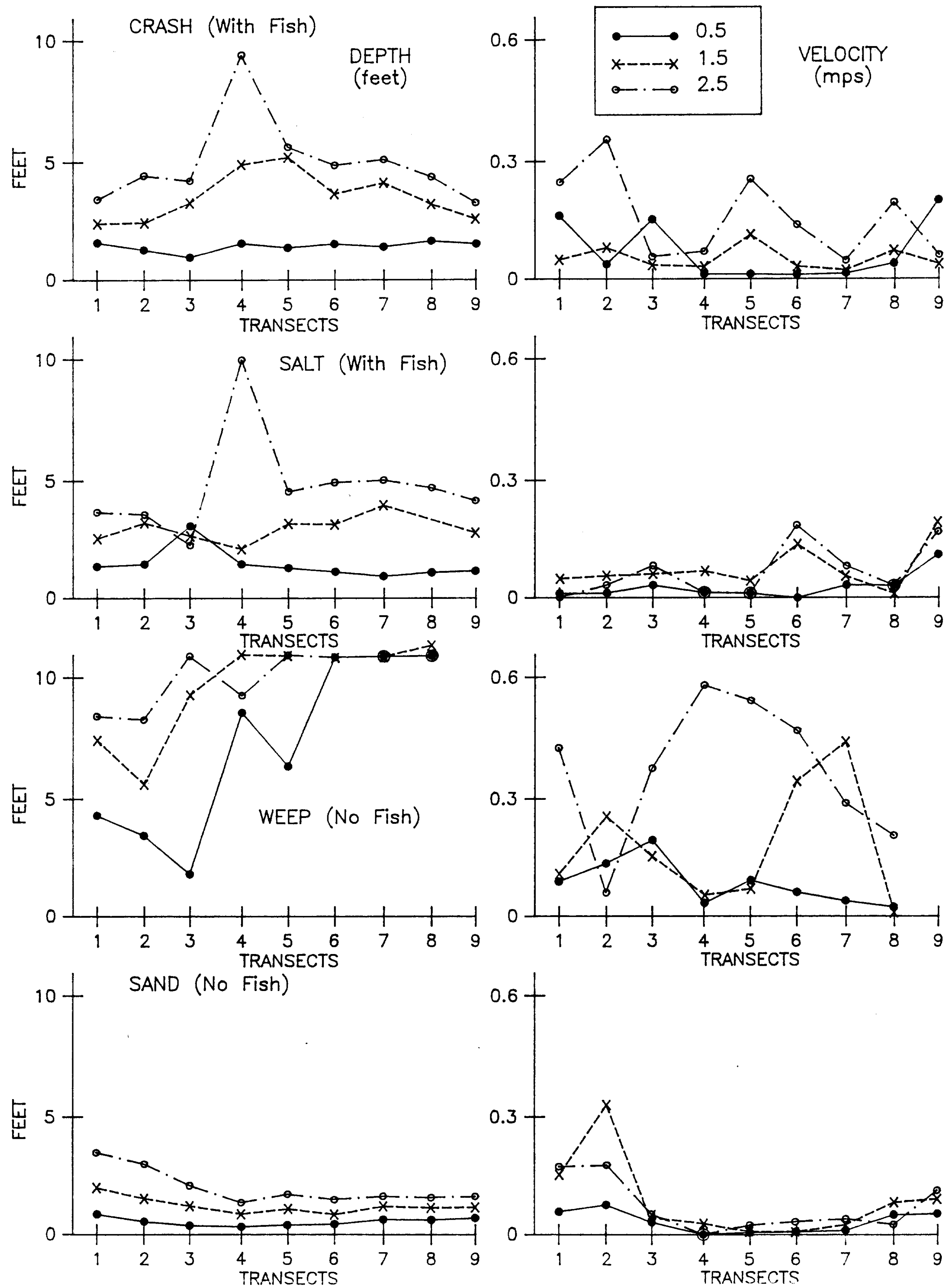

Figure 9. Shoreline microhabitat (depth and velocity) recorded from four sites on the Colorado River in Grand Canyon. Two areas represent shoreline habitats where juvenile humpback chub were captured electrofishing (with fish) and two areas where no chub were captured.

Table 14. Microhabitat measurements for juvenile humpback chub from four sites on the Colorado River in Grand Canyon, at 0.5, 1.5 and 2.5 m from shore[a].

SITE	AVERAGE DEPTH (feet)			OVERALL MEANS	AVERAGE VELOCITY (mps)			OVERALL MEANS	DOMINANT SUBSTRATE[b]		
	0.5	1.5	2.5		0.5	1.5	2.5		0.5	1.5	2.5
WITH FISH											
1:CRASH	1.19 (0.29)	3.01 (1.38)	4.64 (2.10)	2.95*[3,4] (2.01)	0.06 (0.08)	0.04 (0.04)	0.14 (0.12)	0.08*[3] (0.09)	SI/SA	SI/SA	SI/BO
2:SALT	1.04 (0.72)	1.83 (0.93)	4.14 (2.60)	2.45*[3,4] (2.05)	0.16 (0.03)	0.06 (0.05)	0.06 (0.06)	0.04*[3] (0.05)	BO/BO	SI/BO	BO/BO
SUMMARY	1.12 (0.54)	2.59 (1.22)	4.39 (2.31)		0.04 (0.06)	0.05 (0.04)	0.10 (0.10)				
NO FISH											
3:WEEP	7.18 (3.73)	9.67 (2.13)	10.34 (1.23)	9.06*[1,2,4] (2.83)	0.14 (0.21)	0.18 (0.16)	0.37 (0.18)	0.23*[1,2,4] (0.20)	BE/BE	BE/BE	BE/BE
4:SAND	0.49 (0.15)	1.18 (0.41)	1.91 (0.77)	1.19*[1,2,3] (0.77)	0.03 (0.03)	0.08 (0.11)	0.07 (0.07)	0.06*[3] (0.07)	SA/SI	SA/SI	SA/SI
SUMMARY	3.64 (4.24)	5.17 (4.60)	5.88 (4.44)		0.08 (0.14)	0.13 (0.13)	0.21 (0.19)				

[a]Mean (standard deviation) are presented for depth (feet) and velocity (meters per second). Asterisk indicates Fisher's least-significant-difference, LSD <0.05 when compared to sites indicated in superscript.

[b]SI = silt
SA = sand
BO = boulder
BE = bedrock

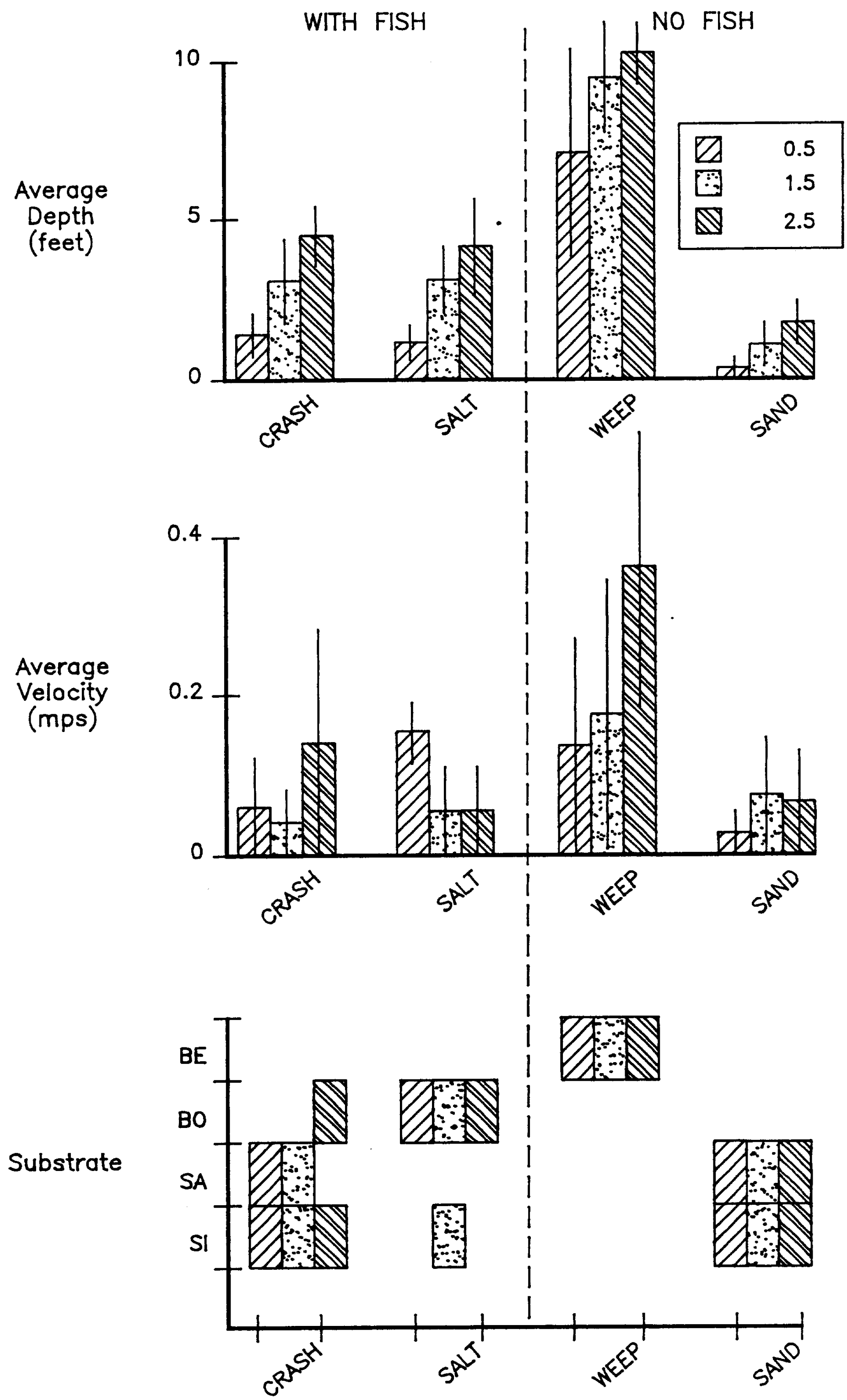

Figure 10. Microhabitat parameters for juvenile humpback chub from four sites on the Colorado River in Grand Canyon. Average depth and velocity are shown for 0.5, 1.5 and 2.5 m from shore. One standard deviation is shown by a vertical line extending through the mean depth and velocity.

are preferred by juvenile humpback chub of this age or size. In the upper Colorado River basin, 49 percent, 31 percent, and 12 percent of humpback chub 21-74 mm TL were found in backwaters, eddies, and shoreline runs, respectively (Valdez et al. 1987). Slightly larger chub (75-259 mm TL) were found more commonly in shoreline runs (38%) than in backwaters (29%) or eddies (26%). For both size ranges, fish found in eddies and shoreline runs were frequently associated with talus or boulders. This suggests a transition in habitat use with size or age from shallow, protected areas such as backwaters or stable shorelines to areas with moderate depth and velocity and uneven substrate for cover.

Adult Humpback Chub

Microhabitat of adult humpback chub was much more variable than that of juveniles. These fish were found at sites of various depths and low velocity with boulder substrate and cover. Triangulated locations of radiotagged fish ranged in depth from 1.2 to 12.0 m with a mean depth of 7.4 m (Table 15). Average water column velocities at these locations were generally low, ranging from 0.01 to 0.5 m/s (meters per second) at two-tenths depth, 0.01 to 0.2 m/s at six-tenths depth, and 0.01 to 0.2 m/s at eight-tenths depth. Substrate at these locations was dominated by a combination of boulders and sand. Boulders were the dominant substrate at 63 percent of locations. Boulders were also identified as the predominant instream cover. Microhabitat data for adult humpback chub in the upper Colorado River basin (Valdez et al. 1990) also showed a large range in depth (range = 0.76-12.22 m, mean = 3.14 m) at low velocities (range = 0.0-1.19 m/s, mean = 0.18 m/s), and dominant substrates of boulder and sand.

These data also showed that individual humpback chub were often positioned in the midwater column. Three of the water depths measured at triangulated locations exceeded signal extinction depth (4.5 m) of radiotransmitters, indicating that the fish were suspended in the water column at least 2 to 4 m above the bottom. These data as well as observations of radiotagged fish and infrequent visual sightings suggest that adult humpback chub often suspend themselves in low-velocity, midwater regions of eddies, slow runs, and reattachment channels in proximity of boulders, sand substrate, and cover. We perceive that adult humpback chub frequently suspend themselves in these low-velocity regions to minimize energy expenditure and maximize lotic feeding opportunities. The large falcate pectoral and pelvic fins allow the fish to adjust position with ebbing local water currents, analogous to the large, broad wings of airborne raptors (i.e., eagles and hawks), soaring on local wind currents with minimum energy expenditure.

Table 15. Microhabitat measurements for adult humpback chub from the Colorado River in Grand Canyon, 1990-1991.

Date	Depth (meters)	Velocity (m/s) 0.2	0.6	0.8	Sub1[a]	Sub2	Cover
910116	2.1	0.01	0.01	0.01	BO	SA	BO
910116	1.2	-	0.1	-	-	-	-
910210	3.7	-	-	<0.1	-	-	-
910210	6.4	-	-	-	-	-	-
910210	3.0	<0.1	<0.1	0.1	BO	SA	BO
910210	2.1	0.1	0.2	<0.1	BO	SA	BO
910210	3.8	0.1	<0.1	0.1	BO	SA	BO
910212	12.0	-	-	-	SA	BO	BO
910212	12.0	-	-	-	SA	BO	BO
910213	4.0	-	-	-	SA	BO	BO
910417	3.7	0.5	-	0.2	BO	SA	BO
Mean	7.4	0.16	0.10	0.11			
Range	1.2-12.0	0.01-0.5	0.01-0.2	0.01-0.2			
Sample Size	11	5	5	6			

[a]BO = boulder
SA = sand

This soaring behavior complicates assessment of microhabitat. Because specific sites occupied by fish during these soaring modes shift with current ebbs, measurement of nose velocity becomes impossible and microhabitat assessments meaningless. For this reason, macrohabitat of humpback chub in the Colorado River in Grand Canyon will be assessed on a macrohabitat level (i.e., eddies, runs, riffles, etc.). The occurrence and amount of these macrohabitats will be related to flows resulting from the operation of Glen Canyon Dam, as well as to geomorphic riverine features which are affected by longterm operations.

Macrohabitat Availability

Runs dominated macrohabitat of areas mapped in the Colorado River in Grand Canyon (Figure 11, Table A-3). This habitat accounted for 29 to 93 percent of the surface area of all areas mapped (Tables A-4 - A-10). Eddies occurred in all map areas, accounting for 2 to 41 percent of surface area, while pools accounted for 3 to 43 percent of surface area, although they were absent in some map areas. Rapids, return channels, and riffles accounted for less than 30 percent of the habitat in map areas.

Mapping was conducted at specific flows between 4,290 and 16,600 cfs. This range of flows was insufficient to establish relationships between flow stage and macrohabitat. Significant changes in some macrohabitats apparently occur at higher flows. Although trends were evident from existing data, it appeared that flow to habitat relationships were complex (i.e., habitat did not necessarily increase or decrease linearly with flow). The following subsections are presented to illustrate macrohabitat dynamics in each of four mapped areas (ESPN, CAMP, LCRI, SALT).

ESPN Map Area

The ESPN map area was dominated by run habitat (48-86%) with substantial eddy (10-34%) formation (Table A-4). Pools were the second most common habitat at 4,290-4,410 cfs, but were absent or insignificant at other flows mapped. These three macrohabitat types made up nearly 100 percent of surface area at all flows in the ESPN area. Although return channels accounted for less than 1 percent of available surface macrohabitat, radiotagged adult humpback chub frequently used these channels, particularly when the reattachment bar was submerged forming a deep incised channel adjacent to the river bank. Macrohabitat to flow relationships indicate that the ESPN area became run-dominated at flows of 9,870; 13,400-14,200; and 15,600-16,000 cfs.

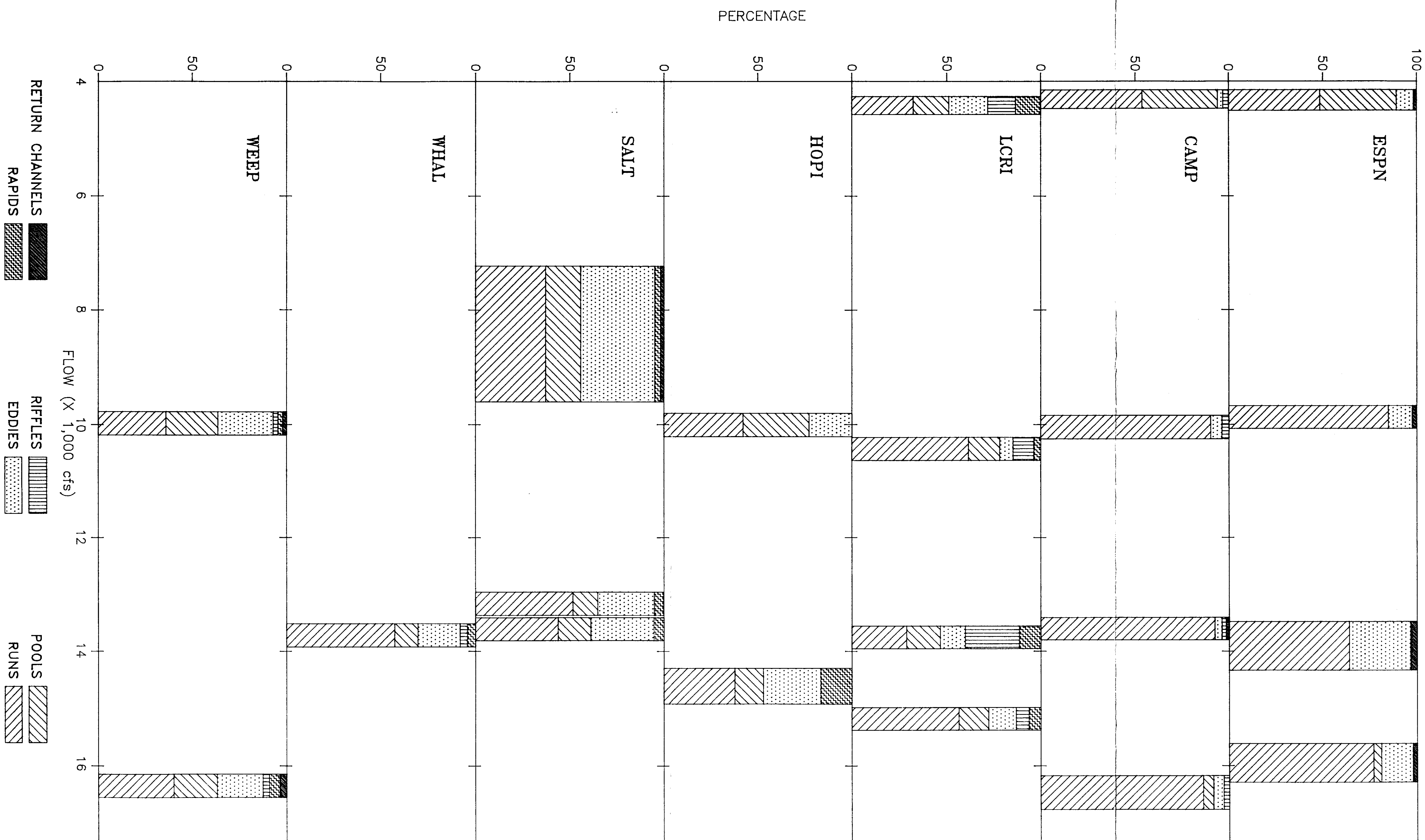

Figure 11. Macrohabitat as a percentage of surface area of seven areas at various estimated flows of the Colorado River in Grand Canyon, 1991.

CAMP Map Area

The CAMP map area was also dominated by run habitat (53-93%) at the flows mapped (Table A-5). As in the ESPN area, pools were the second most common habitat at flows of 4,220-4,290 cfs, but were absent or insignificant at all other flows. Although this area was dominated by run habitat with relatively little eddy and pool formation, shoreline type was primarily sand and cobble with overhanging tapeats ledges which provided lateral cover. Macrohabitat to flow relationships indicate that the CAMP area became dominated by run habitat at flows of 10,000, 13,500, and 14,900-15,200 cfs.

LCRI Map Area

Although the mapped areas of the Colorado River were dominated by run habitat, the immediate inflow of the LCR had the least amount of runs of the three areas mapped (Table A-6). Runs in the LCRI area made up only 29-63 percent of area mapped. This area showed the greatest diversity of fish habitat of any area mapped. This diversity, in combination with substrate type, shoreline type, and shoreline development probably account for the value of this area to humpback chub. The LCRI area also contained the greatest area of riffles, which may account for significant autochthonous production.

Macrohabitat was related to specific flow between 4,300 and 15,200 cfs. Changes in surface area of eddies, pools, small rapids, riffles, and runs indicate complex relationships between habitat and flow that require further mapping at additional intermediate and extreme (high and low) flows.

SALT Map Area

The SALT map area was dominated by runs and eddies at all flows (Table A-8). Runs accounted for 37 to 52 percent of surface area, while eddies were 17 to 41 percent of surface area. Shoreline was characterized by a deep, narrow channel lined with talus and large angular blocks and boulders. The large area of eddy habitat was formed by channel constrictions from alluvial fans and large angular shoreline blocks.

Macrohabitat Use

Of 445 radio-contacts, 70 percent were from fish that occupied eddies, while 18 percent were from return channels, and 17 percent from runs (Figure 12). By comparison, eddies were only 22 percent of surface habitat mapped at an estimated 15,000 cfs, return channels were less than 1 percent, and runs were 59 percent. These macrohabitats typically contained regions of low velocity where the fish were generally found. Within these macrohabitats, these low-velocity regions may enlarge, shrink, or move with changing flow. If humpback chub select these areas, it is vital to know the flows at which these exist and are extinguished.

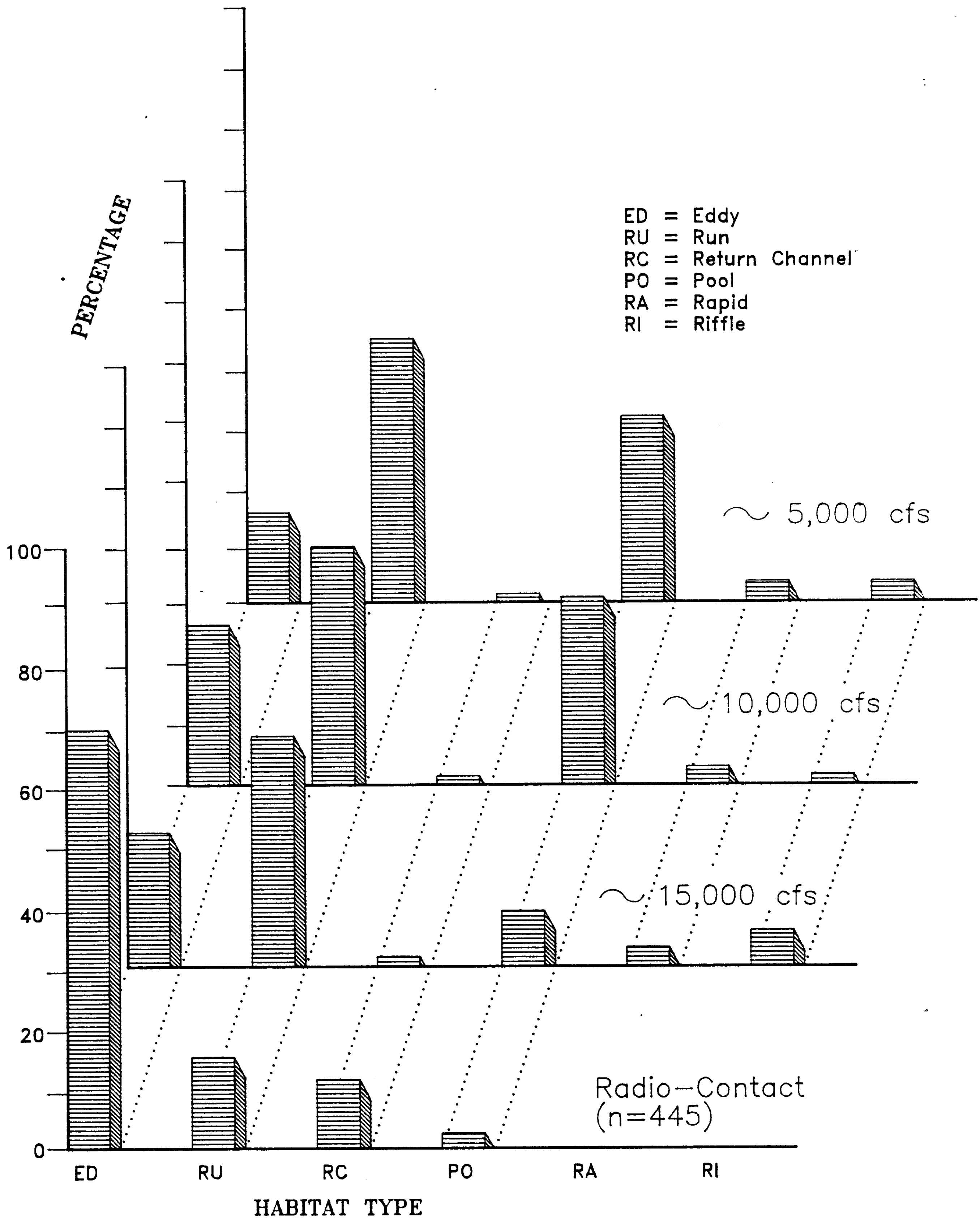

Figure 12. Macrohabitats occupied by radiotagged adult humpback chub compared to percentage surface area at flows of approximately 5,000; 10,000, and 15,000 cfs in the Colorado River in Grand Canyon, 1990-1991.

SPECIES COMPOSITION, DISTRIBUTION, AND ABUNDANCE

Sampling Gear Efficiency

Fourteen gear types were used to sample three study reaches of the Colorado River in Grand Canyon in 1990 and 1991; six types of nets, four types of traps, three sizes of seines, and electrofishing (Table 16). Adult humpback chub were captured with nine of these gears, juveniles with five, and YOY with two. The distribution of these sample efforts and catch rates for humpback chub and rainbow trout are presented in Table A-11.

Nets

Gill and trammel nets were set 4,255 times from October 1990 through November 1991, for a total of 9,002 hours. Humpback chub were captured with all net types used in Reach 1. The 1.5-inch trammel nets (TL) were the most efficient at capturing adult humpback chub with a CPE of 12.11 fish/100 feet/100 hours. However, this gear failed to capture juveniles or YOY. Juveniles and adults were caught at about the same rate with 1.5-inch gill nets, GP (6.76 fish/100 hour), experimental gill nets, GX (6.36 fish/100 hour), and 1-inch trammel nets, TK (6.57 fish/100 hour). Catch of juveniles with nets was lower than expected, particularly with small-mesh experimental gill nets. Either juveniles were not as numerous as adults, or these young fish were using habitats not sampled by gill and trammel nets.

Traps

Adult humpback chub were captured with large (HL) and small (HS) hoop nets at a low rate of 0.43 and 0.35 fish/100 hour, respectively. These gears each captured only two adult chub. A total of 43 YOY and juvenile chub were captured with unbaited minnow traps (MT) at a rate of 0.68 fish/100 hour. This gear proved the second most efficient at capturing YOY with 40 fish, compared to 241 captured by electrofishing.

Electrofishing

Electrofishing accounted for the largest number of chub captured by any gear type with a total of 340 fish and a catch rate of 12.57 fish/10 hour. This was the only gear type with which all three life stages of chub were caught, including 241 YOY, 60 juveniles, and 39 adults. All YOY were captured from May through November of 1991, following movement of these young fish from the LCR into the mainstem Colorado River.

Table 16. Description of fish sample gear and numbers of humpback chub captured in the Colorado River in Grand Canyon, 1990-1991.

Sample Gear Code-Description	Total No. Samples	Number of Chub[a]				Gross CPE (no/hrs)[b]	Total Hours
		Y	J	A	T		
Gill Nets						per 100 hrs	
GP - 100' x 6' x 1.5" Gill net	723	0	1	102	103	6.76	1524.25
GM - 100' x 6' x 2" Gill net	501	0	0	24	24	2.24	1071.78
GX - Experimental gill net, 100'	311	0	7	34	41	6.36	644.24
GZ - Experimental gill net, 60'	30	0	0	0	0	0	58.56
Trammel Nets							
TL - 75' x 6' x 1.5" x 12" Trammel net	1394	0	0	271	271	12.11	2984.72
TK - 75' x 6' x 1" x 12" Trammel net	1296	0	6	128	134	6.57	2717.96
Hoop Nets							
HL - Large hoop net (4' diameter)	36	0	0	2	2	0.43	467.44
HM - Medium hoop net (3' diameter)	14	0	0	0	0	0	197.09
HS - Small hoop net (2' diameter)	44	0	0	2	2	0.35	575.30
Minnow Traps							
MT - Commercial minnow trap	321	40	3	0	43	0.68	6345.02
Electrofishing						per 10 hrs	
EL - 220-V DC	762	241	60	39	340	12.57	270.58
Seines						per 100 m^2	Area(m^2)
SA - 10' x 3' x 1/8" seine	24	0	0	0	0	0	3518.4
SB - 30' x 4' x 1/4" seine	2	0	0	0	0	0	145
TF - Floating trammel net - qualitative haul	6	0	0	4	4	0.02	-
TOTAL	**5464**	**281**	**77**	**606**	**964**		

[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.)

Seines

Only 26 standard seine hauls and 6 sweeps with trammel nets were made. No chub were captured with standard seine hauls, and four adults were captured with sweeping trammel nets.

Distribution Of Effort

Longitudinal Sampling

Netting in Reach 1 occurred primarily between RM 57.0-65.9 (Awatubi Canyon and Lava Chuar Rapid), with peak effort between RM 64.0-64.9 (Carbon Creek) (Figure 13). In Reaches 2 and 3, peak netting effort was between RM 108.0-108.9 (near mouth of Shinumo Creek), and between RM 208.0-208.9 (Granite Park), respectively. Most netting in Reach 2 occurred near mouths of tributaries (i.e., Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek, and Havasu 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 91.3, 41.5, and 63.6, respectively.

Distribution of electrofishing effort was similar to that of netting in all reaches. Peak electrofishing effort in Reach 1 occurred between RM 64.0-64.9 (Carbon Creek), and the general range of intensive sampling was between RM 57.0-65.9 (Blue Moon Grabben Camp and Lava Chuar Rapid) (Figure 14). As with netting, peak effort in Reaches 2 and 3 was near the mouth of Shinumo Creek, and at Granite Park, respectively. The percentages of 1-mile sections sampled by electrofishing in Reaches 1, 2, and 3 were 86.4, 56.6, and 65.2, respectively.

Diel Sampling

In all reaches, most netting occurred between early morning (0601 hours) and late evening (2100 hours). Limited sampling occurred during late night and early morning hours. Sampling with nets in Reaches 1 and 2 occurred between 0100 and 2400 hours with the largest number of sets between 1501 and 1800 hours (Table 17, Figure 15). Sampling in Reach 3 was more evenly during a sample day with more nets set between 1501 and 2100 hours. Diel sampling in Reach 1 was normally distributed (bell-shaped) between these hours, while sampling in the lower Reaches 1 and 2 was more evenly distributed. Few or no nets were set between 0001 and 0300 hours in any reach.

Most electrofishing took place between 1801 and 2100 hours in all reaches (Figure 16). There was practically no electrofishing between 0001 and 0300 hours. Distribution of electrofishing for all reaches was approximately bi-modal, with peak effort occurring in morning (0601-0900) and evening (1801-2100) hours.

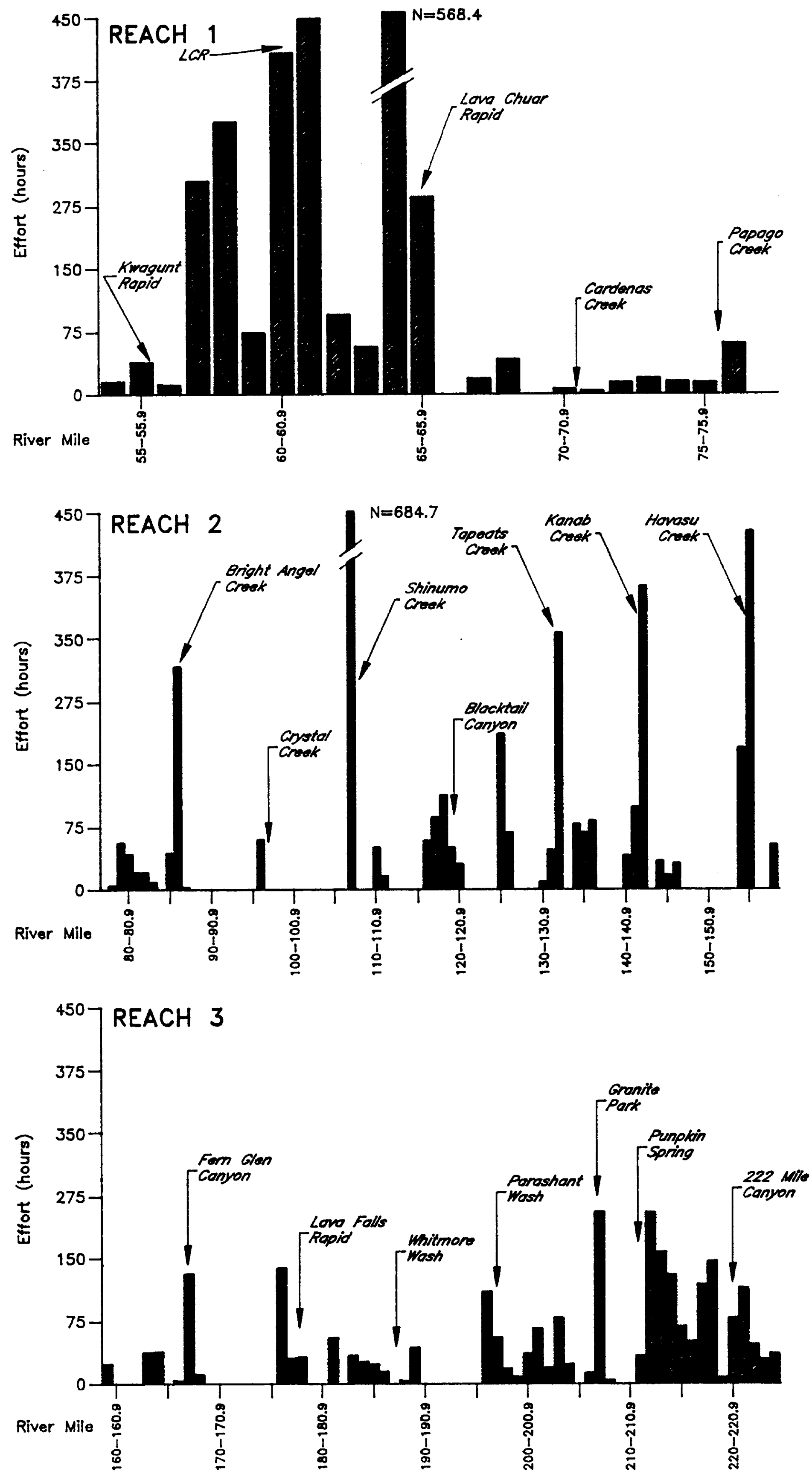

Figure 13. Total netting effort by river mile in Reaches 1, 2, and 3 in Grand Canyon, October 1990-November 1991.

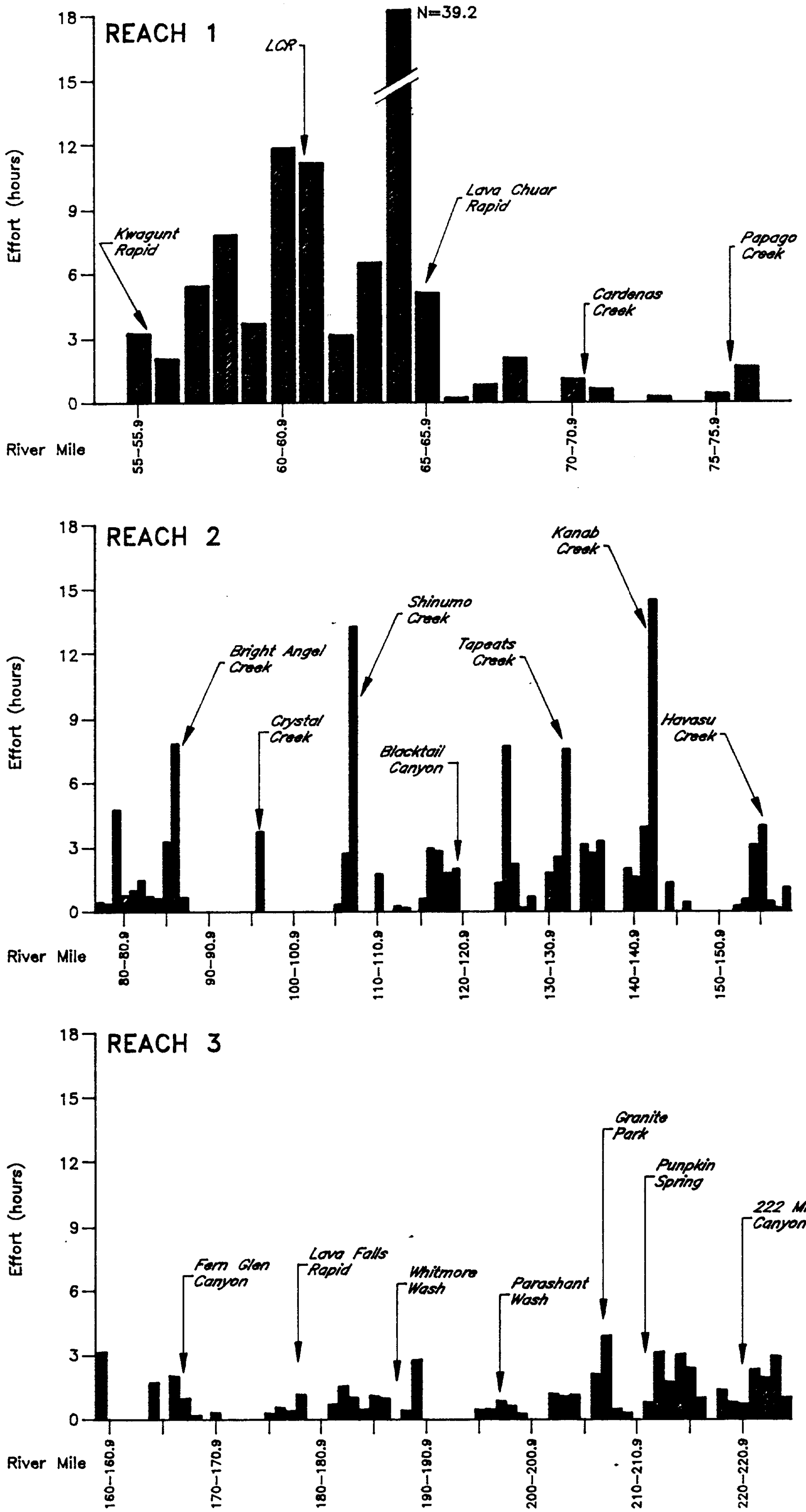

Figure 14. Total electrofishing effort by river mile in Reaches 1, 2, and 3 in Grand Canyon, October 1990-November 1991.

Table 17. Diel analysis of sampling efforts in the Colorado River in Grand Canyon by study reach and gear type.

Time Block	Netting						Electrofishing					
	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 - 0300	-	-	15	48.0	7	20.5	-	-	-	-	1	0.2
0301 - 0600	7	18.0	135	366.79	81	196.0	3	1.2	12	4.7	4	1.8
0601 - 0900	39	198.4	346	888.6	212	470.3	24	7.2	66	22.4	31	11.4
0901 - 1200	114	732.9	237	1057.6	109	298.0	9	2.9	45	12.3	23	6.5
1201 - 1500	277	2100.9	136	541.3	104	287.6	46	11.9	16	4.0	3	1.0
1501 - 1800	502	2981.9	433	2027.7	309	690.2	45	14.0	29	9.6	14	4.2
1801 - 2100	436	982.8	495	1234.2	348	861.8	85	26.5	120	39.9	58	22.1
2101 - 2400	131	243.4	146	272.3	60	129.2	51	14.2	50	16.0	22	7.6

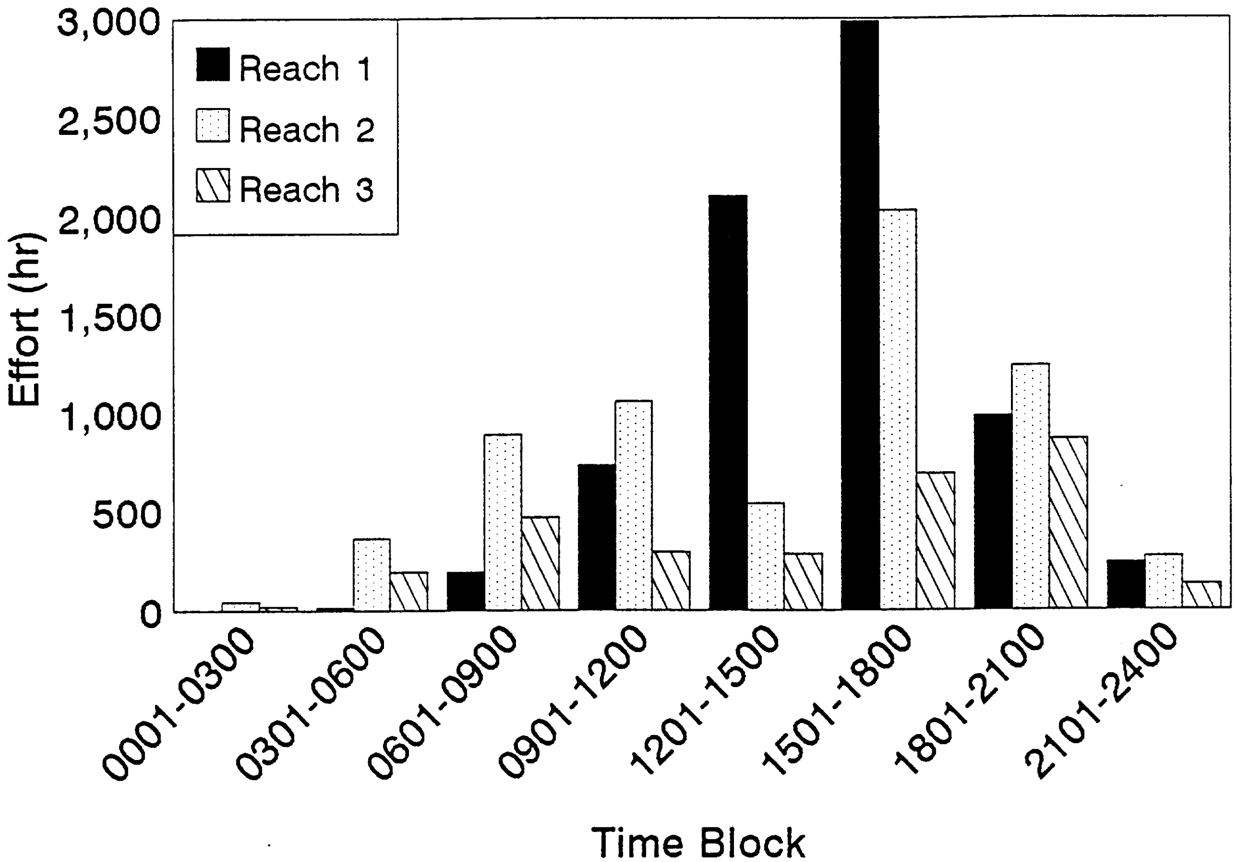

Figure 15. Total netting effort by 3-hour time blocks in the three study reaches of the Colorado River in Grand Canyon, October 1990-November 1991.

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. However, there is a need to adequately sample all time periods in order to make meaningful comparisons of diel catch rates. We will continue to handle as many fish as reasonable to describe the demography of the population, and sample during all time periods in order to characterize diel behavior.

Species Composition

Fifteen species of fish were captured in the Colorado River in Grand Canyon in 1990 and 1991 (Table 18), including five native and ten non-natives. Of the five native species, three were endemic, flannelmouth sucker, razorback sucker, and humpback chub. The ten non-native species represented seven families.

