Report No. TR-250-08
BIO/WEST, Inc.

LIFE HISTORY AND ECOLOGY OF THE HUMPBACK CHUB (Gila cypha) IN THE COLORADO RIVER, GRAND CANYON, ARIZONA

FINAL REPORT
(CONTRACT NO. 0-CS-40-09110)

– DRAFT

Submitted To

Bureau of Reclamation
Upper Colorado River Region
Salt Lake City, Utah 84147

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October 15, 1994

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Report Citation:

Valdez, R.A. and R.J. Ryel. 1994. Life history and ecology of the humpback chub (Gila cypha) in the Colorado River, Grand Canyon, Arizona. Final Report to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08. 168 pp + appendices.

PREFACE

Most people view the Grand Canyon as a land of high scenic mesas and deep rugged canyons bisected by dry washes and few intermittent streams that lead to a brown torrential ribbon of water known as the Colorado River. The desert landscape that surrounds this arid region hardly seems a fitting place for fish. Yet the very nature of this torrential, muddy, and salt-laden river has given rise, over nearly 3 million years, to one of the most unique and highly indigenous fish assemblages in North America.

Known more to native Americans and early explorers as a food source than to recent inhabitants, the fish of the Colorado River were hardly a household word before passage of the Endangered Species Act of 1973. Federal protection of these fishes has brought to the attention of the public not only the decline of these unique life forms, but also the plight of this ancient and overburdened western river. Protection for the bonytail, roundtail chub, and Colorado squawfish--largest of North American minnows at 100 pounds!--was too late, for these species were extirpated from Grand Canyon by the early 1970's. It may also be too late for the razorback sucker, a species that is rarely caught in the region, and declines in flannelmouth suckers and bluehead suckers warn of ongoing and persistent deterrents to these species. While the emphasis of this report is on the humpback chub, the decline of all the Colorado River native fishes serves as a reminder of the connectivity between all life forms, and the need to protect ecosystems that support these forms. Aldo Leopold best described the relationship:

"It is truly the ultimate arrogance of man to discard a part for the sake of not understanding its function."

Today, nearly 1 million people a year visit Grand Canyon National Park, most to peer from the numerous vistas into the depths of the canyon to catch a glimpse of the famous river nearly 1 mi below. Many come for the exciting and spectacular whitewater rafting, marked by 160 recognized rapids in 225 mi of otherwise inaccessible wilderness. These world-renowned rapids attract 15,000 - 20,000 commercial and private boaters annually. An additional 50,000 visitors, mainly anglers and day rafters, use the 15-mi reach between Glen Canyon Dam and Lees Ferry, most to fish the blue-ribbon trout fishery, provided by cold dam releases from the depths of Lake Powell. Far fewer hardy and devout anglers hike into tributaries and inflows to seek additional opportunities for trophy trout and an occasional channel catfish in isolated and scenic settings.

Except for trout and catfish, and those "bizzare" fish, whose technical names dot the pages of so many reports, few people recognize or understand the fish fauna that lies beneath of depths of the deep and torrential Colorado River.

While this report is intended as a scientific document for agency administrators and the scientific community, we have strived to present our findings in a way that might be readable and useable by interested members of the public. We did this to make the document readable and informative, and as a tribute to the unique fishes that remain in Grand Canyon, as well as those alien species that have managed to survive in this arduous environment.

Consistent with our efforts at attempting to reach a wide audience, we have provided both English and metric units of measure, either jointly for ease of conversion, or individually in commonly used terms, such as a measure of river flow in cubic feet per second, instead of cubic meters per second. Scientific and common names are consistent with nomenclature of the American Fisheries Society, and a glossary is provided to facilitate use of scientific terms in the text.

The report is presented as ten chapters. Following the Introduction (Chapter 1) and Study Design (Chapter 2), are a characterization of River Hydrology (Chapter 3) and Water Quality (Chapter 4). The next four chapters describe life history aspects of humpback chub, including Distribution and Abundance (Chapter 5), Demographics (Chapter 6), Habitat (Chapter 7), Movement and Activity (Chapter 8), Drift and Food Habits (Chapter 9). The last chapter is an Integration (Chapter 10) of information presented, and a discussion of effects of dam operations on the life history and ecology of the humpback chub in Grand Canyon.

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CHAPTER 11 - INTERGRATION

ACKNOWLEDGEMENTS

We are indebted to many people who helped bring this project to a successful completion, and appreciate the assistance of those too numerous to mention at this time. Bob Williams of Bureau of Reclamation had the vision and foresight to implement a comprehensive ecological investigation of fishes in Grand Canyon, and Larry Crist, Chris Karas, Rick Gold, and Lee McQuivey continued support of the program. Dave Wegner, Program Manager for Glen Canyon Environmental Studies, and his staff Michael Yard, Allen Haden, Bill Vernieu, Dr. Richard Lechleitner, Judy Weiss, Jeannie Korn, Frank Protiva, Mark Gonzales, Chris Brode, and Karel Malloy provided untiring logistical support and project coordination. Many members of the BIO/WEST staff assisted in the project, including Maggie Bowler□administration/office management, and Chris Carrier, Peggy Wood, John Kleinfelter, and Kirsten Tinning□field assistance.

We thank many agency people who patiently helped with collecting permits and logistical coordination, and shared ideas, data, and personnel, including Bruce Taubert, Jim DeVos, Dennis Kubley, Bill Persons, Tim Hoffnagle, Rob Clarkson, Alan Kinsolving, Mark Seversen, and Brian Bagley of Arizona Game and Fish Department; Frank Baucom, Jim Hansen, Dr. Owen Gorman, Stuart Leon, C.O. Minckley, Don Metz, Kathleen Linder, John Seals, and Deborah Bills of U.S. Fish and Wildlife Service; George Neusaenger, Johnny Ray, Mark Law, Sue Cherry, Tom Workman, and Dave Derossier of the National Park Service; Drs. Duncan Patten, Paul Marsh, Michael Douglas, and W.L. Minckley of Arizona State University; Mike Tremble, Jeff Cole, Pat Ryan and Carol Yazzie of the Navajo Natural Heritage Program; Mike Yates and Jane Bremner of the Hopi Tribe; Dr. Wayne Starnes of the Smithsonian Institute; and the late Dr. Merec Kalizewski of Brigham Young University. Thanks also to Doug Young, Jim Sartoris, Jerry Miller, Mike Pucherelli, and Patrick Wright of Bureau of Reclamation.