Nets

Twelve species of fish were captured in gill and trammel nets. The majority were rainbow trout, flannelmouth suckers, and humpback chub (Table A-12). Rainbow trout were dominant in each sample reach, comprising 46.5 percent of the catch in Reach 1, while humpback chub were 27.4 percent (Table A-13). Two species were unique to Reach 1: brook trout and flannelmouth/razorback variants. Rainbow trout, flannelmouth suckers, and brown trout were dominant in Reach 2, comprising 34.6, 31.2, and 11.8 percent of total net catch, respectively (Table A-14). Humpback chub were the sixth most common of nine species, comprising 4.8 percent of the catch. The three most common species captured with nets in Reach 3 were common carp (31.7%), channel catfish (20.6%), and flannelmouth suckers (18.8%) (Table A-15). Seven chub were captured in Reach 3, representing 3.2 percent of total catch. One species, walleye, was unique to this reach.

Native species captured with nets in Reaches 1, 2, and 3 were 51.1, 43.6, and 28.9 percent of the catch, respectively. Nine striped bass were caught with nets, one in Reach 2 and eight in Reach 3. All striped bass were captured between May and July, presumably during upstream spawning migration from Lake Mead. The furthest upstream capture of a striped bass was netted in Reach 2 at RM 156.4.

Electrofishing

Fourteen species of adult fish were captured by electrofishing. The three most common were rainbow trout, common carp, and brown trout (Table A-16). Rainbow trout were by far the most common species in Reach 1, comprising 90.7 percent of total catch, compared to 2.1 percent for humpback chub (Table A-17). The only species unique to Reach 1 was black bullhead, of which only

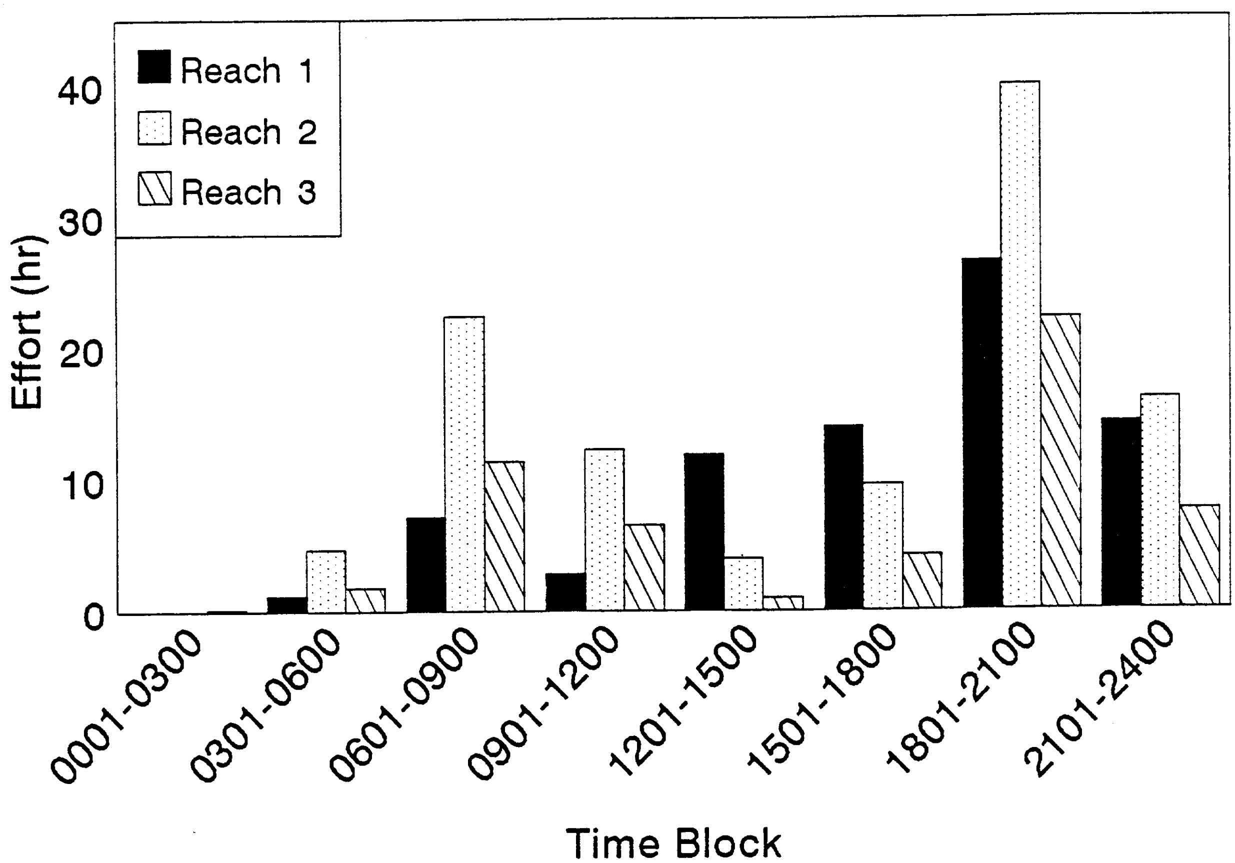

Figure 16. Total electrofishing effort by 3-hour time block in Grand Canyon, October 1990-November 1991.

Table 18. Fish species captured in the Colorado River in Grand Canyon, 1990-1991.

Species Code	Common (Scientific) Name	Y[a]	J	A	T	Per	Status[b]
Family:	Catostomidae (suckers)						
BH	bluehead sucker (Catostomus discobolus)	2	24	183	209	2.3	NA
FM	flannelmouth sucker (C. latipinnis)	10	66	792	868	9.6	EN
RZ	razorback sucker (Xyrauchen texanus)	0	0	1	1	<0.1	EN
FR	flannelmouth x razorback sucker	0	0	1	1	<0.1	
FV	flannelmouth sucker variant	0	0	6	6	<0.1	
Family:	Cyprinidae (minnows)						
CP	common carp (Cyprinus carpio)	3	19	1153	1175	13.0	EX
FH	fathead minnow (Pimephales promelas)	0	1	151	152	1.7	NN
HB	humpback chub (Gila cypha)	281	77	606	964	10.6	EN
SD	speckled dace (Rhinichthys osculus)	1	5	163	169	1.9	NA
Family:	Cyprinodontidae (killifishes)						
RK[c]	plains killifish (Fundulus zebrinus)	0	0	5	5	<0.1	NN
Family:	Ictaluridae (catfishes, bullheads)						
BB	black bullhead (Ameiurus melas)	0	0	1	1	<0.1	NN
CC	channel catfish (Ictalurus punctatus)	1	2	62	65	0.7	NN
Family:	Percichthyidae (temperate basses)						
SB	striped bass (Morone saxatilis)	0	0	15	15	0.2	NN
Family:	Percidae (perches)						
WE	walleye (Stizostedion vitreum)	0	0	1	1	<0.1	NN
Family:	Salmonidae (trout)						
BK	brook trout (Salvelinus fontinalis)	0	0	4	4	<0.1	NN
BR	brown trout (Salmo trutta)	0	27	692	719	7.9	EX
RB	rainbow trout (Oncorhynchus mykiss)	46	392	4270	4708	51.9	NN
TOTALS:		**344**	**613**	**8106**	**9063**	**100.0**	

[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

one was captured near the LCR in November 1991. Most species captured in Reach 2 were rainbow trout (52.0%), common carp (23.2%), or brown trout (22.5%) (Table A-18). Two humpback chub (0.1%) were captured by electrofishing in Reach 2. The three most common species in Reach 3 were common carp (76.9%), speckled dace (8.3%), and rainbow trout (8.1%) (Table A-19). No humpback chub were captured by electrofishing in Reach 3. It should be noted that although only 39 adult and 60 juvenile humpback chub were captured with electrofishing, this gear yielded 241 YOY chub, which are not included in the above analysis.

The percentage of native species captured by electrofishing in Reaches 1, 2, and 3 was 5.2, 2.2, and 11.3 percent, respectively. Six striped bass were captured between May and July of 1991, five in Reach 3 and one in Reach 2 (RM 159.5). Timing and distribution of striped bass captured by electrofishing were consistent with those captured by nets, suggesting seasonal migration from Lake Mead.

Comparisons were made in species composition between 1-mile subreaches around mouths of major tributaries and 1-mile subreaches away from tributaries and in the same geomorphic substrata. Composition of fish of all ages captured by netting around the LCR, Havasu Creek, and Kanab Creek was dominated by native species (flannelmouth suckers and bluehead suckers near Kanab and Havasu, and flannelmouth suckers and humpback chub near the LCR) (Table A-20). Trout were dominant in the other three major tributaries; rainbow trout near Shinumo and Tapeats creeks, and brown trout near Bright Angel Creek. Rainbow trout were dominant in electrofishing catches in all subreaches with tributaries except for Bright Angel and Kanab creeks, where brown trout and common carp were dominant, respectively (Table A-21).

Distribution and Abundance

Humpback Chub

A total of 964 humpback chub were captured and processed by B/W from October 1990 through November 1991, including 281 YOY, 77 juveniles, and 606 adults (Table 19). A total of 619 juveniles and adults were PIT-tagged, 53 adults were radiotagged and PIT-tagged (included in 619), and meristics were measured from 90 adults. A total of 194 humpback chub were recaptured by B/W, including 61 originally PIT-tagged by B/W; 47 PIT-tagged by other researchers; 80 Carlin-tagged, Floy-tagged, fin-clipped, or fin-punched by other researchers; and 8 multiple recaptures of other researcher's PIT tags. Of the total of 964 chub captured by B/W, 770 were original captures. B/W

Table 19. Summary of humpback chub captured and recaptured by BIO/WEST in the Colorado River in Grand Canyon, 1990-1991.

	Total Caught	**PIT Tagged**	**Radio Tagged**	**Recaptured**[a]	**Meristics**
YOY	281	0	0	0	0
Juvenile	77	21	0	12	0
Adult	606	598	53	182	90
Total	964[b]	619	53	194	90

[a]Includes 61 B/W PIT-tags, 47 PIT-tags and scars from other researchers, and 80 Carlin and Floy tags or scars, fin clips and punches from other researchers; 6 were multiple recaptures of other researchers PIT tags.

[b]Three of these fish were captured but escaped before measurements; one additional fish was captured by AGF and measured by B/W; total number includes recaptures.

recaptured 61 of 619 (9.9%) of its own PIT-tagged chub, and 194 of the 964 (20.1%) chub captured had been previously handled by B/W as well as other investigators.

Sex was determined for 535 of 606 adult humpback chub (Table 20). Male:female sex ratio was 45:55. Males averaged 346 mm TL, with a range of 220 to 451 mm. Females averaged 359 mm TL, and ranged from 181 to 480 mm. The average weight of males was 392 gm with a range of 106 to 870 gm. Females averaged 472 gm and ranged from 46 to 999 gm.

Longitudinal Distribution in Study Area. Of 606 adult humpback chub captured, 569 (94%) were from Reach 1 between Malagosa Crest (RM 57.0) and Lava-Chuar Rapid (RM 65.4). Of 77 juveniles, 76 (99%) were captured in Reach 1, also between Malagosa Crest and Lava-Chuar Rapid. Of 281 YOY, 274 (98%) were captured in Reach 1, primarily downstream of the LCR.

Pooled netting catch rates for adult humpback chub were highest, about 55 fish/100 ft/100 hour, between RM 62.0-62.9 (near Crash Canyon) (Figure 17). CPE in Reach 1 was highest between RM 62-62.9 (LCR inflow) and decreased upstream and downstream in a bell-shaped distribution. Pooled netting catch rates for humpback chub in Reach 2 did not exceed 15 fish/100 ft/100 hour for any 1-mile block. The highest CPE was between RM 127.0-127.9 (upper end of Middle Granite Gorge). Within Reach 2, chub were also captured with nets between RM 87.0-87.9 (Bright Angel Creek inflow), RM 108.0-108.9 (Shinumo Creek inflow), RM 119.0-119.9 (just above Blacktail Canyon), RM 126.0-126.9 (upper end of Middle Granite Gorge), and RM 155.0-156.9 (Havasu Creek inflow). The highest pooled CPE for netting in Reach 3 was about 6 fish/100 ft/100 hour between RM 212.0-212.9 (near Pumpkin Spring). Humpback chub were also netted between RM 213.0-213.9 (just below Pumpkin Spring), RM 219.0-219.9 (near 220 Mile Canyon), and RM 221.0-221.9 (near 222 Mile Canyon). Highest electrofishing CPE for adult chub in Reach 1 was over 11 fish/hour between RM 63.0-63.9 (between Crash and Carbon Canyons) (Figure 18). No chub were caught electrofishing above RM 59. Chub were captured by electrofishing in Reach 2 between RM 108.0-108.9 (around Shinumo Creek) and RM 118.0-118.9 (around 119 Mile Creek). No chub were captured electrofishing in Reach 3.

Longitudinal Distribution Within Reach 1. 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. Catch rates in SR-B were substantially higher in March, indicating movement to and staging by fish at the mouth of the LCR (Figure 19). Catch rates in all subreaches

Table 20. Number of males and females, sex ratio, and length and weight by month for adult humpback chub from the Colorado River in Grand Canyon, 1990-1991.

		Oct.	Nov.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Nov.	Summary
Males	(M)	13	19	28	0	58	3	9	13	40	36	22	241
Females	(F)	23	23	40	1	59	4	18	21	34	52	19	294
	M+F	36	42	68	1	117	7	27	34	74	88	41	535
Sex Ratio (%)	M	36.1	45.2	41.2	0	49.6	42.9	33.3	38.2	54.1	40.9	53.7	45.0
	F	63.9	54.8	58.8	100	50.4	57.1	66.7	61.8	45.9	59.1	46.3	55.0
	M+F	100	100	100	100	100	100	100	100	100	100	100	100
TL Mean	M	359	347	337	-	329	313	339	364	360	348	361	346
	F	383	364	375	391	339	333	347	361	366	359	356	359
	M+F	374	356	360	391	334	324	345	362	363	355	357	353
TL Minimum	M	290	225	274	-	263	291	229	328	283	220	258	220
	F	325	294	245	391	235	249	229	181	221	252	256	181
	M+F	290	225	245	391	235	249	229	181	221	220	256	181
TL Maximum	M	451	407	392	-	410	342	395	396	419	420	423	451
	F	439	422	480	391	449	411	410	432	439	462	450	480
	M+F	451	422	480	391	449	411	410	432	439	462	450	480
WT Mean	M	456	418	380	-	361	278	397	389	409	388	427	392
	F	584	487	539	716	409	402	399	461	479	464	462	472
	M+F	537	456	474	716	385	349	398	434	441	430	443	436

Table 20 continued

		Oct.	Nov.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Nov.	Summary
WT Minimum	M	270	125	215	-	194	209	125	296	220	110	106	106
	F	320	250	152	716	104	116	109	46	108	148	199	46
	M+F	270	125	152	716	104	116	109	46	108	110	106	46
WT Maximum	M	790	732	564	-	688	377	576	479	870	703	615	870
	F	865	825	868	716	991	706	857	784	804	942	999[a]	999[a]
	M+F	865	825	868	716	991	706	857	784	870	942	999[a]	999[a]

[a] Reflects actual fish weight and not a data code.

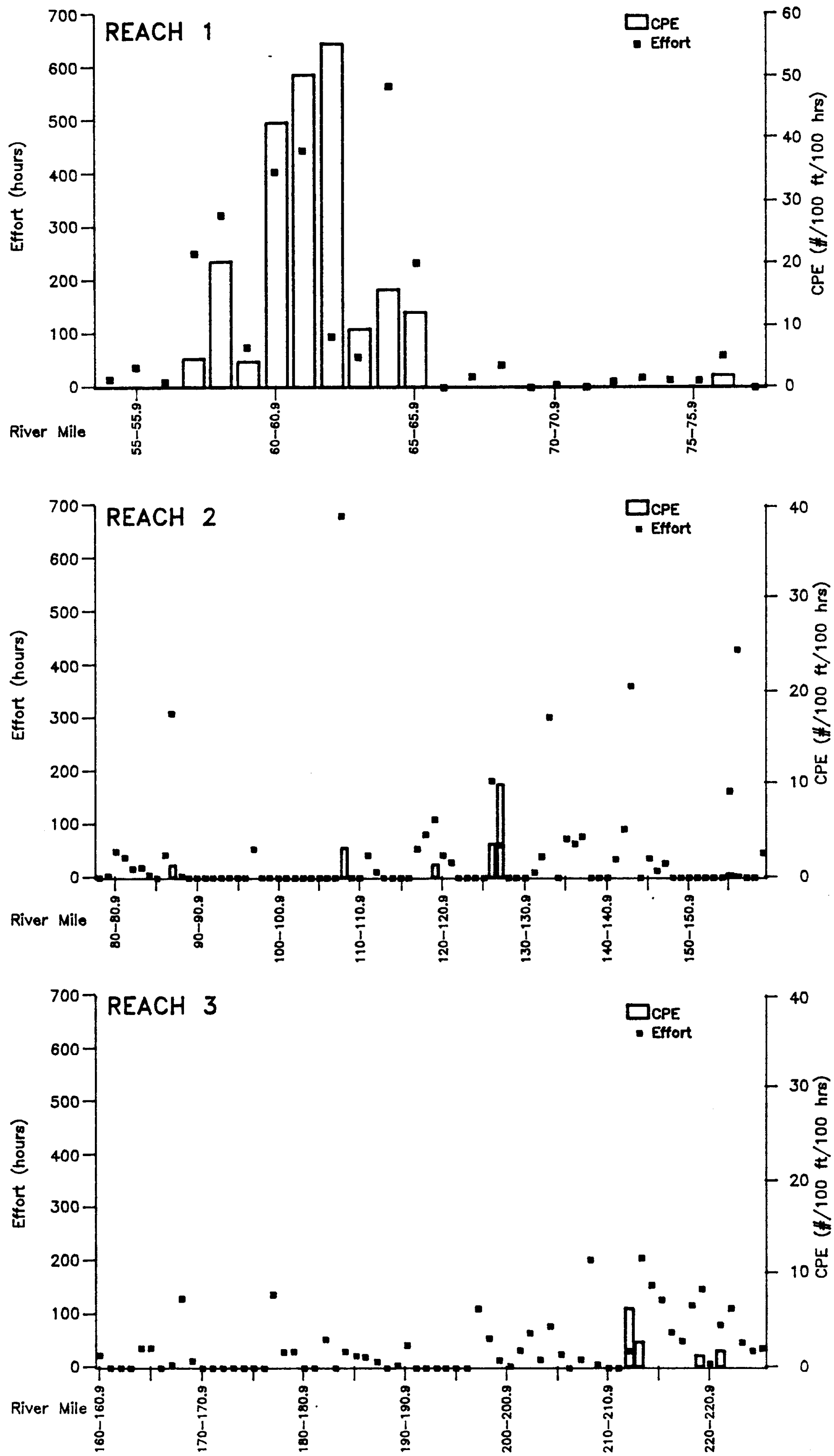

Figure 17. Total effort and netting catch rates of adult humpback chub in Reaches 1, 2, and 3 of the Colorado River in Grand Canyon, October 1990-November 1991.

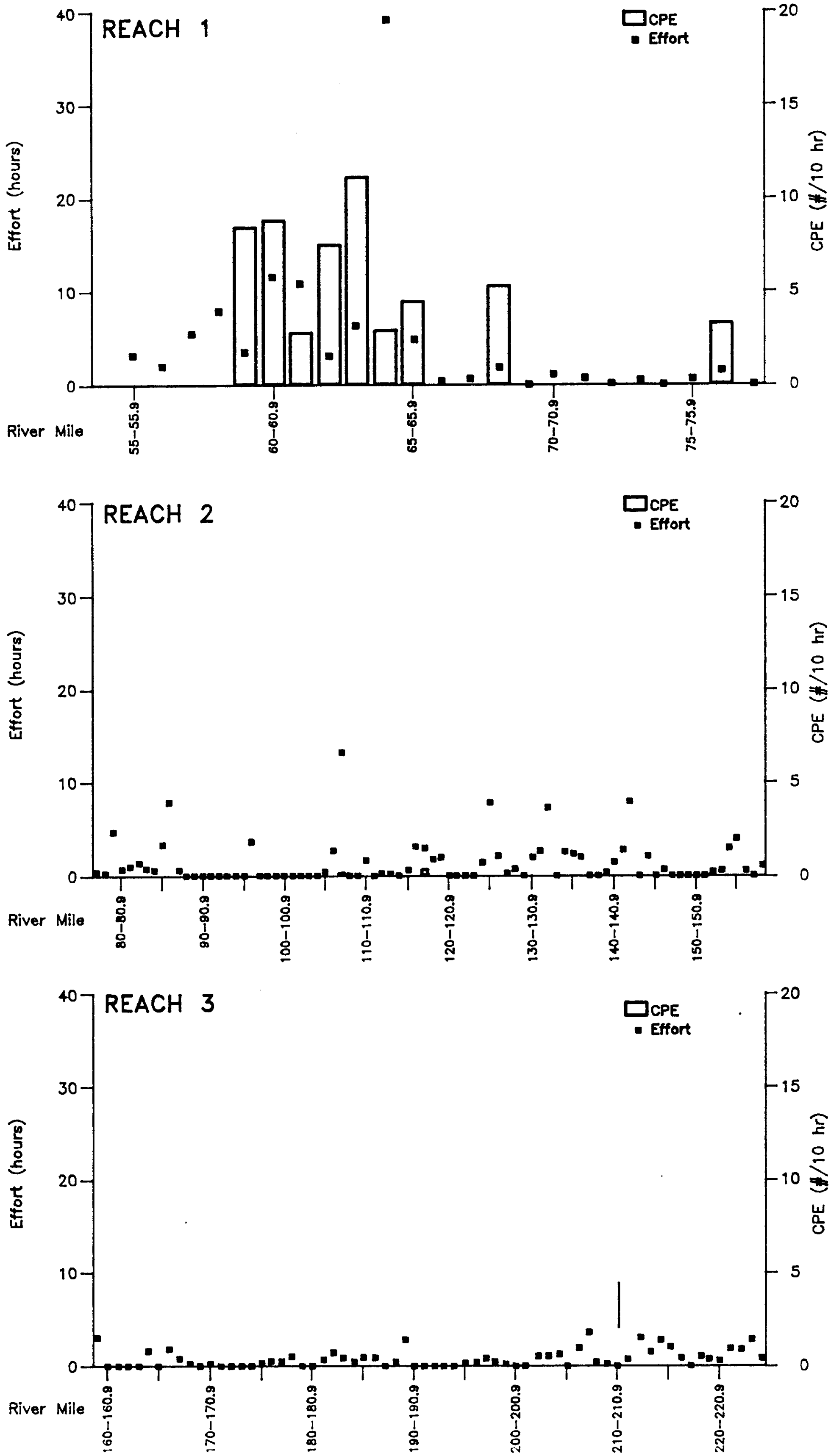

Figure 18. Total effort and electrofishing catch rates of adult humpback chub in Reaches 1, 2, and 3 of the Colorado River in Grand Canyon, October 1990-November 1991.

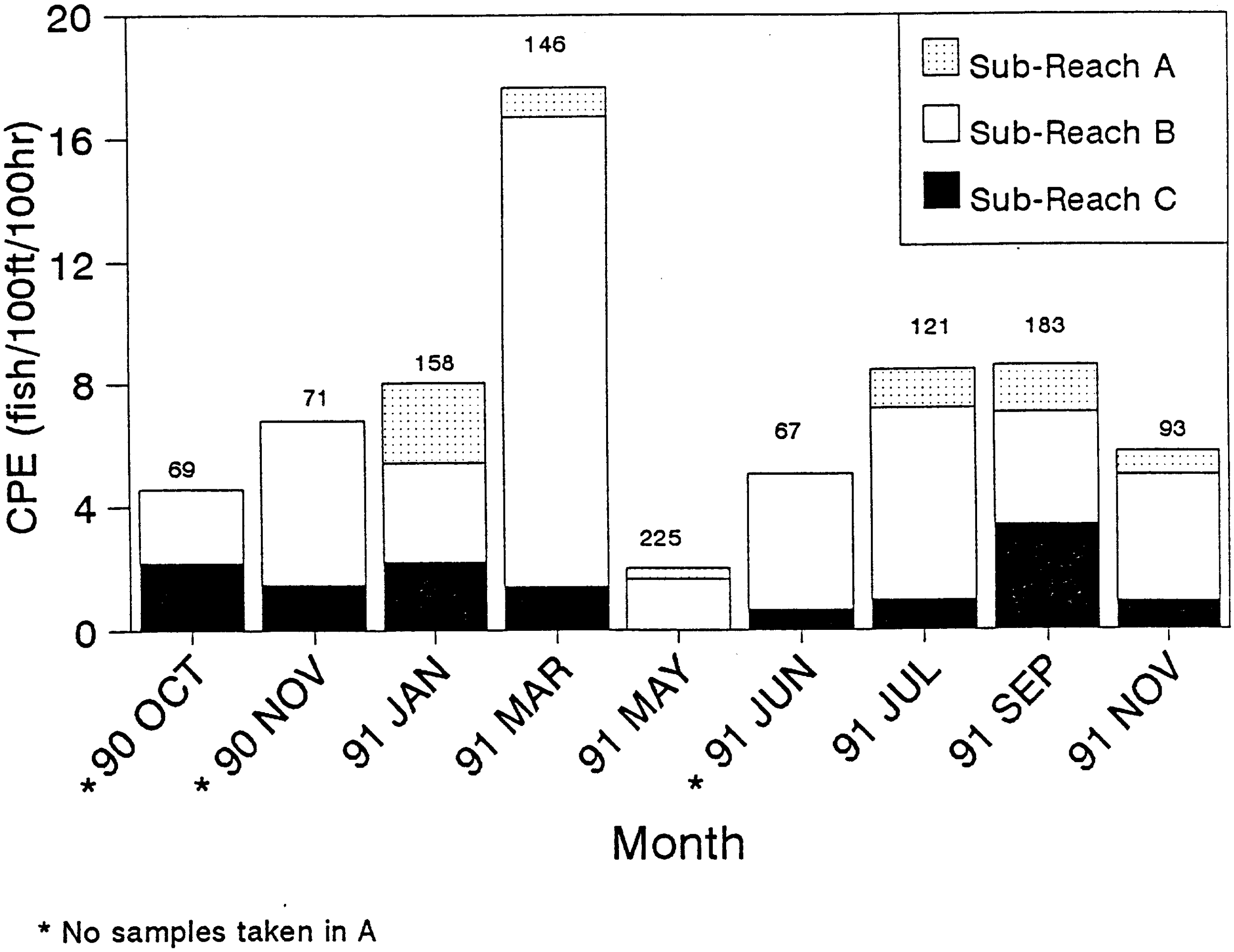

Figure 19. Monthly mean catch per effort of adult humpback chub in nets within three subreaches of Reach 1 of the Colorado River in Grand Canyon. A = RM 57.0-57.9, B = RM 59.75-62.4, C = RM 62.45-65.4.

were substantially lower in May because most adult chub were in the LCR spawning. 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-March levels in July, September, and November, 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 60.9-61.9, a 1-mile section including the LCR inflow. Netting CPE for adult chub was significantly higher (Fisher's LSD, $P < 0.05$) in March than any other month and four to five times higher than in the adjacent months of February and April (Figure 20). This analysis indicates that chub began to congregate at the mouth of the LCR in February, occurred in highest numbers in March, moved into the LCR in April and May, returned to the main channel in June and July, and dispersed in fall and early winter.

Diel Patterns in Catch Rates

Netting CPE's of adult humpback chub were higher at night (after sunset) than day (after sunrise) in every month but March and September (Figure 21). Nighttime CPE's were significantly higher ($P = 0.05$) than daytime CPE's in October and November of 1990, and January and July of 1991. The only significantly higher daytime catch rates occurred in March, when chub were staging at the mouth of the LCR. The significantly higher daytime CPE in March was atypical of nocturnal and crepuscular activity patterns and suggests that phototactic response was overridden by pre-spawning activity. Low mainstem turbidity during the March field trip minimized the possibility that increased daytime activity was affected by turbidity.

Catch rates were computed by 3-hour time blocks (Figures 22 and 23), comparable to those used in the diel effort analysis. Catch rates of adult humpback chub during these time periods were calculated and pooled for all trips except March, when day and night catches showed atypical behavioral trends. Netting CPE's were significantly lower for all time blocks between 0301 and 1200 hours, than for time blocks between 1201 and 2400 hours. Highest catch rate occurred between 1201 and 1500 hours, although this was not significantly different than any other time block between 1501 and 2400 hours. Relatively high daytime catch rates (1201-1800 hours) were biased by sampling during high turbidity and at select locations to increase catch of chubs for radioimplant. Also, netting catch rates did not necessarily correlate with near-surface activity of radiotagged fish because nets frequently fished depths greater than 4.5 m.

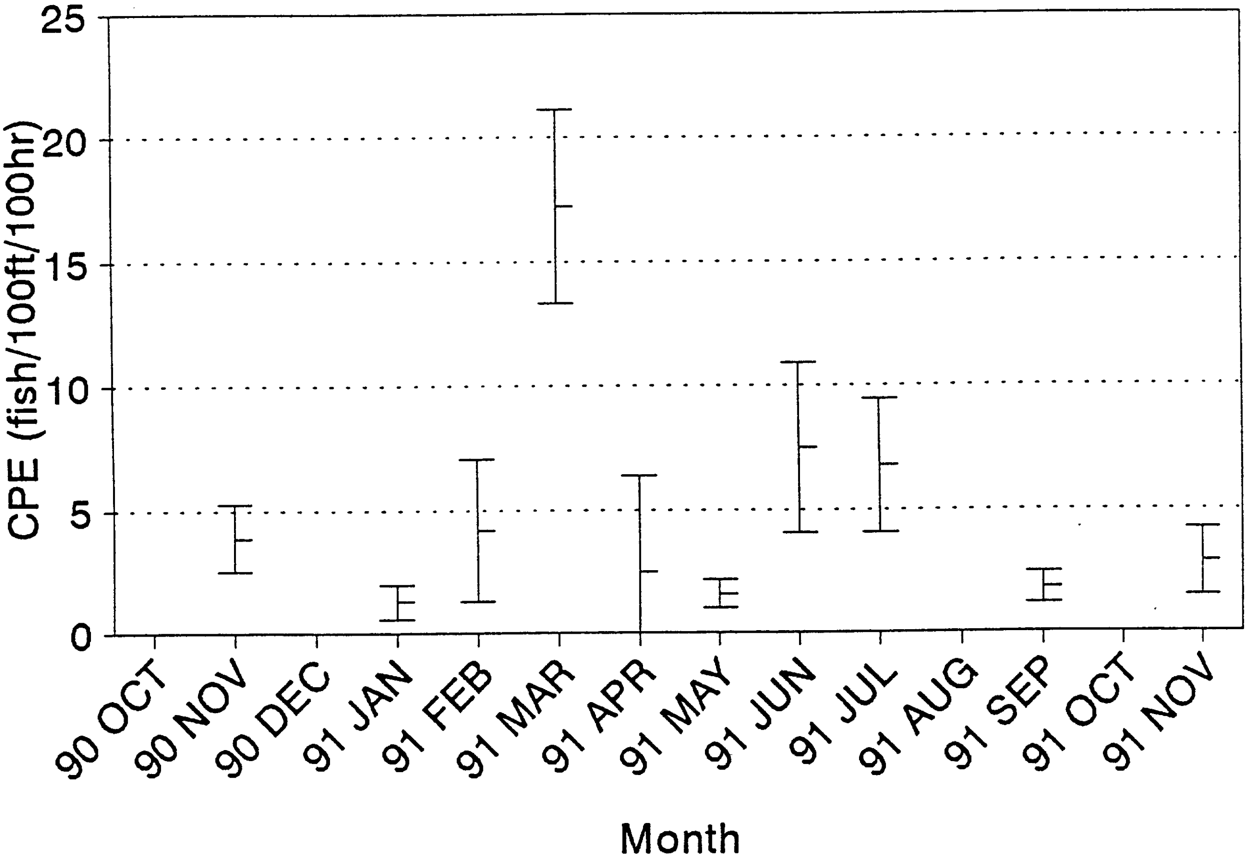

Figure 20. Monthly mean catch per effort of adult humpback chub captured in nets in Reach 1, RM 60.0-61.9 in the Colorado river in Grand Canyon.

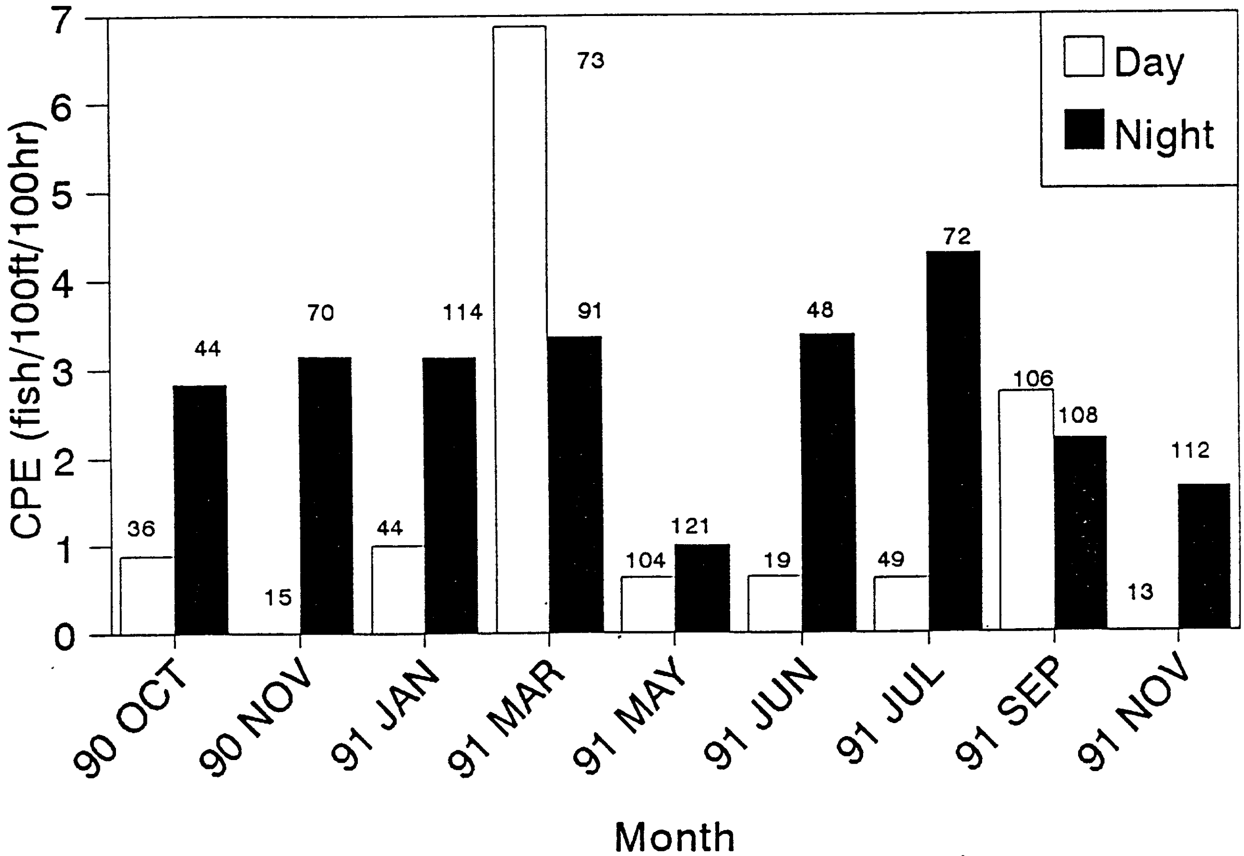

Figure 21. Monthly catch per unit effort of adult humpback chub captured in nets in Reach 1 by day and night in the Colorado River in Grand Canyon, 1990-1991. Sample number is shown above each bar.

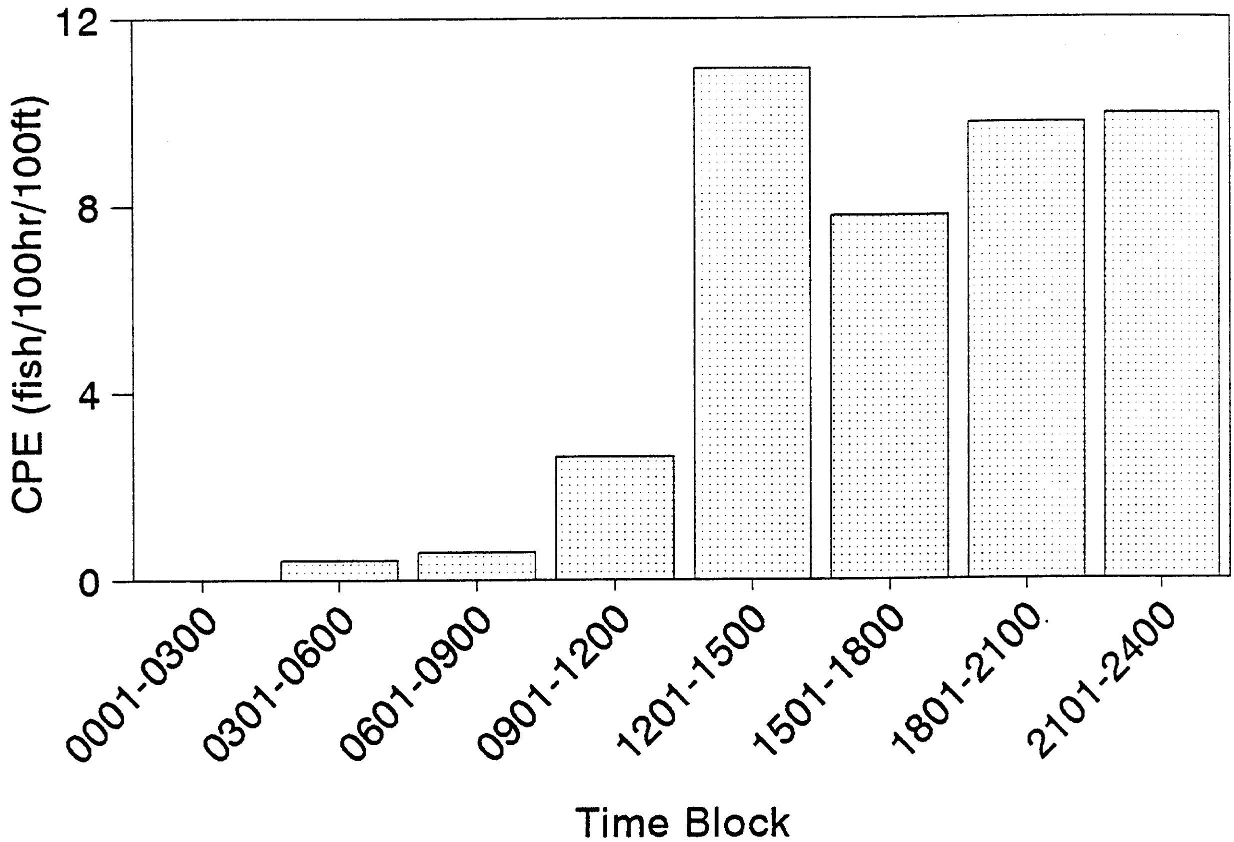

Figure 22. Pooled catch per unit effort for 3-hour time blocks for adult humpback chub captured in nets in the Colorado River in Grand Canyon, October 1990-November 1991.

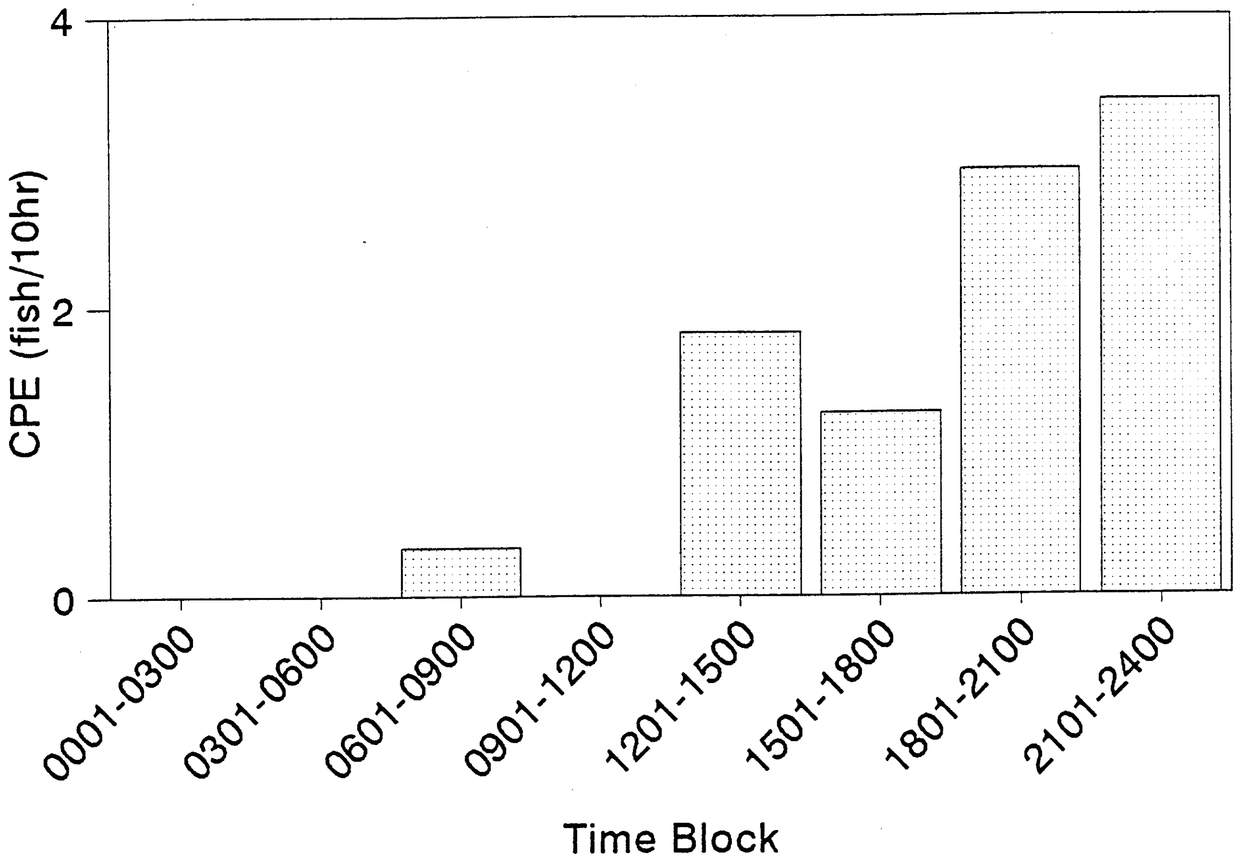

Figure 23. Pooled catch per unit effort for 3-hour time blocks for adult humpback chub captured by electrofishing in the Colorado River in Grand Canyon, October 1990-November 1991.

Electrofishing catch rates were similar to net catch rates in that CPE's were highest from 1201 to 2400 hours. Unlike netting, electrofishing CPE was significantly higher from 2101-2400 hours than in time blocks between 0601 and 1200 hours (Figure 23), possibly because greater near-surface activity by chubs increased their susceptibility to electrofishing. Higher electrofishing CPE's from 1801 to 2400 hours may also reflect greater nighttime effort. Evening and nighttime electrofishing catch rates were much higher for YOY and juvenile humpback chub than for adults as shown in Figure 30.

Effect of Turbidity on Catch Rates

A visual assessment of high or low turbidity was recorded for each net set. There were no significant differences in adult catch rates within trips between "high" and "low" turbidity conditions, although the ability to detect differences within a trip may be affected by small sample sizes. Pooled net catch rates for chub were significantly higher during periods of high turbidity, but there was no significant difference in electrofishing catch rates. Part of the reason for this discrepancy may be that most electrofishing was conducted early morning and after dark, when effect of turbidity was offset by cover of darkness. Turbidity also affected the ability of netters to see stunned fish and possibly affected electrofishing catch rates. Netting effort, however, peaked in the afternoon and was more influenced by turbidity. Also, sample size for electrofishing was much smaller than for netting. Presumably, high net catch rates during periods of high turbidity were because of increased chub activity under the cover of turbidity. The interaction of turbidity and ambient light on chub behavior could not be determined from netting and electrofishing data.

Age and Growth

Length-Frequency

Humpback chub of the 1991 year class were first captured in the mainstem in May 1991 (Figure 24). These young fish probably originated in the LCR, and may have entered the mainstem as early as April, when electrofishing and minnow traps were not used. Young chub were 50-90 mm TL in May, 60-100 mm in June, 40-100 mm in July, 40-120 mm in September, and 40-125 mm in November 1991. These samples probably contained chub from the 1990 (1-year olds) and 1991 (YOY) year classes. Juveniles between 100-200 mm TL were also captured in May. Kaeding and Zimmerman (1983) reported that chub remaining in the LCR reached a length of about 100 mm TL in 1 year, and 250-300 mm after 3 years (Kaeding and Zimmerman 1983). Although nearly all YOY and age 1 fish were captured below the confluence with the LCR, eight fish, ranging in size from 64-148 mm

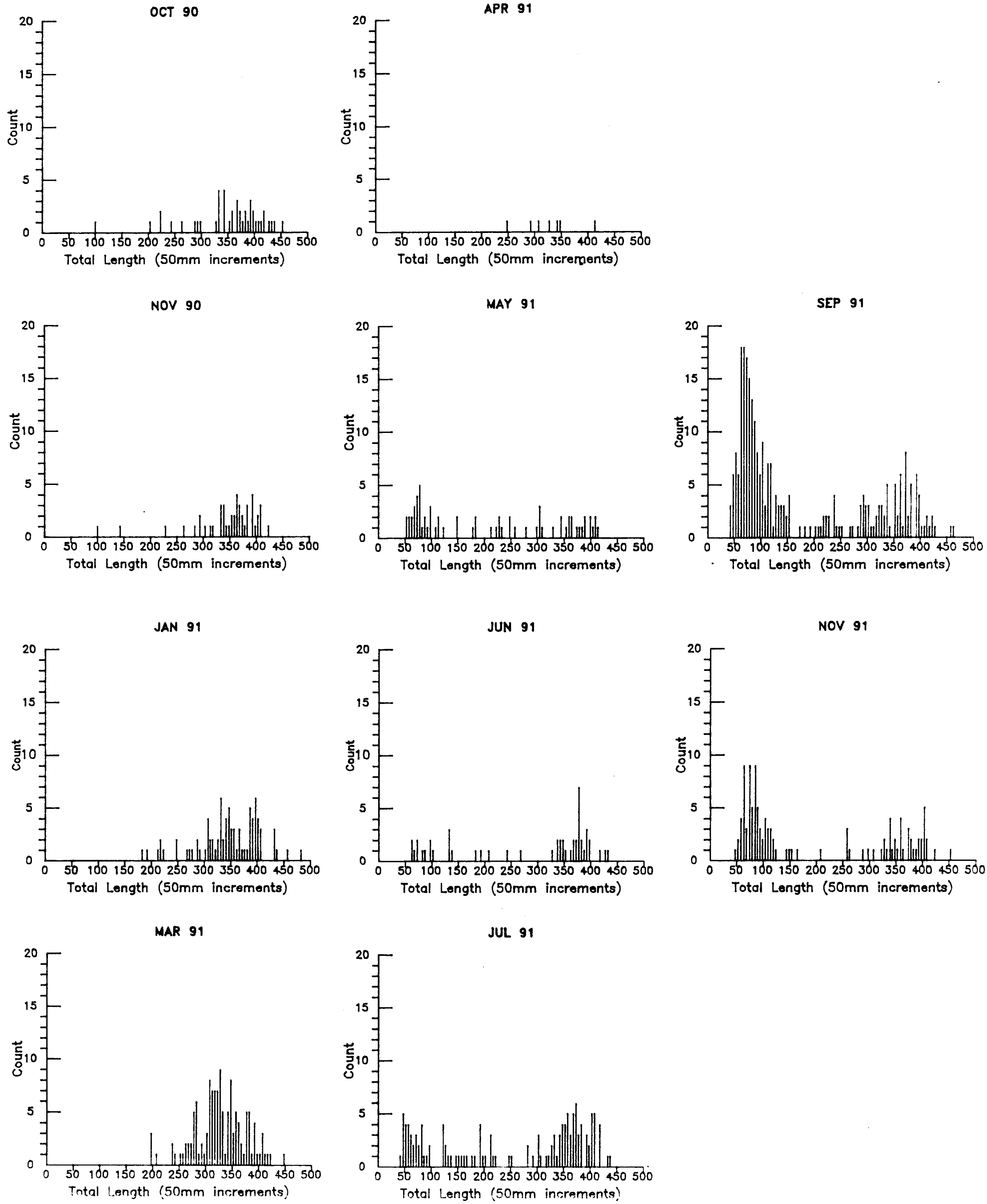

Figure 24. Length-frequency histograms of humpback chub captured in the Colorado River in Grand Canyon, October 1990-November 1991.

TL, were captured up to 1.8 km above the LCR from May through November. Kaeding and Zimmerman (1983) failed to collect chub smaller than 145 mm TL in the mainstem upstream of the LCR in October-November of 1980 and 1981, and April-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.

Relative Condition Factor

Relative condition (K_n) was calculated for adult humpback chub (TL > 150 mm) for each month (Table 21). Relative condition was above 1.00 from October 1990 to March 1991, and subsequently decreased from March to June (Figure 25). This trend in condition coincided with spawning activity. High condition prior to spawning was expected as the fish became robust with sex products and fat. Decline in condition after spawning was normal since fish lose substantial amounts of weight from release of sex products and energy expenditure during spawning. However, a return in October and November of 1991 to a level of condition comparable with October and November of 1990 was expected. Instead, relative condition was significantly lower in June, July, September, and November of 1991 than in October of 1990 and January and March of 1991 (Table 22). Although Kn was not significantly different between November 1990 and November 1991, it was significantly higher in October 1990 and January 1991 than in September and November of 1991. With only one year's data it should not be assumed that this represents a general decline in the health of the population. Decreased condition could be an anomaly of a self-regulating annual Kn curve, or perhaps the population follows normal, long-term cyclic changes. The possibility cannot be ruled out that the decline in condition was related to dam operations, since interim flows were initiated in early August 1991 about the time that Kn for adult chub should have increased. It is possible that interim flows had an adverse impact on the chub population, possibly because of changes in food transport. This cannot be substantiated without further data collection.

Monthly Kn was also calculated for adult rainbow trout (> 150 mm TL) in 1990 and 1991 (Table 23). Relative condition factor for rainbow trout increased from October 1990 to January 1991, at which time the majority of spawning activity occurred (Figure 26). Condition decreased from January

Table 21. Monthly relative condition (Kn) of 550 humpback chub (>150 mm TL) from the Colorado River in Grand Canyon, 1990-1991.

Month	Sample Size	Relative Condition	Standard Error
October, 1990	35	1.070	0.025
November	41	1.026	0.022
January, 1991	75	1.052	0.013
March	110	1.058	0.014
April	7	0.994	0.048
May	34	1.001	0.025
June	29	0.930	0.022
July	77	0.988	0.019
September	100	0.987	0.016
November	42	0.979	0.022

Table 22. A statistical comparison of mean monthly relative condition factors for humpback chub (>150 mm TL) from the Colorado River in Grand Canyon, 1990-1991. See Table 21 for Kn values.

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

	Oct.	Nov.	Jan.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Nov.
Oct.	1.000									
Nov.	0.188	1.000								
Jan.	0.549	0.354	1.000							
Mar.	0.666	0.231	0.794	1.000						
Apr.	0.207	0.591	0.311	0.026	1.000					
May	0.049*	0.457	0.088	0.046*	0.909	1.000				
Jun.	0.000*	0.006*	0.000*	0.000*	0.293	0.053	1.000			
Jul.	0.006*	0.174	0.006*	0.001*	0.913	0.660	0.067	1.000		
Sep.	0.004*	0.147	0.003*	0.000*	0.899	0.626	0.062	0.967	1.000	
Nov.	0.006*	0.135	0.009*	0.003*	0.791	0.500	0.166	0.734	0.748	1.000

*significant at 0.05

Table 23. Monthly relative condition (Kn) of 3,568 rainbow trout (>200 mm TL) from the Colorado River in Grand Canyon, 1990-1991.

Month	Sample Size	Relative Condition	Standard Error
October, 1990	87	1.055	0.030
November	334	1.054	0.014
January, 1991	177	1.072	0.046
February	4	0.985	0.072
March	516	0.994	0.029
April	10	0.961	0.044
May	648	1.056	0.014
June	24	1.153	0.052
July	677	1.094	0.035
September	667	0.958	0.009
November	424	1.107	0.029

Table 24. A statistical comparison of mean monthly relative condition factors for rainbow trout (>200 mm TL) from the Colorado River in Grand Canyon, 1990-1991. See Table 23 for Kn values.

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

	Oct.	Nov.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Sep.	Nov.
Oct.	1.000										
Nov.	0.988	1.000									
Jan.	0.815	0.727	1.000								
Feb.	0.810	0.810	0.761	1.000							
Mar.	0.355	0.133	0.113	0.975	1.000						
Apr.	0.623	0.613	0.549	0.945	0.859	1.000					
May	0.983	0.949	0.740	0.803	0.063	0.601	1.000				
Jun.	0.454	0.409	0.514	0.571	0.180	0.371	0.413	1.000			
Jul.	0.550	0.296	0.657	0.703	0.003*	0.466	0.232	0.615	1.000		
Sep.	0.137	0.012*	0.018*	0.926	0.287	0.986	0.002*	0.100	0.000*	1.000	
Nov.	0.441	0.206	0.502	0.671	0.003*	0.426	0.158	0.697	0.715	0.000*	1.000

*significant at 0.05

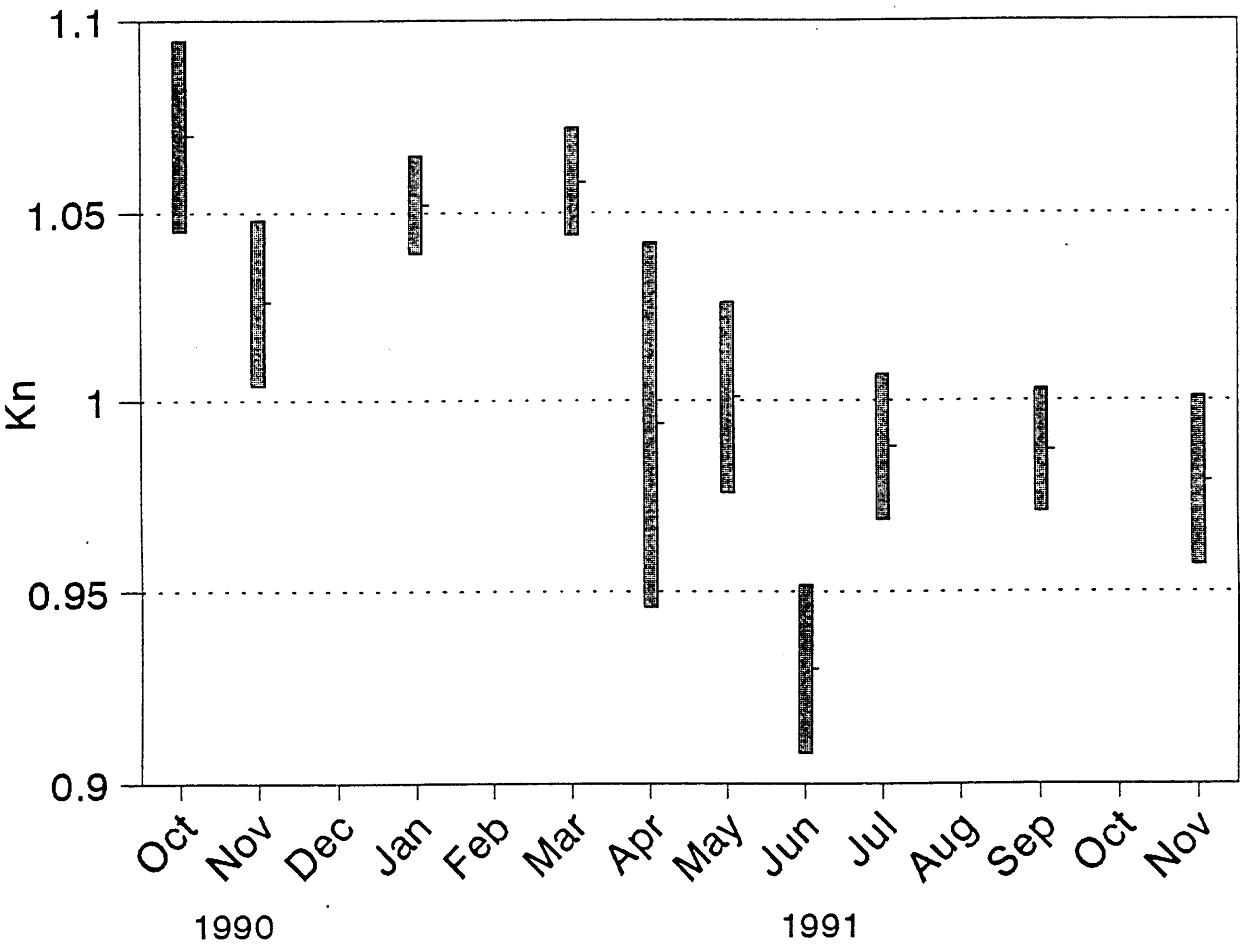

Figure 25. Relative condition factor (Kn) of adult humpback chub (TL > 150 mm TL) from the Colorado River in Grand Canyon. Values represent means ± one standard error.

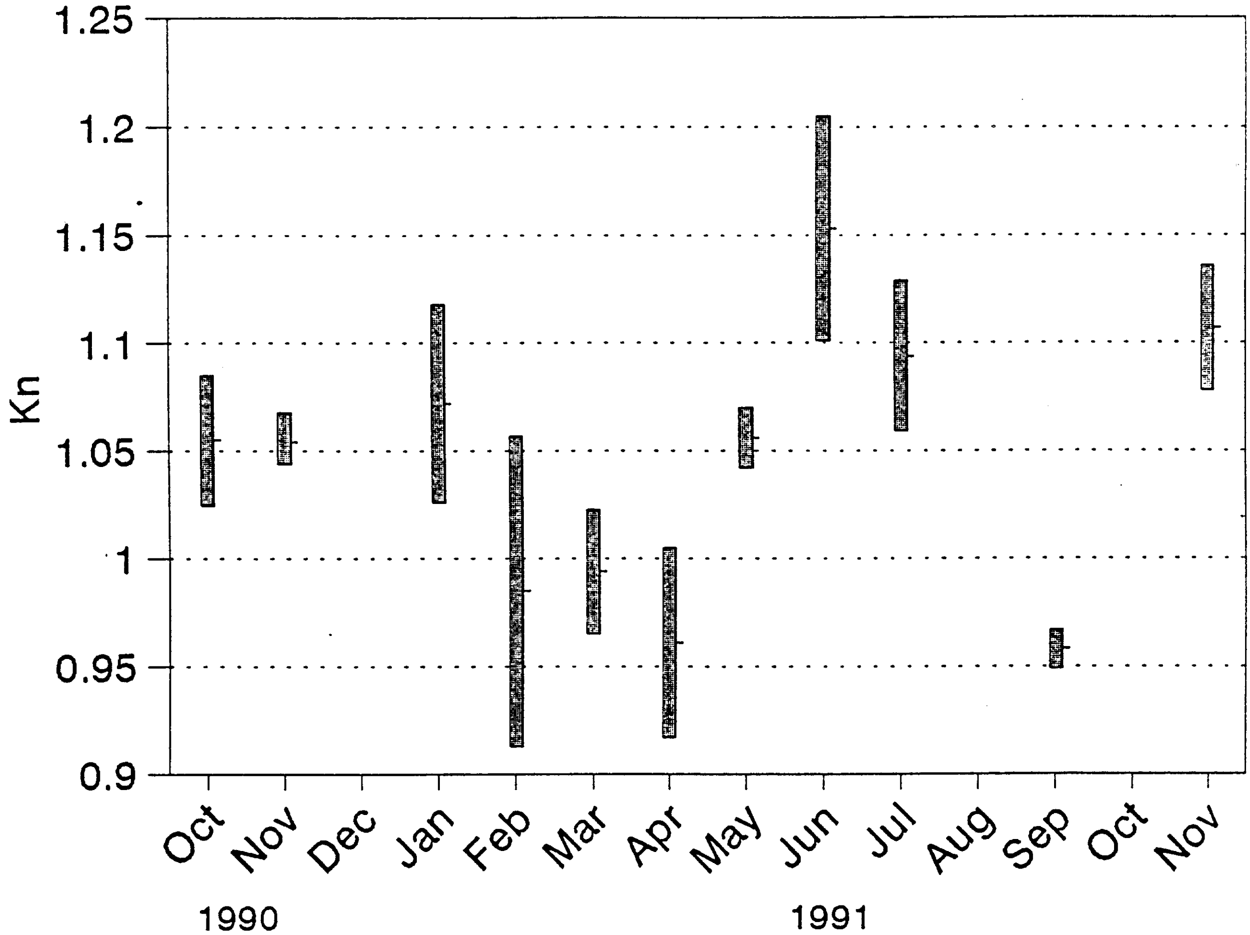

Figure 26. Relative condition factor (Kn) of adult rainbow trout (TL > 200 mm) from the Colorado River in Grand Canyon. Values represent means ± one standard error.

to April, and then increased to its highest point in June. There was a seemingly anomalous decline in Kn in September 1991. Relative condition factor of rainbow trout in September was significantly lower than in July and November (no fish were sampled in August and October 1991) (Table 24).

Population Estimates

Population estimates of humpback chub were conducted in the mainstem Colorado River near the mouth of the LCR. The estimate was based on recaptured fish over 175 mm TL that had been marked with PIT tags by BIO/WEST; recaptures of fish marked by other investigators were not considered. A complete explanation of the estimation technique is presented in EVALUATION OF METHODS.

The estimate was divided into two periods, pre-spawning (October 1990 through March 1991), and post-spawning (July through September of 1991), since the large numbers of chub migrating into the LCR in April, May, and June violated one of the assumptions of the estimator model.

The estimate in March 1991 was 1,395 fish (95% C.I. = 916-2254), and the estimate in September 1991 was 2,407 fish (95% C.I. = 1,102-6,564) (Table 25). While we recognize that the March estimate was bound by 66 percent and 162 percent of the estimator, and the September estimate by 46 percent and 273 percent of the estimator, these population estimates provide a perspective for the size of the adult portion of the humpback chub population in the mainstem near the LCR inflow.

Evaluation of PIT-tagged Recaptures

A total of 133 humpback chub captured by B/W had been previously tagged or marked by other researchers (Table 19). 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. A total of 61 chub were captured by B/W, PIT-tagged, and subsequently recaptured. Seventeen fish lost weight in the interim and 13 gained weight. Average weight change of PIT-tagged recaptures at large at least 30 days was -12.3 g, or 1.3 percent loss in body weight (Table 26). Average weight change per 30 days was -2.5 gm.

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 gm (Table 27). 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

Table 25. Population estimate[a] for humpback chub larger than 175 mm TL in the Colorado River (RM 57.0-65.4) in Grand Canyon, 1990-1991[b]

Month	C_t	R_t	Sum R_t	No. at Large less recaps	M_t	C_t*	Sum C_t*M_t	N	Poisson Lower Limit	Nlow	Poisson Upper Limit	Nhigh
Oct - 1990	43	0	0	43	0	0	0	-	-	-	-	-
Nov	43	2	2	41	43	1849	1849	924	0.2	257	7.2	9245
Dec	0	0	2	0	84	0	0	-	-	-	-	-
Jan - 1991	80	4	6	76	84	6720	8569	1425	2.2	654	13.1	3895
Feb	3	1	7	2	160	480	9049	1293	2.8	628	14.4	3232
Mar	125	14	21	111	162	20250	29299	1395	13	916	32	2254
Apr	7	0	0	7	0	0	0	-	-	-	-	-
May	29	0	0	29	7	203	203	-	-	-	-	-
Jun	37	0	0	37	36	1332	1535	-	-	-	-	-
Jul	77	1	1	76	0	0	0	-	-	-	-	-
Aug	0	0	1	76	76	0	0	-	-	-	-	-
Sep	95	5	6	166	152	14440	14440	2407	2.2	1103	13.1	6564

[a]The estimate was based on Schnabel's Method of maximum liklihood using PIT-tagged fish marked and recaptured by BIO/WEST.

[b]C_t = total number of fish captured on day t
R_t = number of recaptures in the sample C_t
M_t = total marked fish at large at the start of day t
Poisson Lower and Upper Confidence Limits for variable Sum R_t

Table 26. Weight change and net displacement of recaptured PIT-tagged and radiotagged humpback chub in the Colorado River in Grand Canyon, 1990-1991.

	Average		SD		Range	
	PIT	RAD	PIT	RAD	PIT	RAD
Number[a]	30	12	-	-	-	-
No. lost weight	17	11	-	-	-	-
No. gained weight	13	1	-	-	-	-
Weight change (gm)	-12.3	-58.7	47.9	56.1	-267/+75	-226/+1
Percentage change	-1.3	-9.0	11.5	6.8	-51.4/+22.1	-28/+0.2
Days at large	150.3	117.8	86.0	92.5	31/357	52/357
Weight change/30 days (gm)[b]	-0.4	-16.2	11.9	8.3	-22.7/+19.2	-29.4/+0.3
Displacement (km)[c]	-0.08	-8.69	0.9	17.7	-3.2/+1.9	-61.5/+0.8
Displacement/30 days (miles)	-0.14	-1.13	0.63	2.1	-3.1/+0.1	-7.1/+0.3

[a]Only fish at large >30 days were included.
[b]Average weight change computed from individual fish.
[c]A negative value indicates downstream displacement.

Table 27. A comparison of length, weight, and sex determination for four adult humpback chub at capture (C) and recaptured (R) from the Colorado River in Grand Canyon, 1990-1991. All four fish were at large less than 24 hours.

	Individual Fish				Difference in Measures		
	1	2	3	4	Average	SD	Range
TL-C	356	318	325	311			
TL-R	347	315	322	306	5.0	2.8	3-9
FL-C	310	299	290	282			
FL-R	323	297	288	278	5.2	5.3	2-13
SL-C	285	274	271	261			
SL-R	293	274	270	256	3.5	3.7	0-8
WT-C	355	328	350	318			
WT-R	349	340	326	326	12.5	8.1	6-24
SEX-C	M	F	M	F	-	-	-
SEX-R	M	F	F	F	Sex different for 1 fish		

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 scale was tared each time before measuring a fish, (2) the fish was carefully lifted from the live well and excess water allowed to drip for several seconds, and (3) 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. Regurgitation during capture and handling could have also 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=61) and adult chub captured for the first time (n=770) 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.

MOVEMENT OF HUMPBACK CHUB

Long-Range Movement

Long-range movement is defined as displacement between gross habitat features or large habitat complexes. It does not include localized movement or activity within habitats or small habitat complexes. Long-range movement was assessed from radiotagged adult humpback chub and PIT-tagged adults and juveniles. Individual fish locations were identified from day and night boat surveillances and from periodic diel observations of 2 to 24 hours duration. Only locations with a high observer confidence of '1' were used for the long-range movement database. Because these telemetry observations were not ongoing, fish displacement was used as an index to movement. "Net displacement" was defined as the average horizontal distance from release site to last contact point for an individual fish. "Gross displacement" was defined as the cumulative distance between successive contact points for an individual fish.

Long-Range Movement of Radiotagged Fish

A total of 48 radiotagged adults, implanted between October 1990 and September 1991, were used to evaluate long-range movement or displacement (Table A-22). Five fish implanted in November 1991 were not used in the analysis because the 2-week, post-surgical, acclimation period had not expired. The average length of time for the 48 subject fish between release date and last contact was 86 days, with a range of 5 to 178 days. During this time the fish exhibited a mean "net displacement" of 1.34 km, with a range of 0 to 5.55 km. Mean "gross displacement" during the same period was 4.23 km and ranged from 0 to 16.33 km.

Of the 48 radiotagged adults, 83.3 percent exhibited a net displacement of less than 2 km (Figure 27). The corresponding gross displacement varied between fish, but the majority displayed a ratio of net to gross movement of between 1:3 and 1:4. This gross displacement occurred either within a relatively localized area or as a result of a spawning migration. Net displacement of recaptured PIT-tagged juveniles and adults was similar in that 88.1 percent of the fish were recaptured within 2 km of the previous capture location.

Radiotelemetry studies with adult humpback chub in Black Rocks, Colorado, revealed a similar affinity by individual fish for specific riverine sites. Valdez and Clemmer (1982) reported "average movement" by eight fish of 0.8 km (range, 0-3.7 km) over an average period of 38 days (range, 4-93 days). Kaeding et al. (1990) also showed a "mean displacement" by 33 radiotagged adults of 0.8 km from release site to last contact, and a "mean maximum displacement" of 1.4 km.

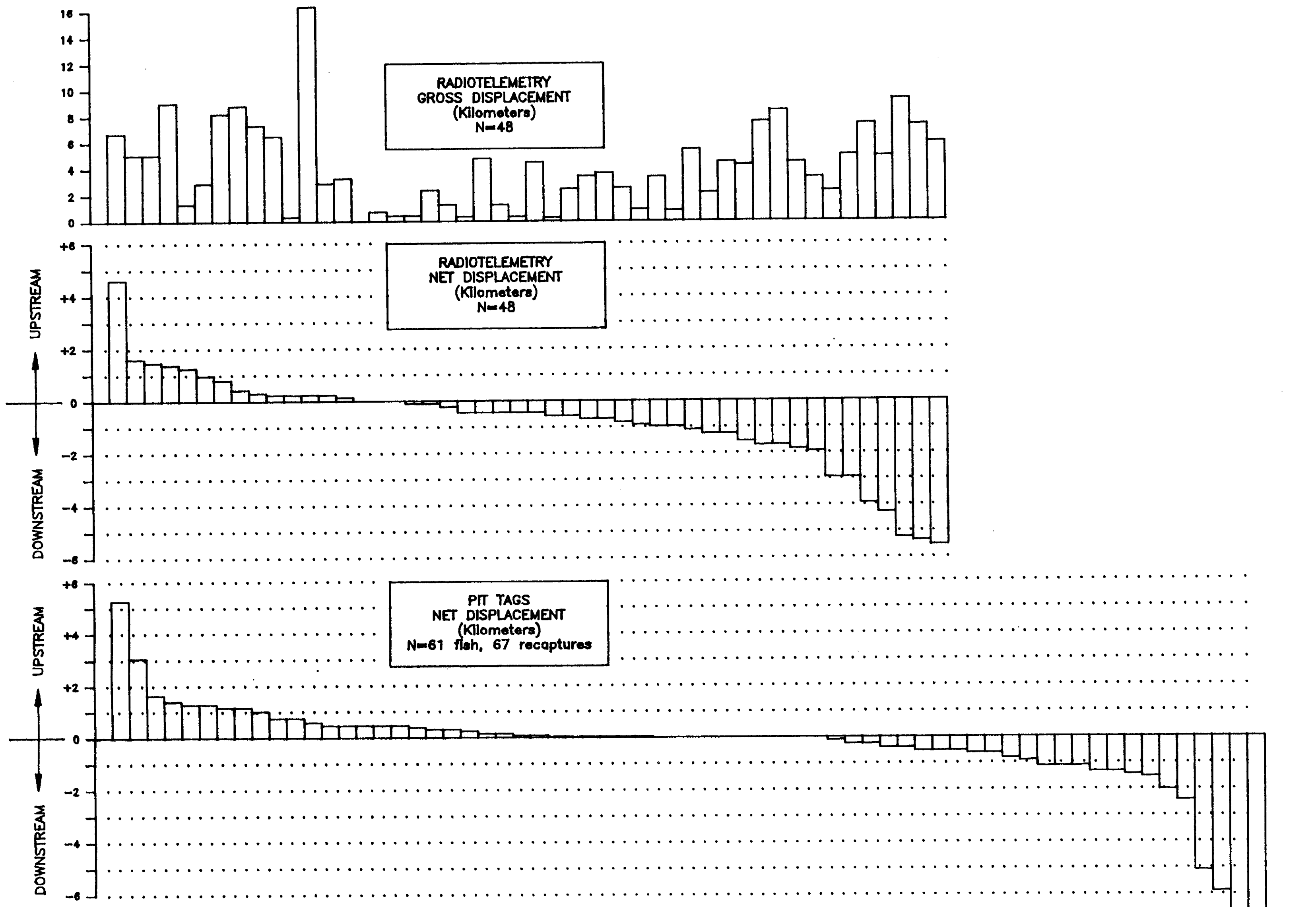

Figure 27. Gross and net displacement of radiotagged adult humpback chub and net displacement of PIT-tagged adults and juveniles in the Colorado River in Grand Canyon, 1990-1991.

Our observations of movement by radiotagged adult humpback chub in the Grand Canyon are comparable and similar to those of Valdez and Clemmer (1982) and Kaeding et al. (1990) in Black Rocks (Figure 28). "Average movement" of 0.8 km reported by Valdez and Clemmer (1982) equates to "mean displacement" of 0.8 km reported by Kaeding et al. (1990). These measures of movement equate to mean "net displacement" of 1.34 km expressed for the Grand Canyon fish.

We hypothesize that the difference in mean "net displacement" between the Black Rocks fish (0.8 km) and the Grand Canyon fish (1.34 km) was attributed to a spawning migration by the latter from the mainstem Colorado River to the LCR. Kaeding and Zimmerman (1983) and Maddux et al. (1986) recaptured tagged humpback chub that had moved between the mainstem Colorado River and LCR. Cold water released from Glen Canyon Dam precludes reproductive success in the mainstem (Maddux et al. 1986).

The hypothesis to explain differences in movement was tested by comparing displacement of migratory and non-migratory adults. 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. Non-migratory fish were never located in these areas. Of the 48 radiotagged fish monitored, 50 percent (24) were classified as migratory and 50 percent (24) were non-migratory (Table A-23), although several exhibited movement toward the LCR (as near as RM 61.2). Mean "gross displacement" was significantly greater ($t=3.33$, $P<0.01$) for migratory chub (5.66 km) than for non-migratory chub (2.78 km) (Table 28). However, mean "net displacement" of migratory (1.68 km), and non-migratory (0.98 km) individuals was not significantly different at the 5 percent level ($t=1.45$, $P=0.16$). These findings support the hypothesis that long-range movement by the Grand Canyon humpback chub is primarily attributed to migration. We note the similarity in mean "net displacement" of non-migratory Grand Canyon fish (0.98 km) and fish from Black Rocks (0.8 km).

It is not known if the entire adult portion of the mainstem population migrated to the LCR to spawn in 1991. Higher gross displacement for migratory fish was attributed to spawning-related activity and suggests that only a portion of the population migrated. However, the short-lived radiotransmitters and discontinuous monitoring precluded following a given fish through its entire migrational cycle. The lack of significant difference in net displacement between migratory and non-migratory fish could also be associated with limited opportunity to observe the same individual through an entire migrational sequence (i.e., to and from a location). Several fish were observed migrating long distances and returning to approximately the starting location, resulting in large gross

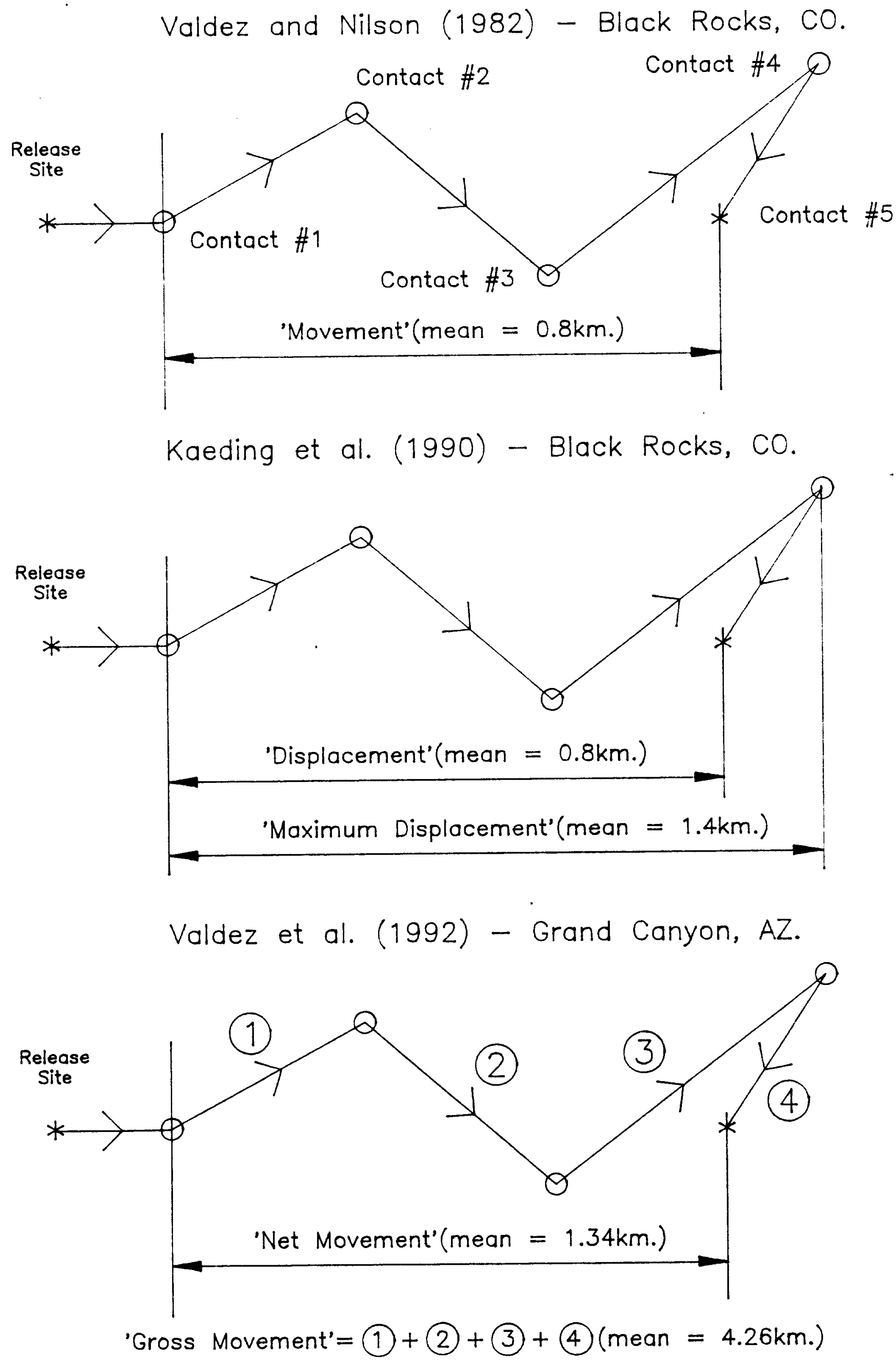

Figure 28. Comparison of methods and terminology used to assess movement of humpback chub from two previous studies and the BIO/WEST study in the Colorado River in Grand Canyon.

Table 28. Gross and net displacement of migratory and non-migratory radiotagged adult humpback chub in the Colorado River in Grand Canyon, 1990-1991.

	MIGRATORY			NON-MIGRATORY	
PIT Tag No.	GROSS (km)	NET (km)	PIT Tag No.	GROSS (km)	NET (km)
7F7F3F5050	4.42	1.53	7F7F3F3626	2.74	0.80
7F7F3E2D2D	3.22	0.64	7F7F3E2253	0	0
7F7F3C4452	7.64	1.61	7F7F3F4054	0.32	0.32
7F7F3C303B	3.54	1.93	7F7F3F5044	1.45	1.29
7F7F3F4E77	8.93	0.32	7F7F3F4E11	0.97	0
7F7F3E3C5C	1.45	0.32	7F7F3E2F3A	1.13	0.16
7F7F3E3030	7.32	5.39	7F7F456B2C	0.88	0.08
7F7F3C3171	5.15	2.90	7F7F3C311C	4.83	0.32
7F7F3F3A5C	7.40	4.02	NO PITTAG	0.32	0.32
7F7F3C2D06	4.26	1.85	7F7F3C2919	3.54	0.64
7F7F3E3D23	8.53	1.61	7F7F3C4162	8.21	0.80
7F7F3E2727	2.17	1.21	7F7F3C4208	2.57	2.90
7F7F3E2661	5.15	4.34	7F7F3E362E	0.40	0.40
7F7F3F4453	2.33	0.08	7F7F3C243E	6.68	4.67
7F7F3F520D	4.59	1.21	7F7D076050	2.98	0.16
7F7F3E3B00	2.57	0.40	7F7D086032	5.15	1.53
7F7F3E372A	2.98	1.05	7F7D084C05	3.46	0.08
7F7F3C6F15	9.25	5.23	7F7D08545E	7.48	0.24
7F7D026506	9.09	1.45	7F7D081904	5.87	5.55
7F7D075B05	3.54	0.97	7F7D08552A	0.97	0.97
7F7F04461F	4.42	0.32	7F7D09067B	5.47	1.13
7F7D07776A	5.15	1.61	7F7F3F3764	0.24	0.16
7F7F3E276F	16.33	0.16	7F7F3E3149	1.05	0.88
7F7F3F4E45	6.44	0.16	7F7F3E2542	0.03	0
MEAN	5.66	1.68	**MEAN**	2.78	0.98
STD. DEV.	3.28	1.58	**STD. DEV.**	2.57	1.44
MINIMUM	1.45	0.08	**MINIMUM**	0	0
MAXIMUM	16.33	5.39	**MAXIMUM**	8.21	5.51
NO. OF FISH	24	24	**NO. OF FISH**	24	24

displacement but relatively small net displacement. Others could only be monitored through a portion of the migration because of timing of field observations or expiration of radiotransmitter. In some cases, fish were tracked into the LCR area, where contact was lost because of water quality. Some fish that were radiotagged near the LCR returned to a mainstem location, indicating that a substantial number of radiotagged fish were probably observed on only one leg of the migration, resulting in higher net displacement.

The difference in displacement from release site to last contact between Black Rocks fish (0.8 km) and Grand Canyon fish (1.34 km) may also be attributed to differences in habitat distribution. Suitable habitat in Black Rocks is limited to a small reach of river (3 to 4 km) such that migrational movements within the area are limited. Main channel spawning habitat in Black Rocks may be readily available, requiring little migration. Migration of Grand Canyon humpback chub appeared strongly associated with movement to and from the LCR. The magnitude of these movements may be associated with how far the fish can (habitat limited) or will (behavioral limitations) disperse from this discrete area.

Fidelity by adult humpback chub for specific river sites was first reported by Valdez and Clemmer (1982) and then by Kaeding et al. (1990). Patterns of displacement by Grand Canyon chub also suggest fidelity to specific locales. To illustrate this phenomenon, all high confidence telemetry locations for PIT-tagged fish #7F7F3E276F were plotted on Figure 29. This fish moved approximately 5.0 km from its original location near RM 58.4 to the LCR and back in a period of 34 days (July 13 - August 16, 1991). Over the total observation time of 62 days, gross displacement was 16.33 km, while net displacement (distance from first to last contact) was only 0.16 km. The fish frequented two areas between RM 58.0 and 59.0, and returned to its original contact location following a presumed spawning migration.

Although the fish depicted in Figure 29 was only one of several fish tracked to and from the LCR, a majority of the 48 radiotagged fish demonstrated some degree of fidelity to specific locales. Table 29 presents a summary of radiotagged fish that reoccupied a locale following movements of 1.0, 0.5, or 0.1 km. Twenty-seven percent of the radiotagged fish moved more than 1 km and returned to the same locale. Forty-two percent moved more than 0.5 km and returned to the same locale, and 80 percent returned to the same locale after a move of 0.1 km or more. Nineteen percent of the radiotagged fish failed to reoccupy a specific locale, and only 2 percent failed to move during the monitoring period.

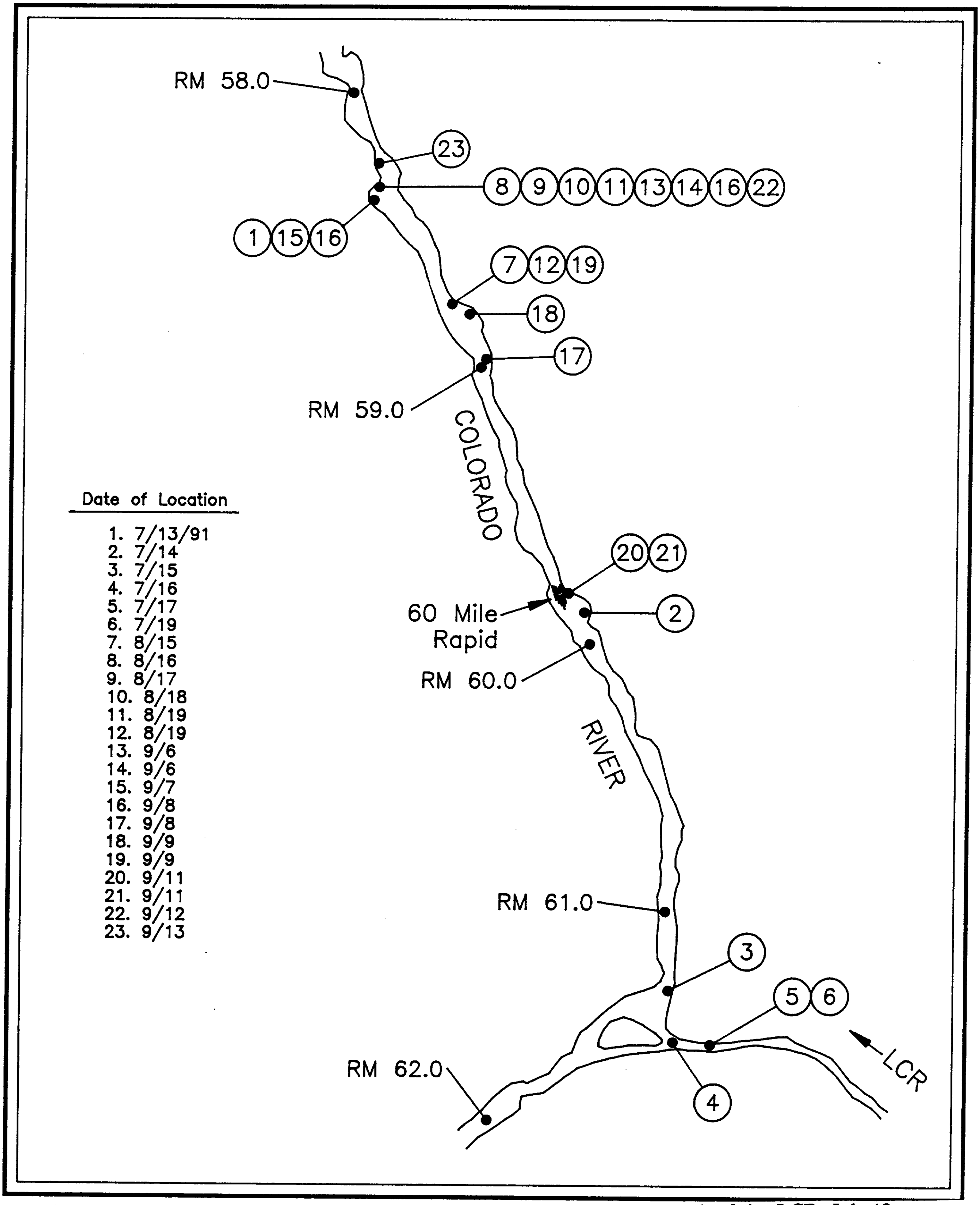

Figure 29. Locations of a radiotagged adult humpback chub near the mouth of the LCR, July 13-September 13, 1991. (PIT tag #7F7F3E276F).

Table 29. A summary of radiotagged adult humpback chub which reoccupied a locale following movement of 1.0, 0.5 or 0.1 km.

	Distance moved			Failed to Relocate	Failed to Move	Total
	>1 km	>0.5 km	>0.1 km			
No fish	13	7	18	9	1	48
% of Total	27%	15%	38%	19%	2%	100%

Long-Range Movement of PIT-Tagged Fish

A total of 61 humpback chub PIT-tagged by BIO/WEST were recaptured between October 1990 and November 1991 (Table A-24). Five of these fish were recaptured twice and one fish (PIT tag #7F7F3E3212) was recaptured three times. Average elapsed time from original capture to recapture was 99.3 days (range, 0 - 357 days). Average distance from original capture to recapture location was 2.40 km (range, 0 to 98.95 km).

Two fish were omitted from this database as anomalies or outliers (rationale for omission is presented in the following paragraph) and the data reanalyzed. Excluding these two fish, average elapsed time between original capture and recapture was 98.3 days (range, 0 - 357 days). Average distance from the original capture location was 0.83 km with a range of 0 to 5.79 km. Similar findings have been reported by other investigators. "Average movement" of Carlin-tagged humpback chub in Black Rocks over an average of 137 days (range, 1-434 days) was 1.6 km (range, 0-23.0 km). All but one of these fish (recaptured 23 km upstream) were recaptured less than 0.7 km from their release site. Excluding this fish from the dataset means that the average movement was less than 0.7 km and therefore, similar to that observed for Grand Canyon chub. Maddux et al. (1986) reported an "average distance moved" of 0.5 km (SD=1.8) for tagged humpback chub in the Grand Canyon. They reported that six fish moved distances of 0.2 to 10.0 km from mainstem sites into the LCR.