We especially thank the "river community"--guides and boatmen--for sharing their knowledge of Grand Canyon, their immeasurable whitewater expertise, and for helping to promote continuation of sound scientific investigations of Glen Canyon Dam operations. The Grand Canyon River Guides--President Brad Dimock and Vice President Teresa Yates--continually challenged and improved many aspects of our study. Mike Walker of OARS coordinated river logistics, and provided specially-designed boats to accommodate our research needs. Special thanks to river guides and assistants: Alister Bleifuss, Ann Cassidy, Kelly Smith, Stuart Reider, Billy Ellwanger, Steve Bledsoe, Tony Anderson, Nicole Bellows, Duffy McCabe, Jan Kempster, Cindy Kzmarich, Dave Stonebraker, Lars Niemi, Sue Rhodes, Chris Hunsaker, Bruce Helin, Larry Bluth, Rachael Running, Dan Dierker, Kelly Burke, Chris Geanious, John Toner, Bob Grusy, Alan Tinnes, Curtis "Whale" Hanson, Jack Weir, Mark Jensen, Ricky Valdez, Doree Stonebraker, Dave Edwards, Mondell Hebbert, Suzanne Dalton, O'Conner

Dale, Anna Stanfield, Brian Mitchell, Butch Hutton, Mille Birdwell, Kurt Burnett, Tyler Jones, Bart Henderson, Tim Deutchlander, K.C. Deutschlander, mark Plassman, Dick Clark, Monte Becker, Jimmy Hall, Scott Stevens, Sarah Posegate, Butch Schimpp, Tim Hillman, and Josh Winnicki.

Finally, our deepest gratitude to the volunteers who unselfishly gave of their time: Paul Lauck, Karren Grady, Joe Mansour, Tom Martin, Illa Bromberg, Stuart Houston, Deb Combly, Sue Shuhardt, Peg Abbott, S. Trimmer, Ralf Buckley, Diane Wydoski, Debbie Reynolds, Debbie Kuznitz, Mark Littlefield, Merideth Gregg, Jody Williams, Miles Moretti, Drew Erickson, Sandy Kaplan, Jeff Wasowicz, Juan Pedro Sustaita, Adele Fegley, Walt Burkhardt, Bill Davis, Mike Cooper, Brian Roberts, Lorraine Wasowicz, Margie Hensley, Gabe Jaramillo, Steve Lanigan, Marjorie Preus, Paula Trater, S. Saunders, Dave Phillips, Omar Ghani, Kathy Klein, Lisa Gelchis, John Larson, Bob Cowdell, Richard Blaylock, Ann Zwinger, Roy Hugie, Kurt Pruhs, Mark Leyda, Lynn Vogel, Lilly Jonas, Matt Buhler, B. Smith, Ross Freeman, Cody Lange, Peggy Gaudet, Steve Nelson, Rhonda Williams, Evelyn Kay, Kathleen Mitchell, Rick Hedlund, Mike Hylton, Jim White, John Olwine, Melissa Trammell, A. Larue, Bruce Roberts, Todd Tyrell, Georgia Schubilske, Dan Kendrick, Kristi Young, Paula Kelsey, Dave Perault, Krista Roney, Constance Graham, Mark Littlefield, Gerald Champorial, Molly Houston, Rick Treager, Mark Locatelli, Debbie Brown, Jeff Pomeroy, Luis Allen, Patrick Metz, Greg Miner, Brian Hoskins, Charlie Scully, James Kennedy, Joshua Smith, Phil Dean, Michael Neville, Clair Jensen, Doug Covey, John Whinery, Liz Bergy, Ken Hobson, Kathy McNiel, Chris Sands, Tom Wester, Beth Pyle, Steve Lanigan, Scott George, Heidi George, Jean Witzman, Scott Hawxhurst, Dave Phillips, S. Ford, B. Ford, and D. Walker.

The Grand Canyon leaves an inescapable impression on all who visit the canyon bottom, but studying the fish that inhabited its depths is especially rewarding and exciting. We thoroughly enjoyed working in this wonderful place, and sincerely hope that our involvement and scientific contribution help to better understand and conserve the Grand Canyon ecosystem.

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CHAPTER 1 - INTRODUCTION

This Final Report was submitted to Bureau of Reclamation (Reclamation) by BIO/WEST, Inc. (B/W), in partial fulfillment of Reclamation Contract No. 0-CS-40-09110, entitled Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon. The report presents findings of a fisheries investigation conducted from September 1, 1990 through October 15, 1994 as part of Reclamation's evaluation of Glen Canyon Dam operations. Information contained in this report was collected in 36 monthly trips through Grand Canyon, from October 1990 through November 1993, and summarized in Trip Reports and Annual Reports for 1990 (Valdez 1991), 1991 (Valdez et al. 1992), and 1992 (Valdez and Hugentobler 1993). An Executive Summary is available as a companion document to this Final Report, and a separate Appendix contains detailed tables and figures. A complete list of all reports and publications produced during this investigation is included in Appendix A. A Data Collection Plan and computerized database are also available from B/W or Reclamation for all data collected under this investigation.