The two fish omitted from the above movement analysis were PIT tag #7F7F3E2F3A (movement=98.95 km) and PIT tag #7F7E43193F (movement=6.76 km). The fish that was displaced 98.95 km was originally PIT-tagged and radiotagged at RM 65.50, and recaptured 261 days later downstream at RM 127.00 (radiotransmitter had expired). The fish did not appear stressed but seemed recovered from the surgery. This recapture suggests the possibility of long-distance movement to areas of the canyon far removed from the LCR. However, the relative magnitude of movement compared to that of the other recaptures led to exclusion of this data point in order to evaluate more typical movement. The individual data point is interesting in and of itself, in that it represents the longest recorded movement for the species. Kaeding et al. (1990) also observed two relatively long movements of Carlin-tagged humpback chub which were considered anomalous. These two fish were tagged in Westwater Canyon of the Colorado River and recaptured in Black Rocks, approximately 22 km upstream, 3 and 4 years later. The capacity of these fish for long transitory movement between distant river reaches with suitable habitat appears to exist, but the frequency or reason of such movements is not understood.

The second fish excluded from the above analysis was a juvenile recaptured 6.80 km downstream after 3 days. At the time of recapture, the fish was behaving abnormally, possibly as a result of original capture by electrofishing, and so movement during the period at large was not considered normal. This fish expired 19 hours after the second capture. The carcass was X-rayed but the examination was inconclusive.

Movement of PIT-tagged fish following release was approximately evenly distributed in upstream and downstream directions (Figure 27). Of 67 recaptures, 26 fish were located upstream and 25 downstream of the original or previous capture location. The remaining 16 fish exhibited no long-range movement from the capture location. Thirteen of these 16 fish were recaptured within 2 days of release; three were at large 54, 186, and 242 days. These data support the idea that humpback chub show fidelity to specific locales or river reaches.

Local Movement

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. Near-surface activity was assessed by presence or absence of radiotagged fish above the radio-signal extinction depth of approximately 4.5 m. 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).

Effect of Season, Time of Day and Turbidity

Seasonal effects on behavior and local movement are difficult to assess because of the influence of many factors including seasonal shifts in food availability, migration, staging and spawning behavior, water temperature, photoperiod, and flow regimes. Kaeding et al. (1983) speculated that spawning-related movements into the LCR region from February through May increased the vulnerability of humpback chub to capture during daylight hours. This suggests that spawning behavior may over-ride or influence normal diel behavior during a portion of the year.

Diurnal and nocturnal behavior of humpback chub was previously documented in Black Rocks (Valdez and Nilson 1982) and in Grand Canyon (Kaeding et al. 1983). Valdez and Nilson (1982) reported patterned diurnal and nocturnal movements of radiotagged humpback chub, with fish occupying shallow shorelines during the crepuscular period and deeper water during day and night. Kaeding et al. (1983) reported higher catch rates in seines and trammel nets during darkness and crepuscular periods than during daylight hours. It was hypothesized that fish activity increased as light diminished. Shallow, near-shore activity reportedly also increased with diminished light associated with both time of day and turbidity. Valdez and Nilson (1982) also observed vertical movement and increased near-surface activity of adult humpback chub in Black Rocks during crepuscular periods. Apparent differences in behavior between Black Rocks and Grand Canyon populations may be related to physical and biological differences between the two areas. The activity of humpback chub in Black Rocks may be more influenced by diel patterns of food availability (i.e., invertebrate drift) since relatively natural conditions exist including at least moderate turbidity year-round. Vertical movements may be a response to increased food availability. Flow cycles from Glen Canyon Dam and day/night time periods were approximately in phase during this study in the area of the LCR inflow, with increasing and peak flows occurring at night and decreasing and low flows in the day. Assuming increased availability of food material in the water column during flow surges, food availability near the LCR was probably higher at night (during higher flows).

The effect of turbidity on behavior and fitness of humpback chub is poorly understood. Kaeding et al. (1983) observed that juvenile humpback chub utilized shallow littoral areas under turbid conditions, and not during clear conditions, suggesting that turbidity functions as cover for early life stages. Field observations of radio-tagged humpback chub, net catches of adults, and shoreline electrofishing of juveniles by B/W indicated that adult fish exhibited a negative phototactic response by avoiding at least the upper 4.5 m of the water column during daylight, but occupying areas within 4.5 m of the surface during darkness or periods of high turbidity.

These studies indicate that near-surface activity of humpback chub was influenced by season, turbidity, and time of day. Flow patterns may also affect vertical movement, but data from this study were not available to complete an analysis for this report. To test this hypothesis, near-surface activity or presence of radiotagged humpback chub above signal extinction depth was assessed using two separate radiotelemetry databases including telemetry surveillance and remote telemetry.

Telemetry Surveillance. Telemetry surveillance data were used to assess 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 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 presence of fish within 4.5 m of the surface was related to three external factors (season, time of day, and turbidity).

Season was divided into a spawning-related period (February - July) and a nonspawning-related period (August - January). Turbidity values were assigned to each surveillance run based on field observations and secchi disk readings for the corresponding day. Turbidities were classified as "high" when secchi disk readings were 0 to 0.5 m and "low" when readings were greater than 0.5 m. 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 and latitude for a date in the middle of the corresponding field trip. This value was used for all days of the trip.

The influence of the three factors on near-surface activity of radiotagged humpback chub was compared using analysis of variance (ANOVA). No significant difference ($F = 2.43$, $P=0.12$) was found in average percentage of fish located (APFL) during spawning (N = 102, mean = 27%, SD = 28%) and nonspawning periods (N = 122, mean = 33%, SD = 29%). Although catch rates reported earlier in this report were highest during March of the spawning-related period, this ANOVA indicates no change in local movement for spawning or nonspawning periods. This seasonal data were pooled and APFL compared between day and night. Diel near-surface activity of radiotagged adult humpback chub was examined without accounting for effects of turbidity. A significant difference was found ($t = 1.71$, $P < .088$) in the APFL between day (mean = 28%, SD = 29) and night surveillances (mean = 34%, SD = 29%). Fish activity was greater at night than day during monthly surveillance periods from October 1990 through November 1991.

By isolating the influence of turbidity using ANOVA, more specific diel patterns were identified (Figure 30). At low turbidity, APFL above the 4.5 m depth was significantly higher ($F=10.07$, $P=0.0018$) at night (30%) than during the day (19%). This indicates that fish exhibited diel

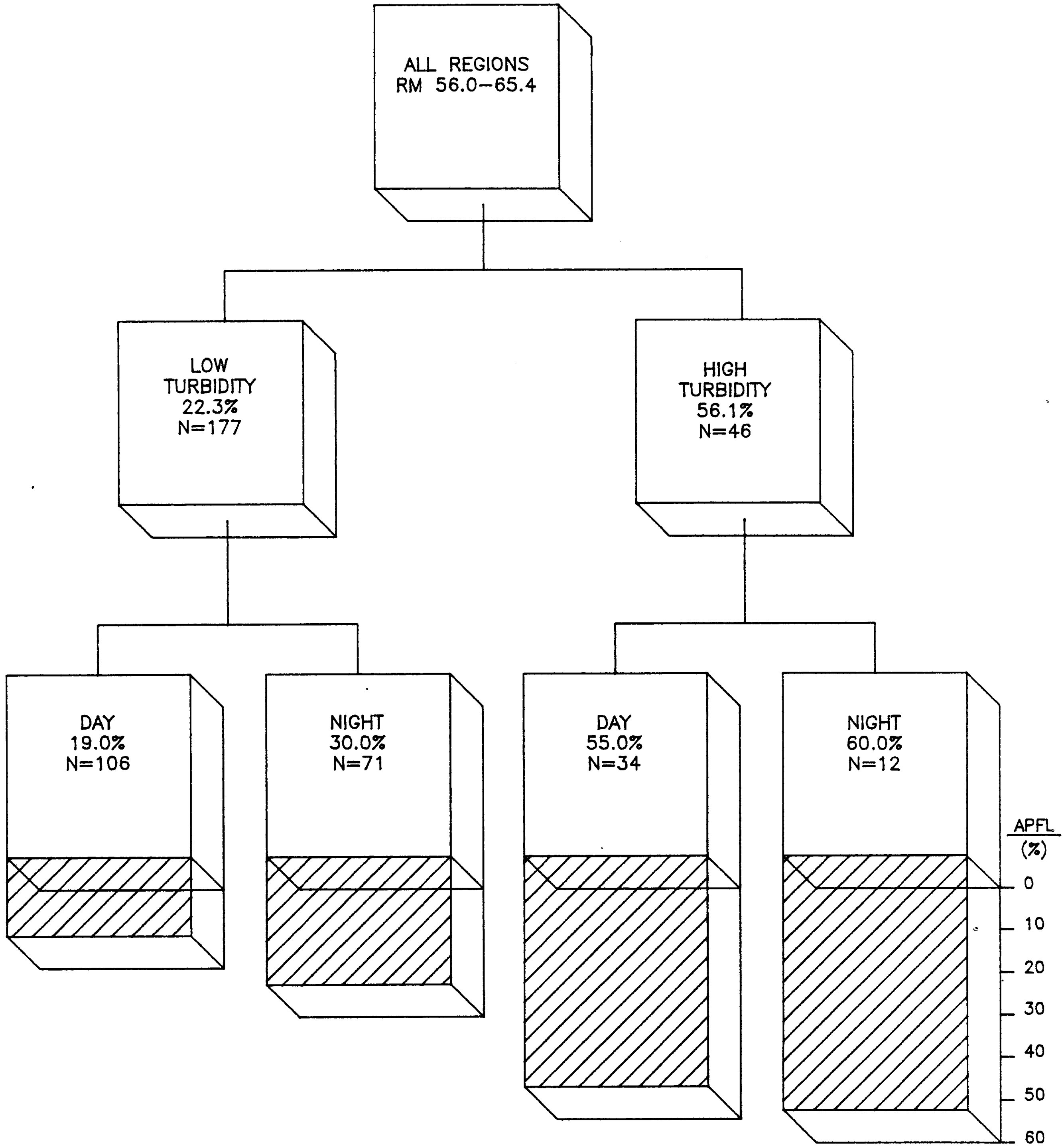

Figure 30. Near-surface occurrence of radiotagged adult humpback chub as average percentage of fish located (APFL) at low and high turbidity during day and night. The fish were located during monthly telemetry surveillance of the Colorado River in Grand Canyon, November 1990-November 1991.

movements, seeking the cover of deeper water during relatively clear conditions. However, under high turbidity, there was no significant difference (F=0.21, P=0.65) in APFL between day (55%) and night (60%), indicating that diel patterns in vertical movement were less prominent during periods of high turbidity.

The effects of turbidity were further analyzed by isolating time of day. APFL was compared between low and high turbidity individually for day and night. APFL above 4.5 m was significantly greater (F=55.6, P<=0.0001) in the daytime when turbidity was high. Similarly, nighttime near-surface activity was significantly higher (F=11.52, P=0.0011) during high than low turbidity.

Remote Telemetry. Near-surface activity of radiotagged adult humpback chub was also monitored by the omni-directional KILR remote telemetry station. 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 comparing 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 only during part of the nonspawning period (August through November), seasonal differences in near-surface activity could not be evaluated. Sunrise/sunset times and turbidity values were the same as used for the surveillance analysis.

Diel patterns of near-surface activity were summarized for data collected continuously with the KILR remote telemetry station. The average percent of radio-contacts (APRC) was higher at night during field trips in August (day = 21.3%, night = 29.8%), September (day = 23.9%, night = 29.9%), October (day = 13.1%, night = 28.0%), and November 1991 (day = 1.8%, night = 12.7%) (Table 30). Although a strong trend existed, no significant differences (t=1.49, P=0.142) were observed in APRC between night (mean = 34.6%, SD = 29.8%) and day (mean = 22.9%, SD = 27.3%).

Diel patterns in near-surface activity and the effect of turbidity became apparent through ANOVA (Table A-25) (Figure 31). Under low turbidity, APRC was significantly higher (F=5.16 P=0.0315) at night (29.3%) than during the day (9.5%). Under high turbidity no significant difference (F=0.7, P=0.7874) in APRC occurred between day (24.0%) and night (25.4%). Like the telemetry surveillance analysis, this analysis showed differences in near-surface activity between day and night at low turbidity but no difference under high turbidity.

Table 30. Monthly number and average percentage of radio-contacts (APRC) for individual adult humpback chub by day and night contacted by remote telemetry stations during trips 8-11 (August - November 1991).

Month (Trip No.)	Observed/Expected (APRC)	
	Day	**Night**
August (8)	567/2655 (21.3)	593/1989 (29.8)
September (9)	1409/5899 (23.9)	1720/5761 (29.9)
October (10)	243/1848 (13.1)	408/1456 (28.0)
November (11)	45/2464 (1.8)	232/1820 (12.7)
Total Observed/Expected (APRC)	2264/12,866 (17.6)	2953/11,026 (26.8)

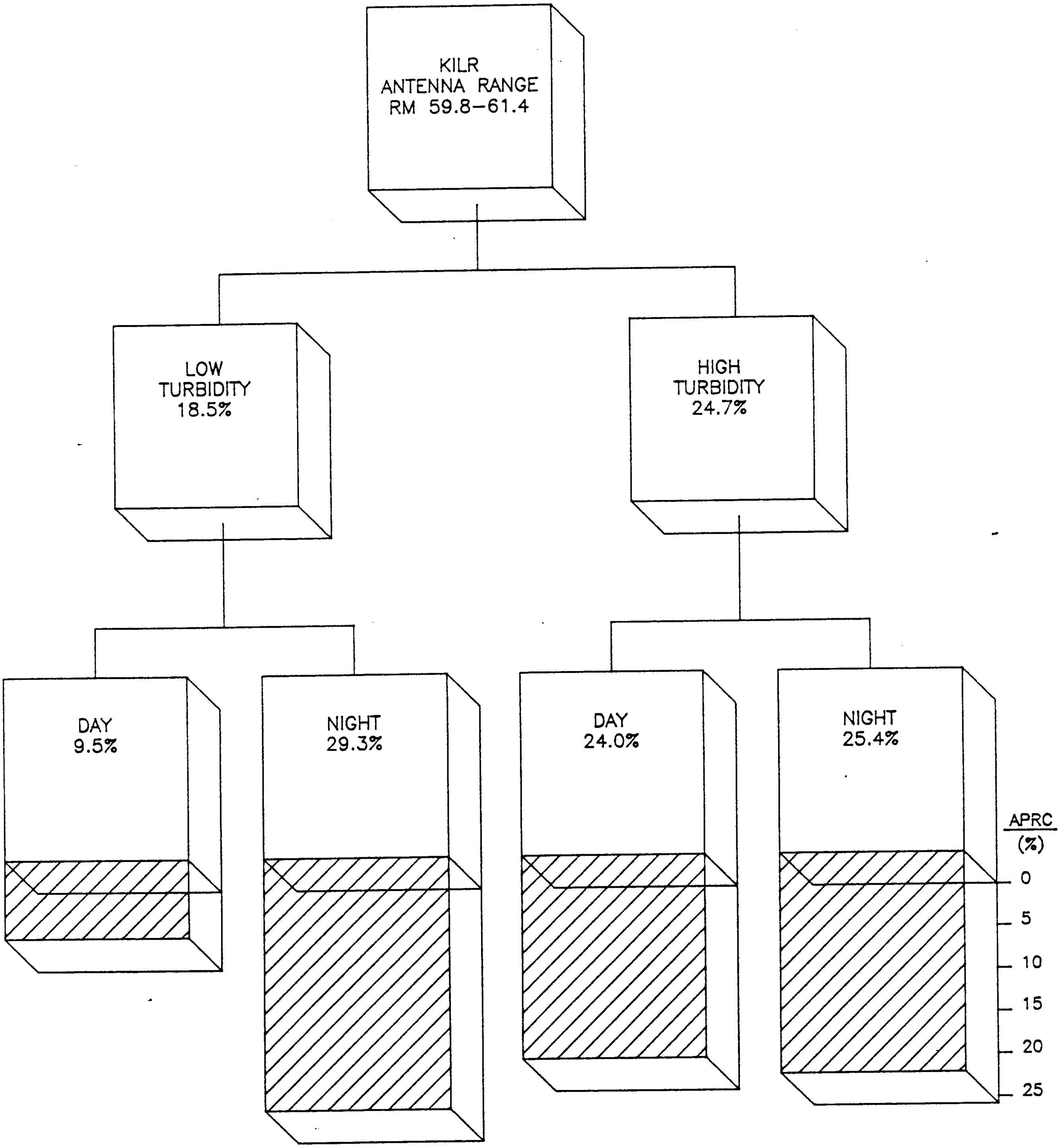

Figure 31. Near-surface occurrence of radiotagged adult humpback chub as average percentage of radio-contacts (APFL) at low and high turbidity during day and night. The fish were contacted by the KILR remote telemetry station on the Colorado River in Grand Canyon, November 1990-November 1991.

To isolate the effect of turbidity, day and night activity were each examined under low and high levels. Daytime APRC was significantly higher (F=3.87, P=0.0584) at high turbidity (24.0%) than at low turbidity (9.5%). In contrast to the telemetry surveillance analysis, nighttime APRC did not differ significantly (F=0.05, P=0.8283) between low (29.3%) and high turbidity (25.4%). Limited sample size of surveillance data under high turbidity, particularly at night (N=12) may partially explain the contrasting results.

Summary

Changes in distribution of catch rates and close association between radiotagged fish during the current study showed that humpback chub aggregated locally in eddies prior to spawning. Movement to the LCR and aggregations at the inflow also indicate pre-spawning staging prior to ascent of the LCR. Inspite of these local aggregations, spawning-related migration, and pre-spawning staging, no significant seasonal differences were seen in local movement or near-surface activity of radiotagged adult humpback chub. Seasonal measures of activity were based only on telemetry surveillances which are discrete and may not fully evaluate subtle changes in behavior. Additional research is needed to better describe seasonal activity as it is impacted by the operation of Glen Canyon Dam. It is important, for example, to determine if periods of increased feeding activity occurred in January and February, prior to spawning. Seasonal activity of humpback chub is not reported by other investigators.

Increased near-surface daytime activity during high turbidity supports the idea that these fish are negatively phototactic and use shallower areas when light penetration into the water column is reduced by suspended sediments. These fish may use turbidity as cover, or the increased activity may mean that greater food availability is associated with large sediment loads.

It is estimated that the humpback chub or its progenitors evolved in the Colorado River basin about 2 million years ago. Geologic evidence suggests that this species evolved in a swift, turbid, riverine environment, and that the river in the Grand Canyon has continued to flow turbid for most of this Quaternary Period. Construction of Glen Canyon Dam in 1963 had a dramatic influence on the level of sediment in the Colorado River in Grand Canyon, reducing the average annual suspended load at Lees Ferry from 65.4 million tons (based on period from 1948 to 1962) to 0.4 million tons (based on period from 1982 to 1986). This represents a 99.4 percent decrease in suspended sediment from pre-dam conditions (U.S. Department of Interior 1988). It is important to understand the role of turbidity in the life history of the humpback chub in the Grand Canyon in light of this great reduction of suspended sediment to the system. Reduced suspended sediment will decrease turbidity which we hypothesize is used as cover by native fish. Reduced sediment is also likely to reduce nutrient loads and suspended food levels, and reduce the availability of habitats structured by sand (e.g., eddy return channels) and productivity promoted by sediment.

We believe that the adults, and possibly all life stages of humpback chub, use turbidity as cover. For a small, mainstem, non-piscivorous species with virtually no defense mechanism (chub have no jaw or tongue teeth) except for escape to nearby interstitial rock spaces, turbidity may be vital protection from aquatic, avian, and terrestrial predators. Clear water conditions may lead to increased predation by sight feeders such as trout. Present conditions of low sediment load year-round and high numbers of non-native fishes may be affecting the survival of this endangered species (Maddux et al. 1986 reported 15 species of non-native fish and 5 native species). We plan to continue to examine interspecies interactions and the influence of turbidity. Humpback chub evolved in a system with relatively few predators. Only Colorado squawfish were large enough to prey on all sizes of chub and this species probably did not frequent whitewater regions such as the Grand Canyon except for passage and spawning (Tyus 1984). Other chub (roundtail, bonytail, and other humpbacks) may have preyed on small humpback chub. River otters living in the mainstem and tributaries probably also preyed on adults in the mainstem and during spawning runs into tributaries. Avian predators such as bald eagles and ospreys are also capable of capturing juvenile and adult chub; an airborne osprey was observed at close range carrying an adult humpback chub in its talons near the mouth of the LCR in August 1991 (Wasowicz and Yard, August 1991, personal communication). We also attribute the loss of a radiotagged adult humpback chub to predation by an osprey in May 1991 (Masslich and Haden, May 1991, personal communication). An active radiotransmitter was recovered from the tapeats ledges near the mouth of the LCR at a time when an adult osprey was frequently seen in the area. One small feather was found adhering to the transmitter antenna, but no sign of the carcass or evidence of the predator were present.

Since turbidity in the system is dependent upon sediment input from tributaries (e.g., Paria River, LCR, Shinumo Creek, Kanab Creek, etc.) during spring runoff and from all drainages during rain spates, light conditions for humpback chub in the Grand Canyon vary and are unpredictable on a seasonal and daily basis. It is unknown if this has disrupted the life cycle of the species, or if individuals have adjusted behaviorally. Besides using turbidity as cover, chub may also make use of increased drift of aquatic and terrestrial macroinvertebrates that usually accompany tributary runoff.

Having evolved in a highly stochastic system, we believe that the feeding schedule of the humpback chub evolved with low-level food supplies and periodic large influxes of food upon which the fish gorged themselves. In upper basin populations, humpback chub fed voraciously on migrating bands of Mormon crickets (Anabrus simplex) crossing the Green and Yampa rivers in Dinosaur National Monument, Colorado and Utah (Tyus and Minckley 1988). Valdez (R.A. Valdez, BIO/WEST, Inc., Logan, Utah, personal communication) observed humpback chub in Westwater Canyon feeding actively on flotsams of dead and dying adult mayflies. Clear water conditions preclude near-surface activity and may impede feeding or restrict it to nighttime.

Activity Relative to Flow Level and Stage Change

We hypothesize that flow level and stage change cause increased fish activity. Valdez and Masslich (1992) reported increased wintertime activity by radiotagged adult Colorado squawfish and razorback suckers in the Green River with fluctuating flows from Flaming Gorge Dam. This increased activity may be attributed to altered habitats or to increased or decreased availability of food supplies. The hypothesis is being tested by observing movement of radiotagged fish over diel periods and during specific ramping flows. Preliminary movement data from 1990 and 1991 suggest a relationship between near-surface activity and stage change. The data are inconclusive to demonstrate a relationship with flow levels. Observations of radiotagged fish, studies of river drift, and diets of humpback chub, as well as quantification of habitat dynamics will be conducted in 1992 to determine the cause of increased activity. The energetic impact of increased fish activity will be evaluated with the aid of literature.

Activity (local horizontal movement in meters) was examined for nine radiotagged adult humpback chub over periods of 6 to 12 hours with concurrent measures of river stage. River flow was presented as stage change from temporary staff gages near the fish's location. The elevation of each of these temporary staff gages was related to temporary bench marks which will enable us to translate staff gage readings to river flow at a future date. Three fish were observed during low flows (Figure 32 and Figures A-1 - A-3) (Table A-26), three were observed at low and high flows (Figure 33, and Figures A-4 - A-6) (Table A-27), and three were observed during high flows (Figure 34 and Figures A-7 - A-9) (Table A-28). The duration of observation is indicated by the length of time in which relative stage is shown. Greatest activity or distance moved was frequently observed during the greatest rate of stage increase or decrease suggesting a relationship between ramping rate and fish activity.

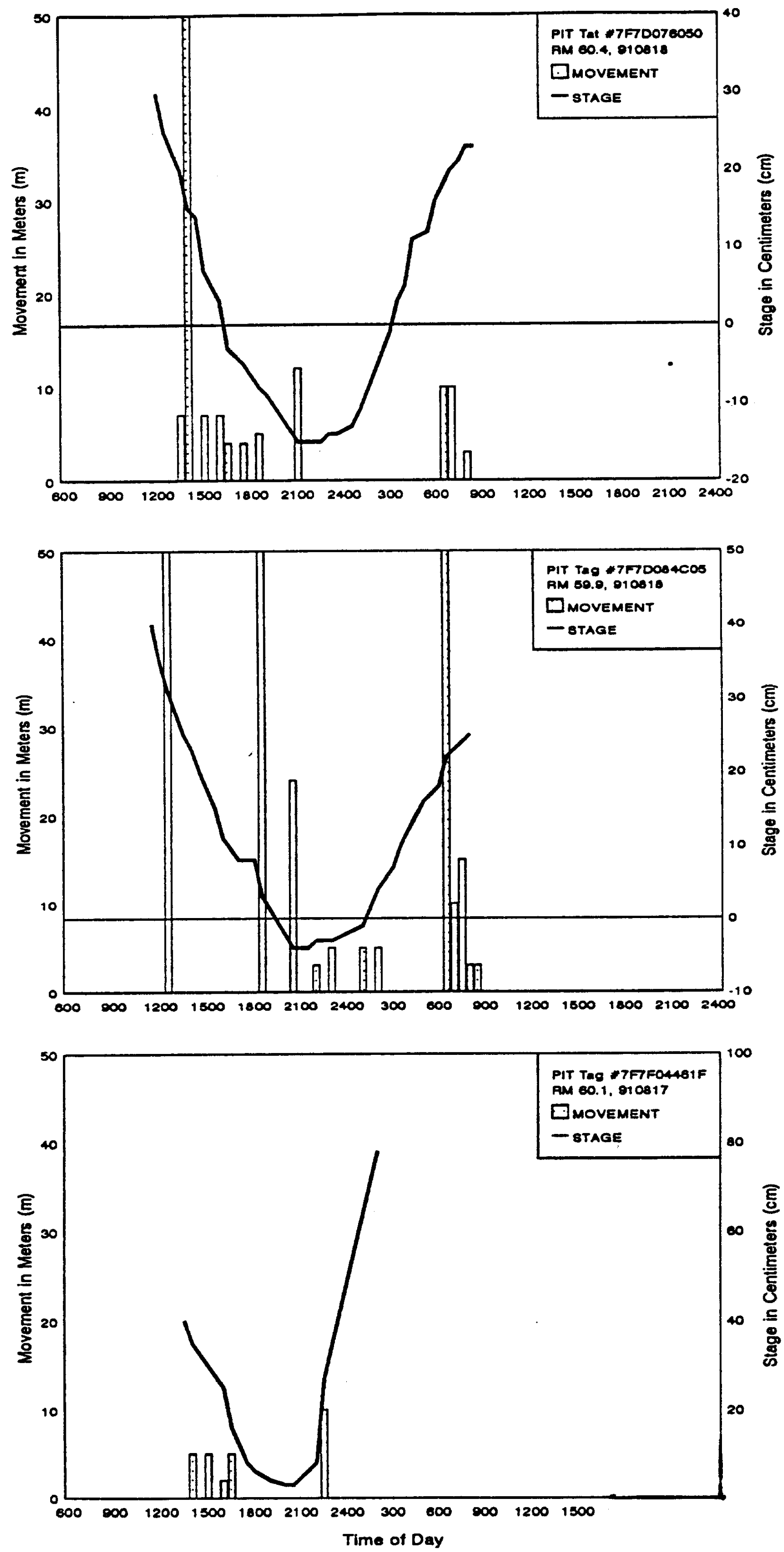

Figure 32. Local movement of three radiotagged adult humpback chub during a hydrological sequence including descending limb, low flow, and ascending limb of the Colorado River in Grand Canyon, 1991.

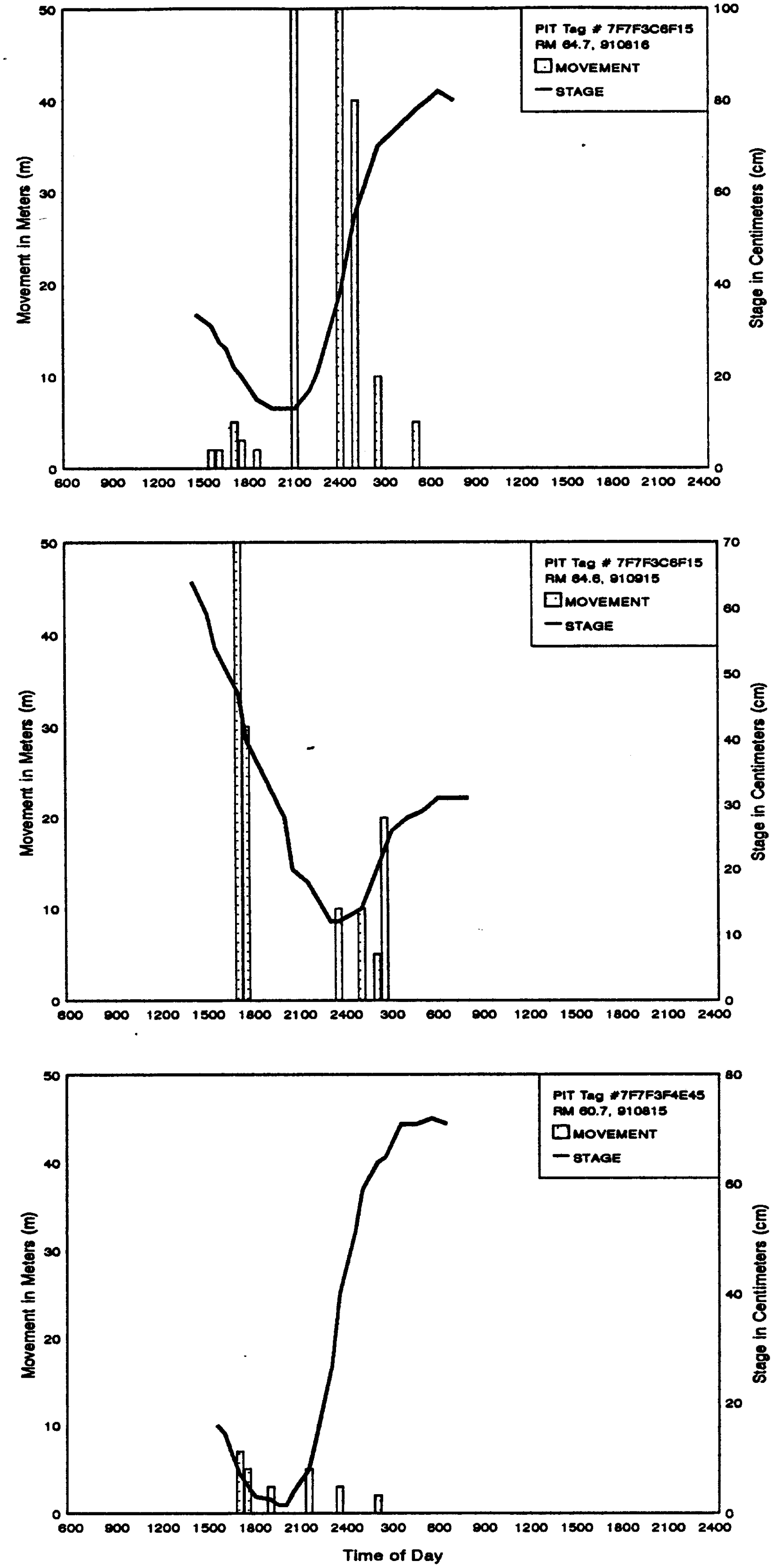

Figure 33. Local movement of two radiotagged adult humpback chub during a hydrological sequence including low flow and ascending limb, and high flow of the Colorado River in Grand Canyon, 1991.

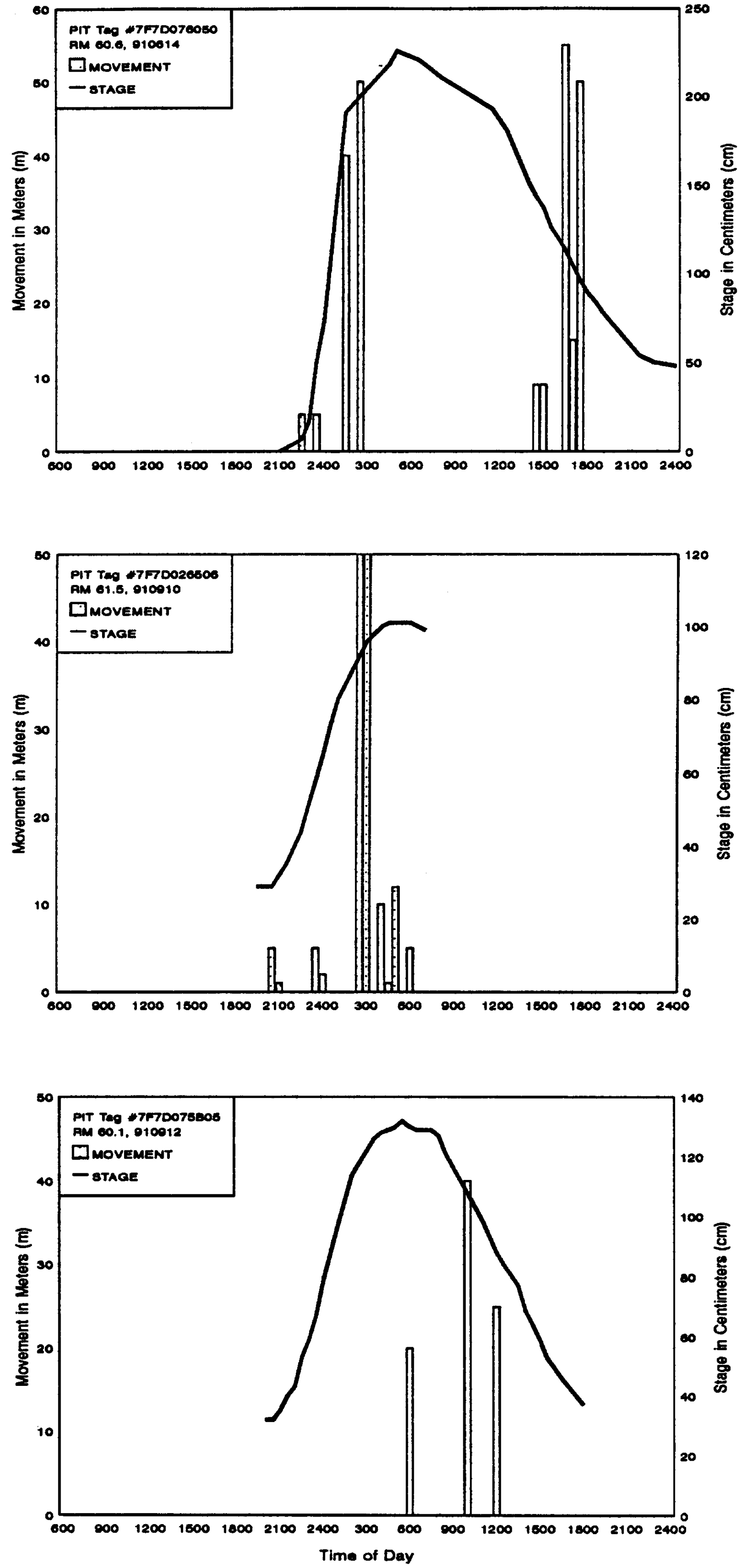

Figure 34. Local movement of three radiotagged adult humpback chub during a hydrological sequence including ascending limb and peak flow of the Colorado River in Grand Canyon, 1991.

Observations of five radiotagged humpback chub in the suspected staging area above the LCR inflow in March also suggest relationships between flow and movement of fish. For purposes of monitoring a large number of fish for an extended period, the river was divided into four zones (Figure 35) and fish movement between zones recorded (Figures 36-40). During the descending limb of the hydrograph, fish frequently moved from zone 1 to zone 3 or toward the mouth of the LCR. On the ascending limb and during high flow, the fish frequently moved from zone 3 to zone 1 or away from the LCR inflow. Although this movement pattern was typical for many fish, other movement patterns were also seen. Additional observations and analyses of movement rates with various ramping rates will be conducted in 1992.

Movement To and From the Little Colorado River

Migrational movements of humpback chub between the mainstem Colorado River and the LCR have been documented by past researchers (Kaeding and Zimmerman 1983, Maddux et al. 1986). Direct observations of radiotagged humpback chub moving between the two river systems were made by B/W during 1991. Increased understanding of timing and movement patterns to and from the LCR will help us understand the cues and conditions that elicit fish movement and the effect of Glen Canyon Dam operations. Two remote telemetry stations (KLCR and KRSH) were deployed at the inflow of the LCR to monitor movement of radiotagged fish between the two river systems. These data, together with data collected from surveillance runs and observations were used to determine the timing of this movement.

Radiotagged adult humpback chub moved to the LCR inflow in February and March 1991 in an apparent pre-spawn staging (Figure 41). This staging was marked by a dramatic increase in number of radiocontacts in the LCR inflow (Figure 42) and ascent of the LCR in March. A number of these fish ascended the LCR in March. The numbers in the confluence area remained high during April but those in the LCR decreased as fish were seen leaving the system during a period of high flow, high turbidity, and low temperatures from spring runoff. The number of fish entering the LCR increased dramatically in May as runoff subsided, and a concomitant decrease in fish was seen in the mainstem confluence area. The low number of fish in the confluence area in June and July was attributed to a large number of fish in the LCR. The numbers of fish in the confluence area and the LCR declined substantially in August, and by September, few radiotagged fish were contacted at the confluence area and none were contacted in the LCR.

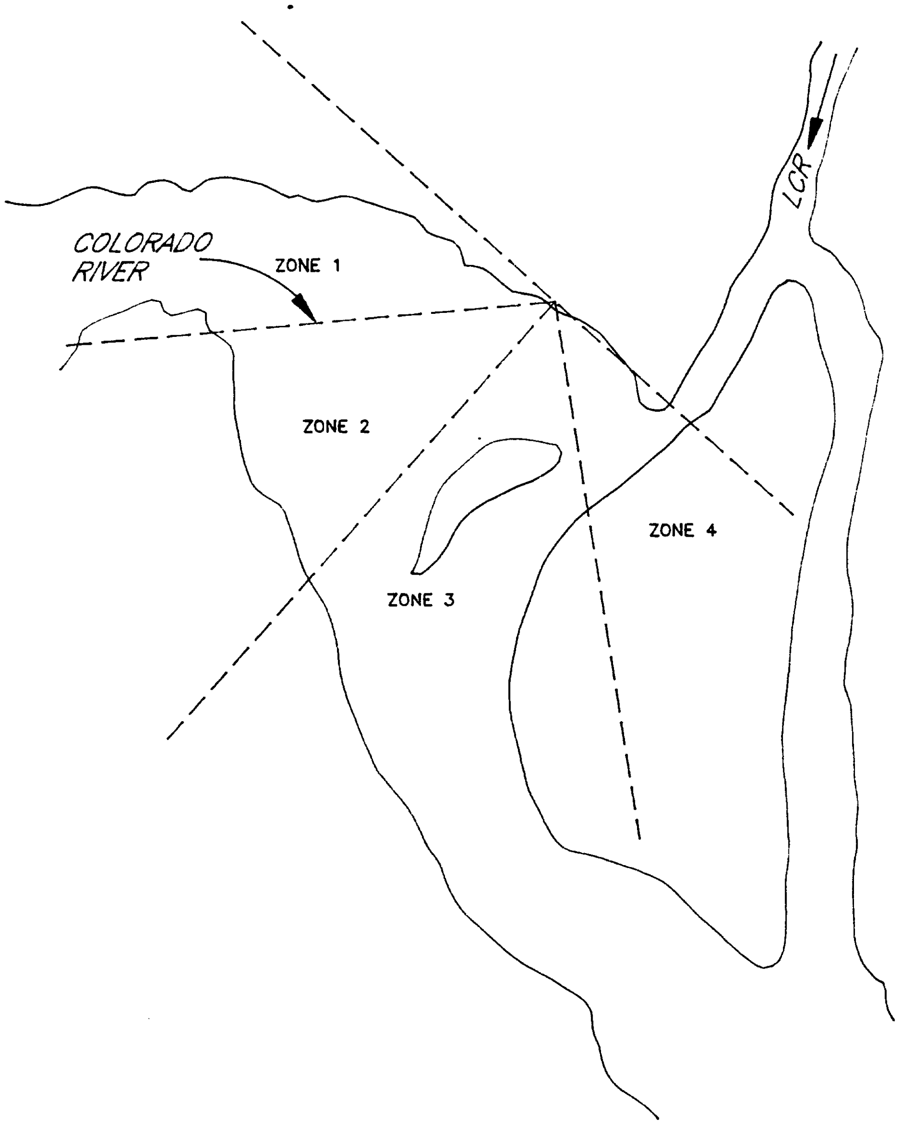

Figure 35. Zones used to delineate movement of five radio-tagged humpback chub during observations on March 8-11, 1991.

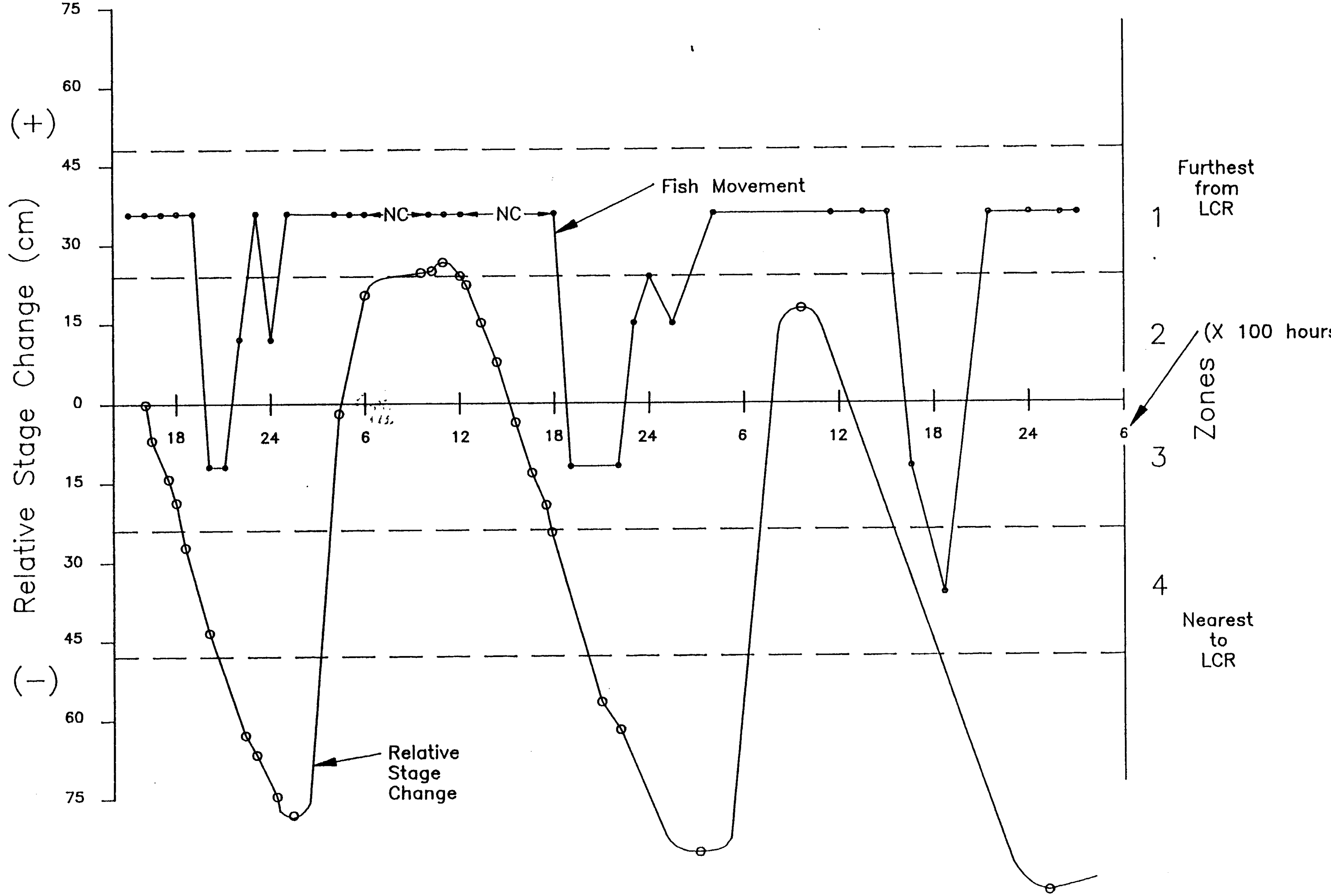

Figure 36. Movement of radiotagged adult humpback chub relative to river stage change and time of day in four zones at the LCR inflow (PIT tag #7F7F3C3171).