BACKGROUND

This investigation was conducted as part of the Native and Endangered Fish (NEF) Studies (Fig. 1-1) of the Phase II Draft Integrated Research Plan (DIRP) of the Glen Canyon Environmental Studies (GCES 1990). This plan was developed as a roadmap to provide overall research direction and logic, as well as technical information transfer to GCES researchers, the scientific community, and the interested public. The objective of the NEF Studies was to understand population ecology of the fish and identify responses to the operation of Glen Canyon Dam. These studies were a cooperative effort between Arizona Game and Fish Department (AGF), U.S. Fish and Wildlife Service (Service), National Park Service (NPS), Arizona State University (ASU), Reclamation, and the Navajo Nation, Hopi Tribe, and Hualapai Tribe. These entities comprised the Aquatic Coordination Team (ACT)--a group of researchers that worked jointly and cooperatively to ensure an integrated research approach, and provided guidance to a Senior Scientific Advisor and the GCES Program Manager.

The NEF Studies consisted of Native Fish Studies in the mainstem Colorado River, Little Colorado River (LCR), and other tributaries, and Endangered Fish Studies consisting of eight study plans (Fig. 1-2). BIO/WEST was contracted by Reclamation to conduct ecological studies of humpback chub in the mainstem Colorado River, from Lees Ferry to Diamond Creek, including early life history studies in all habitats except backwaters, adult movement studies, adult and juvenile studies, and habitat studies (Table 1-1). Results of these studies were provided in this report and associated datasets to aid Reclamation in its mandated responsibility, under Section 7(a)(1) of the Endangered Species Act of 1973, as amended, to "...utilize their authorities in furtherance of the

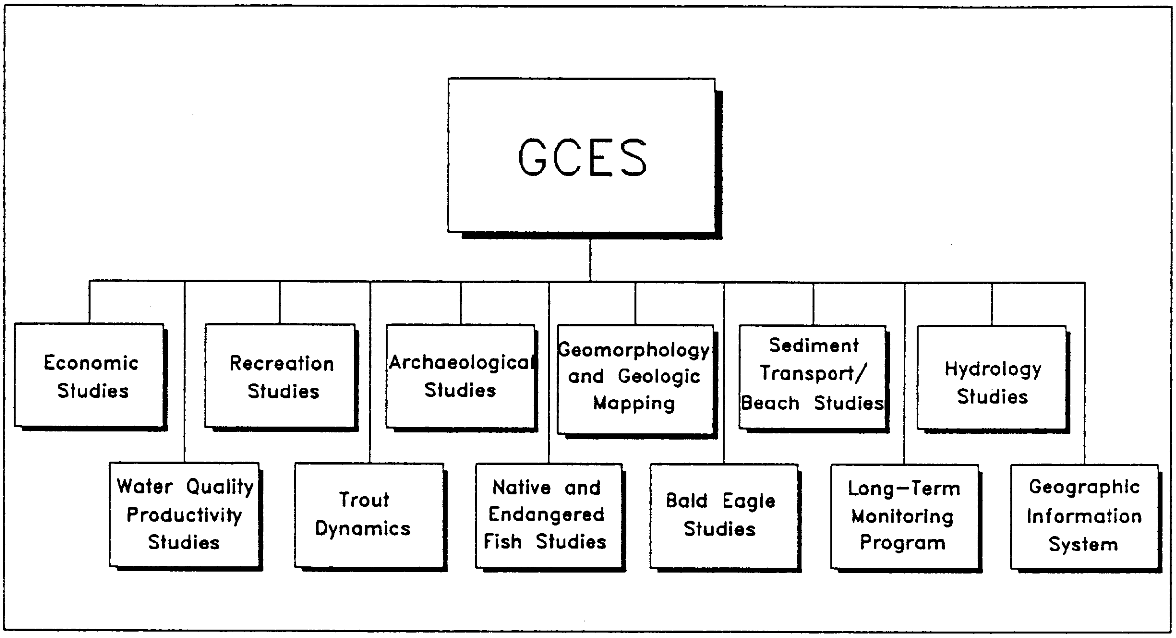


Fig 1-1. Components of the Glen Canyon Environmental Studies (GCES) Phase II Integrated Research Plan.

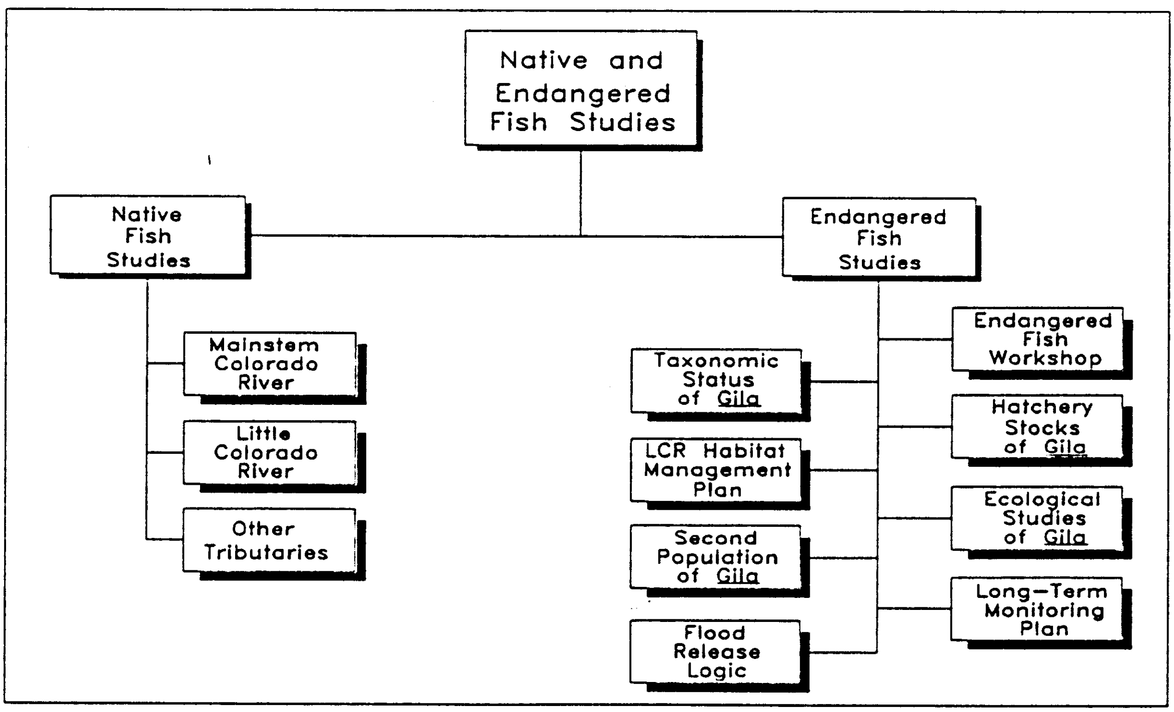


Fig. 1-2. Technical study plans for the Native and Endangered Fish Studies component of the GCES Phase II Integrated Research Plan.

Table 1-1. Study titles and investigators for ecological studies of humpback chub.

Study Title	Investigator
Mainstem Colorado River (Lees Ferry to Diamond Creek)	
Early Life History Studies	Arizona Game and Fish Department (backwaters and beach faces)
	BIO/WEST (all habitats except backwaters)
	Hualapai Tribe (Diamond Creek to Pearce Ferry)
Adult Movement Studies	BIO/WEST
Adult and Juvenile Studies	BIO/WEST
Habitat Studies	BIO/WEST (all habitats except backwaters)
	Arizona Game and Fish Department (backwaters and beach faces)
Little Colorado River	
Early Life History Studies	Arizona Game and Fish Department
Adult Movement Studies	Arizona State University
Adult and Juvenile Studies	Arizona State University
Habitat Studies	U.S. Fish and Wildlife Service
Other Tributaries	
All Studies	University of Arizona
	U.S. Fish and Wildlife Service

purposes of this Act by carrying out programs for the conservation of endangered species and threatened species...".

Glen Canyon Environmental Studies was formed on April 15, 1983, in response to public concern over the effects of Glen Canyon Dam operations on Grand Canyon resources. Reclamation Commissioner Robert M. Broadbent instructed Regional Director Clifford Barrett (letter dated December 6, 1982) to determine the effect of present (1982) flow patterns on the canyon environment. In 1988, GCES submitted a Phase I Report (U.S. Department of Interior 1988), which determined that flood releases and fluctuating flows had substantial adverse effects on downstream resources. A review by the National Research Council (1987) of the National Academy of Sciences, recommended further investigations to identify the causes of these effects.

On June 19, 1988, the U.S. Department of Interior directed Reclamation to continue GCES, with the recognition that sufficient data had not been collected or analyzed under Phase I to make operational decisions on Glen Canyon Dam. The Phase II program focused on better understanding the relationship of low and fluctuating flows on specific resources in Grand Canyon, and the potential economic impact of operational modification. The Phase II DIRP identified ten primary study components and two monitoring components to assess impacts of operations on specific resources. A series of hypotheses was developed by the GCES Senior Scientific Advisor, GCES researchers, interested groups, and the National Academy of Sciences to address specific questions for each resource (GCES 1990). These hypotheses became the foundation for this and other NEF Studies in Grand Canyon.

On July 27, 1989, Secretary of Interior, Manuel Lujan, directed the initiation of an Environmental Impact Statement (EIS) on the Operation of Glen Canyon Dam. Passage of the Grand Canyon Protection Act of 1992 (PL 102-575) on October 30, 1992, mandated completion of a Final EIS not later than 2 years after the date of enactment (Sec. 1804). Most of the NEF Studies identified in Fig. 1-2 were not completed in time for the Draft EIS of April 1994, and only preliminary findings and results were provided from this B/W investigation to the EIS Team.

The Endangered Fish Studies of the Phase II DIRP were formulated in response to a 1978 Biological Opinion that determined that the operation of Glen Canyon Dam "...is likely to jeopardize the continued existence of the humpback chub...". This jeopardy determination was considered in developing the GCES Phase I Studies, and at their conclusion, the Service reinitiated consultation with the new information collected. The reconsultation resulted in seven conservation measures developed jointly by AGF, NPS, the Service, the Navajo Nation, and Reclamation. A Draft Biological Opinion, with a no-jeopardy determination, was being prepared when Interior Secretary Lujan announced the initiation of the EIS on the Operation of Glen Canyon Dam. The opinion was withdrawn, pending selection of a preferred alternative, but the Service requested continued implementation of the seven conservation measures, which became the technical study plans identified in Fig. 1-2.

Conservation Measure 1: Taxonomic status of the genus Gila

Conservation Measure 2: Maintenance of hatchery stocks of Grand Canyon humpback chub

Conservation Measure 3: Ensure that flood releases from Glen Canyon Dam occur with a frequency of not greater than one in twenty years

Conservation Measure 4: Development of a management plan for the Little Colorado River

Conservation Measure 5: Conduct research to identify impacts of Glen Canyon Dam operations on the humpback chub in the mainstem and tributaries

Conservation Measure 6: Establish a long-term monitoring program to assess the relationship of project operations to the humpback chub

Conservation Measure 7: Establish a second spawning population of humpback chub in the Grand Canyon

Conservation measures 5 and 7 provided the framework for purpose and objectives of the B/W investigation, as detailed in the following section. These measures also guided study designs of other investigations, as part of the Phase II DIRP.

PURPOSE AND OBJECTIVES

The purpose of this investigation, as stated in the project contract, was to:

> "Evaluate 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."

This investigation was designed to coordinate and integrate with other studies, a description of physical, chemical, and biological components of the aquatic ecosystem in Grand Canyon to provide an understanding of principal factors that limit the endangered humpback chub. By itself, this investigation addressed only certain aspects of these components, and shared roles and responsibilities with other investigators, as outlined in Table 1-1. The study objectives for B/W were to determine the following for humpback chub in the mainstem Colorado River in Grand Canyon:

1. Resource availability and use (i.e., habitat, food).
2. Distribution, abundance and movement.
3. Reproductive capacity and success.
4. Survivorship of early life stages.
5. Important biotic interactions with other species for all life stages.
6. The life history schedule.