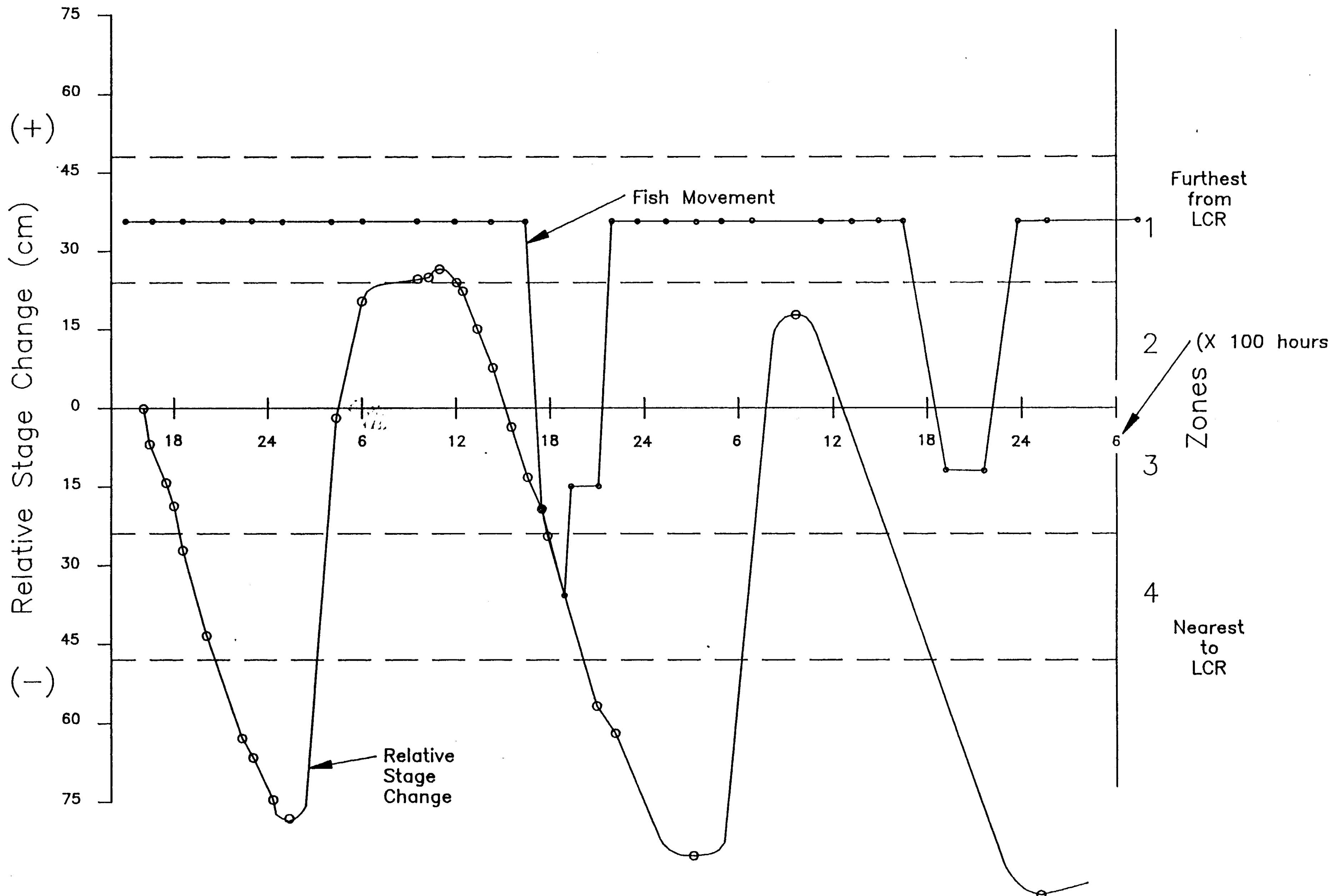

Figure 37. Movement of radiotagged adult humpback chub relative to river stage change and time of day in four zones at the LCR inflow (PIT tag #7F7F3C2D06).

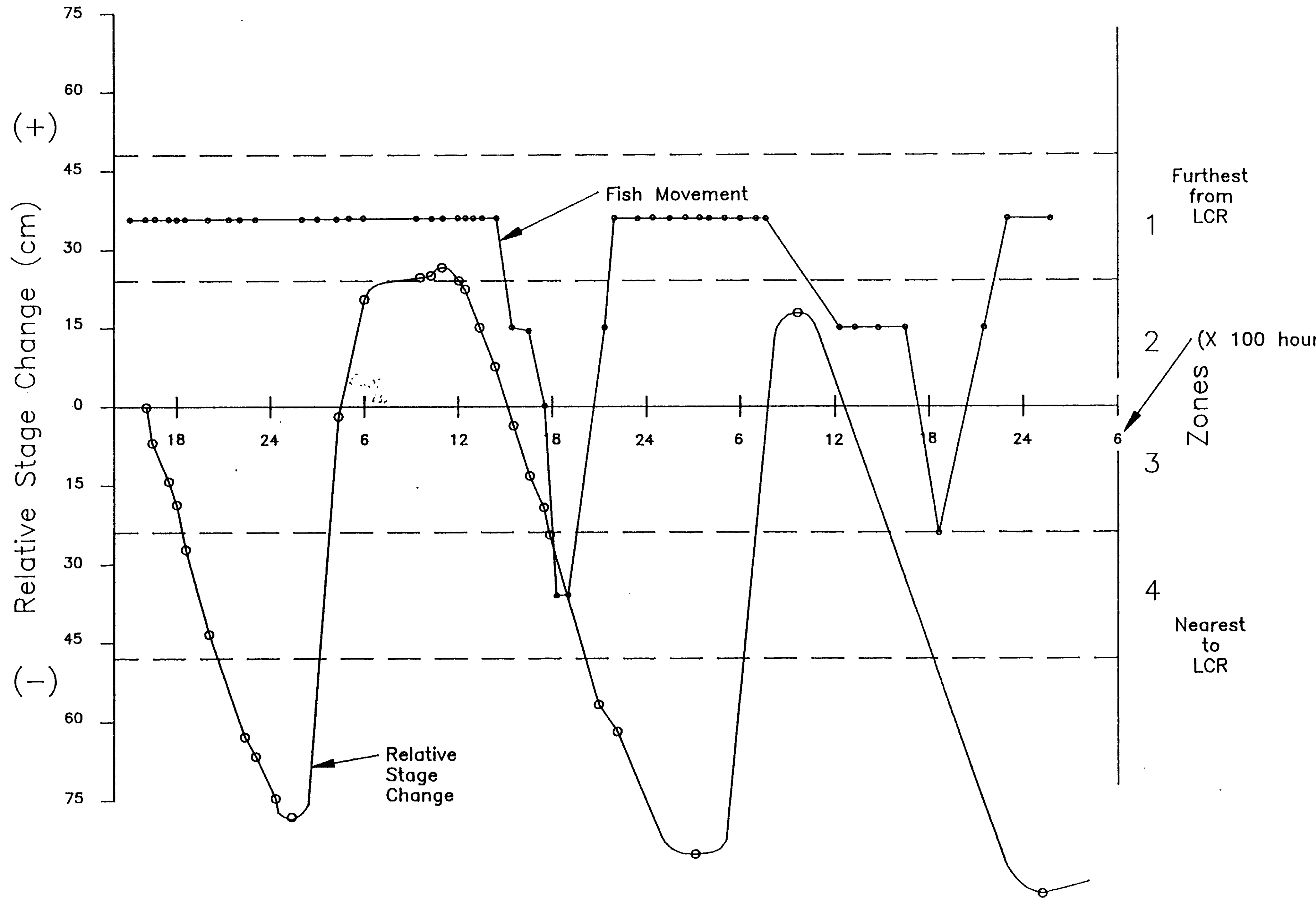

Figure 38. Movement of radiotagged adult humpback chub relative to river stage change and time of day in four zones at the LCR inflow (PIT tag #7F7F3E2727).

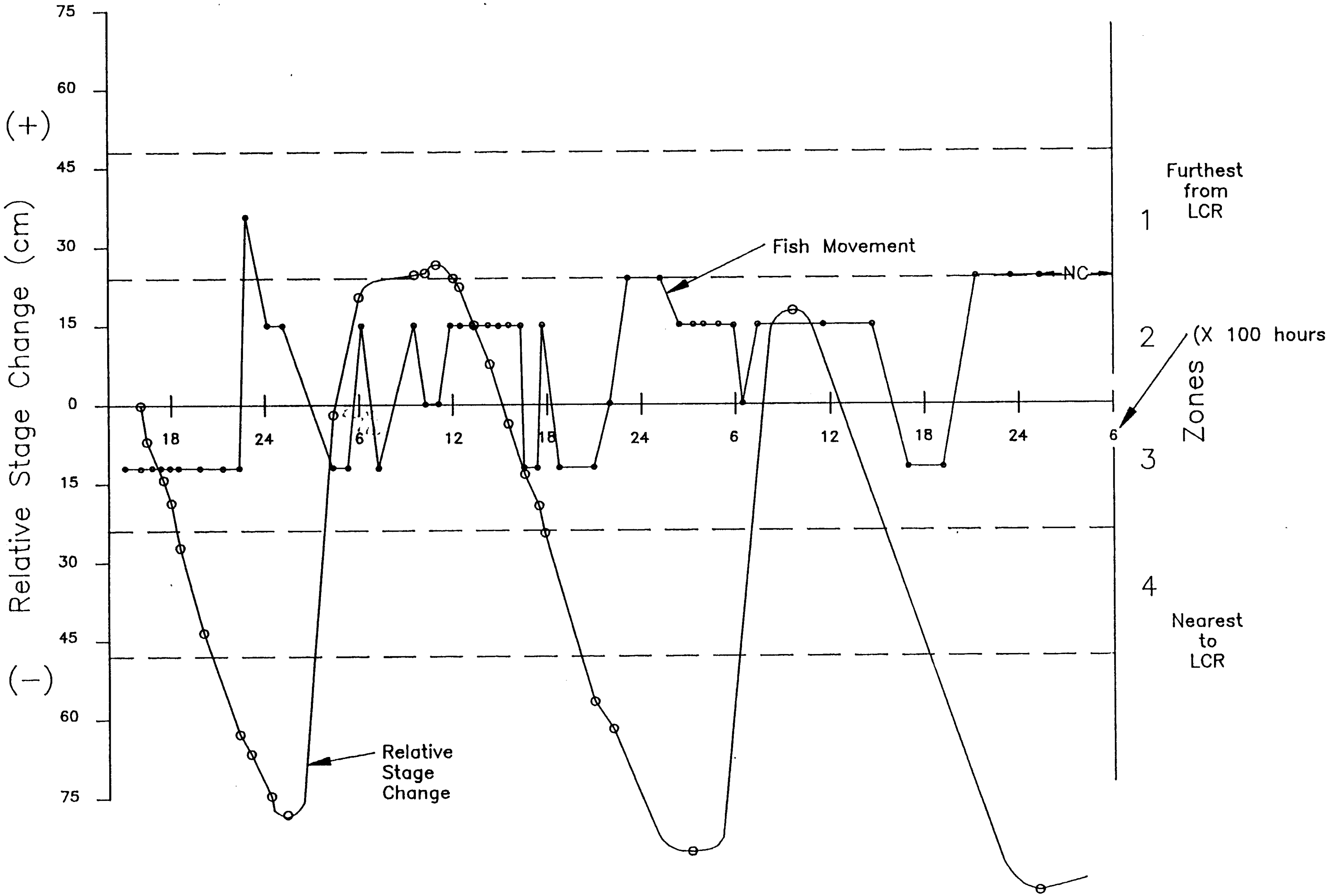

Figure 39. Movement of radiotagged adult humpback chub relative to river stage change and time of day in four zones at the LCR inflow (PIT tag #7F7F3E3030).

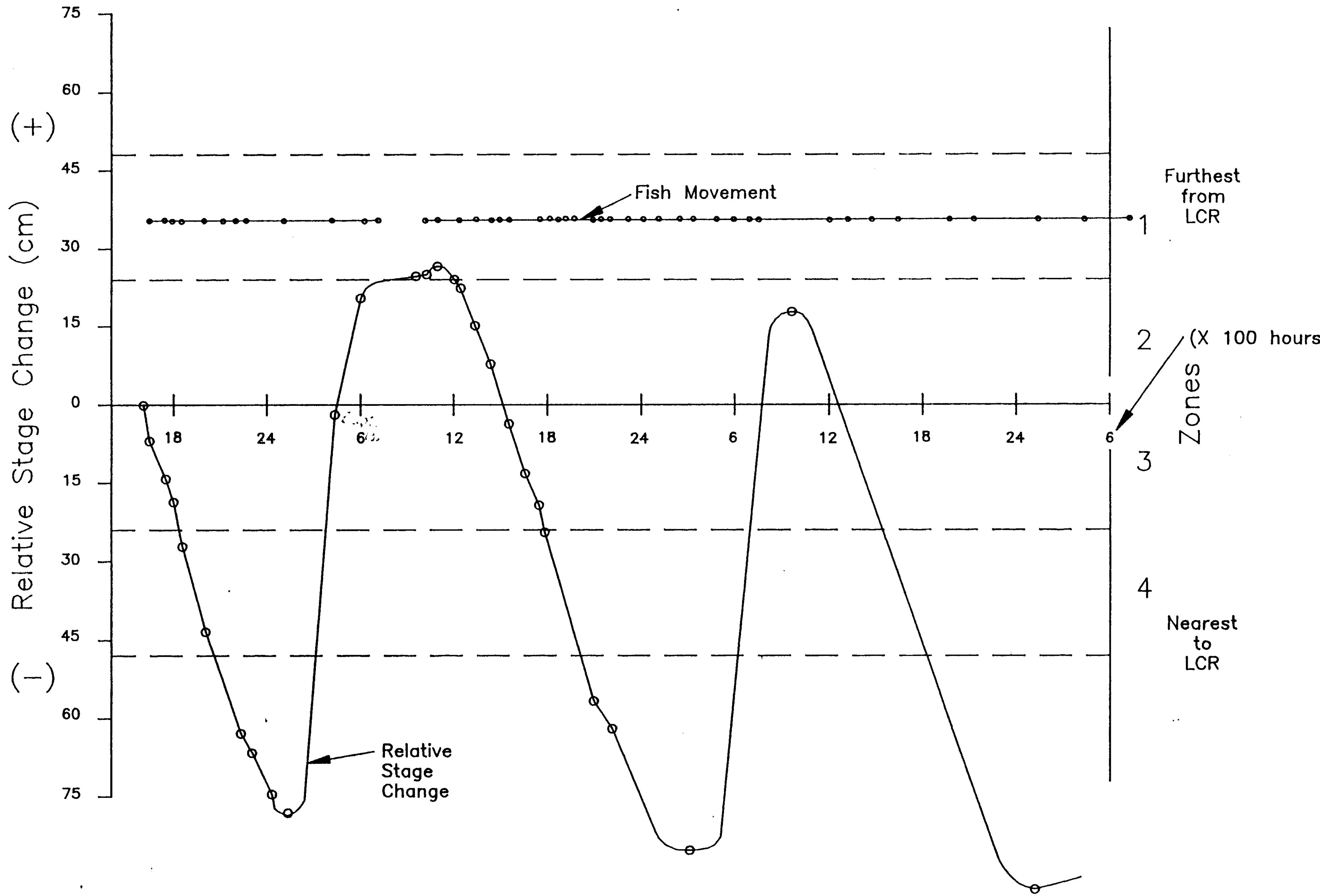

Figure 40. Movement of radiotagged adult humpback chub relative to river stage change and time of day in four zones at the LCR inflow (PIT tag #7F7F3C303B).

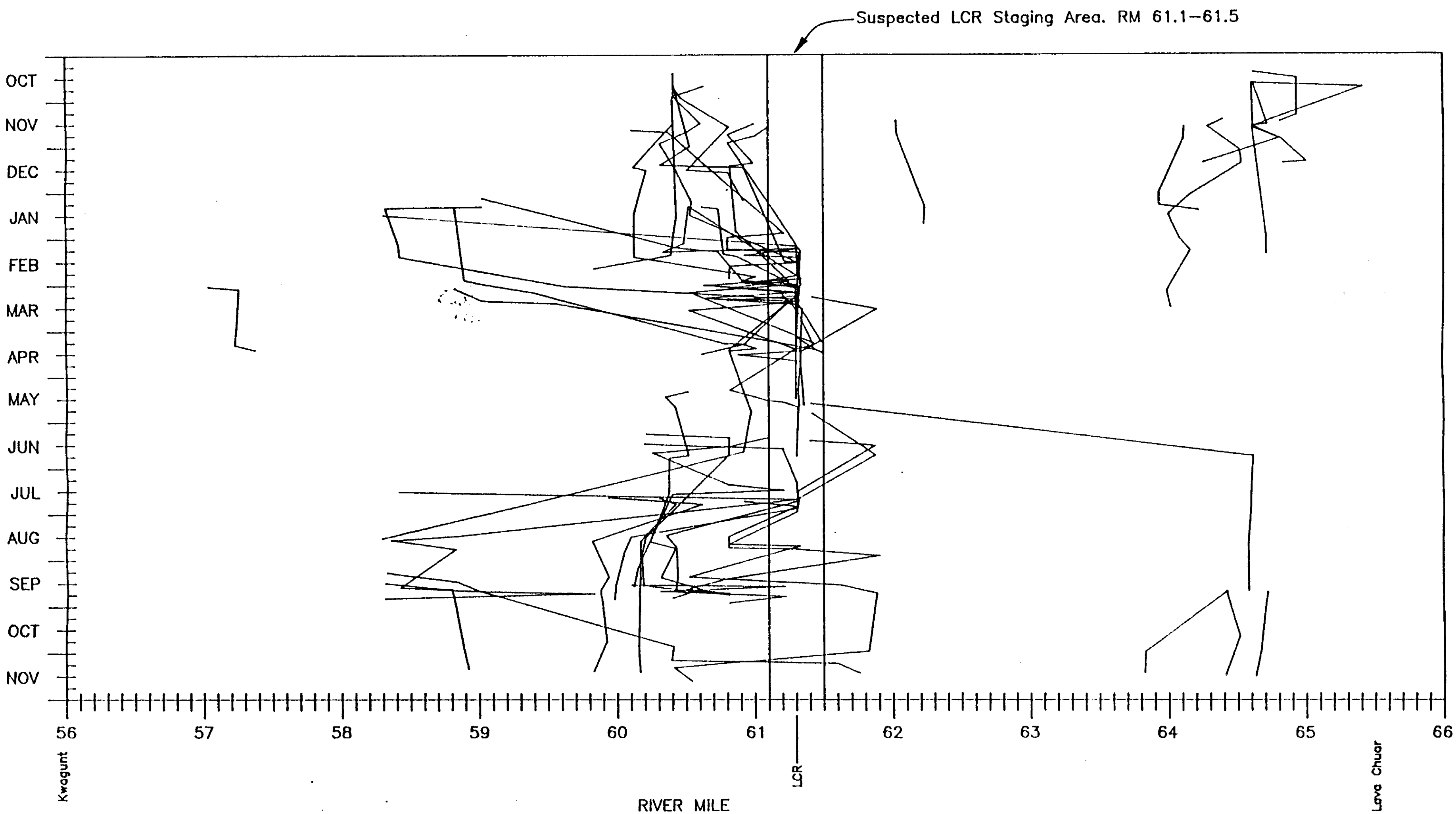

Figure 41. Movement of radiotagged adult humpback chub in the Colorado River in Grand Canyon, 1990-1991.

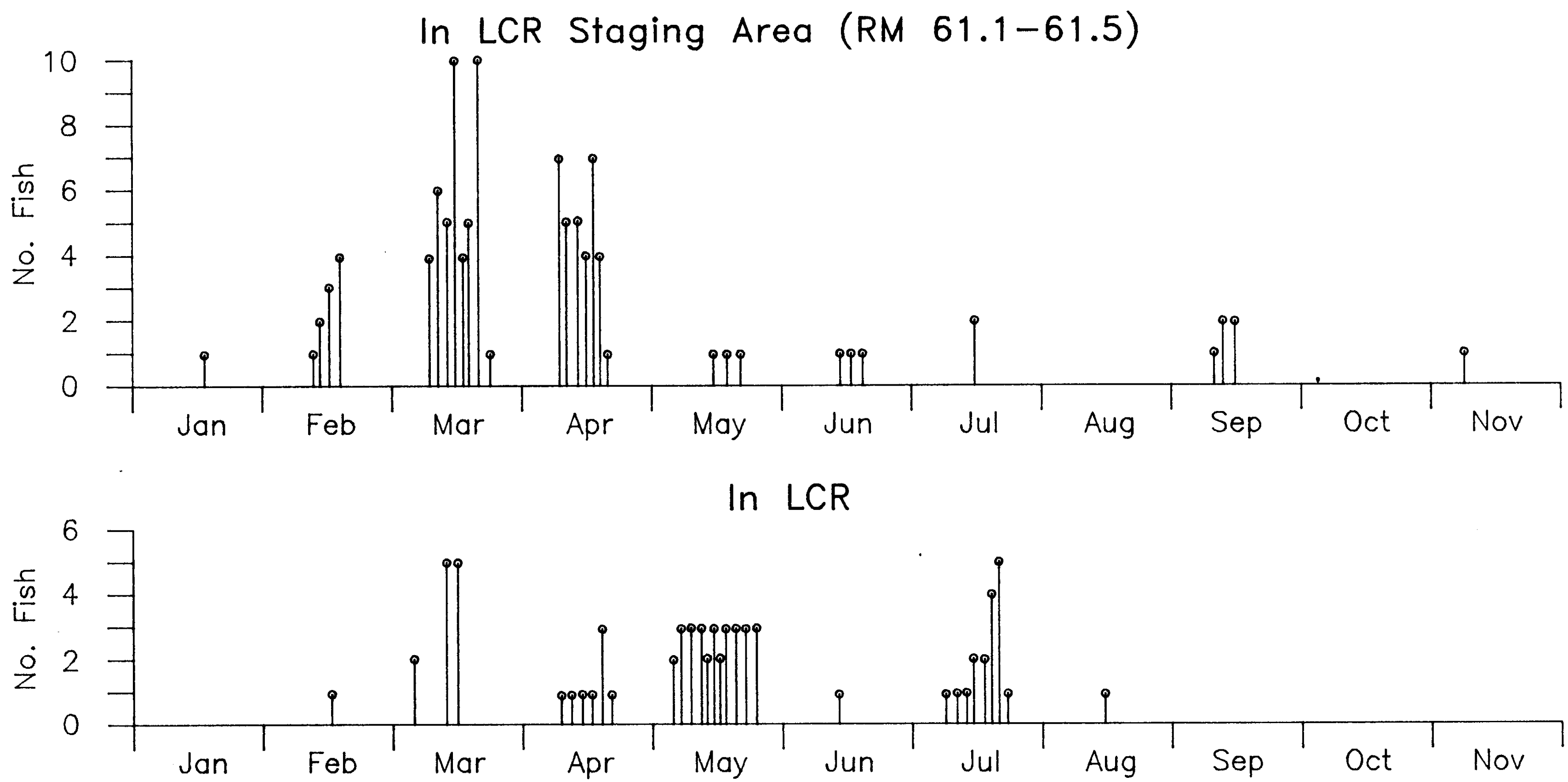

Figure 42. Numbers of radiotagged adult humpback chub contacted daily in the suspected LCR staging area (RM 61.1-61.5) and in the LCR, January-November 1991. Data are from radio-telemetry surveillance and observations.

Twenty-seven radiotagged fish were contacted by the KLCR remote station (Table A-29). Additional signal contacts were excluded that were believed to be caused by local or atmospheric signal interference (i.e., static or noise). Further refinement of the data for future reports may result in further omission of contacts attributed to signal interference.

Initial and last contact dates for unique frequency/pulse combinations were used to estimate timing of movement by individual fish to and from the LCR confluence area. Field observations of radiotagged fish indicated that the deep eddy/pool complex immediately above the confluence of the LCR served as a staging or holding area for humpback chub prior to entering the LCR. Initial contact dates for fish at the confluence area ranged from February 13 to July 26, 1991. Eleven radiotagged chub were initially contacted from February 13 to 19 in the area. We believe that three of these fish moved into the area prior to this date since they were previously contacted in the area by telemetry surveillance and the KLCR remote station was first deployed on February 13. We note that of 13 fish implanted before the KLCR remote station was operational, 11 moved into the confluence area in February, while the remaining two were first contacted in the area in March. This suggests that a significant movement of pre-spawning adults occurred in February 1991. Of 27 radiotagged chub contacted by KLCR, the remaining 14 were initially contacted during the same month they were implanted, indicating that there was immediate movement to the LCR confluence area. Last contact dates for the KLCR remote station ranged from February 18 to August 13 (when the station deactivated). This suggests that spawning-related activities (migration, staging, and spawning) may have continued until August of 1991. It is unknown if a post-spawning aggregation occurred or if fish returned individually to the mainstem.

Radiotagged fish remained within range of the KLCR station for periods of 1 to 39 days (mean = 15 days), or the number of days (not necessarily in sequence) that individual fish occupied the immediate confluence area or the lower 25 to 100 m of the LCR. Antenna range was variable depending on conductivities in the LCR. During floods, low conductivity enabled better signal transmission and better contact of fish in the LCR. These data show that in 1991, a substantial proportion of adult humpback chub from the mainstem frequented the LCR confluence from early February through August for presumably pre-spawning staging and possibly spawning in the inflow.

We attempted to estimate the actual date that individual fish moved into the LCR by using all three telemetry databases (i.e., remote, surveillance, observation). A substantial amount of fish passage data were lost or not collected because of untimely electrical (e.g., lightning storms) or mechanical (e.g., drained power source) failures in the station. Also, high conductivities in the LCR precluded data collection during some periods. Although surveillance radiotracking in the LCR was possible, it required a large expenditure of time that was not scheduled into the study. Consequently, tracking of radiotagged chub in the LCR was limited. Dates or ranges of dates were established for 14 separate movements into the LCR by 10 fish. These dates ranged from February 13 to June 16, 1991. Two fish were observed moving into the LCR on three separate occasions indicating that conditions in the LCR became intermittently inhospitable and forced fish to retreat to the mainstem. The fish left the LCR during high flow, high turbidity, and low water temperatures. Further analyses of water quality and hydrology data from the LCR are needed to identify the cues and deterrents for movement.

ENERGETICS

Drift

A total of 137 drift samples were analyzed in 1991. The three dominant taxa were Simuliidae, Chironomidae and the amphipod, Gammarus lacustris. The filamentous green algae, Cladophora glomerata, was present in most samples, and terrestrial invertebrates were found occasionally. Only total numbers of invertebrate taxa were used, and the volume of algae was not determined for the present analysis.

Drifting invertebrate density for the period from March through October 1991 was calculated for both eddy and run habitats. Small sample sizes from eddies precluded statistical analyses. Mean drift density for eddy collections (n=14) was 0.061 organisms/100 m^3 of water filtered (orgs/100 m^3wf). Collections from runs (n=123) averaged 0.167 orgs/100 m^3wf.

There was a significant difference ($P<0.05$) between samples collected from March through July 1991 and those from August through October 1991. These periods coincide with the onset of interim operating criterion for Glen Canyon Dam. Mean drift density for March through July (0.337 orgs/100 m^3wf) decreased for August through October (0.053 orgs/100 m^3wf, n = 137, DF = 1, F = 18.919).

Food Habits

A total of 82 fish were sampled for stomach contents. Food habits of rainbow trout were dominated by Cladophora and aquatic invertebrates, primarily Gammarus lacustris and chironomids. No fish were found in any of the rainbow trout sampled. Brown trout were feeding mainly on aquatic insects and no fish were found in any stomachs. Fifteen striped bass stomachs were examined and most were found empty. One 5.45-kg striped bass contained one 210 mm trout. Twenty channel catfish stomachs were found to contain mostly aquatic and terrestrial invertebrates and Cladophora glomerata. One 5.45-kg channel catfish from the LCR inflow contained one 150 mm flannelmouth sucker and one 170 mm bluehead sucker. One walleye had one unidentified 50 mm fish in its stomach.

The stomachs of eight humpback chub were evacuated using a nonlethal stomach pump technique. These fish were feeding primarily on aquatic invertebrates and some Cladophora glomerata. Gammarus lacustris was the dominant aquatic invertebrate.

Bioenergetics of Increased Activity

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 fully test this hypothesis afield, but can gain a better understanding of this effect by examining movement and diets of the affected fish. We have also initiated a search of bioenergetics literature in order to provide additional insight from particular laboratory studies.

Investigators agree that increased swimming activity by a fish means increased energy expenditure. Thus, an organism must maintain a balance between the energy and materials it gets from its environment, and that required for metabolism, growth, and reproduction (Fausch 1983). This is the main idea behind bioenergetic research on an animal-specific level. Several investigation techniques have been developed to measure or estimate various components of this energy equation, and the Optimal Foraging and Potential Profit (most advantageous position) models are both based on this tenet. Researchers have measured swim speed, oxygen consumption, body composition, and weight loss or gain as indicators of genetic viability or an individual's ability to handle the stresses of its environment. The bulk of research in fish bioenergetics has been conducted on salmonid species or on commercially harvested marine species. In most studies, a fish is acclimated to a set of ambient conditions then placed in a swimming chamber with an electrified screen at the rear of the chamber to encourage the animal to perform. Certain environmental parameters are varied and the animal's response is recorded. Few studies have related these laboratory observations to a fish's performance in a natural system. In other words, a fish may in fact become fatigued swimming under conditions of sustained elevated velocity at reduced temperatures, but in a natural system that same fish might alter its behavior to avoid both the reduced temperature by seeking warmer water, and increased flow by seeking blocking cover.

Valdez and Masslich (1989) found that adult radiotagged Colorado squawfish and razorback suckers changed position when flow changes from Flaming Gorge Dam altered microhabitat parameters. Rising flows produced excessive velocities, and decreased flows violated a minimum depth requirement. It is also reported that fish exposed to high velocities or undesireably low or high temperatures expend more energy than fish within an optimal range of velocity and temperature (personal communication, Keith Lawrence 1992). Chart (personal communication, Tom Chart 1992) reported that bonytail (Gila elegans) held in pens in still water lost less weight than those held in a pen in flow. Salmonids held in slight velocity in hatcheries grew faster (produced more growth hormone) and converted food better than fish held in still water (Besner 1980). Additional literature research is needed to quantify energy expenditure relative to flow changes and determine if increased activity by humpback chub in response to Glen Canyon Dam operations is detrimental or beneficial.

SUMMARY OF FINDINGS

This report presents the results of fourteen field trips conducted on the Colorado River in Grand Canyon from October 1990 through November 1991. Data collected during these trips represent only one year in the life cycle of the humpback chub. Patterns or trends evident from one year of research may or may not persist, and others not detected in this first year may become evident with more investigation. It is too early for us to satisfy the objectives of the investigation and accept or reject the associated hypotheses. Nevertheless, we offer our interpretation of one year of data, and caution the reader against deducing or inducing more than these data and our interpretation allow.

Objective 1: Determine Ecological and Limiting Factors

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 the Glen Canyon Dam operations on the humpback chub.**

A literature review was conducted to assimilate known ecological requirements of the humpback chub which may be identified as limiting factors in the Colorado River in Grand Canyon. These ecological requirements are presented by four life history phases including (1) spawning/egg incubation, (2) larvae/YOY, (3) juvenile, and (4) adult (Table A-30).

Spawning/Egg Incubation

The important ecological factors associated with spawning and egg incubation include flow, water temperature, and habitat. Spawning times for humpback chub are similar for upper and lower basin populations. Humpback chub in Black Rocks, Colorado, were reported spawning in May, June and July (Valdez and Clemmer 1982, Kaeding et al. 1990), while the fish in Yampa Canyon, Colorado spawned in mid-May to late-June (Karp and Tyus 1990). Humpback chub in the Grand Canyon were found spawning in the LCR in April and May (Kaeding and Zimmerman 1983) and in June and July (Suttkus and Clemmer 1977). We found the majority of adult humpback chub ascending the LCR in April and May, although exchange with the system extended from March through July of 1991. These reports indicate that spawning time for humpback chub is variable, and may span up to 5 months.

Humpback chub have been reported spawning in a variety of flows. Valdez and Clemmer (1982) reported spawning in Black Rocks in 1980 at 21,500 to 26,000 cfs; and in 1981 at 3,000 to 5,000 cfs. Kaeding et al. (1990) reported spawning in Black Rocks in 1983 at 17,000 to 3,000 cfs; and in 1984 at 12,000 to 3,000 cfs. The fact that humpback chub in the upper basin spawn in the mainstem

Colorado River and that the species also spawns in the LCR suggests a wide range of flow tolerance for spawning conditions, but preference for medium to large river systems.

Proper water temperatures for egg incubation and larval survival are critical to the life history of this species. Hamman (1982) reported that optimum egg incubation temperatures for humpback chub in hatchery conditions were 19-20°C (84% hatching success). Temperatures of 21-22°C resulted in 79 percent hatching success, while 16-17°C yielded 62 percent, and 12-13°C yielded only 12 percent success. Hamman also reported that eggs incubated exclusively at 12-13°C failed to develop. Bulkley et al. (1982) found similar results with 100 percent hatching success (4 days) at 20°C, 90 percent at 26°C (3 days), 50 percent at 14°C (16 days), 30 percent at 10°C (19 days), and 0 percent at 5°C. Marsh (1985) incubated embryos of humpback chub at 5, 10, 15, 20, 25, and 30°C that had been spawned and fertilized at 18°C. Total mortality of embryos occurred in 12 to 96 hours at 5, 10, and 30°C. Survival and percentage hatched were highest at 20°C. Hatched prolarvae were 0.2 to 1.3 mm TL longer at 20°C than at 15 or 25°C. Spinal deformity or other anomalies were more frequent at 15 and 25°C than at 20°C.

The diameter of water-hardened eggs from hatchery fish was 2.2-2.9 mm and average fecundity was 3,193 eggs (Hamman 1982). Average diameter of water-hardened eggs stripped from wild Black Rocks fish was 2.5-3.0 mm with an average fecundity of 6,000 eggs (Valdez and Valdes-Gonzales 1991).

Spawning habitat of humpback chub is currently unknown. We captured ripe males and gravid females in the LCR inflow and recovered three eggs (2.2-2.5 mm diameter) from small pockets of pea-size gravel behind large boulders in the upstream inflow channel. These eggs may have been deposited in these pockets or were washed from upstream deposits in the LCR. Average depths of the three gravel pockets from which eggs were recovered were 18, 25, and 12 cm, and average velocities were 0.11, 0.09, and 0.11 m/s. The three pockets were 0.3 m x 0.4 m, 1.1 m x 0.6 m, and 0.4 m x 0.4 m in dimension, and average substrate size was 1.82, 2.29, and 2.19 cm, based on twenty randomly selected particles. These measurements were taken on May 18, 1991 during stable 5,000 cfs research flows of the Colorado River, and when the LCR flowed through the inflow channel at approximately 300 cfs.

Larvae/YOY

According to Hamman (1982), newly hatched larvae of humpback chub are 6-7 mm long. These larvae are sensitive to temperature; mortality was seen at changes of 6°C from 10 to 4°C (U.S. Fish and Wildlife Service 1979). Larval humpback chub occupy shallow shorelines and backwaters with silt (Valdez and Clemmer 1982, Holden 1973, Valdez et al. 1990). Maddux et al. (1986) reported post-larval chub in the Grand Canyon in water 24 cm deep with a velocity of 0.10 m/s. Food habits of this life stage are unknown, and only growth rates from the hatchery are available.

Juveniles

Juveniles are fish that range from one calendar year of age to maturity (3 or 4 years of age). Bulkley et al. (1982) reported that final temperature preferendum of juvenile humpback chub in a laboratory situation was 24°C, while TDS (total dissolved solids) preference was at a specific conductance of 1,300-3,000 μmhos/cm (1.0-3.5 mg/l), and TDS avoidance occurred at levels above 8,500 μmhos/cm. Habitat of juveniles differs from that of larvae and YOY; juveniles use backwaters and shorelines with firm silt, sand, and boulders with a depth of 0.6 m and average velocity of 0.15 m/s (Holden 1973). Valdez et al. (1990) reported juveniles from depths of 0.7 to 3.4 m and average velocity of 0.18 m/s. Valdez and Clemmer (1982) reported that juvenile humpback chub in Black Rocks occupied rocky shorelines with intermittent sand beaches in depths of 0.4-10.7 m and velocities of 0.06-0.60 m/s. Bulkley et al. (1982) determined a sustained swimming speed for juvenile humpback chub of 0.66 m/s; the fish swam 2 hours at 0.32 m/s; and for only minutes at 0.78 m/s. Valdez and Clemmer (1982) reported a 17 percent incidence of the parasitic copepod Lernaea cyprinacea in juveniles and adults of Black Rocks and Westwater Canyon.

Adults

The temperature tolerance of adult humpback chub is unknown. Adults occupied eddies and deep runs with depths of 0.7-12.2 m (mean = 4.3) and velocities of 0.03-1.16 m/s (mean = 0.18) (Valdez and Clemmer 1982). They were also reported primarily in eddies at depths of 0.8-12.2 m (mean = 3.1) and velocities of 0-1.19 m/s (Valdez et al. 1990). Karp and Tyus (1990) also reported adult humpback chub primarily in large shoreline eddies 1.3 m deep in Yampa Canyon.

The food of adult humpback chub is not well documented. Kaeding and Zimmerman (1983) reported immature Chironomidae and Simuliidae from fish from the Grand Canyon. Valdez (personal communication, Richard Valdez 1981) observed adults in Westwater Canyon feeding actively on surface-floating adult mayflies.

The parasites of this species are also not well known. Kaeding and Zimmerman (1983) reported Aeromonas hydrophila and Lernaea cyprinacea in chub from the Grand Canyon, while Valdez and Clemmer (1982) reported a 31 percent incidence of Lernaea cyprinacea in 182 adults from Black

Rocks and Westwater Canyon. We observed few Lernaea cyprinacea in humpback chub we handled in the Grand Canyon. However, segments of tapeworms were noted in holding pens after handling this species. According to J. Landye (Personal communication with Jerry Landye, November 1991; Dennis Kubley, February 1992), the Asian tapeworm Bothriocephalus acheilognathi was present in adult humpback chub taken from the LCR inflow in May 1991, and transported to the AGF Page Springs Hatchery. The adult of B. acheilognathi lives in the intestine of fish. The eggs, usually containing well-developed larvae, are shed from the adult and pass into the water with the feces of the host. After 2 to 5 days, the oncosphere (first larval stage) emerges. The free-swimming coracidia are then eaten by a copepod (e.g., Acanthocyclops, Cyclops, Ectocyclops, Mesocyclops, or Thermocyclops). The coracidia then burrow through the intestinal wall of the copepod and lodge in the body cavity where they develop into procercoids (second larval stage). If the copepod is eaten by a fish, the final host, the fish becomes infected. The larval worms mature in the intestinal tract of the fish and become egg-laying adults in 20 to 25 days. The entire life cycle lasts about 1 year (Hoffman 1976). The Asian tapeworm, B. acheilognathi, identified in North America in 1975, was probably carried into this country by grass carp (Ctenopharyngodon idella). It has been reported from many cyprinids including fathead minnows (Pimephales promelas), golden shiners (Notemigonus crysoleucas), mosquitofish (Gambusia affinis), and carp (Cyprinus carpio). The adult is a large tapeworm, up to 100 mm long and 2 mm wide, and can attain such size and numbers as to cause abdominal distention and intestinal blockage. In severe cases, this infection can lead to intestinal perforation and eventually death of the host.

Summary

Many ecological requirements of the humpback chub remain unknown. Laboratory studies and field work are needed to obtain information on life history requirements. This information will enable us to determine if specific ecological factors are lacking or limiting in the Grand Canyon, and how these are impacted by Glen Canyon Dam operations. BIO/WEST field investigations currently focus on filling data gaps and satisfying informational needs on critical life history requirements of humpback chub in the mainstem Colorado River. Intensive sampling is being conducted to determine seasonal distribution, abundance, movement patterns, resource use and availability, and survivorship of various life stages. Changes in habitat parameters are being monitored to determine if the operation of Glen Canyon Dam limits or enhances basic ecological needs of the species. Each of the following objectives and tasks will be addressed by testing one or more hypotheses (Ho):

Objective 1A: Determine Resource Availability and Use

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

Ho 1A-1: Habitat is limiting under certain flow conditions to humpback chub in the mainstem Colorado River, Grand Canyon.

Testing this hypothesis involves assessing habitat availability and use. Habitat availability was assessed in 1990 and 1991 by mapping surface areas of macrohabitats and shoreline types and measuring depth, velocity, and substrate along shorelines occupied and not occupied by the fish. Surficial maps of mainstem areas occupied by humpback chub in the vicinity of the LCR clearly reveal a stream dominated by run habitat at flows seen between May and October 1991. In spite of this preponderance of runs, few humpback chub were reported from this habitat. The majority of radiotagged adults were contacted in eddies. In 14 monthly field trips, we failed to observe a radiotagged humpback chub in the central third of the river channel. All near-surface activity was associated with the shoreline thirds of the channel.

Our observations suggest that humpback chub selected regions of low velocity that were not dominant features of the riverine environment. Of 445 radio-contacts, 70 percent were from fish that occupied eddies, while 18 percent were from return channels, and 17 percent from runs. By comparison, eddies were only about 20 percent of the surface habitat mapped at all flows, return channels were less than 1 percent, and runs were about 56 percent. Clearly, the fish selected macrohabitats with regions of low velocity. These regions were typically contained within eddies and eddy-return channels. Within these macrohabitats, these low-velocity regions may enlarge, shrink, or move with changing flow. If humpback chub select these areas, it is vital to know the flows at which these exist and are extinguished.

In order to make these determinations, it will be necessary to observe radiotagged fish at flows ranging from 3,000 to 30,000 cfs. Aerial photographs of 1:1200 scale were not available to map habitat during the research flows, and these flow ranges were not observed under Interim Flow Criteria. Unless a wider range of flows can be seen during our research period, this hypothesis is not fully testable.

Ho 1A-2: Water quality is limiting under certain flow conditions to humpback chub in the mainstem Colorado River, Grand Canyon.

Water quality data were collected monthly with Hydrolab Survey II's and Datasondes to characterize water chemistry at fish sample locations, tributary inflows, and during storm events.

These data will be used with data from existing USGS water quality gages to monitor ongoing water quality parameters of the Colorado River in Grand Canyon.

The information on optimal and avoidance levels of water quality parameters of humpback chub is scant. Bulkley et al. (1982) found a TDS preference of specific conductance of 1,300-3,000 μmhos/cm and an avoidance of 8,500 μmhos/cm. Maddux et al. (1986) reported mainstem levels of 701 to 751 μmhos/cm, and 3,898 μmhos/cm in the LCR. From these data, it appears that TDS is not sufficiently high to adversely affect humpback chub in the Grand Canyon.

Other parameters, such as dissolved oxygen and pH, cannot be related to fish requirements since optima and ranges are unknown. The limitations of water temperature are discussed in Task 1D.

The most significant water quality parameter recognized in 1990 and 1991 was turbidity. We found significant relationships between near-surface activity of radiotagged adult humpback chub and turbidity. There was significantly less near-surface activity at low turbidity and in the daytime than at high turbidity and at night. These findings are significant because they indicate that chub behavior is influenced by sediment in the water. The fish may use turbidity as cover to more readily forage along shallow, more productive shorelines, and as escape from predators. Survival of the year class observed emerging from the LCR in May through November of 1991 may have depended on main channel turbidity for escaping predators.

Increased turbidity in the system may also cue the fish to feed. Since the species evolved in a highly turbid, stochastic system, the majority of food was probably allochthonous, washed in by spring runoff, snow melt, or summer rain storms. Dislodged invertebrates and terrestrial insects are common when local rain storms flood a watershed.

Ho 1A-3: Food is limiting under certain flow conditions to humpback chub in the mainstem Colorado River, Grand Canyon.

A food habits study of humpback chub in the Grand Canyon will be initiated in 1992. Stomach content analysis is critical in characterizing the life history and ecology of the species. Food habits, combined with food availability information from drift and benthic samples, will be assessed to determine if dam operations affect food availability. Stomach contents of humpback chub will be sampled during various flow scenarios to determine if changes in behavior (i.e., additional movement) are induced by greater food availability or changes in habitat.

Leibfried (1988) found that rainbow trout below Glen Canyon Dam ingested large quantities of Cladophora, deriving nutritional benefit through digestion of lipid-rich diatoms epiphytic on algae.

It is important to know if humpback chub exhibit similar feeding strategies since Cladophora production is closely linked to stream flow and hence dam operation. This relates to flow as well as temperature regimes. Certain flow scenarios may affect production of Cladophora and temperature changes are likely to affect epiphytic diatom communities (Blinn et al. 1989).

Food habits of humpback chub will be examined by a nonlethal method using a stomach pump. An inlet tube is inserted into the esophagus, and the stomach mildly irrigated with water to flush material into a collecting funnel and container. Material pumped from each fish will be stored separately and examined in the laboratory to determine composition and volume.

Objective 1B: Determine Reproductive Capacity and Success

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

Ho 1B-1: Humpback chub do not actively spawn in the mainstem Colorado River, Grand Canyon.

Main channel reproduction by humpback chub in the Grand Canyon is at best extremely limited, or more likely nonexistent as a result of cold water temperatures (Maddux et al. 1987). Tubercled fish and one ripe male were found in Reaches 2 and 3. In March of 1991, we observed a large aggregation of chub at the LCR inflow. We found many milting males and some females with expressible eggs in the upstream inflow channel of the LCR. We found three chub eggs in small gravel pockets behind large boulders at the inflow that were either washed downstream from the LCR or deposited locally. At the time, this channel was subject to high fluctuations from the mainstem that allowed the LCR to flow through at low mainstem levels, and was pushed to the downstream channel at high flows. With 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. Larry Harris (personal communication, February 1991) reported disintegration of Colorado squawfish eggs incubated at low temperatures.

Objective 1C: Determine Survivorship of Early Life Stages

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

Ho 1C-1: Survival of early life stages of humpback chub is low in the mainstem Colorado River, Grand Canyon.

A demographic analysis has not been conducted on young humpback chub captured in 1991. A total of 281 YOY and 77 juveniles were captured. Nearly all YOY captured from May through

November of 1991 were downstream of the LCR. We believe these fish originated in the LCR and were washed or descended into the mainstem. The numbers of YOY in the mainstem varied by month since it appeared that fish continued to emerge from the LCR through most of the summer. This 1991 cohort will be monitored in 1992 by electrofishing CPE and mark-recapture methods to evaluate the survival of these fish and determine the extent of their distribution downstream and upstream of the LCR.

We note that no YOY of the 1990 cohort were found in the mainstem from October 1990 through April 1991. Several reasons are offered to explain this absence of young fish. The fish could have been present in the mainstem but were not captured because of relative low electrofishing effort prior to May of 1991. It is also possible that the majority of YOY remained in the LCR after hatching in spring 1990 and did not descend into the mainstem Colorado River until spring of 1991. The young fish may have also been flushed from the LCR inflow area by high fluctuating flows from dam operations or by periodic highs and lows from the research flows (June 1, 1990 to July 29, 1991).

These young fish may be subject to temperature shock as they emerge from the 20°C LCR water into the 8-10°C water of the mainstem. Mortality has been reported in YOY 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.

Survival of age-I and age-II fish may also be difficult to assess without the aid of a permanent mark. Kaeding and Zimmerman (1983) reported that chub were about 125 mm TL when they became age-II fish. Age-I fish are too small to PIT tag and fin clips retain their identity for only short time periods. Fish that are age-II and older should be large enough to PIT tag (>150 mm TL) so that and assessing survival of age-II, age-III and age-IV fish is possible using mark-recapture techniques. However, distinguishing age-V fish and older is difficult because of variable and inconsistent growth rates for individual adults. Information currently being assimilated by other investigators (D. Hendrickson, AGF; C.O. Minckley, ASU) on age-length and age-growth relationships for humpback chub will aid in differentiating age groups, particularly of the younger fish. Length-frequency analyses will be conducted for fish captured in this investigation and others in the Grand Canyon to relate survival of fish of known length to age group survival. It is anticipated that age-0 through age-IV fish will be distinguishable from length-frequency analysis, but older fish may not be distinguishable because of the effect of maturation and spawning on growth. Thus, survival rates of humpback chub will be determined separately for age-0, age-I, age-II, age-III, and age-IV fish while survival of adults is treated as a group.

Objective 1D: Determine Distribution, Abundance and Movement

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

Ho 1D-1: The distribution and abundance of humpback chub in the mainstem Colorado River, Grand Canyon, is affected by Glen Canyon Dam operations.

The above hypothesis will be tested by assessing the potential effects of dam operation on the distribution and abundance of the species. First, the distinction must be made between the effect of the presence of the dam and its operation. Most investigators (Carothers et al. 1981, Maddux et al. 1987) believe that cold water releases, irrespective of fluctuating flows, have reduced the pre-dam distribution and abundance of the species.

We have shown the pre-dam and current post-dam distribution of humpback chub in the mainstem Colorado River in Grand Canyon (information from C.O. Minckley). Pre-dam data from the mainstem were scant except for some sampling at the LCR and its inflow (Kolb and Kolb 1914, Miller 1946, Wallis 1951). Post-dam information is primarily from Reach 1 but scant from the other sample reaches.

Of the 606 adult humpback chub captured in 1990 and 1991, 94 percent (569) were within a 13.5-km reach of the LCR inflow, approximately 6.9 km upstream and 6.6 km downstream. The fish in the peripheral areas of this distribution, as well as those captured downstream were found primarily in March and May, when pre-spawning activity was high and during the scheduled research flows. Since August 1991, the Interim Flow Criteria have resulted in less fluctuation and we have seen less dispersal of fish.

Ho 1D-2: Cold water releases from Glen Canyon Dam affect the distribution and abundance of humpback chub in the mainstem Colorado River, Grand Canyon, independent of dam operations.

Many investigators (Carothers et al. 1981, Maddux et al. 1987) believe that cold water releases, irrespective of fluctuating flows, have reduced the distribution and abundance of the species. The influence of cold water releases (8°C) on the distribution and abundance of humpback chub in the Colorado River, Grand Canyon, independent of fluctuating flows, can be evaluated by examining historic records and examining the temperature requirements of each life stage of the species, and comparing with existing temperature regimes in the Grand Canyon (Table 31, Figure 43).

In all likelihood cold mainstem releases affect the distribution of at least YOY and juveniles, since these life stages are more temperature sensitive than adults. We saw evidence of this from the downstream dispersal of YOY from the LCR in May through November of 1991. Cold mainstem temperatures also account for the close association of chub throughout the canyon with tributary inflows. The fish were probably attracted to these areas by warmer inflows and possibly higher autochthonous production.

Another aspect of temperature is its effect on epiphytic diatom communities. Leibfried (1988) determined that rainbow trout in the Grand Canyon utilized diatoms epiphytic on Cladophora as a primary source of lipids. Blinn et al. (1989) observed significant changes in these epiphytic diatom communities when water temperature was increased from 12°C to 18°C, but no change was observed between 18°C and 21°C, suggesting a temperature threshold between 12°C and 18°C for diatom flora below Glen Canyon Dam. Increased water temperature could significantly affect food resources of fish species in the Grand Canyon that exhibit the same feeding strategy as humpback chub.

Ho 1D-3: Movement of humpback chub in the mainstem Colorado River, Grand Canyon, is greater during fluctuating flows than during stable flows.

Preliminary movement data from 1990 and 1991 suggest a relationship between near-surface activity and stage change. The data are inconclusive to demonstrate a relationship with flow levels. Fish movement typically occurred during rapid changes in river stage. This relationship was observed for fish staging at the mouth of the LCR as well as fish residing in mainstem eddies. The reasons for and effects of these movements are unknown. The fish may be adjusting to changing habitat conditions (i.e. depth or velocity). Or, the fish may be responding to increased food availability. The effect of these two responses may be quite different. Fish that have to alter their position with changing habitat conditions may expend excessive energy, while fish that are actively feeding are procuring energy.

We intend to continue exploring this hypothesis by examining habitat availability and use for juvenile and adult humpback chub. We also plan to collect drift samples simultaneous to stomach contents of adults to determine if feeding periodicity is related to flow phenomena.

Increased activity of these fish with changing river stage may not create an energetic deficit for the fish. We have initiated a review of bioenergetics literature to gain more insight on this question.

Table 31. Temperature requirements (°C) of selected native and non-native fishes. Point values and ranges are provided where available.

SPECIES	SPAWNING	EGG INCUBATION	OPTIMUM GROWTH	TOLERANCE RANGE	FINAL PREFERENDUM
NATIVE					
Humpback Chub	11.5-24	19-20 (4.8-6.6d) (16-22°C)			24
Razorback Sucker	11-20	20-21 (4.0-6.0d) (14-22°C)		8.0-31.6	22.9-24.8
Flannelmouth Sucker	18-21	18-21			25.9
Bluehead Sucker	18.2-24.6	18-21			
Speckled Dace	18-19	18-19 (~6d)		-36.8	15.8
NON-NATIVE					
Channel Catfish	21.7 21-29			0-35	31.1
Common Carp	17-23	17-23 (3-16d)			
Fathead Minnow	15.6-27	23-30 (~5d)		1.5-33.2	
Striped Bass	15-20	15-21 (2.6-1.4d)	20-24	-27	22
Red Shiner	15.5-29.5	24.5 (4.4d)		-38.8	27
Sand Shiner					
Green Sunfish	15-31				26-31
Black Bullhead	20+				
Rainbow Trout	5-15	7-12	13-21	0-28.3 avoid residence above 18	
Cutthroat Trout	5.5-9.0				
Brown Trout	2-9	2-13	12-19	-27	

d=days

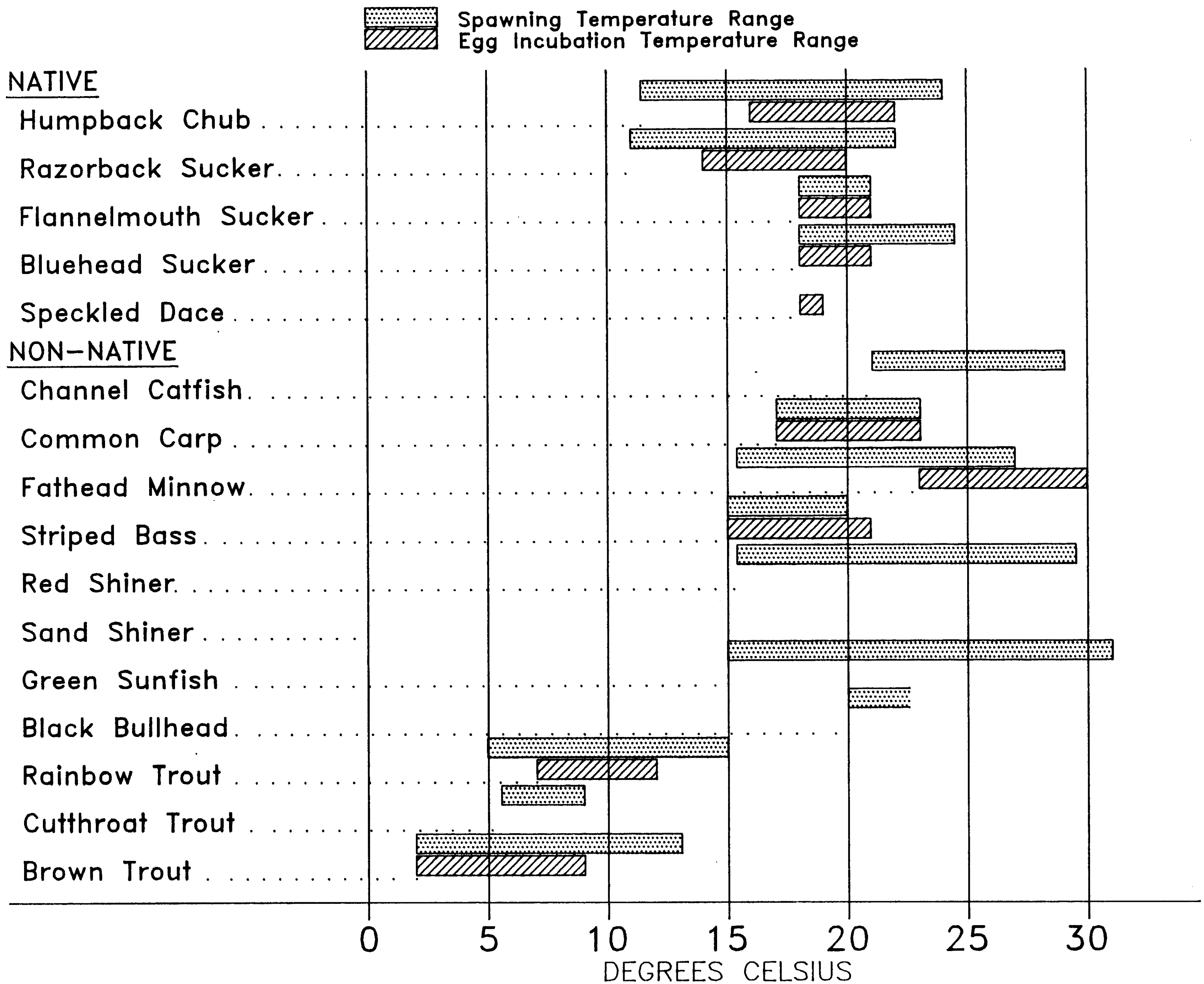

Figure 43. Spawning and egg incubation temperature ranges of selected native and non-native fishes.

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

Ho 1E-1: Introduced non-native fish species have a negative effect on humpback chub in the mainstem Colorado River, Grand Canyon.

Maddux et al. (1986) reported that 20 species of non-native fish and 8 native species have been documented from the Grand Canyon since 1958. We reported 11 non-native and 5 native species from October 1990 through November 1991.

Various aspects of the life history of the humpback chub may be affected by certain biotic interactions with other species of fish such as channel catfish, carp, rainbow trout, brown trout, and striped bass. Competition, predation, and introduction of diseases are the most significant interactions.

We found a high level of sympatry between humpback chub and rainbow trout, brown trout, carp, and channel catfish that indicates possible competition. Stomachs of 82 fish were examined, including rainbow trout, brown trout, channel catfish, striped bass, and walleye, and no chub were found. We recognize, however, that predation by these species could be sporadic and occur mostly at night or at certain flow events. We intend to continue to investigate this issue of predation by angling with artificial lures for predators at tributary inflows during the descent of YOY chub from the LCR.

Objective 2: Determine Life History Schedule for Humpback Chub

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

We have described the approximate life history schedule for the humpback chub in the Colorado River in Grand Canyon from October 1990 through November 1991 (Figure 44). From October through February, we found the fish dispersed in the main channel; nearly 95 percent of the chub were caught in a 13.6-km reach between RM 57.0 and RM 65.4. In February, we noted local aggregations in eddies and deep pools close to and away from the LCR. In March, there was a large aggregation of adult humpback chub in the mainstem at the mouth of the LCR. Fish ascended the LCR from April through mid-July, and descended in July and August. The adults had redispersed in the main channel by August. From May through September, we saw large numbers of YOY and young chub descend the LCR with peak numbers in August and September.

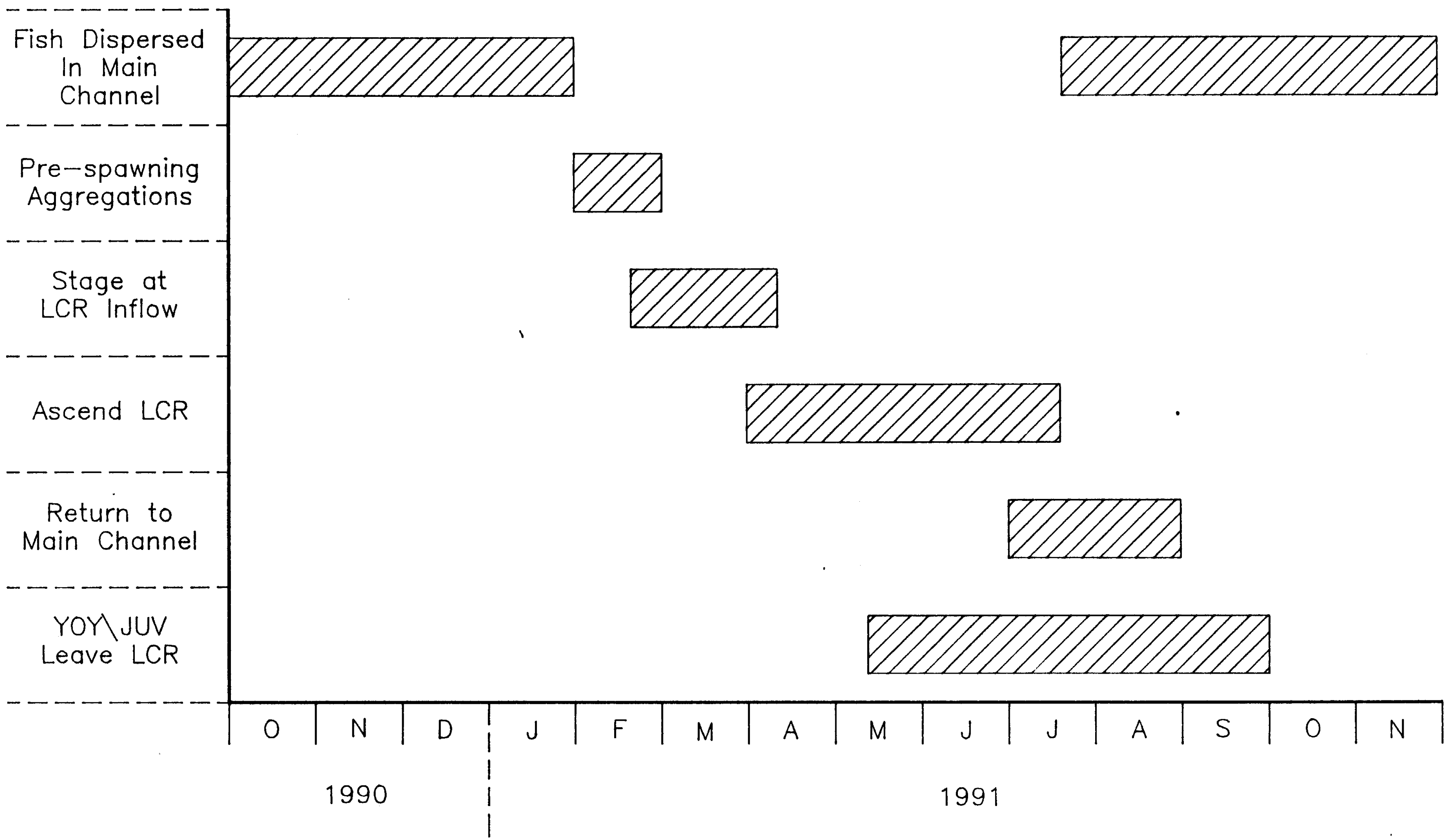

Figure 44. Life history schedule for humpback chub in the Colorado River in Grand Canyon as observed by BIO/WEST in 1990-1991.

Objective 2A: Develop a Population Model

Task 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.

Information and data assimilated from literature as well as collected from year-around sampling will be used to describe the life history of the humpback chub in the Grand Canyon. The empirical data collected on various life history aspects of the species will be integrated with other investigations into an existing population model being developed under the guidance of GCES. This model will be used as a tool to identify relationships and functions of components.

B/W currently has a statistician/population modeler on this project to advise data collection and analyses, as well as input to demographic modeling. All collections are being made, to the extent possible, to provide as much information as possible to this modeling effort.

RECOMMENDATIONS

1. 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 small-mesh hoop nets and minnow traps. Closely monitor electrofishing efforts and try to work at low amperage levels (<12 amps).

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

3. Continue to define extent of LCR population in the mainstem, both upstream and downstream bounds.

4. Further use of radiotelemetry in Reaches 2 and 3 to help locate concentrations of humpback chub, and verify observations made in Reach 1 under a different flow sequence.

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

6. Continue volunteer program to satisfy personnel needs during both 20-day trips (to clean nets) and 10-day trips (to help sample fish and radiotrack).

7. Track and monitor radiotagged fish in the LCR and provide locational information to AGF, ASU, the Service.

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

9. Refine telemetry observation routine for more consistent collection of movement and stage change data.

10. Initiate stomach pumping of adult humpback chub (>350 mm TL) to evaluate use of food resources.

11. Schedule April and May 1993 trips to optimize assessment of spawning of humpback chub.

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

13. Define mapping issues (i.e., use of GIS, MIPPS, etc.).

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

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

16. Decrease the number of radiotagged fish implanted from 60 per year to about 40 per year.

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

18. Conduct meristic measurements on one of every ten chub, and discontinue photographs and video of humpback chub with the following exceptions: anomolous morphs (e.g., bonytail or roundtail-like fish), razorback or razorback x flannelmouth hybrids, evidence of predation or other unique observations, recaptured radiotagged chub.

19. 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.

20. Initiate specific turbidity measurements to correlate to near-surface fish activity.

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

22. Simultaneously collect drift samples and humpback chub with netting and electrofishing to determine food preference with the aid of a stomach pump.

23. Continue sampling those substrata in Reaches 2 and 3 that produced humpback chub in 1990 and 1991.

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APPENDIX A

Table A-1. Collecting localities of the humpback chub between Glen Canyon Dam and the United States-Mexican border, 1942-present (from Minckley 1992).

Date	Locality	Reference
1963	Lee's Ferry	ASU
1964	Above Lee's Ferry	J.L. Stone 1964
1966	"	J.L. Stone 1966
1967	"	Stone and Queenan 1967
1968	"	Stone and Rathbun 1968
1967	"	Holden and Stalnaker 1970; Holden 1973
1970	Lee's Ferry	Museum of Northern Arizona 1970
1985	RM 8.0	D. Pearson, Eric's building supply, Flagstaff, AZ
1980	RM 17.8	Kaeding and Zimmerman 1983
1978	RM 19.5	Carothers and Minckley 1981
1977	RM 27.0	C.O. Minckley 1977
1979	RM 27.5	Carothers and Minckley 1981
1985	RM 31.0	Maddux et al 1987
1971	RM 31.5	Museum of N. Az. 1971
BP*	RM 31.8	Euler 1978; Miller and Smith 1984
1971	RM 31.9	"
1968	"	R.R. Miller 1975a,b
1969	"	"
1978	RM 33	Carothers and Minckley 1981
1984	"	Maddux et al 1987
1970	RM 44	Suttkus et al 1976
1971	"	Museum of Northern Arizona 1971
1981	RM 52.8	Kaeding and Zimmerman 1983
1981	RM 53.2	"
1978	RM 55.0	Carothers and Minckley 1981
1981	RM 57.1	Kaeding and Zimmerman 1983
1981	RM 57.2	"
1981	RM 58.0	"
1981	RM 58.2	"
1981	RM 58.7	"
1981	RM 58.9	"
1981	RM 59.0	"
1985	RM 59.0	Maddux et al 1987
1981	RM 59.3	Kaeding and Zimmerman 1983
1981	RM 59.4	"
1984	RM 60.0	Maddux et al 1987
1980	RM 60.5	Kaeding and Zimmerman 1983
1980	RM 60.6	"
1980	RM 60.8	"
1980	RM 60.9	"
1981	RM 60.9	"

Table A-1 continued

1984	RM 61.0	Maddux et al 1987
1980	RM 61.1	Kaeding and Zimmerman 1983
1981	RM 61.1	"
1981	RM 61.2	"
1981	RM 61.3	"
1980	RM 61.4	"
1981	"	"
1989	"	Kubly 1990
1968	RM 61.5	R.R. Miller 1975a,b
1975	"	Suttkus et al 1976
1975	"	Minckley and Blinn 1976 (reported as G. elegans, a mistake)
1976	"	Suttkus and Clemmer 1977
1977	"	C.O. Minckley 1977, 1978
1978	"	Carothers and Minckley 1981
1979	"	"
1984	"	Maddux et al 1987
1986	"	"
1981	RM 61.9	Kaeding and Zimmerman 1983
1984	RM 62	Maddux et al 1987
1981	RM 62.2	Kaeding and Zimmerman 1983
1981	RM 62.5	"
1985	"	Maddux et al 1987
1981	RM 62.6	Kaeding and Zimmerman 1983
1981	RM 62.7	"
1968	RM 63	R.R. Miller 1975a,b
1975	RM 63	"
1985	RM 63.5	Maddux et al 1987
1981	RM 63.6	Kaeding and Zimmerman 1983
1985	RM 64.0	Maddux et al 1987
1985	RM 64.1	"
1981	RM 64.2	Kaeding and Zimmerman 1983
1985	RM 64.3	Maddux et al 1987
1968	RM 64.5	R.R. Miller 1975a,b
1981	"	Kaeding and Zimmerman 1983
1985	"	Maddux et al 1987
1980	RM 64.6	Kaeding and Zimmerman 1983
1981	"	"
1980	RM 64.7	"
1981	"	"
1980	RM 64.8	"
1980	RM 64.9	"
1981	"	"

Table A-1 continued

1985	RM 65.0	Maddux et al 1987
1985	RM 65.2	"
1985	RM 65.5	"
1988	RM 65.6	Kubly 1990
1985	RM 66.3	Maddux et al 1987
1980	RM 66.8	Kaeding and Zimmerman 1983
1988	RM 67.8	Kubly 1990
1981	RM 67.9	Kaeding and Zimmerman 1983
1988	"	Kubly 1990
1981	RM 68.0	Kaeding and Zimmerman 1983
1987	"	Maddux et al 1987
1981	RM 68.2	Kaeding and Zimmerman 1983
1981	RM 68.3	"
1975	RM 69.0	Suttkus et al 1976
1981	RM 69.1	Kaeding and Zimmerman 1983
1981	RM 69.3	"
1987	RM 69.5	Maddux et al 1987
1981	RM 69.9	Kaeding and Zimmerman 1983
1981	RM 70.0	"
1985	"	Maddux et al 1987
1977	"	C.O. Minckley 1977
1981	RM 70.1	Kaeding and Zimmerman 1983
1987	RM 71.0	Maddux et al 1987
1975	"	Suttkus et al 1976; Suttkus and Clemmer 1976
1981	RM 71.1	Kaeding and Zimmerman 1983
1989	RM 71.2	Kubly 1990
1981	RM 71.4	Kaeding and Zimmerman 1983
1979	RM 72.0	Carothers and Minckley 1981
1989	RM 72.3	Kubly 1990
1984	RM 73.0	Maddux et al 1987
1985	RM 73.5	"
1985	RM 74.0	"
1985	RM 75.0	"
1985	RM 76.0	"
1985	RM 84.0	"
1984	RM 86.0	"
1984	RM 87.0	"
1942	Bright Angel (RM 87.5)	R.R. Miller 1946
1944	"	GCNP
1968	"	GCNP
1984	"	Maddux et al 1987
1987	"	Law, M. 1990
1990	"	Valdez 1990
1991	"	Valdez et al 1991

1979	RM 93.5	Carothers and Minckley 1981
1984	RM 94.0	Maddux et al 1987
1986	RM 104.0	"
1984	RM 107.0	"
1975	Shinumo Creek (RM 108.5)	Suttkus et al 1976; Suttkus and Clemmer 1977
1978	"	Carothers and Minckley 1981
1984	"	Maddux et al 1987
1986	RM 109.0	"
1985	"	"
1984	RM 112.0	"
1985	RM 114.0	"
1985	RM 117.0	"
1988	RM 120.0	"
1984	RM 122.0	"
1985	RM 126.0	"
1978	RM 132	Carothers and Minckley 1981
1985	RM 136	Maddux et al 1987
1985	RM 136.5	"
1989	Kanab Creek (RM 143.5)	Kubly 1990
1986 "	M. Yard, pers. comm.	
1979	Havasu Creek (RM 157)	Carothers and Minckley 1981
1987	"	Maddux et al 1987
1988	"	Kubly 1990
1991	"	Valdez et al 1991
1985	RM 165.0	Maddux et al 1987
1985	RM 165.1	"
1985	RM 165.4	"
1989	RM 165.5	Kubly 1990
1985	RM 165.6	Maddux et al 1987
1985	RM 165.8	"
1985	RM 166.3	"
1989	RM 167.5	Kubly 1990
1985	RM 171.0	Maddux et al 1987
1985	RM 174.0	"
1985	RM 176.5	"
1985	RM 178.0	"
1985	RM 178.5	"
1968	RM 179.1	Miller and Smith 1968
1985	RM 182.0	Maddux et al 1987
1987	RM 187.0	"
1987	RM 187.5	"
1985	RM 190.5	"
1984	RM 191.0	"
1985	RM 192.0	"

Table A-1 continued

1978	RM 194	Carothers and Minckley 1981 (boatman report, C.O. Minckley's notes)
1985	"	Maddux et al 1987
1985	RM 196.0	"
1985	RM 197.5	"
1985	RM 197.8	"
1987	RM 198.0	"
1987	RM 200.0	"
1985	RM 203.2	"
1985	RM 204.0	"
1985	RM 208.0	"
1985	RM 211.0	"
1985	RM 213.5	"
1984	RM 214.0	"
1985	"	"
1985	RM 216.0	"
1985	RM 217.0	"
1991	RM 241	B. Mitchell, Fredonia AZ
1955	RM 246	Wallis, O.L. 1955 (in Kubly, 1990)
1955	Catclaw Cave site	R.R. Miller 1955

* BP = 4000 yrs. before present, Stanton's cave archeological site.
GCNP = Grand Canyon National Park (Specimens preserved at Arizona State University)

Table A-2. Microhabitat measurements for juvenile humpback chub from four sites on the Colorado River in Grand Canyon, 1991.

	Sample	Date	River	River Mile	Transect	At 0.5 m[a]				At 1.5 m				At 2.5 m			
						Depth	Vel.	Sub 1	Sub 2	Depth	Vel.	Sub 1	Sub 2	Depth	Vel.	Sub 1	Sub 2
Site 1: Crash Canyon	001	910915	CO	62.6	1	0.4	0.17	SI	SA	0.5	0.04	BE	SI	0.8	0.23	BE	BE
	001	910915	CO	62.6	2	0.3	0.02	SI	SA	0.5	0.06	BO	BE	1.2	0.35	BO	BE
	001	910915	CO	62.6	3	0.2	0.15	SI	SI	0.7	0.02	SI	BO	1.2	0.03	SI	BE
	001	910915	CO	62.6	4	0.4	0.00	SI	SI	1.5	0.01	SI	BO	2.8	0.05	BO	SI
	001	910915	CO	62.6	5	0.3	0.00	SI	SI	1.6	0.12	SI	SA	1.8	0.23	BO	BE
	001	910915	CO	62.6	6	0.4	0.00	SI	SI	0.9	0.02	SI	SI	1.5	0.12	SI	SI
	001	910915	CO	62.6	7	0.4	0.00	SI	BO	1.2	0.00	SI	SA	1.6	0.02	SI	SA
	001	910915	CO	62.6	8	0.5	0.02	SI	SA	0.7	0.05	SI	SA	1.2	0.16	SI	SA
	001	910915	CO	62.6	9	0.4	0.18	SI	SA	0.6	0.01	BO	SI	0.7	0.03	BO	BE
Site 2: Salt Mines	002	910916	CO	63.1	1	0.3	0.00	BO	SI	0.6	0.04	SI	SI	0.9	0.00	BO	SI
	002	910916	CO	63.1	2	0.3	0.00	BO	BO	0.9	0.03	SI	SI	0.9	0.02	BO	SA
	002	910916	CO	63.1	3	0.9	0.02	SI	SI	0.7	0.06	SI	SI	0.6	0.07	BO	BO
	002	910916	CO	63.1	4	0.3	0.01	BO	BO	0.5	0.05	BO	BO	3.0	0.01	BO	BO
	002	910916	CO	63.1	5	0.3	0.00	CO	SI	0.7	0.02	SI	BO	1.3	0.00	SI	SI
	002	910916	CO	63.1	6	0.2	0.00	SI	CO	0.7	0.12	BO	BO	1.5	0.17	BO	BO
	002	910916	CO	63.1	7	0.2	0.01	BO	SA	1.0	0.03	SI	SI	1.6	0.07	BO	BO
	002	910916	CO	63.1	8	0.2	0.01	BO	BO	0.0	0.00	BO	BO	0.2	0.02	BO	BO
	002	910916	CO	63.1	9	0.2	0.09	BO	BO	0.7	0.17	BO	BO	1.2	0.15	BO	SA
Site 3: Weeping Wall	003	910916	CO	63.0	1	1.3	0.09	BE	BE	2.2	0.10	BE	BE	2.6	0.42	BE	BE
	003	910916	CO	63.0	2	1.0	0.64	BE	BE	1.7	0.26	BE	BE	2.5	0.06	BE	BE

Table A-2 continued

	Sample	Date	River	River Mile	Transect	At 0.5 m[a]				At 1.5 m				At 2.5 m			
						Depth	Vel.	Sub 1	Sub 2	Depth	Vel.	Sub 1	Sub 2	Depth	Vel.	Sub 1	Sub 2
	003	910916	CO	63.0	3	0.6	0.16	BE	BE	2.8	0.16	BE	BE	3.4	0.37	##	##
	003	910916	CO	63.0	4	2.6	0.03	BE	BE	3.4	0.04	##	##	3.4	0.58	##	##
	003	910916	CO	63.0	5	1.9	0.09	BE	BE	3.4	0.06	##	##	3.4	0.55	##	##
	003	910916	CO	63.0	6	3.4	0.06	##	##	3.4	0.34	##	##	3.4	0.47	##	##
	003	910916	CO	63.0	7	3.4	0.04	##	##	3.4	0.46	##	##	3.4	0.28	##	##
	003	910916	CO	63.0	8	3.4	0.03	##	##	3.4	0.02	BE	BE	3.4	0.21	##	##
Site 4: Sand Beach	004	910916	CO	63.5	1	0.2	0.06	SA	SA	0.6	0.16	SA	SA	1.0	0.17	SA	SA
	004	910916	CO	63.5	2	0.2	0.08	SA	SA	0.5	0.33	SA	SA	0.9	0.18	SA	SA
	004	910916	CO	63.5	3	0.1	0.03	SA	SA	0.4	0.04	SA	SA	0.6	0.04	SI	SI
	004	910916	CO	63.5	4	0.1	0.00	SA	SI	.02	0.01	SA	SI	0.4	0.00	SA	SI
	004	910916	CO	63.5	5	0.1	0.00	SA	SI	0.3	0.00	SA	SI	0.5	0.02	SA	SI
	004	910916	CO	63.5	6	0.1	0.00	SA	SI	0.2	0.00	SA	SI	0.4	0.03	SA	SI
	004	910916	CO	63.5	7	0.2	0.00	SA	SI	0.3	0.02	SA	SI	0.5	0.03	SA	SI
	004	910916	CO	63.5	8	0.2	0.06	SA	SI	0.3	0.09	SA	SI	0.4	0.04	SA	SI
	004	910916	CO	63.5	9	0.2	0.06	SI	SA	0.3	0.10	SI	SA	0.5	0.11	SI	SA

[a]Depth in meters, Velocity in meters per second; Sub 1 = dominant substrate, Sub 2 = secondary substrate; SI = silt, SA = sand, CO = cobble, BO = boulder, BE = bedrock

Table A-3. Surface area (m^2) and percentage of macrohabitat by flow of selected map areas of the Colorado River in Grand Canyon, 1991.

MAP Total Area (percent)	FLOW (cfs) (approx.)	EDDY	POOL	RAPID	RETURN CHANNEL/ BACKWATER	RIFFLE	RUN	SLACKWATER
ESPN								
40,959 (100%)	4,290-4,410	4,221 (10%)	16,931 (41%)		147 (<1%)		19,660 (48%)	
41,240 (100%)	9,870	5,942 (14%)			60 (<1%)		35,238 (86%)	
42,507 (100%)	13,400-14,200	14,412 (34%)			102 (<1%)	235 (1%)	27,758 (65%)	
44,004 (100%)	15,600-16,000	7,976 (18%)	1,375 (3%)		136 (<1%)		34,516 (78%)	
CAMP								
39,647 (100%)	4,220-4,290	604 (2%)	16,893 (43%)			997 (3%)	21,153 (53%)	
37,210 (100%)	10,000	2,910 (8%)				477 (1%)	33,823 (91%)	
42,584 (100%)	13,500	2,185 (5%)			86 (<1%)	661 (2%)	39,652 (93%)	
40,457 (100%)	16,000-16,600	3,098 (8%)	2,072 (5%)			321 (1%)	34,967 (86%)	
LCR								
35,840 (100%)	4,300-4,390	7,257 (20%)	6,463 (18%)	4,919 (14%)		5,142 (14%)	12,021 (34%)	39 (<1%)
42,286 (100%)	10,000-10,200	3,211 (8%)	6,635 (16%)	732 (2%)		5,137 (12%)	25,371 (60%)	1,199 (3%)
43,457 (100%)	13,500-13,700	5,697 (13%)	7,571 (17%)	4,754 (11%)		12,681 (29%)	12,755 (29%)	

Table A-3 continued.

MAP Total Area (percent)	FLOW (cfs) (approx.)	EDDY	POOL	RAPID	RETURN CHANNEL/ BACKWATER	RIFFLE	RUN	SLACKWATER
46,557 (100%)	14,900-15,200	7,197 (15%)	6,996 (15%)	2,930 (6%)		2,752 (6%)	26,682 (57%)	
HOPI								
58,078 (100%)	~10,000	12,970 (22%)	20,971 (36%)				24,137 (42%)	
107,764.46 (100%)	14,200-14,900	34,352 (32%)	15,184 (14%)	16,376 (15%)			41,852 (39%)	
SALT								
28,860 (100%)	7,250-9,640	11,867 (41%)	4,993 (17%)	1,058 (4%)	289 (1%)		10,653 (37%)	
33,431 (100%)	~8,000	5,696 (17%)	8,005 (24%)	1,506 (5%)	206 (1%)		18,018 (54%)	
37,268 (100%)	13,500	12,789 (34%)	6,547 (18%)	2,127 (6%)			15,805 (42%)	
65,023 (100%)	13,200-13,600	20,325 (31%)	8,320 (13%)	2,659 (4%)			33,720 (52%)	
WHAL								
76,361 (100%)	13,600-13,700	17,915 (23%)	8,990 (12%)	944 (1%)		2,479 (3%)	46,033 (60%)	

Table A-3 continued.

MAP Total Area (percent)	FLOW (cfs) (approx.)	EDDY	POOL	RAPID	RETURN CHANNEL/ BACKWATER	RIFFLE	RUN	SLACKWATER
WEEP								
62,388 (100%)	10,000	19,742 (32%)	16,643 (27%)	2,703 (4%)	69 (<1%)	147 (<1%)	23,084 (37%)	
66,308 (100%)	16,300-16,400	16,650 (25%)	15,776 (24%)	4,536 (7%)	274 (<1%)	251 (<1%)	28,821 (43%)	

Table A-4. Surface area (m^2) and percentage of macrohabitats in the ESPN map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	4,290-4,410 cfs		9,870 cfs		13,400-14,200 cfs		15,600-16,000 cfs		
	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AVERAGE PERCENT
EDDY	4,221(2)	10	5,942(3) (+1,721;41%)	14	14,412(10) (+8,470;143%)	34	7,976(5) (-6,436;45%)	18	19
POOL	16,931(1)	41	0 (-16,931;100%)	-	0 (0,0%)	-	1,375(1) (+1,375;100%)	3	11
RAPID	0	-	0	-	0	-	0	-	-
RETURN CHANNEL/ BACKWATER	147(2)	<1	60 (-87;59%)	<1	102(1) (+42;70%)	<1	136(1) (+34;33%)	<1	<1
RIFFLE	0	-	0	-	235(1)	1	0	-	<1
RUN	19,660(2)	48	35,238(1) (+15,578;79%)	86	27,758(2) (-7,480;21%)	65	34,516(1) (+6,758;20%)	78	69
SLACKWATER	0	-	0	-	0	-	0	-	-
TOTALS:	40,959	100	41,240 (+281;1%)	100	42,507 (+1,267;3%)	100	44,003 (+1,496;4%)	100	

Table A-5. Surface area (m^2) and percentage of macrohabitats in the CAMP map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	4,220-4,290 cfs		10,000 cfs		13,500 cfs		16,100-16,600 cfs		
	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AVERAGE PERCENT
EDDY	604(3)	2	2,910(5) (+2,306;382%)	8	2,185(5) (-725;25%)	5	3,098(9) (+913;42%)	8	6
POOL	16,893(3)	43	0 (-16,893;100%)	-	0 (0;0%)	-	2,072(1) (+2,072;100%)	5	12
RAPID	0	-	0	-	0	-	0	-	-
RETURN CHANNEL/ BACKWATER	0	-	0	-	86(1)	<1	0	-	<1
RIFFLE	997(5)	3	477(1) (+520;52%)	1	661(3) (+184;39%)	2	321(1) (-340;51%)	1	2
RUN	21,153(2)	53	33,823(1) (+12,670;60%)	91	39,652(1) (+5,829;17%)	93	34,967(2) (-4,685;12%)	86	81
SLACKWATER	0	-	0	-	0	-	0	-	-
TOTALS:	**39,647**	**100**	**37,210** (-2,437;6%)	**100**	**42,584** (+5,374;14%)	**100**	**40,457** (-2,127;5%)	**100**	

Table A-6. Surface area (m^2) and percentage of macrohabitats in the LCRI map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	4,300-4,390 cfs		10,100-10,200 cfs		13,500-13,700 cfs		14,900-15,200 cfs		
	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AVERAGE PERCENT
EDDY	7,257	20	3,211 (-4,046;56%)	8	5,697 (+2,486;77%)	13	7,197 (+1,500;26%)	15	14
POOL	6,463	18	6,635 (+172;3%)	16	7,571 (+936;14%)	17	6,996 (-575;8%)	15	17
RAPID	4,919	14	732 (-4,187;85%)	2	4,754 (+4,022;550%)	11	2,930 (-1,824;38%)	6	8
RETURN CHANNEL/ BACKWATER	0	-	0	-	0	-	0	-	-
RIFFLE	5,142	14	5,137 (-5;<1%)	12	12,681 (+7,544;147%)	29	2,752 (-9,929;78%)	6	15
RUN	12,021	34	25,371 (+13,350;111%)	60	12,755 (+12,616;50%)	29	26,682 (+13,927;109%)	57	45
SLACKWATER	39	<1	1,199 (+1,160;3,000%)	3	0	-	0	-	1
TOTALS:	**35,841**	**100**	**42,285 (+6,444;18%)**	**100**	**43,458 (+1,173;3%)**	**100**	**46,557 (+3,099;7%)**	**100**	

Table A-7. Surface area (m^2) and percentage of macrohabitats in the HOPI map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	~10,000 cfs		14,200-14,900 cfs		
	AREA (m^2)	**PERCENT**	**AREA (m^2)**	**PERCENT**	**AVERAGE PERCENT**
EDDY	12,970(5)	22	34,352(4)	32	27
POOL	20,971(2)	36	15,184(1)	14	25
RAPID	0	-	16,376(1)	15	8
RETURN CHANNEL\ BACKWATER					
RIFFLE					
RUN	24,137(2)	42	41,852(2)	39	41
SLACKWATER					
TOTALS:	**58,078**	**100**	**107,764**	**100**	

Table A-8. Surface area (m^2) and percentage of macrohabitats in the SALT map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	7,250-9,640 cfs		~8,000 cfs		13,500 cfs		13,200-13,600 cfs		
	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AREA (m^2)	PERCENT	AVERAGE PERCENT
EDDY	11,867(6)	41	5,696(4) (-6,171;52%)	17	12,789(8) (+7,093;125%)	34	20,325(5) (+7,536;59%)	31	31
POOL	4,993(1)	17	8,005(1) (+3,012;60%)	24	6,547(1) (-1,458;18%)	18	8,320(1) (+1,773;27%)	13	18
RAPID	1,058(1)	4	1,506(1) (+448;42%)	5	2,127(1) (+621;41%)	6	2,659(1) (+532;25%)	4	5
RETURN CHANNEL/ BACKWATER	289(2)	1	206(1)	1	0	-	0	-	<1
RIFFLE	0	-	0	-	0	-	0	-	-
RUN	10,653(1)	37	18,018(1) (+7,365;69%)	54	15,805(1) (-2,213;12%)	42	33,720(1) (+17,915;113%)	52	46
SLACKWATER									
TOTALS:	**28,860**	**100**	**33,431** (+4,571;16%)	**100**	**37,268** (+3,831;11%)	**100**	**65,024** (+27,756;74%)	**100**	

Table A-9. Surface area (m^2) and percentage of macrohabitats in the WHAL map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	13,600-13,700 cfs		
	AREA (m^2)	**PERCENT**	**AVERAGE PERCENT**
EDDY	17,915$^{(5)}$	23	
POOL	8,990$^{(2)}$	12	
RAPID	944$^{(1)}$	1	
RETURN CHANNEL/ BACKWATER	0	-	
RIFFLE	2,479$^{(2)}$	3	
RUN	46,033$^{(2)}$	60	
SLACKWATER			
TOTALS:	**76,361**	**100**	

Table A-10. Surface area (m^2) and percentage of macrohabitats in the WEEP map area with number of habitats shown in parenthetical superscript. Change in surface area and percentage change from the next lower flow are shown in parentheses.