These objectives were developed by Reclamation as part of the NEF Studies and to address conservation measures 5 and 7.

These objectives were also designed to provide insight into Question 6 and Hypotheses Ho-6.1, Ho-6.1a, and Ho-6.1b of the Phase II DIRP (Volume 1, pages 10-11):

Question 6: "How do discharge fluctuations and rates of change in fluctuating discharges affect other fish, especially native fish species? Do the USFWS Conservation Measures adequately address this question?"

Ho-6.1: "There is no significant relationship between the population dynamics (including short-term abundance of early life stages and potential predation relationships) of native (especially the humpback chub) and introduced fish species in the mainstem Colorado, including mainstem backwaters and the confluence of the Little Colorado, and the magnitude of fluctuations, minimum discharges and rates of change of fluctuating discharges."

Ho-6.1a: "There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of discharge fluctuations."

Ho-6.1b: "There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of minimum discharges."

SCOPE OF WORK

The scope of work for this investigation was founded on a sampling program that provided an understanding of the life history of the humpback chub, and simultaneously addressed hypotheses on operational effects. The ecological nature of the study objectives required an ecosystem approach to link life history requirements with physical, chemical, and biological components affected by dam operations. Evaluating limiting factors first required a comprehensive understanding of life history requirements for humpback chub from throughout its range. Although the species was described in 1946, and variously investigated since the late 1960's, only general life history information and schedules were known for each of the six populations in the basin. While the population in Grand Canyon was the most intensively studied, the focus of past investigations has been in the LCR, rather than the mainstem Colorado River. This limited understanding of the species required parallel and sometimes simultaneous assimilation of life history information, and hypothesis development and testing (Fig. 1-3). Limiting factors were identified and explained through a process of life history descriptions leading to multiple sequential hypotheses and multiple parallel hypotheses (Schumm 1991).

Because flow characteristics of the Colorado River in Grand Canyon have varied dramatically since Glen Canyon dam began impounding water in 1963 (See Chapter 3 - HYDROLOGY), this scope of work focused on operational components (i.e., magnitude of fluctuations, minimum discharges, and rates of change of fluctuating discharges) rather than operational regimes. Operational regimes during this investigation included "research flows" (June 1, 1990 through July 29, 1991) and "interim flows" (starting August 1, 1991). Their short duration precluded identifying, isolating, and tracking important physical, chemical, and biological variables and identification of biological responses.

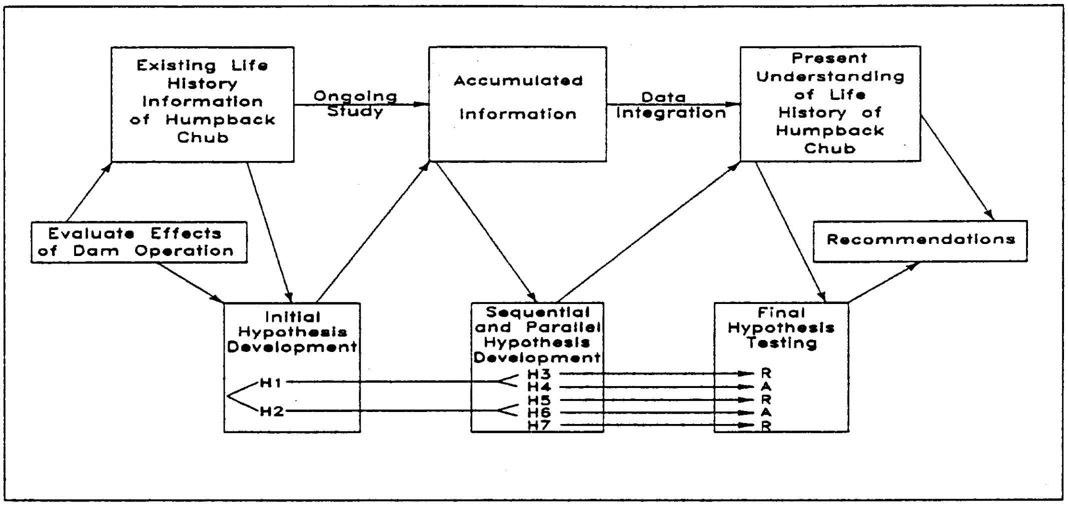


Fig. 1-3. Relationship of assimilation of life history information and hypothesis development and testing.

Changes in operational regimes during this study provided limited opportunity for inducing and observing long-term ecosystem responses. Rigorous testing of hypotheses was not possible because the system under investigation was not experimentally manipulated for ichthyofaunal responses, and replicate systems were not identified and simultaneously studied. Cause-effect relationships were first identified through systematic sampling, and hypotheses developed from inferences of these relationships. These hypotheses provided valuable insight into ecological limitations for humpback chub, and helped to identify mechanisms and causes of effects from dam operations.

Inferences were made to identify possible effects of dam operations on humpback chub, based on literature and available data collected from this and other investigations. Few inferences were made for operational effects on other trophic levels, because data collected in parallel studies by other researchers were not available. Linkages to tributary studies, particularly in the LCR, were also minimal since information from these investigations were not available.

Selected physical, chemical, and biological components were described and quantified, where possible, to provide an integrated understanding of those elements of the ecosystem that most likely affected and limited humpback chub in Grand Canyon. Data were systematically collected in this study, or in cooperation with other studies, to minimize overlap with other research efforts, and provide a comprehensive database to GCES for development of an integrated report.

STUDY AREA

This investigation was conducted in a 226-mi (364-km) area of the Colorado River in Grand Canyon, from Lees Ferry (RM 0) to Diamond Creek (RM 226) (Fig. 1-4), in which the river flows for 15 mi (24 km) within Glen Canyon National Recreation Area (Glen Canyon Dam to Lees Ferry), and 241 mi (388 km) within Grand Canyon National Park (Lees Ferry to Separation Rapid). The lower 75 mi (121 km) of river, downstream of National Canyon (RM 164.5), is bordered on the south by the Hualapai Indian Reservation.

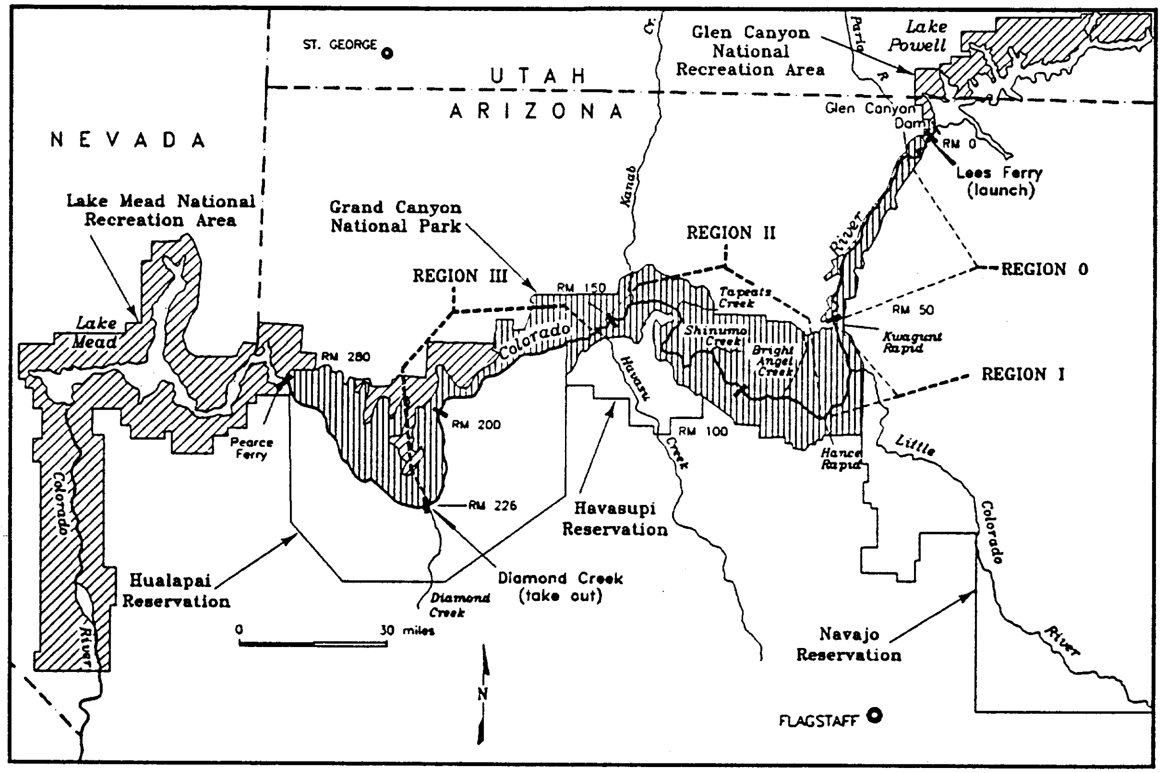


Fig. 1-4. BIO/WEST study area in Grand Canyon and four sample regions.

This area was divided into four study regions and 11 geomorphic reaches in order to approximate uniform distribution of sampling (See Chapter 2 - METHODS). The four study regions included: (1) Region 0--Lees Ferry to Kwagunt Rapid (RM 56.0), (2) Region I--Kwagunt Rapid to Hance Rapid (RM 76.6), (3) Region II--Hance Rapid to below Havasu Creek (RM 160.0), and (4) Region III--below Havasu Creek to Diamond Creek (RM 226.0). Regions I, II, and III, were sampled from October 1990 through December 1992, when Region 0 was added to extend the investigation upstream. A fifth region--Region IV (Diamond Creek to Pearce Ferry, RM

280)--was investigated by B/W, as part of an aquatic resources study for the Hualapai Indian Tribe and GCES (Valdez 1993, 1994).

Reference landmarks along the river corridor were located to the nearest tenth (0.1) of a river mile (i.e., distance downstream from Lees Ferry along the center of the river) according to Belknap and Evans (1989), and sample sites were entered in the database to the nearest twentieth (0.05) of a river mile. It should be noted that Lees Ferry is 15.2 river miles downstream of Glen Canyon Dam, and river miles cited in this report are in reference to Lees Ferry and not Glen Canyon Dam. A list of sites commonly referenced in this report are provided with river miles in the GLOSSARY.

The following is a description of the four study regions and the geomorphic reaches identified by Schmidt and Graf (1988a, 1988b, 1990). This description is provided to familiarize the reader with the physical character of the study area, and to develop a foundation for later discussion of fish habitat availability and use. (See Chapter 7 - HABITAT).

Region 0 (Lees Ferry to Kwagunt Rapid)

The study was expanded upstream to Lees Ferry in January 1993 to sample additional locations for humpback chub and to provided a more complete characterization of the ichthyofauna of the river. This region was 56.0 miles (90.1 km) long from the Lees Ferry to Kwagunt Rapid, and was characterized by three geomorphic reaches--Permian Section, Supai Gorge, Redwall Gorge, and Lower Marble Canyon (Table 1-2; Howard and Dolan 1981, Schmidt and Graf 1988a, 1988b, 1990). Average channel widths in the three reaches were 280, 210, 220, and 350 ft (79, 64, 67, and 107 m), respectively, and channel slope was low to moderate. Substrate was composed of 25-30 % bedrock and boulders, and shoreline was typically rock talus with intermittent tributary alluvial fans, sand bars, or earthen banks with vegetation.

Shoreline features in Region 0 were formed primarily by the Toroweap Formation and Coconino Sandstone (RM 2-5); Hermit Shale (RM 5-11.5); the Supai Group, including Esplanade Sandstone (RM 11.5-15), Wescogame, Manakacha, Watahomigi, and Surprise Canyon Formations (RM 15-23); Red Wall Limestone (RM 23-35); and Muav Limestone (RM 37-56).