	~10,000 cfs		16,300-16,400 cfs		
	AREA (m^2)	**PERCENT**	**AREA (m^2)**	**PERCENT**	**AVERAGE PERCENT**
EDDY	$19,742^{(4)}$	32	$16,650^{(5)}$	25	
POOL	$16,643^{(2)}$	27	$15,776^{(1)}$	24	
RAPID	$2,703^{(1)}$	4	$4,536^{(1)}$	7	
RETURN CHANNEL/ BACKWATER	$69^{(1)}$	<1	$274^{(1)}$	<1	
RIFFLE	$147^{(2)}$	<1	$251^{(1)}$	<1	
RUN	$23,084^{(2)}$	37	$28,821^{(2)}$	43	
SLACKWATER					
TOTALS:	**62,388**	**100**	**66,308**	**100**	

Table A-11. Catch rate (CPE) of adult, juvenile and YOY humpback chub and rainbow trout by gear in the Colorado River in Grand Canyon, October 1990-November 1991.

	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	154	214	133	332.10	453.71	285.97	7.56 (24)	0	0	0	0	0	0	0	0
GP	259	291	173	546.20	589.85	388.20	20.21 (101)	0.13 (1)	0	0.25 (1)	0	0	0	0	0
GX	112	111	88	234.42	234.09	175.73	18.87 (34)	0	0	2.49 (7)	0	0	0	0	0
GZ	-	25	5	-	49.04	9.52	-	0	0	-	0	0	0	0	0
TK	336	513	447	718.42	1082.93	916.61	22.09 (114)	1.44 (11)	0.46 (3)	1.05 (5)	0.10 (1)	0	0	0	0
TL	429	614	351	921.45	1294.09	769.18	37.12 (252)	1.73 (15)	0.72 (4)	0	0	0	0	0	0
Totals	**1,290**	**1768**	**1197**	**2752.6**	**3703.7**	**2545.2**									
							TRAPS[c]								
HL	4	25	7	37.10	369.74	60.60	5.58 (2)	0	0	0	0	0	0	0	0
HM	1	13	-	14.62	182.47	-	0	0	-	0	0	-	0	0	-
HS	4	40	-	30.78	544.52	-	1.96 (1)	1.15 (1)	-	0	0	-	0	0	-

Table A-11 continued

	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
MT	206	93	22	4398.88	1605.23	340.91	0	0	0	0.10 (3)	0	0	1.17 (33)	1.68 (7)	0
Totals	**215**	**191**	**29**	**4481.4**	**2701.9**	**401.5**									
							ELECTROFISHING[d]								
EL	265	341	156	106.12	109.53	54.93	4.19 (37)	0.83 (2)	0	6.83 (60)	0	0	26.86 (241)	0	0
							SEINES[e]								
				Total Area (m^2)											
SA	5	6	13	-[f]	1161.40	2357.00	0	0	0	0	0	0	0	0	0
SB	1	1	-	120.00	25.00	0.00	0	0	-	0	0	-	0	0	-
TF	3	1	2	-[f]	-[f]	22500	- (4)	0	0	0	0	0	0	0	0
Totals	**9**	**8**	**15**	**120**	**1186.4**	**24857.0**	**(569)**	**(30)**	**(7)**	**(76)**	**(1)**	**(0)**	**(274)**	**(7)**	**(0)**

Table A-11 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 (no. of fish) Rainbow Trout - all ages REACH 1	Catch Per Effort (no. of fish) Rainbow Trout - all ages REACH 2	Catch Per Effort (no. of fish) Rainbow Trout - all ages REACH 3
NETS[b]									
GM	154	214	133	332.10	453.71	285.97	10.02 (24)	0.46 (2)	0
GP	259	291	173	546.20	589.85	388.20	43.38 (231)	6.78 (35)	1.26 (5)
GX	112	111	88	234.42	234.09	175.73	25.78 (48)	7.15 (14)	3.48 (6)
GZ	-	25	5	-	49.04	9.52	-	0	0
TK	336	513	447	718.42	1082.93	916.61	32.58 (154)	12.75 (98)	1.26 (9)
TL	429	614	351	921.45	1294.09	769.18	58.7 (414)	6.96 (61)	2.29 (12)
Totals	**1290**	**1768**	**1197**	**2752.6**	**3703.7**	**2545.2**			
TRAPS[c]									
HL	4	25	7	37.10	369.74	60.60	0	10.14 (26)	0
HM	1	13	-	14.62	182.47	-	0	21.48 (38)	-
HS	4	40	-	30.78	544.52	-	0	17.27 (96)	-

Table A-11 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 (no. of fish) Rainbow Trout - all ages REACH 1	REACH 2	REACH 3
MT	206	93	22	4398.88	1605.23	340.91	0	0	0
Totals	**215**	**171**	**29**	**4481.4**	**2701.9**	**401.5**			
				ELECTROFISHING[d]					
EL	265	341	156	106.12	109.53	54.93	238.08 (1781)	182.38 (1545)	13.05 (69)
				SEINES[e]					
				Total Area (m^2)					
SA	5	6	13	-[f]	1161.40	2357.00	0	20.33 (35)	0.08 (1)
SB	1	1	-	120.00	25.00	0.00	1.67 (2)	0	-
TF	3	1	2	-[f]	-[f]	22500	0 (3)	0	0
Totals	**9**	**8**	**15**	**120**	**1186.4**	**24857.0**	**(2657)**	**(1950)**	**(102)**

[a]see Table 16 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/100 m^2
[f]sample area not available for qualitative seine hauls

Table A-12. Number (percentage) of adults captured in gill and trammel nets by trip in all study reaches of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	BK	BR	CC	CP	FM	FR	FV	HB	RB	SB	WE
90-01	75/80			6 (8.0)		1 (1.3)	8 (10.7)			36 (48.0)	24 (32.0)		
90-02	211/302	4 (1.9)	1 (0.5)	8 (3.8)	7 (3.3)	7 (3.3)	32 (15.2)		1 (0.5)	45 (21.3)	106 (50.2)		
91-01	304/555	5 (1.6)		3 (1.0)	4 (1.3)	7 (2.3)	40 (13.2)			74 (24.3)	171 (56.3)		
91-02	19/3						14 (73.7)			1 (5.3)	4 (21.1)		
91-03	462/698	38 (8.2)		12 (2.6)	3 (0.6)	24 (5.2)	68 (14.7)			126 (27.3)	191 (41.3)		
91-04	37/13	1 (2.7)			4 (10.8)	1 (2.7)	16 (43.2)			6 (16.2)	9 (24.3)		
91-05	498/697	26 (5.2)		12 (2.4)	4 (0.8)	25 (5.0)	207 (41.6)	2 (0.4)	1 (0.2)	29 (5.8)	188 (37.8)	4 (0.8)	
91-06	96/66	2 (2.1)				2 (2.1)	35 (36.5)			31 (32.3)	26 (27.1)		
91-07	382/593	6 (1.6)		5 (1.3)	19 (5.0)	21 (5.5)	94 (24.6)			73 (19.1)	158 (41.4)	5 (1.3)	1 (0.3)
91-09	331/695	10 (3.0)		33 (10.0)	11 (3.3)	38 (11.5)	59 (17.8)		1 (0.3)	87 (26.3)	92 (27.8)		
91-11	239/560	3 (1.3)		10 (4.2)	4 (1.7)	13 (5.4)	47 (19.7)		1 (0.4)	35 (14.6)	126 (52.7)		
Total	**2654/4262**	**95** **(3.6)**	**1** **(<0.1)**	**89** **(3.4)**	**56** **(2.1)**	**139** **(5.2)**	**620** **(23.4)**	**2** **(0.1)**	**4** **(0.2)**	**543** **(20.5)**	**1095** **(41.3)**	**9** **(0.3)**	**1** **(<0.1)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-13. Number (percentage) of adults captured in gill and trammel nets by trip in Reach 1, of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	BK	BR	CC	CP	FM	FR	FV	HB	RB
90-01	75/80			6 (8.0)		1 (1.3)	8 (10.7)			36 (48.0)	24 (32.0)
90-02	134/85	1 (0.7)	1 (0.7)	5 (3.7)		1 (0.7)	12 (9.0)		1 (0.7)	41 (30.6)	72 (53.7)
91-01	212/158	2 (0.9)			1 (0.5)	1 (0.5)	37 (17.5)			69 (32.5)	102 (48.1)
91-02	19/3						14 (73.7)			1 (5.3)	4 (21.1)
91-03	300/163	18 (16.0)		2 (0.7)	1 (0.3)		21 (7.0)			122 (40.7)	136 (45.3)
91-04	37/13	1 (2.7)			4 (10.8)	1 (2.7)	16 (43.2)			6 (16.2)	9 (24.3)
91-05	299/225	8 (2.7)			1 (0.3)	2 (0.7)	99 (33.1)	2 (0.7)	1 (0.3)	24 (8.0)	162 (54.2)
91-06	96/66	2 (2.1)				2 (2.1)	35 (36.5)			31 (32.3)	26 (27.1)
91-07	286/121				1 (0.3)	3 (1.0)	85 (29.7)			63 (22.0)	134 (46.9)
91-09	205/214	4 (2.0)		7 (3.4)		2 (1.0)	31 (15.1)			80 (39.0)	81 (39.5)
91-11	190/161	2 (1.1)			1 (0.5)	2 (1.1)	39 (20.5)			35 (18.4)	111 (58.4)
TOTAL	**1853/1289**	**38 (2.1)**	**1 (0.1)**	**20 (1.1)**	**9 (0.5)**	**15 (0.8)**	**397 (21.4)**	**2 (0.1)**	**2 (0.1)**	**508 (27.4)**	**861 (46.5)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-14. Number (percentage) of adults captured in gill and trammel nets by trip in Reach 2 of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	BR	CC	CP	FM	FR	HB	RB	SB
90-02	55/110	3 (5.5)	3 (5.5)	2 (3.6)		18 (32.7)		1 (1.8)	28 (50.9)	
91-01	70/178	1 (1.4)	3 (4.3)		4 (5.7)	1 (1.4)		4 (5.7)	57 (81.4)	
91-03	110/349	12 (10.9)	10 (9.1)		10 (9.1)	32 (29.1)		1 (0.9)	45 (40.9)	
91-05	173/304	15 (8.7)	12 (6.9)		13 (7.5)	102 (59.0)		5 (2.9)	26 (15.0)	
91-07	56/304	6 (10.7)	5 (8.9)		5 (8.9)	6 (10.7)		10 (17.9)	23 (41.1)	1 (1.8)
91-09	78/245	5 (6.4)	26 (33.3)		17 (21.8)	15 (19.2)		7 (9.0)	8 (10.3)	
91-11	41/279	1 (2.4)	10 (24.4)		6 (14.6)	8 (19.5)	1 (2.4)		15 (36.6)	
TOTAL	**583/1769**	**43** **(7.4)**	**69** **(11.8)**	**2** **(0.3)**	**55** **(9.4)**	**182** **(31.2)**	**1** **(0.2)**	**28** **(4.8)**	**202** **(34.6)**	**1** **(0.2)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-15. Number (percentage) of adults captured in gill and trammel nets by trip in Reach 3 of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	CC	CP	FM	FV	HB	RB	SB	WE
90-02	22/107		5 (22.7)	6 (27.3)	2 (9.1)		3 (13.6)	6 (27.3)		
91-01	22/219	2 (9.1)	3 (13.6)	2 (9.1)	2 (9.1)		1 (4.5)	12 (54.5)		
91-03	52/186	8 (15.4)	2 (3.8)	14 (26.9)	15 (28.8)		3 (5.8)	10 (19.2)		
91-05	26/168	3 (11.5)	3 (11.5)	10 (38.5)	6 (23.1)				4 (15.4)	
91-07	40/168		18 (45.0)	13 (32.5)	3 (7.5)			1 (2.5)	4 (10.0)	1 (2.5)
91-09	48/236	1 (2.1)	11 (22.9)	19 (39.6)	13 (27.1)	1 (2.1)		3 (6.3)		
91-11	8/120		3 (37.5)	5 (62.5)						
TOTAL	**218/1204**	**14** **(6.4)**	**45** **(20.6)**	**69** **(31.7)**	**41** **(18.8)**	**1** **(0.5)**	**7** **(3.2)**	**32** **(14.7)**	**8** **(3.7)**	**1** **(0.5)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes

Table A-16. Number (percentage) of adults captured by electrofishing by trip in all study reaches of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BB[b]	BH	BK	BR	CC	CP	FH	FM	FV	HB	RB	RK	SB	SD
90-01	101/19				2 (2.0)	1 (1.0)	12 (11.9)		3 (3.0)		1 (1.0)	82 (81.2)			
90-02	358/31			1 (0.3)	29 (8.1)		86 (24.0)		2 (0.6)		2 (0.6)	236 (65.9)	1 (0.3)		1 (0.3)
91-01	489/57			1 (0.2)	21 (4.3)		111 (22.7)		1 (0.2)		1 (0.2)	354 (72.4)			
91-03	528/65		2 (0.4)		120 (22.7)	2 (0.4)	134		1 (0.2)			266 (50.4)			3 (0.6)
91-05	755/102		2 (0.3)		161 (21.3)		122 (16.2)	1 (0.1)	13 (1.7)		2 (0.3)	446 (59.1)		1 (0.1)	7 (0.9)
91-06	160/32				1 (0.6)		4 (2.5)	1 (0.6)	2 (1.3)		4 (2.5)	137 (85.6)			11 (6.9)
91-07	898/150		1 (0.1)		59 (6.6)	2 (0.2)	274 (30.5)	2 (0.2)	9 (1.0)		5 (0.6)	527 (58.7)	1 (0.1)	5 (0.6)	13 (1.4)
91-09	910/161		3 (0.3)		78 (8.6)		130 (14.3)	1 (0.1)	16 (1.8)	2 (0.2)	14 (1.5)	622 (68.4)			44 (4.8)
91-11	649/145	1 (0.2)	2 (0.3)		130 (20.0)		135 (20.8)	3 (0.5)	5 (0.8)		10 (1.5)	343 (52.9)			20 (3.1)
TOTAL	**4848/762**	**1 (<0.1)**	**10 (0.2)**	**2 (<0.1)**	**601 (12.4)**	**5 (0.1)**	**1008 (20.8)**	**8 (0.2)**	**52 (1.1)**	**2 (<0.1)**	**39 (0.8)**	**3013 (62.1)**	**2 (<0.1)**	**6 (0.1)**	**99 (2.0)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-17. Number (percentage) of adults captured by electrofishing by trip in Reach 1 of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BB[b]	BH	BR	CC	CP	FH	FM	HB	RB	RK	SD
90-01	101/19			2 (2.0)	1 (1.0)	12 (11.9)		3 (3.0)	1 (1.0)	82 (81.2)		
90-02	99/8			2 (2.0)		11 (11.1)			2 (2.0)	83 (83.8)	1 (1.0)	
91-01	53/6					2 (3.8)		1 (1.9)	1 (1.9)	49 (92.5)		
91-03	9/2			1 (11.1)						8 (88.9)		
91-05	220/32		1 (0.5)	1 (0.5)		4 (1.8)	1 (0.5)	4 (1.8)	1 (0.5)	205 (93.2)		3 (1.4)
91-06	160/32			1 (0.6)		4 (2.5)	1 (0.6)	2 (1.3)	4 (2.5)	137 (85.6)		11 (6.9)
91-07	400/50		1 (0.3)	2 (0.5)		6 (1.5)		5 (1.3)	4 (1.0)	374 (93.5)		8 (2.0)
91-09	465/67			3 (0.6)		7 (1.5)		5 (1.1)	14 (3.0)	428 (92.0)		8 (1.7)
91-11	284/49	1 (0.4)				6 (2.1)	3 (1.1)		10 (3.5)	259 (91.2)		5 (1.8)
TOTAL	**1791/265**	**1 (0.1)**	**2 (0.1)**	**12 (0.7)**	**1 (0.1)**	**52 (2.9)**	**5 (0.3)**	**20 (1.1)**	**37 (2.1)**	**1625 (90.7)**	**1 (0.1)**	**35 (2.0)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-18. Number (percentage) of adults fish captured by electrofishing by trip in Reach 2 of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	BK	BR	CC	CP	FM	FV	HB	RB	SB	SD
90-02	223/17		1	26		50	2			143		1
			(0.4)	(11.7)		(22.4)	(0.9)			(64.1)		(0.4)
91-01	382/37			20		63				299		
				(5.2)		(16.5)				(78.3)		
91-03	483/48			119	2	105				255		2
				(24.6)	(0.4)	(21.7)				(52.8)		(0.4)
91-05	525/63	1		160		113	9		1	240		1
		(0.2)		(30.5)		(21.5)	(1.7)		(0.2)	(45.7)		(0.2)
91-07	293/60			56		87	1			144	1	3
				(19.1)		(29.7)	(0.3)			(49.1)	(0.3)	(1.0)
91-09	349/51	1		73		72	6	1	1	188		8
		(0.3)		(20.9)		(20.6)	(1.7)	(0.3)	(0.3)	(53.9)		(2.3)
91-11	343/65	2		130		113	5			82		11
		(0.6)		(37.9)		(32.9)	(1.5)			(23.9)		(3.2)
TOTAL	**2598/341**	**4**	**1**	**584**	**2**	**603**	**23**	**1**	**2**	**1351**	**1**	**26**
		(0.2)	**(<0.1)**	**(22.5)**	**(0.1)**	**(23.2)**	**(0.9)**	**(<0.1)**	**(0.1)**	**(52.0)**	**(<0.1)**	**(1.0)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-19. Number (percentage) of adults captured by electrofishing by trip in Reach 3 of the Colorado River in Grand Canyon, 1990-1991.

Trip	F/S[a]	BH[b]	BK	BR	CC	CP	FH	FM	FV	RB	RK	SB	SD
90-02	36/6			1 (2.8)		25 (69.4)				10 (27.8)			
91-01	54/14		1 (1.9)	1 (1.9)		46 (85.2)				6 (11.1)			
91-03	36/15	2 (5.6)				29 (80.6)		1 (2.8)		3 (8.3)			1 (2.8)
91-05	10/7					5 (50.0)				1 (10.0)		1 (10.0)	3 (30.0)
91-07	205/40			1 (0.5)	2 (1.0)	181 (88.3)	2 (1.0)	3 (1.5)		9 (4.4)	1 (0.5)	4 (2.0)	2 (1.0)
91-09	96/43	2 (2.1)		2 (2.1)		51 (53.1)	1 (1.0)	5 (5.2)	1 (1.0)	6 (6.3)			28 (29.2)
91-11	22/31					16 (72.7)				2 (9.1)			4 (18.2)
TOTAL	**459/156**	**4** **(0.9)**	**1** **(0.2)**	**5** **(1.1)**	**2** **(0.4)**	**353** **(76.9)**	**3** **(0.7)**	**9** **(2.0)**	**1** **(0.2)**	**37** **(8.1)**	**1** **(0.2)**	**5** **(1.1)**	**38** **(8.3)**

[a]F = total number of fish, S = total number of samples or net sets.
[b]See Table 18 for fish codes.

Table A-20. 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.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	314	339	140	40	398	23	141	131	35	12	209	12
Effort (hrs)	2047.6	1591.9	683.9	73.8	1416.3	47.6	445.9	382.9	521.9	31.2	674.3	31.2
River mile	60.9-61.9	64-65	87.2-88.2	80-81	108-109	111-112	133.2-134.2	126-127	143-144	147-148	156.2-157.2	147-148
Species[a]												
BH	26 (3.7)	4 (1.7)	1 (1.0)		9 (4.2)		1 (1.8)	1 (3.1)	70 (30.3)		31 (17.6)	
BK											1 (0.6)	
BR	6 (0.9)	7 (2.9)	47 (48.0)		7 (3.3)	2 (28.6)		1 (3.1)	2 (0.9)			
CC	7 (1.0)	2 (0.8)							2 (0.9)			
CP	6 (0.9)	4 (1.7)			1 (0.5)	1 (14.3)	2 (3.6)	9 (28.1)	22 (9.5)		4 (2.3)	
FH									1 (0.4)			
FM	254 (36.4)	15 (6.3)	26 (26.5)		14 (6.6)	1 (14.3)	1 (1.8)	3 (9.4)	120 (51.9)		120 (68.2)	
FR	1 (0.1)											
FV	2 (0.3)										1 (0.6)	

Table A-20 continued

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	314	339	140	40	398	23	141	131	35	12	209	12
Effort (hrs)	2047.6	1591.9	683.9	73.8	1416.3	47.6	445.9	382.9	521.9	31.2	674.3	31.2
River mile	60.9-61.9	64-65	87.2-88.2	80-81	108-109	111-112	133.2-134.2	126-127	143-144	147-148	156.2-157.2	147-148
Species[a]												
HB	198 (28.4)	108 (45.0)	1 (1.0)		22 (10.3)			9 (28.1)			2 (1.1)	
RB	153 (21.9)	99 (41.3)	23 (23.5)	3 (100)	153 (71.8)	3 (42.9)	52 (92.9)	9 (28.1)	9 (3.9)		15 (8.5)	
SB											1 (0.6)	
SD	45 (6.4)	1 (0.4)			7 (3.3)				5 (2.2)		1 (0.6)	
TOTAL	698	240	98	3	213	7	56	32	231	0	176	0

[a]See Table 18 for species codes

Table A-21. 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.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	40	45	30	14	44	3	12	25	20	3	12	3
Effort (hrs)	12.2	40.5	6.3	5.0	13.3	1.8	4.9	9.3	7.5	0.5	2.8	0.5
River mile	60.9-61.9	64-65	87.2-88.2	80-81	108-109	111-112	133.2-134.2	126-127	143-144	147-148	156.2-157.2	147-148
Species[a]												
BB	1 (0.3)											
BH	1 (0.3)	3 (0.9)	1 (0.2)		1 (0.2)		1 (1.0)	2 (1.4)				
BK											1 (3.3)	
BR	1 (0.3)	2 (0.6)	357 (69.5)	6 (6.5)	34 (7.6)	3 (30.0)	5 (5.2)	11 (7.5)			1 (3.3)	
CC		1 (0.3)			2 (0.4)							
CP	10 (3.5)	21 (6.4)	2 (0.4)		59 (0.4)	1 (10.0)	21 (21.6)	53 (36.1)	72 (62.1)	2 (66.7)	6 (20.0)	2 (66.7)
FH		1 (0.3)										
FM	7 (1.0)	6 (1.8)	8 (1.6)	1 (1.1)	8 (1.8)			1 (0.7)	6 (5.2)		8 (26.7)	
FV									1 (0.9)			

Table A-21 continued

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	40	45	30	14	44	3	12	25	20	3	12	3
Effort (hrs)	12.2	40.5	6.3	5.0	13.3	1.8	4.9	9.3	7.5	0.5	2.8	0.5
River mile	60.9-61.9	64-65	87.2-88.2	80-81	108-109	111-112	133.2-134.2	126-127	143-144	147-148	156.2-157.2	147-148
Species[a]												
HB	27 (9.4)	116 (35.5)			1 (0.2)							
RB	213 (74.5)	172 (52.6)	141 (27.4)	86 (92.5)	343 (76.2)	6 (60.0)	70 (72.2)	79 (53.7)	29 (25.0)	1 (33.3)	14 (46.7)	1 (33.3)
RK		1 (0.3)										
SD	23 (8.0)	4 (1.2)	5 (1.0)		2 (0.4)			1 (0.7)	8 (6.9)			
TOTAL	286	327	514	93	450	10	97	147	116	3	30	3

[a]See Table 18 for species codes

Table A-22. 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	7F7F3F5050	670/60	901017	910308	143	60.40	61.35	2.75	-0.95	28	yes
2	7F7F3E2D2D	640/59	901017	910216	123	60.40	60.80	2.00	-0.40	10	yes
3	7F7F3F3626	620/78	901017	910109	85	60.40	60.90	1.70	-0.50	11	no
4	7F7F3E2253	650/81	901017	901021	5	60.40	60.40	0.00	0.00	2[b]	no
5	7F7F3F4054	630/39	911018	901214	58	60.40	60.60	0.20	-0.20	3	no
6	7F7F3F5044	680/77	901018	910213	119	60.60	59.80	0.90	+0.80	8	no
7	7F7F3F4E11	690/40	901019	901117	30	64.60	64.60	0.60	0.00	6	no
8	7F7F3E2F3A[c]	660/39	901020	901215	57	64.60	64.70	0.70	-0.10	6	no
9	7F7F456B2C	610/58	901020	900117	90	64.60	64.65	0.55	-0.05	13	no
10	7F7F3C311C	600/40	901020	901217	59	64.60	64.80	3.00	-0.20	15	no
11	7F7F3C4452	600/62	901116	910411	147	60.40	61.40	4.75	-1.00	29	yes
12	7F7F3C303B	700/62	901116	910311	116	60.10	61.30	2.20	-1.20	13	yes
13	7F7F3F4E77	710/79	901117	910414	149	61.00	60.80	5.55	+0.20	35	yes
14	7F7F3E3C5C	730/61	901118	910310	113	61.10	61.30	0.90	-0.20	9	yes
15	NO PITTAG	740/79	901119	910115	58	62.00	62.20	0.20	-0.20	10	no
16	7F7F3C2919	640/78	901121	910115	56	64.10	64.50	2.20	-0.40	11	no
17	7F7F3C4162	630/62	901123	910314	113	64.40	63.90	5.10	+0.50	26	no
18	7F7F3C4208	660/64	910108	910416	99	58.80	60.60	1.60	-1.80	16	no
19	7F7F3E3030	680/44	910109	910318	119	58.30	0.30LC	4.55	-3.35	18	yes

Table A-22 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
20	7F7F3C3171	730/86	910109	910311	62	59.00	60.80	3.20	-1.80	14	yes
21	7F7F4F3A5C	710/41	910109	910417	99	59.00	61.50	4.60	-2.50	45	yes
22	7F7F3C2D06	740/42	910110	910416	97	60.50	0.30LC	2.65	-1.15	26	yes
23	7F7F3E3D23	670/84	910110	910417	97	60.50	61.50	5.30	-1.00	25	yes
24	7F7F3E2727	720/66	910110	910314	64	60.60	0.00LC	1.35	-0.75	23	yes
25	7F7F3E362E	640/42	910304	910417	44	57.00	57.25	0.25	-0.25	5	no
26	7F7F3E2661	670/39	910307	910415	39	58.80	61.50	3.20	-2.70	14	yes
27	7F7F3F4453	600/40	910309	910416	38	61.30	61.35	1.45	-0.05	8	yes
28	7F7F3C243E	620/64	910311	910814	146	61.25	58.35	4.16	+2.90	33	no
29	7F7F3F520D	630/86	910311	910613	94	61.30	0.70LC	2.85	-0.75	22	yes
30	7F7F3E3B00	680/66	910311	910520	70	61.20	0.10LC	1.60	-0.25	20	yes
31	7F7F3E372A	600/85	910311	910517	67	61.40	0.60LC	1.85	+0.65	18	yes
32	7F7F3C6F15	700/42	910518	910916	121	61.40	64.65	5.75	-3.25	29	yes
33	7F7D076050	650/40	910513	910914	124	60.50	60.40	1.85	+0.10	37	no
34	7F7D026506	730/41	910519	911113	178	61.80	60.50	5.65	+0.90	26	yes
35	7F7D075B05	610/82	910612	910916	96	60.20	60.80	2.20	-0.60	23	yes
36	7F7F04461F	640/60	910612	910914	94	60.20	60.00	2.75	-0.20	36	yes
37	7F7D086032	650/60	910613	910914	93	61.10	60.15	3.20	+0.95	18	no

Table A-22 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
38	7F7D07776A	740/59	910614	910916	94	61.40	60.40	3.20	+1.00	18	yes
39	7F7F3E276F	620/80	910713	910913	62	58.40	58.30	10.15	+0.10	21	yes
40	7F7D084C05	630/38	910715	911111	119	59.90	59.85	2.15	+0.05	23	no
41	7F7D08545E	610/59	910715	911109	117	60.30	60.15	4.65	+0.15	24	no
42	7F7F3F4E45	720/80	910716	910916	62	60.90	60.80	4.00	+0.10	22	yes
43	7F7D081904	700/87	910908	911113	65	58.30	61.75	3.65	-3.45	22	yes
44	7F7D08552A	660/87	910908	911110	63	58.30	58.90	0.60	-0.60	7	no
45	7F7D09067B	670/61	910910	910916	6	60.10	60.80	3.40	-0.70	9	no
46	7F7F3F3764	600/60	910914	911115	62	64.70	64.60	0.15	+0.10	9	no
47	7F7F3E3149	710/80	910915	911113	59	64.40	63.85	0.65	-0.55	7	no
48	7F7F3E3542	680/78	910915	911115	61	64.40	64.40	0.20	0.00	6	no
			Mean		86			2.63	0..83	18	
			Standard Deviation		38			2.02	-	10	
			Minimum		5			0.00	0	2	
			Maximum		178			10.15	3.45	45	

[a]0.30LC = 0.30 km upstream into LCR.
bFish not positively located; two "probable" signals contacts received.
[c]Recaptured at RM 127.0 on 910718.

Table A-23. Proportion of radiotagged adult humpback chub from implant groups classified as migratory and non-migratory.

Implant Groups	No. Implanted	Number (Percent)	
		Migratory	Non-migratory
	1990		
October	10	2(20)	8(80)
November	7	4(57)	3(43)
	1991		
January	7	6(86)	1(14)
March	7	5(71)	2(29)
May	3	2(67)	1(33)
June	4	3(75)	1(25)
July	4	2(50)	2(50)
September	6	0(0)	6(100)
Totals:	48	24(50)	24(50)

Table A-24. Elapsed time and distance displaced for 61 juvenile and adult humpback chub PIT-tagged and recaptured by BIO/WEST, October 1990 - November 1991.

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
1	7F7F3F441C	901017	910715	271	60.40	60.50	-0.10
2	7F7F3F3626	901017	910112	56	60.40	61.40	-1.00
3	7F7F3F452E	901018	910614	239	61.20	61.50	-0.30
4	7F7F3C4554	901018	910308	141	61.20	60.20	+1.00
5	7F7F3E2F3A	901020	910708	261	65.50	127.0	-61.50
6	7F7F456B2C	901020	910116	88	65.50	64.70	+0.80
7	7F7F3E4105	901116	901119	3	61.20	61.50	-0.30
8	7F7F3E3310	901117	910613	208	61.20	60.90	+0.30
9	7F7F3F4E77	901117	910311	114	61.00	61.20	-0.20
10	7F7F3C277A	901118	910911	297	61.20	60.75	+0.45
	"	901118	911110	357	61.20	60.90	+0.30
11	7F7F3E3C5C	901118	911110	357	61.10	60.90	+0.20
12	7F7F3C4477	901121	901124	3	64.20	65.50	-1.30
13	7F7F3C4162	901123	910114	52	64.40	64.10	+0.30
14	7F7F3E3212	901130	901201	2	212.80	212.80	0
	"	901130	901201	2	212.80	212.50	+0.30
	"	901130	910320	110	212.80	213.60	-0.80
15	7F7F3F4B6C	901201	910320	109	212.80	213.60	-.80
16	7F7F3C3457	910108	910908	243	58.30	58.80	-0.50
17	7F7F3F427E	910108	910908	242	58.80	58.80	0
18	7F7F3E2640	910108	910713	186	58.30	58.30	0
19	7F7F3E3E15	910109	910306	56	58.90	57.05	+1.85
20	7F7F3E3675	910109	910306	56	58.90	58.80	+0.10
21	7F7F3F3D79	910109	910908	242	58.90	58.80	+0.10
22	7F7F3C3B2D	910111	910912	244	60.00	61.05	-1.05
23	7F7F3F5144	910112	910113	1	108.30	108.30	0
	"	910112	910307	54	108.30	108.30	0
24	7F7F3C4111	910112	910113	1	108.30	108.30	0

Table A-24 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
25	7F7F3C2E7A	910112	910311	58	60.50	61.20	-0.70
	"	910112	910311	58	60.50	61.20	-0.70
26	7F7F3C4279	910114	910214	31	64.60	61.40	+3.20
27	7F7F3E2865	910115	910117	2	64.40	64.40	0
28	7F7F3E2F26	910116	910715	241	61.20	60.35	+0.85
29	7F7F3F3C2F	910116	910914	241	64.80	64.65	-0.15
30	7F7F3F4146	910116	910916	243	65.30	65.25	+0.05
31	7F7F3F4D30	910308	910309	1	60.20	60.90	-0.70
32	7F7F3E2913	910308	910309	1	61.40	61.40	0
33	7F7F3F5108	910308	910308	0	61.50	61.50	0
34	7F7F3E2B48	910309	910311	2	61.90	61.50	+0.40
35	7F7F3F4F0A	910310	910310	0	61.15	61.15	0
	"	910310	910911	185	61.15	60.35	+0.80
36	7F7F3F4942	910311	910311	0	61.50	61.50	0
37	7F7F3F520D	910311	910515	65	61.20	60.95	+0.25
38	7F7F3C243E	910311	910612	93	61.20	60.90	+0.30
39	7F7F3E3A28	910311	910311	0	61.30	61.50	-0.20
40	7F7F431A46	910312	910312	0	64.45	64.45	0
41	7F7F3E3C5F	910312	910914	186	64.80	64.65	+0.15
42	7F7F3F4F13	910314	910314	0	62.50	62.50	0
43	7F7D085054	910417	910717	91	61.35	60.90	+0.45
44	7F7D085054	910417	910716	90	61.35	60.80	+0.55
45	7F7DO25F6F	910512	910908	90	58.80	58.85	-0.05
46	7F7D085E2B	910517	910911	117	61.50	60.75	+0.75
47	7F7F3C6F15	910518	910914	119	61.50	64.65	-3.15
48	7F7D075B05	910612	911110	152	60.20	60.80	-0.60
49	7F7D08030B	910613	911109	149	60.90	60.15	+0.75
50	7F7F3F4E5B	910712	910712	0	57.00	57.00	0

Table A-24 continued

Fish No.	PIT tag No.	Capture Date (ymd)	Recapture Date (ymd)	Elapsed Time (days)	Capture Location (RM)	Recapture Location (RM)	Distance (miles)
51	7F7F3E3D45	910717	910912	57	61.35	61.15	+0.20
52	7F7D081904	910908	910908	0	58.35	58.30	+0.05
53	7F7D027E29	910911	911110	60	60.75	60.90	-0.15
54	7F7D17336C	910913	910913	0	62.00	62.00	0
55	7F7D07124A	910913	910914	1	62.10	65.70	-3.60
56	7F7F3F3764	910914	911112	59	64.70	64.80	-0.10
57	7F7F3F3A24	910915	910915	0	63.20	63.20	0
58	7F7F3E3542	910915	911113	59	64.35	65.25	-0.90
59	7F7D07604C	910916	911112	57	63.90	65.40	-1.50
60	7F7E43193F	911112	911115	3	63.80	68.00	-4.20
61	7F7F456D7D	910614	911110	149	61.50	61.75	-.02
	Average			99.3			1.48
	Minimum			0			0
	Maximum			357			61.5

Table A-25. 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 8-11 (August - November, 1991). APRC = Average percentage of radio-contacts.

Trip 8 August 1991	Low Turbidity				High Turbidity			
	D (E=0)		N (E=0)		D (E=295)		N (E=221)	
	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E
40.610/82	-	-	-	-	109	36.9	140	63.3
40.620/80	-	-	-	-	21	7.1	31	14.0
40.630/38	-	-	-	-	19	6.4	27	12.2
40.630/62	-	-	-	-	-	-	-	-
40.640/60	-	-	-	-	96	2.5	93	42.1
40.650/40	-	-	-	-	280	94.9	220	99.5
40.650/60	-	-	-	-	1	0.3	39	17.6
40.660/87	-	-	-	-	-	-	-	-
40.670/61	-	-	-	-	-	-	-	-
40.700/87	-	-	-	-	-	-	-	-
40.720/80	-	-	-	-	16	5.4	14	6.3
40.730/41	-	-	-	-	18	6.1	19	8.6
40.610/59	-	-	-	-	7	2.4	10	4.5
APRC						21.3		29.8
Trip 9 September 1991	D (E=200)		N (E=188)		D (E=409)		N (E=387)	
	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E
40.610/82	14	7.0	155	82.4	157	38.4	188	48.6
40.620/80	0	-	0	-	63	15.4	36	9.3
40.630/38	0	-	0	-	141	34.5	59	15.2
40.630/62	0	-	0	-	0	-	0	-
40.640/60	0	-	0	-	115	28.1	62	16.0
40.650/40	43	21.5	149	79.3	380	92.9	369	92.7
40.650/60	1	0.5	82	43.6	25	6.1	65	16.9
40.660/87	0	-	0	-	6	1.5	4	1.0

Table A-25 continued

40.670/61	153	76.5	143	76.1	64	15.6	37	10.0
40.700/87	28	14.0	54	28.7	0	-	0	-
40.720/80	17	8.5	101	53.7	150	36.7	131	33.9
40.730/41	0	-	1	0.5	42	10.3	23	5.9
40.610/59	1	0.5	43	22.9	9	2.2	18	4.7
APRC		14.3		48.4		25.6		23.3
Trip 10 October 1991	D (E=308)		N (E=364)		D (E=0)		N (E=0)	
	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E
40.610/82	-	-	-	-	-	-	-	-
40.620/80	2	0.6	1	0.3	-	-	-	-
40.630/38	0	-	2	0.5	-	-	-	-
40.630/62	-	-	-	-	-	-	-	-
40.640/60	1	0.6	0	-	-	-	-	-
40.650/40	-	-	-	-	-	-	-	-
40.650/60	-	-	-	-	-	-	-	-
40.660/87	2	0.6	00	-	-	-	-	-
40.670/61	-	-	-	-	-	-	-	-
40.700/87	233	75.6	351	96.5	-	-	-	-
40.720/80	3	1.0	0	-	-	-	-	-
40.730/41	-	-	-	-	-	-	-	-
40.610/59	2	0.6	54	15.4	-	-	-	-
APRC		13.1		28.0		-		-
Trip 11 November 1991	D (E=308)		N (E=364)		D (E=0)		N (E=0)	
	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E	no. contacts	O/E
40.610/82	-	-	-	-	-	-	-	-
40.620/80	6	2.1	1	0.3	-	-	-	-
40.630/38	11	3.9	0	-	-	-	-	-
40.630/62	7	2.4	93	24.2	-	-	-	-

Table A-25 continued

40.640/60	-	-	-	-	-	-	-	-
40.650/40	-	-	-	-	-	-	-	-
40.650/60	-	-	-	-	-	-	-	-
40.660/87	2	0.7	1	3.3	-	-	-	-
40.670/61	-	-	-	-	-	-	-	-
40.700/87	9	3.1	0	-	-	-	-	-
40.720/80	4	1.5	0	-	-	-	-	-
40.730/41	1	0.4	112	29.1	-	-	-	-
40.610/59	5	1.7	25	7.5	-	-	-	-
APRC		1.8		12.7				

Table A-26. Local movement of three radiotagged adult humpback chub during a hydrological sequence including descending limb, low flow and ascending limb of the Colorado River, Grand Canyon, 1990-1991.

Time of Day	RM 60.4, 910818 PIT tag No. 7F7D076050		RM 59.9, 910818 PIT tag No. 7F7D084C05		RM 60.1, 910817 PIT tag No. 7F7F04461F	
	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)
1130				40		
1200		30		35		
1230		25	90	31		
1300						
1330	7	20		25		40
1400	50	15		23	5	35
1430		14		20		
1500	7	7			5	30
1530				15		
1600	7	3		11	2	25
1630	4	-3			5	16
1700				8		12
1730	4	-5				8
1800				8		6
1830	5	-8	75	3		
1900		-9				4
1930						
2000						3
2030			24	-4		3
2100	12	-15				
2130				-4		
2200		-15	3	-3		8
2230		-15			10	27
2300		-14	5	-3		
2330		-14				

Table A-26 continued

Time of Day	RM 60.4, 910818 PIT tag No. 7F7D076050 Movement[a] (m)	Stage (cm)	RM 59.9, 910818 PIT tag No. 7F7D084C05 Movement[a] (m)	Stage (cm)	RM 60.1, 910817 PIT tag No. 7F7F04461F Movement[a] (m)	Stage (cm)
2400						
0030		-13				
0100		-11	5	-1		
0130						
0200			5	4		78
0230						
0300		-1		7		
0330		3		10		
0400		5		12		
0430		11		14		
0500				16		
0530		12				
0600		16		18		
0630	10	18	70	22		
0700	10	20	10			
0730		21	15			
0800	3	23	3	25		
0830		23	3			

[a]Movement greater than 50 m shown as 50 m on graph

Table A-27. Local movement of two radiotagged adult humpback chub during a hydrological sequence including a descending limb, low flow and ascending limb to a peak flow of the Colorado River, Grand Canyon, 1990-1991.

Time of Day	RM 64.7, 910816 PIT tag No. 7F7F3C6F15		RM 64.6, 910915 PIT tag No. 7F7F3C6F15		RM 60.7, 910815 PIT tag No. 7F7F3F4E45	
	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)
1400				64		
1430		33.5				
1500				59		
1530	2	31		54		16
1600	2	27.5				14.5
1630		26				10.5
1700	5	22	50	47	7	7
1730	3	20	20	40	5	5
1800						3
1830	2	15				
1900					3	2.5
1930		13		28		1.5
2000		13		20		1.5
2030						4
2100	75	13		18		
2130					5	8
2200		17		14		14
2230		21		12		
2300				12		27
2330			10		3	40
2400	75	38				
0030						51
0100	40	55	10	14		59
0130				17		
0200			5	20	2	64

Table A-27 continued

Time of Day	RM 64.7, 910816 PIT tag No. 7F7F3C6F15		RM 64.6, 910915 PIT tag No. 7F7F3C6F15		RM 60.7, 910815 PIT tag No. 7F7F3F4E45	
	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)
0230	10	70	20	23		65
0300				26		
0330				27		71
0400				28		71
0430						71
0500	5	78		29		
0530				30		72
0600				31		
0630		82		31		71
0700						
0730		80				
0800				31		

[a]Movement greater than 50 m shown as 50 m on graph

Table A-28. Local movement of three radiotagged adult humpback chub during a hydrological sequence including an ascending limb and peak flow of the Colorado River, Grand Canyon, 1990-1991.