The Paria River (RM 1.0) and Nankoweap Creek (RM 52.2) were the only perennial tributaries in this region. Several local drainages flowed intermittently during rain spates in June, July, and August, introducing large amounts of sediment into the river; the largest contributor of sediment to this upper portion of the study area was the Paria River. Large alluvial boulder fans at tributary inflows in this region constricted the channel, forming 12 minor and 6 major rapids (Badger Creek, Soap Creek, House Rock, North Canyon, 21-Mile, Nankoweap).

Region I (Kwagunt Rapid to Hance Rapid)

Region I was 20.6 mi (33.2 km) long from Kwagunt Rapid to Hance Rapid, and was characterized by two geomorphic reach--Lower Marble Canyon and Furnace Flats (Table 1-2). The river channel in these reaches averaged 350 and 390 ft (107 and 119 m) in width, respectively, and channel slope was low to moderate at 0.10 and 0.21 %, respectively. Substrate was composed of 30-36 % bedrock and boulders, and shoreline was typically rock talus, tapeats ledges, or vertical cliffs with intermittent tributary alluvial fans, sand bars, or earthen banks with vegetation.

Shoreline features in Region I 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. Soft shales and sandstones of Bright Angel Shale and Tapeats Sandstone created characteristic ledges and shorelines lined with fractured and collapsed rock fragments.

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

The only perennial tributary in Region I was the LCR (RM 61.3), which was the largest tributary and contributor of sediment to the Colorado River in Grand Canyon. Large alluvial boulder fans formed 9 minor and 5 major rapids (60-Mile, Lava Canyon, Tanner, Unkar, Nevills) in this region.

Region II (Hance Rapid to below Havasu Creek)

Region II was 83.4 miles (134.2 km) long, and extended from Hance Rapid to below Havasu Creek. This region was composed of four geomorphic reaches, including Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge (Table 1-2). Upper Granite Gorge (RM 77.4-117.8) had the lowest average ratio of top canyon width to mean depth (7), the second narrowest average channel width (190 ft, 60 m) and the steepest channel slope (0.23%) of any geomorphic reach in Grand Canyon. The river in Upper Granite Gorge flowed primarily through Vishnu Schist (black), Zoroaster Granite (pink), and Hotautu Conglomerate--hard Precambrian formations about 1.8 billion years old, forming steep canyon walls and smooth, scoured shorelines with little talus.

Table 1-2. Characteristics of geomorphic reaches within the four study regions of the Colorado River in Grand Canyon.

Study Region	Extent of Reach (river miles)	Name of Geomorphic Reach	Major geologic units at river level	Description of reach Width	Average Ratio of Top Width to Mean Depth	Average Channel Width (feet)	Channel slope	Percentage of Bed Composed of Bedrock and Boulders
0	0-11.3	Permian Section	Kaibab Limestone Toroweap Formation Coconino Sandstone Hermit Shale	Wide	11.7	260	.00099	42
	11.3-22.6	Supai Gorge	Supai Group	Narrow	7.7	210	0.0014	81
	22.6-35.9	Redwall Gorge	Redwall Limestone	Narrow	9.0	220	0.0015	72
I	35.9-61.5	Lower Marble Canyon	Muav Limestone Bright Angel Shale Tapeats Sandstone	Wide	19.1	350	0.0010	36
	61.5-77.4	Furnace Flats	Tapeats Sandstone Unkar Group	Wide	26.6	390	0.0021	30
II	77.4-117.8	Upper Granite Gorge	Zoroaster Plutonic Complex Trinity and Elves Chasm Gneisses Vishnu Schist	Narrow	7	190	0.0023	62
	117.8-125.5	Aisles	Tapeats Sandstone Vishnu Schist	Narrow	11	230	0.0017	48
	125.5-139.9	Middle Granite Gorge	Tapeats Sandstone Unkar Group Vishnu Schist	Narrow	8.2	210	0.0020	68
	139.9-159.9	Muav Gorge	Muav Limestone	Narrow	7.9	180	0.0012	78
III	159.9-213.9	Lower Canyon	Basalt Muav Limestone Bright Angel Shale	Wide	16.1	310	0.0013	32
	213.9-225.0	Lower Granite Gorge	Vishmu Schist	Narrow	8.1	240	0.0016	58

[a]Adopted from Schmidt and Graf (1988, 1990), with slight variation in river miles (0.1 mi) for Middle Granite Gorge, Muav Gorge, and Lower Canyon.
[b]Wilson, R.

The Aisles (RM 117.8-125.5) included Stephen Aisle and Conquistador Aisle, and was characterized by the reappearance of Tapeats Sandstone (RM 120-130), found in Lower Marble Canyon. Average channel width was 230 ft (70 m), and 48 % of the bed was composed of bedrock and boulders.

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

The river in Muav Gorge (RM 140.0-160.0) flowed through hard, Precambrian vishnu schist and zoroaster granite, which contained the river to the narrowest average channel width of any geomorphic reach in Grand Canyon--180 ft (55 m)--and the highest percentage of bedrock and boulders (78%).

Eight perennial tributaries flowed into the Colorado River in Region II, including Clear Creek (RM 84.1), Bright Angel Creek (RM 87.7), Crystal Creek (RM 98.1), Shinumo Creek (RM 108.6), Tapeats Creek (RM 133.7), Deer Creek (RM 136.3), Kanab Creek (RM 143.5), and Havasu Creek (RM 156.7). These streams typically had low base flows with little effect on mainstem flows, and only local effects on water chemistry and biology. Occasionally, high spring flows or severe local thunderstorms produced high tributary flows and short-term effects on mainstem water quantity and quality. The majority of native fishes found in this region were in close proximity to these perennial tributary inflows (Maddux et al. 1986, Valdez et al. 1992).

Region II 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).