Time of Day	RM 60.6, 910614 PIT tag No. 7F7D076050		RM 61.5, 910910 PIT tag No. 7F7D026506		RM 60.1, 910912 PIT tag No. 7F7D075B05	
	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)
1930				29		
2000				29		32
2030			5	29		32
2100		0	1	32		35
2130				35		40
2200						43
2230	5	7		44		53
2300		17		51		59
2330	5	51	5	58		67
2400		73	2	65		79
0030				73		
0100				80		97
0130	40	191				
0200						114
0230	100		100	92		
0300			50	96		122
0330				98		126
0400			10	100		128
0430		218	1	101		129
0500		226	12			130
0530				101		132
0600		221	5	101	20	130
0630		218		100		129
0700				99		129
0730		211				129

Table A-28 continued

Time of Day	RM 60.6, 910614 PIT tag No. 7F7D076050		RM 61.5, 910910 PIT tag No. 7F7D026506		RM 60.1, 910912 PIT tag No. 7F7D075B05	
	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)	Movement[a] (m)	Stage (cm)
0800						127
0830						121
0900						
0930						
1000					40	108
1030						
1100						99
1130						
1200		193			25	88
1230						84
1300		181				
1330						77
1400		151				69
1430	9	143				
1500	9	137				59
1530		126				53
1600		120				
1630	55	113				46
1700	15	104				43
1730	50	96				40
1800		89				37
1830		84				
1900		78				
1930						
2000						

Table A-28 continued

Time of Day	RM 60.6, 910614 PIT tag No. 7F7D076050 Movement[a] (m)	Stage (cm)	RM 61.5, 910910 PIT tag No. 7F7D026506 Movement[a] (m)	Stage (cm)	RM 60.1, 910912 PIT tag No. 7F7D075B05 Movement[a] (m)	Stage (cm)
2030						
2100		54				
2130		52				
2200		50				
2230						
2300		48				
2330						
2400						

[a]Movement greater than 50 m shown as 50 m on graph

Table A-29. Radiotagged adult humpback chub contacted by the KLCR remote telemetry station in 1990 and 1991 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	7F7F3C4452	600/62	901116	910216	910226	910411	7	-	-
2	7F7F3E372A	600/85	910311	910312	910223	910518	11	910323	-
3	7F7F3F4453	600/40	910308	910302	910501	910416	16	-	-
4	7F7D075B05	610/82	910612	9106612	910724	910916	5	910613	910724
5	7F7F3F3626	620/78	901017	910214	910227	910109	14	-	-
6	7F7F3C243E	620/64	910311	910303	910615	910814	23	-	-
7	7F7F3E276F	620/80	910713	910726	910726	910913	1	-	910726
8	7F7F3F520D	630/86	910311	910313	910516	910613	28	910314	-
	"	"	"	"	"	"	"	910416	910419
	"	"	"	"	"	"	"	910516	-
9	7F7D084C05	630/38	910715	9107/0	910805	911111	5	-	-
10	7F7F3E2D2D	640/60	901017	901217	910228	910216	13	-	-
11	7F7F04461F	640/60	910612	910616	910727	910914	3	910616	910726
12	7F7D086032	650/60	910613	910614	910802	910914	6	-	-
13	7F7F3F5050	670/60	901017	910218	910218	910308	1	-	910218
14	7F7F3E2D23	670/80	910110	910312	910424	910417	15	910311-910313	-
15	7F7F3E2661	670/39	910307	910318	910423	910415	18	-	-

Table A-29 continued

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)
16	7F7F3E3030	680/44	910109	910214	910228	910518	25	910310-910314	-
17	7F7F3E3B00	680/66	910311	910312	910813	910520	39	-	-
18	7F7F3C303B	700/62	901116	910216	910314	910311	10	-	-
19	7F7F3F3A5C	710/41	910109	910219	910524	910417	28	910311-910313	-
20	7F7F3F4E77	710/79	901117	910318	910323	910414	5	-	-
21	7F7F3E2727	720/66	910110	910213	910519	910314	30	910310-910313	-
22	7F7F3F4E45	720/80	910716	910723	910814	910916	10	-	-
23	7F7F3C3171	730/86	910109	910213	910324	910311	13	-	-
24	7F7F3E3C5C	730/61	901118	910215	910324	910310	25	-	-
25	7F7D026506	730/40	910519	910519	910801	911113	11	-	-
26	7F7F3C2D06	740/42	910110	910213	910524	910416	29	910213	-
	"	"	"	"	"	"	"	910314	-
	"	"	"	"	"	"	"	910417	-
27	7F7D07776A	740/59	910614	910615	910616	910916	2	910616	-

Table A-30. Ecological factors for four life phases of humpback chub.

SPAWNING/EGG INCUBATION

A. Spawning Times

1. April-May, 1981 - Little Colorado River (Kaeding and Zimmerman 1983).
2. June 2-15, 1980; May 15-25, 1981 - Black Rocks (Valdez and Clemmer 1982).
3. June 20-July 30, 1983 and 1984 - Black Rocks (Kaeding et al. 1990).
4. Mid-May to late-June, 1987-1989 - Yampa Canyon (Karp and Tyus 1990).
5. June-July - LCR (Suttkus and Clemmer 1977).

B. Flow

1. 21,500-26,00 cfs; 3,000-5,000 cfs - Black Rocks (Valdez and Clemmer 1982).
2. 17,000-3,000 cfs; 12,000-3,000 Yampa Canyon cfs Black Rocks (Kaeding et al. 1990).
3. 220-30 m^3/s. Yampa Canyon (Karp and Tyus 1990).

C. Water Temperature

1. 18-22°C - Little Colorado River (Kaeding and Zimmerman 1983).
2. 11.5-16.0°C; 16.0-16.5°C - Black Rocks (Valdez and Clemmer 1982).
3. 14-24°C - Black Rocks (Kaeding et al. 1990).
4. 14.5-23°C - Yampa Canyon (Karp and Tyus 1990).
5. 19-20°C = optimum egg incubation (84%) (Hamman 1982) 21-22°C (79%); 16-17°C (62%), 12-13°C (12%).
6. Eggs in 12-13°C failed to develop (Hamman 1982).
7. 5°C (0%), 10°C (30%-19d), 14°C (50%-16d), 20°C (100%-4d), 26°C (90%-3d) (Bulkley et al. 1982).
8. Total embyo mortality at 5, 10, and 30°C (Marsh 1985).
9. 20°C (60%), 15°C (0.8%), 25°C (2%).

D. Habitat

1. Spawn in small gravel pockets behind loose boulders - average depth = 0.20 m, average velocity = 0.10 m/s, substrate size = 2.10 cm (pea-size gravel) (Valdez et al. 1992).

E. Fecundity/Egg Diameter

1. 2.2-2.9 mm; 100, 4850,4000,4200,5760,250/fish (Hamman 1982).
2. 2.5-3.0 mm; 48/ml; 4000, 4000, 10000 - Black Rocks (Valdez and Valdes - Gonzales 1991).

LARVAE/AGE-0

A. Temperature Tolerance

1. Mortality at changes of 6°C from 10 to 4°C (USFWS 1979).
2. Total embyo mortality at 5, 10, and 30° C (Marsh 1985).

B. Habitat

1. Small quiet pockets along steep rock walls (Valdez and Clemmer 1982).
2. Backwaters and runs with firm silt (Holden 1978).

Table A-30 continued

3. Larvae; 0.4 m, 0.03 m/s; Age-0; 0.6 m; 0.06 m/s (Valdez et al. 1990)
4. 24 cm depth, 0.34 fps - Colorado River, GC (Maddux et al. 1986).

C. **Food Habits**

***

D. **Size at Hatching**

1. 6-7 mm (Hamman 1982)
2. 6.5-7.5 mm - hatched from Black Rocks eggs (Hamman 1982).

E. **Growth Rates**

1. LCR (kaeding and Zimmerman 1983).
2. Dexter NFH (Hamman 1982).
3. Cataract Canyon (Valdez 1990).

JUVENILE (1 Year to maturity)

A. **Temperature Tolerance**

1. 24°C = final preferendum (Bulkley et al. 1982).
2. TDS preference = 1.3-3.0 mmhos (1.0-3.5 mg/l); TDS avoidance = >8.5 mmhos.

B. **Habitat**

1. Backwaters and runs with firm silt, 0.6 m, 0 - 0.15 mps (Holden 1978).
2. 0.7 m, 0.18 m/s (Green R.); 3.4 m, 0.18 m/s (Colorado/Yamps)(Valdez et al. 1990).
3. SA/SI, BO/BE, 0.4 - 10.7 m, 0.06 - 0.60 m/s, small eddies and pools (Valdez and Clemmer 1982).

C. **Swimming Ability**

1. Sustained speed 0.66 m/s; 2 h at 0.32 m/s, minutes at 0.78 m/s (Bulkley et al. 1982).

D. **Growth Rates**

1. Attain 250 - 300 mm at 3 years - LCR (Kaeding and Zimmerman 1983).

E. **Food Habitats**

***

F. **Parasites**

1. <u>Lernaea cyprinaces</u>[a] in 17% of 36 - (Valdez and Clemmer 1982).

G. **Associated Species**

1. CC, CP, RS, FH, SS, BH, FM, RT, CS (Valdez and Clemmer 1982).
2. FH, SD, CC, RB, CP, FM, BH, PK (Maddux et al. 1986).

Table A-30 continued

ADULT

A. Temperature Tolerance

***

B. Habitat

1. Eddies, deep runs, 0.7 - 12.2 m (x=4.3), 0.03 - 1.16 m/s (x=0.18) (Valdez and Clemmer 1982).
2. Eddies 0.8-12.2 m (x=3.1 m), 0-1.19 m/s (x=0.18) (Valdez et al. 1990).
3. Large shoreline eddies, 1.3 m deep, SA/BO - Yampa (Karp and Tyus 1990).

C. Growth Rates

1. Grand Canyon (Maddux et al. 1986).
2. Cataract Canyon (Valdez 1990).

D. Swimming Ability

***

E. Food Habitats

1. Immature chironomidae and simuliidae (Kaeding and Zimmerman 1983).

F. Parasites

1. Systemic Aeromonas hydroshila, Lernaea cyprinacea - LCR (Kaeding and Zimmerman 1983).
2. Lernaea cyprinacea on 31% of 182 - Black Rocks, Westwater (Valdez et al. 1982).
3. Bothriocephalus acheilognathi - LCR (J. Landye, pers. comm., Nov 1991).

G. Size Range

1. 250 - 300 mm TL at maturity, smallest male 205 mm - LCR (Kaeding and Zimmerman 1983).
2. 232 mm TL smallest male - Yampa Canyon (Karp and Tyus 1990).
3. 180 mm TL smallest male - Cataract Canyon (Valdez 1990).

H. Associated Species

1. CC, CP, RT, BH, FM, CS, (Valdez and Clemmer 1982)
2. RS, SS, CC, CP, CS, RT, BH, FM in eddies - Cataract (Valdez 1990).
3. CC, FM, BH, SD, CP, RB, - Grand Canyon (Maddux 1986).

*** = no information available

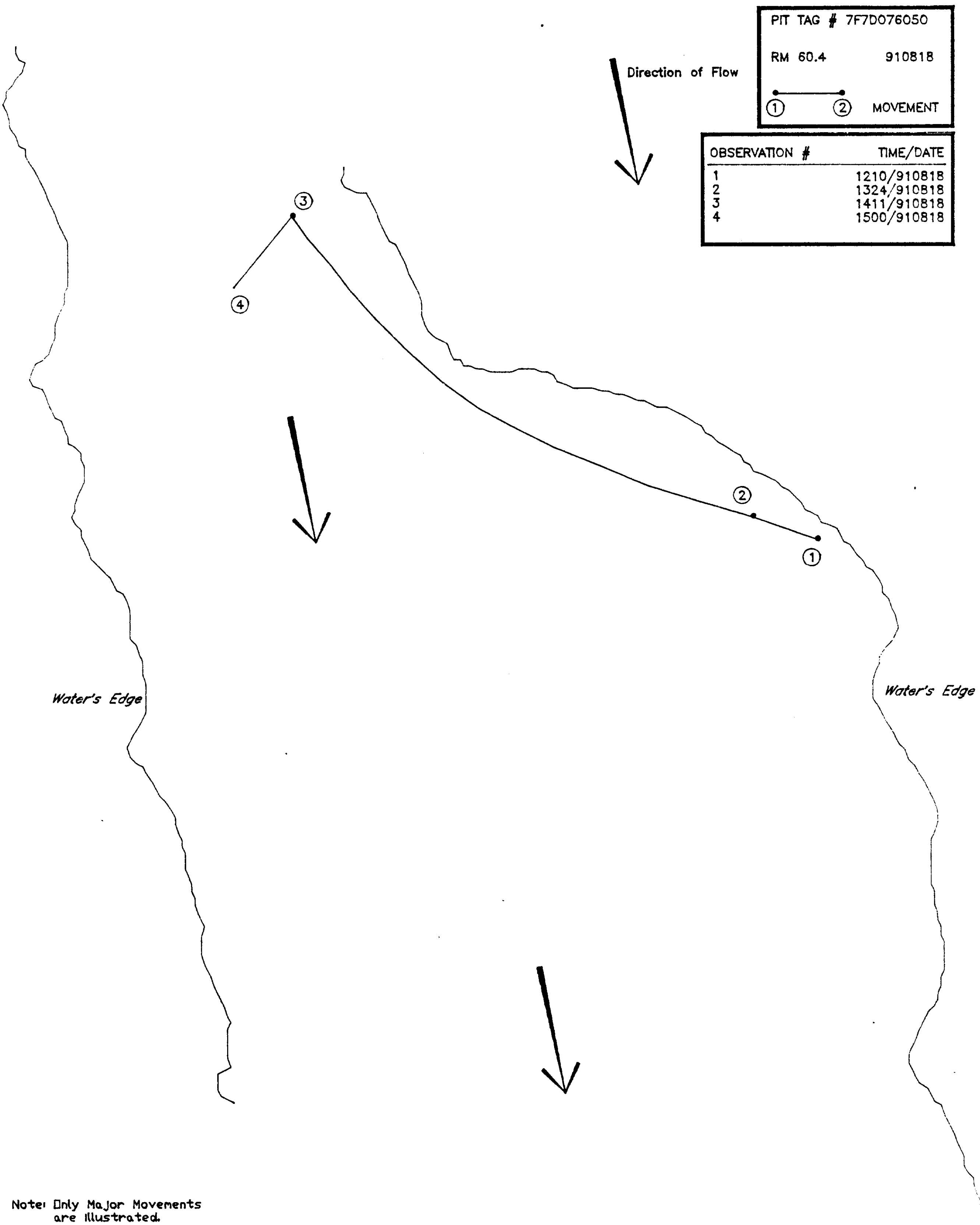

Figure A-1. Local movement of radiotagged humpback chub, PIT tag #7F7D076050 during a hydrological sequence including a descending limb, low flow and ascending limb. Corresponding distance moved and stage data are presented in Table A-26 and Figure 32.

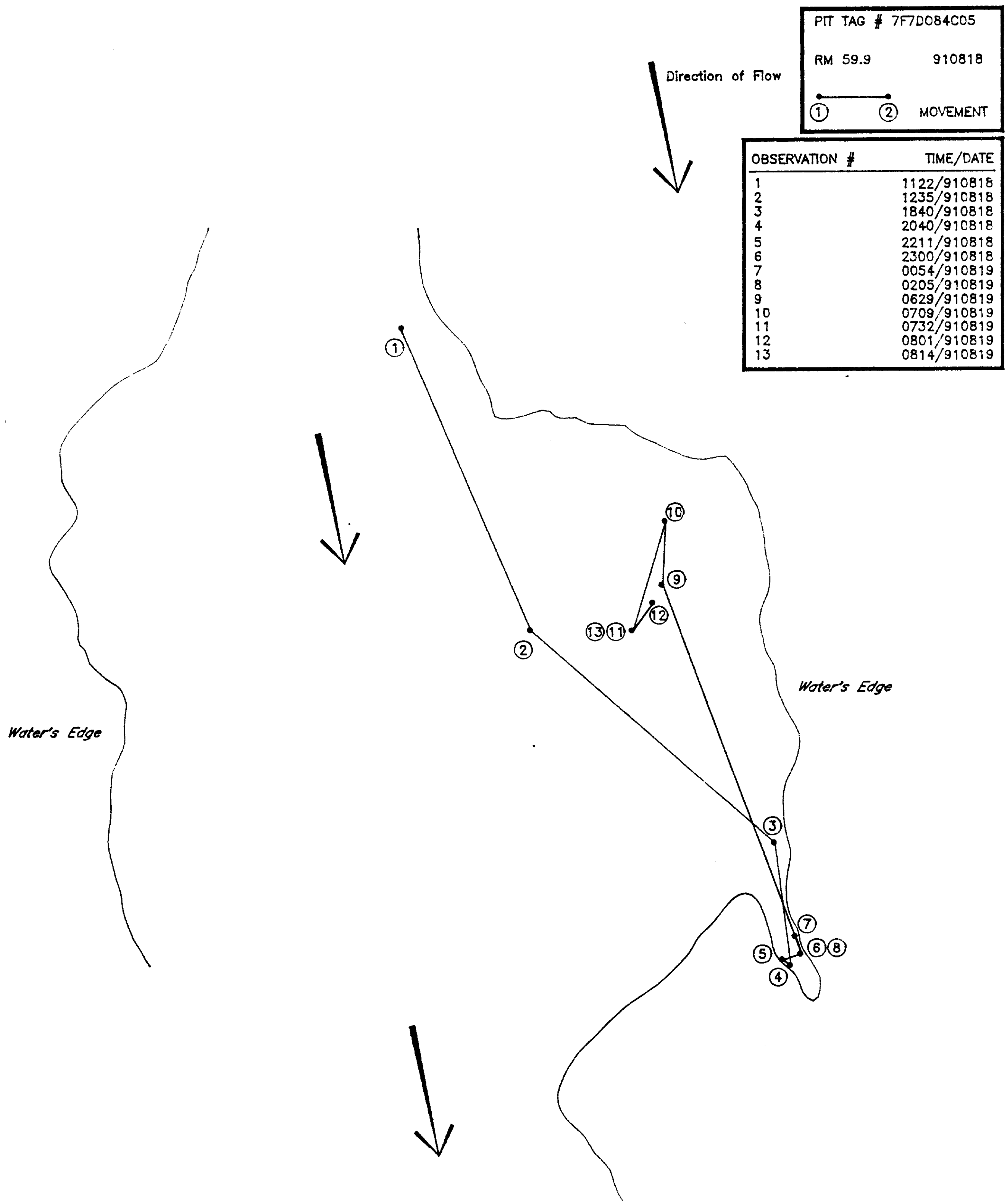

Figure A-2. Local movement of radiotagged humpback chub, PIT tag #7F7D048C05 during a hydrological sequence including a descending limb, low flow and ascending limb. Corresponding distance moved and stage data are presented in Table A-26 and Figure 32.

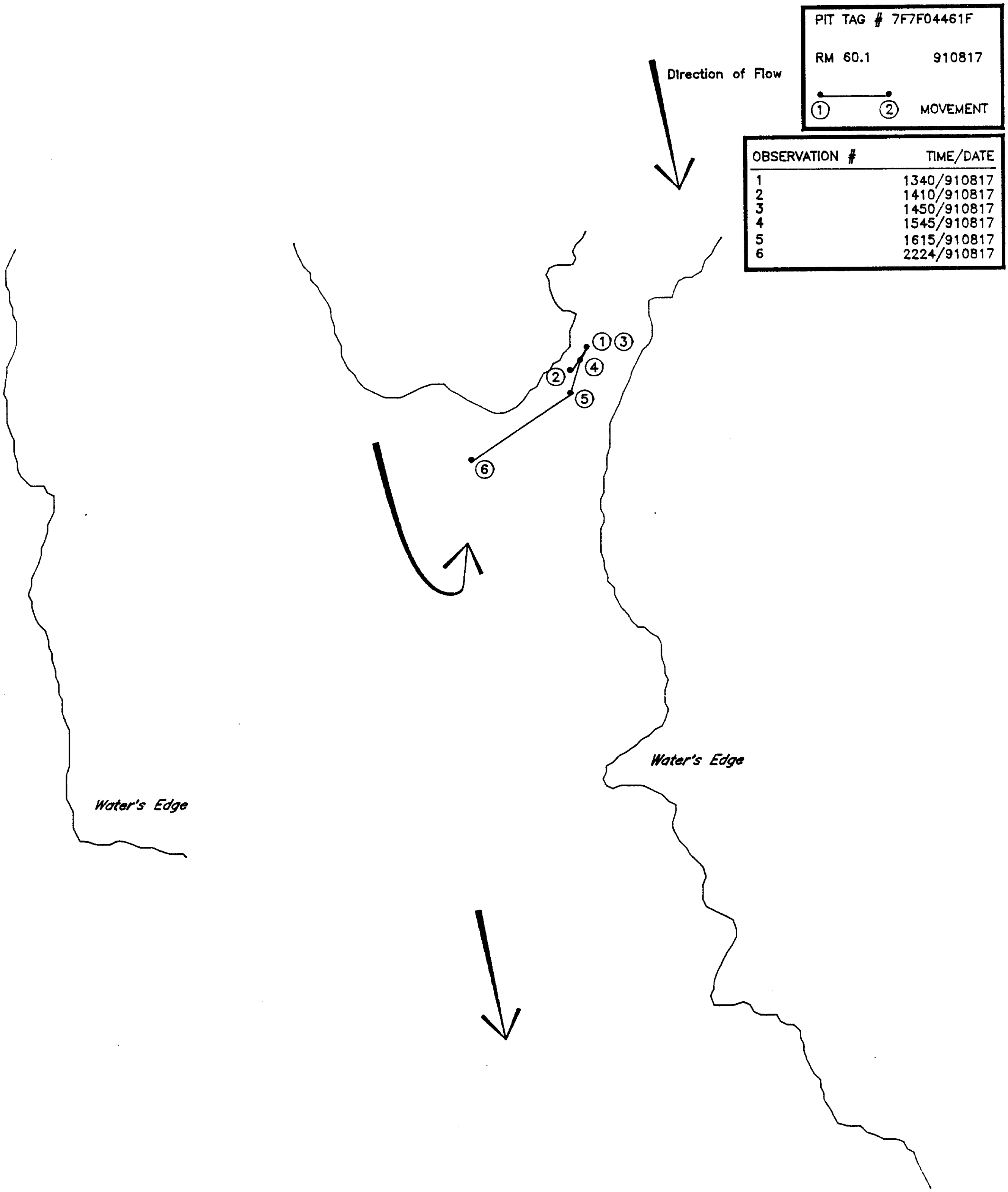

Figure A-3. Local movement of radiotagged humpback chub, PIT tag #7F7F04461F during a hydrological sequence including a descending limb, low flow and ascending limb. Corresponding distance moved and stage data are presented in Table A-26 and Figure 32.

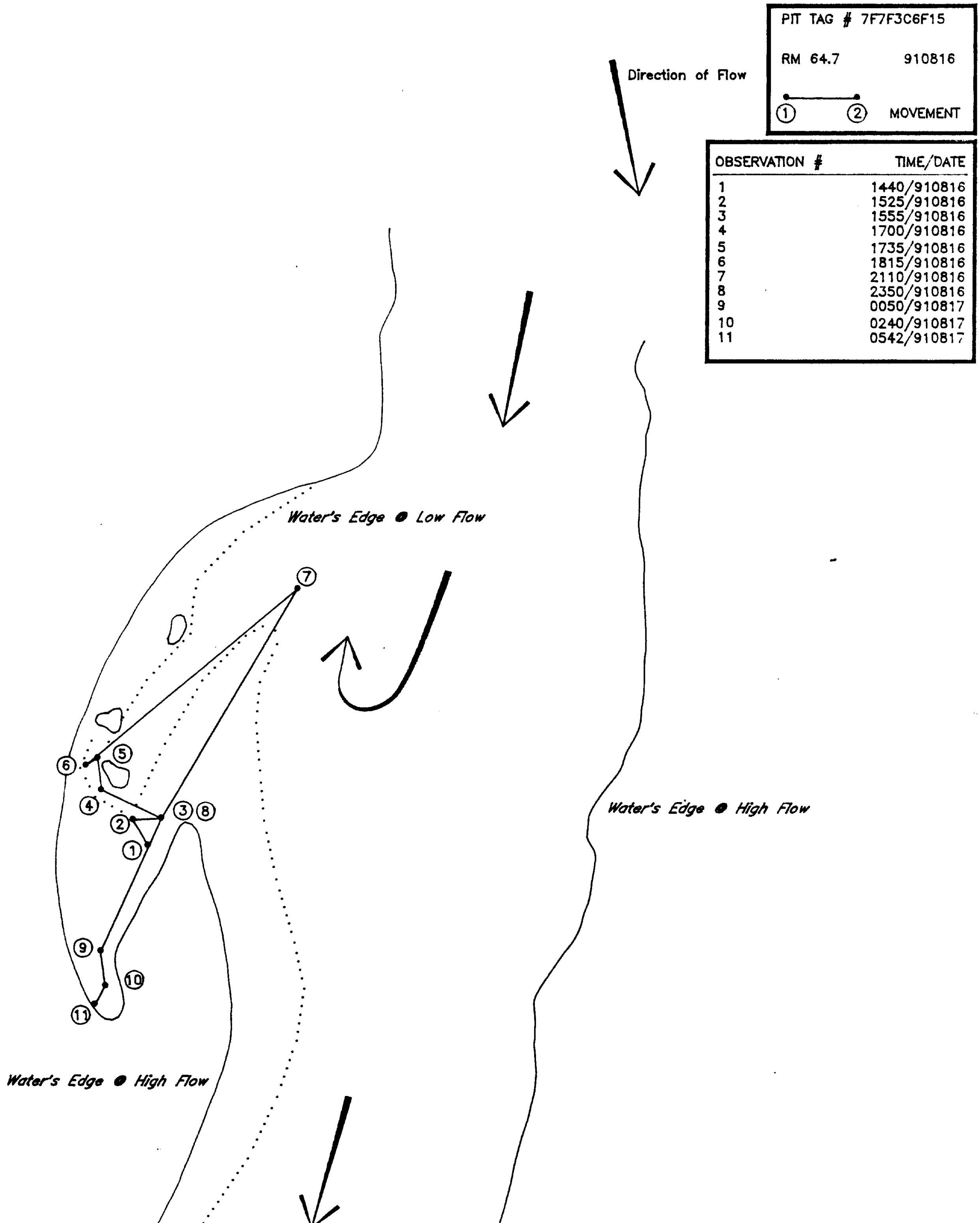

Figure A-4. Local movement of radiotagged humpback chub, PIT tag #7F7F3C6F15 during a hydrological sequence including a descending limb, low flow and ascending limb to a peak flow. Corresponding distance moved and stage data are presented in Table A-27 and Figure 33

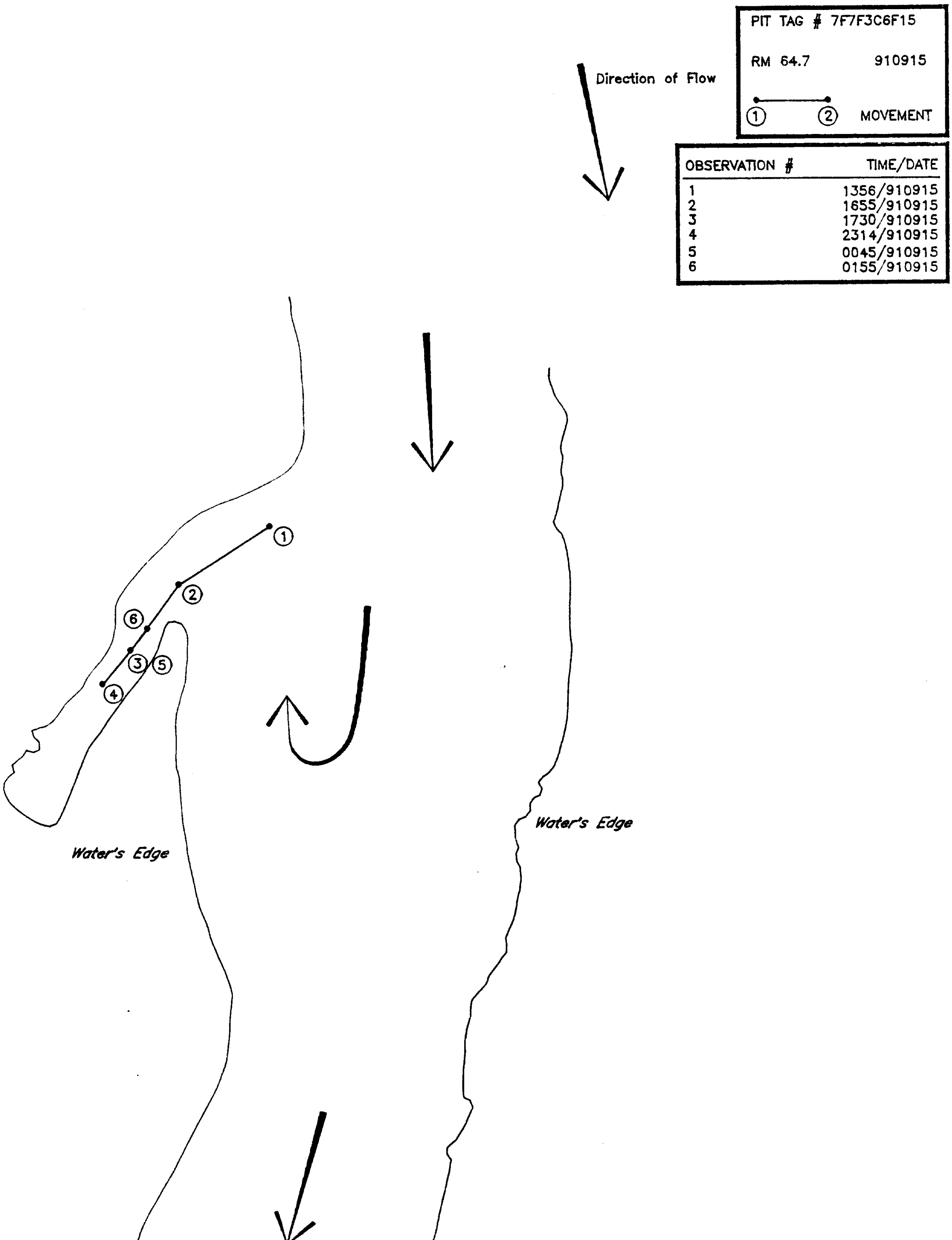

Figure A-5. Local movement of radiotagged humpback chub, PIT tag #7F7F3C6F15 during a hydrological sequence including a descending limb, low flow and ascending limb to a peak flow. Corresponding distance moved and stage data are presented in Table A-27 and Figure 33.

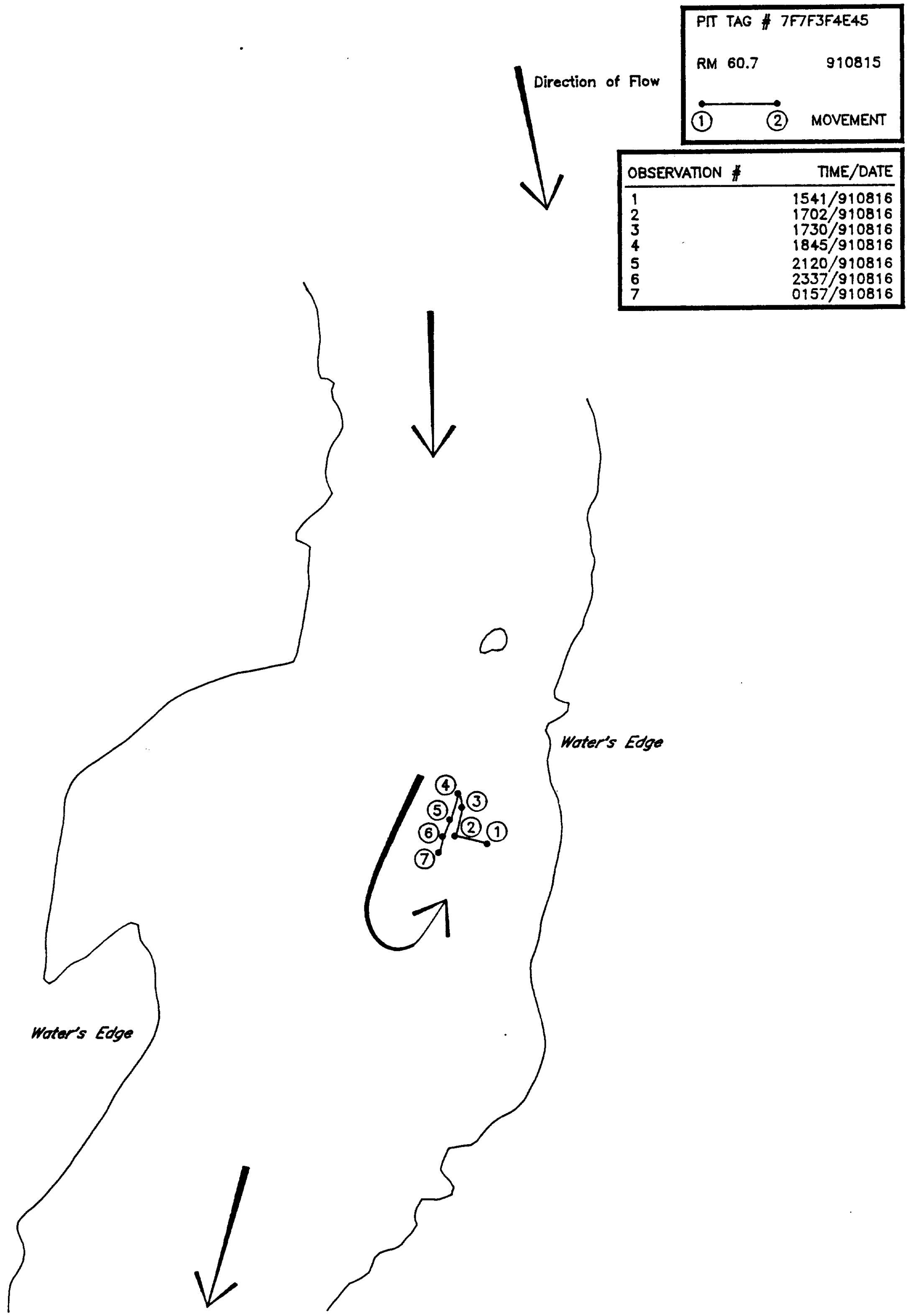

Figure A-6. Local movement of radiotagged humpback chub, PIT tag #7F7F3F4E45 during a hydrological sequence including a descending limb, low flow and ascending limb to a peak flow. Corresponding distance moved and stage data are presented in Table A-27 and Figure 33.

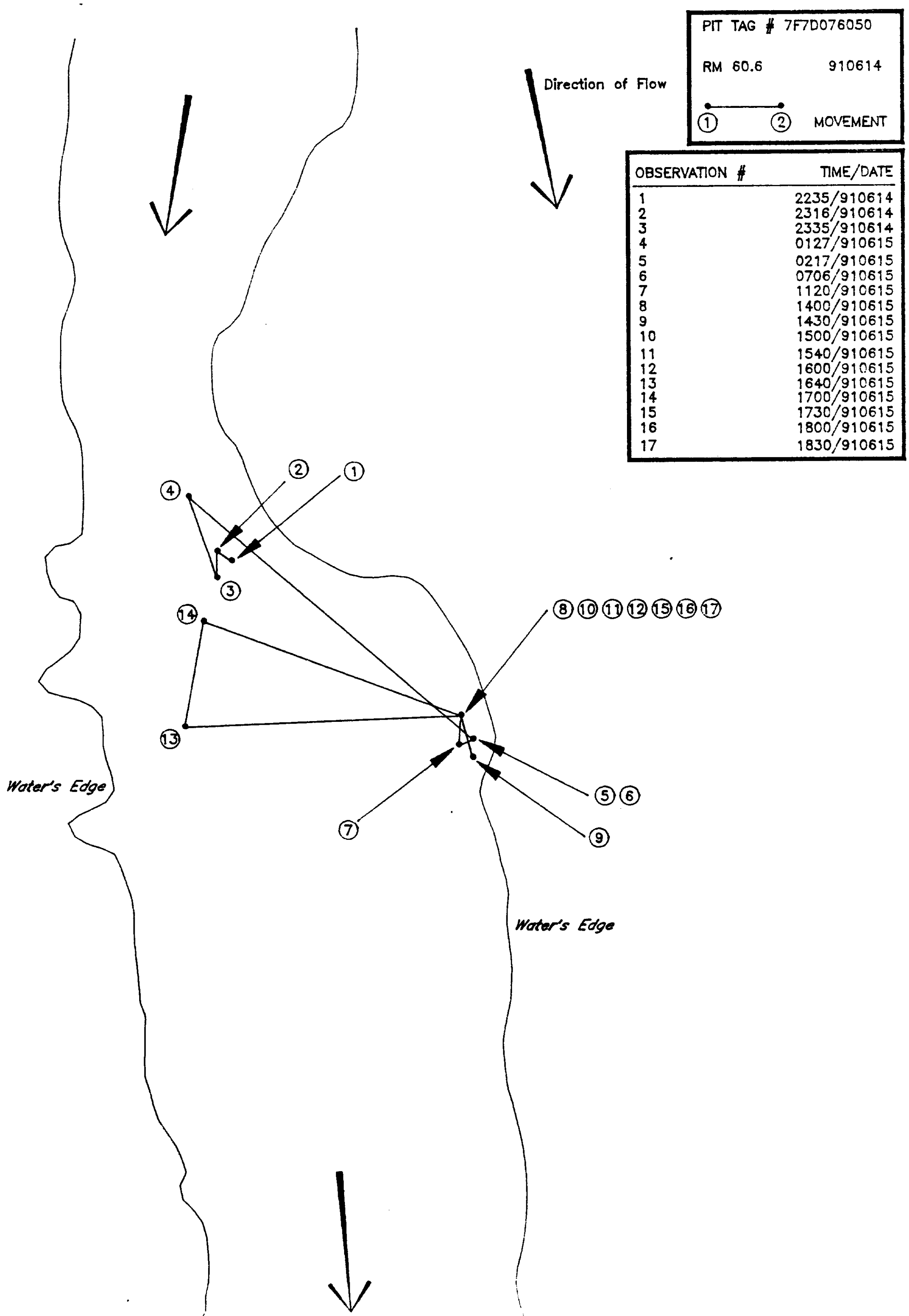

Figure A-7. Local movement of radiotagged humpback chub, PIT tag #7F7D076050 during a hydrological sequence including an ascending limb and a peak flow. Corresponding distance moved and stage data are presented in Table A-28 and Figure 34.

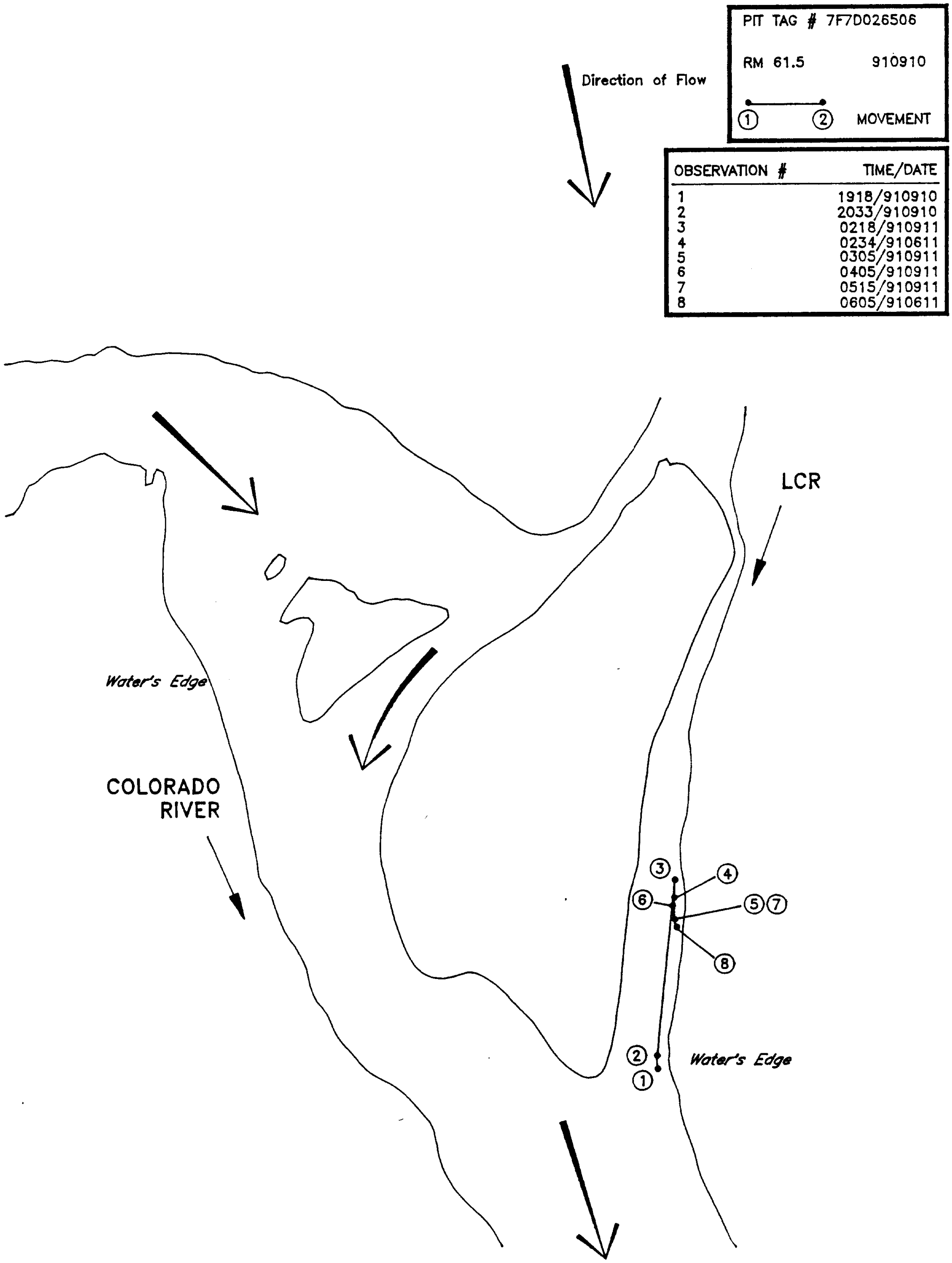

Figure A-8. Local movements of radiotagged humpback chub, PIT tag #7F7D026506 during a hydrological sequence including an ascending limb and a peak flow. Corresponding distance moved and stage data are presented in Table A-28 and Figure 34.

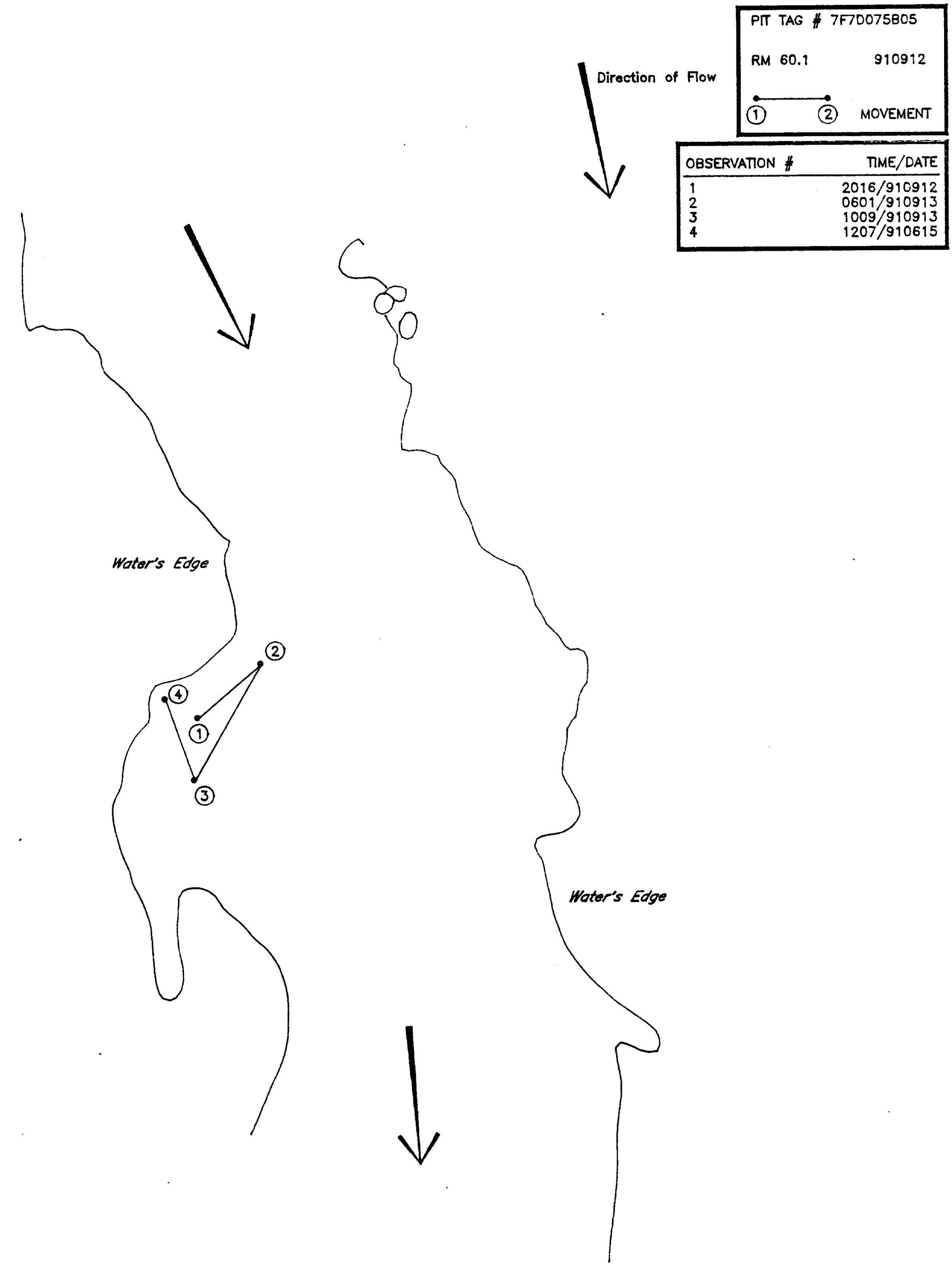

Figure A-9. Local movements of radiotagged humpback chub, PIT tag #7F7D075B05 during a hydrological sequence including an ascending limb and a peak flow. Corresponding distance moved and stage data are presented in Table A-28 and Figure 34.