Region III (Below Havasu Creek to Diamond Creek)

Region III was 66.0 mi (106 km) long from below Havasu Creek to Diamond Creek, and was divided into two geomorphic reaches--Lower Canyon and Lower Granite Gorge (Table 1-2). Lower Canyon (RM 160.0-213.9) had an average channel width of 310 ft (94 m), a moderate slope (0.13%) and a bed composition of only 32% bedrock and boulders. The river flowed through sedimentary deposits consisting primarily of Bright Angel Shale, and the shoreline was characterized by talus slopes, with intermittent alluvial boulder fans. Tertiary lava flows extended downstream of RM 180, shaping much of the shoreline with emergent boulders and cliffs formed by columnar basalt.

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

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

CHAPTER 2 - STUDY DESIGN

This chapter describes the elements common to the overall sampling program, including project schedule, sampling design, sampling gear, and fish handling methods. Specific methods used to gather hydrology and water quality data, and unique methods, techniques, formulas, and calculations used to determine distribution and abundance, demographics, habitat use, movement, and food habits are presented in respective chapters.

PROJECT SCHEDULE

This study was initiated in September 1990, and completed with this report in October 1994 (Fig. 2-1). Project workshops were held in December of 1990, 1991, 1992, and 1993 to provide ongoing staff coordination, identify and resolve problems, update data collection status, and provide progress reports to Reclamation and GCES. A Data Collection Plan , issued as a supplement to this Final Report was drafted early in the project to standardize techniques and establish protocols to provide consistent data collection, compatible with other GCES investigations. This plan provides detailed descriptions of field sampling methods, care and handling of fish, and database management that were too lengthy to include in this report.

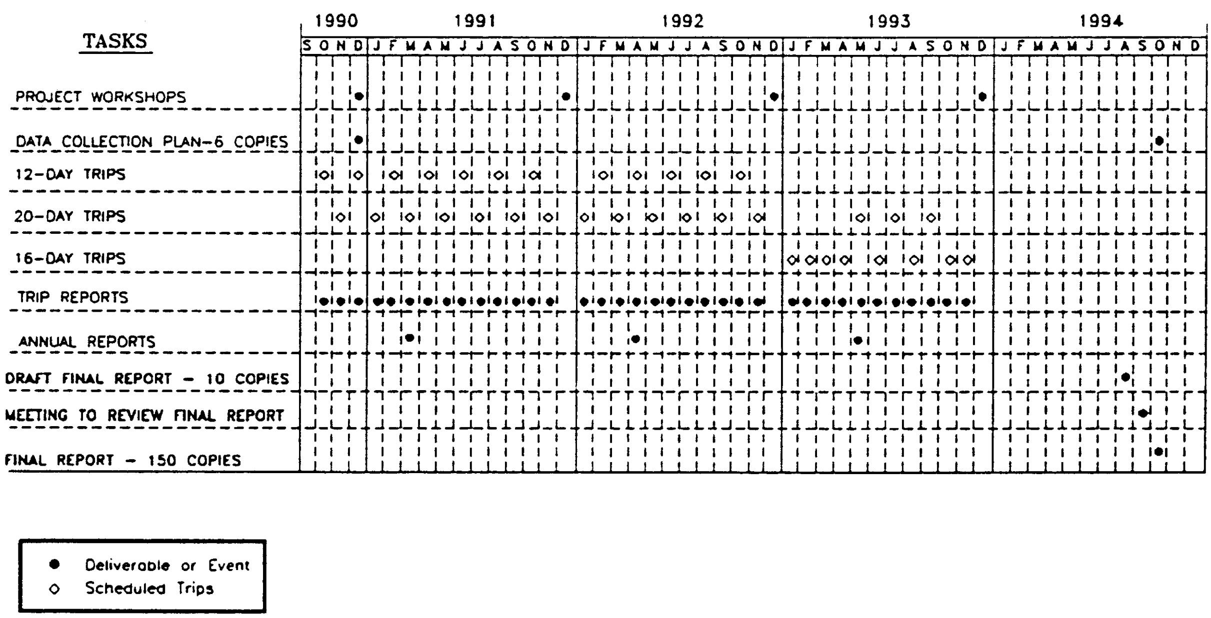


Fig. 2-1. BIO/WEST project schedule.

Field Trips

A total of 36 monthly field trips were conducted on the Colorado River in Grand Canyon, from Lees Ferry (RM 0) to Diamond Creek (RM 226), starting in October 1990 and ending in November 1993 (Fig. 2-1). Trips were held monthly, except for December 1991 and 1992. From October 1990 through November 1992, trip length alternated between 12 and 20 d, resulting in five 12-d trips each in 1991 and 1992 (February, April, June, August, October) and six 20-d trips (January, March, May, July, September, November). The schedule was modified in 1993 to include eight 16-d trips (January, February, March, April, June, August, October, November), and three 20-d trips (May, July, September). Launch dates and sampling locations were coordinated with AGF, when possible, to provide concurrent sampling and comparable data.

Twenty-day trips were conducted to assess composition and distribution of fish, monitor habitat availability and use, determine important biotic interactions between humpback chub and other fish species, and capture humpback chub for implanting radiotransmitters. These trips included two field teams, one with 6 B/W and 1 ACT biologists sampling Region I, and one with 4 B/W and 1 ACT biologists sampling concurrently in Region II. The two teams jointly sampled Region III during the last 5 d of the trip, so that each of the three study regions was sampled with equal effort of about 10 team-days.

Twelve-day trips were conducted primarily to recontact previously radiotagged adult humpback chub, and monitor their movement and habitat use in Region I. These trips involved one field team with 6 B/W and 2 ACT biologists. Fish were usually equipped with radiotransmitters during 20-d trips, and tracked and monitored during 12-d trips from October 1990 through November 1992.

Sixteen-day trips were conducted from January through November 1993, when radiotelemetry was discontinued in Region I and implemented in Region II. The 16-d schedule allowed teams to allocate more time to tracking fish in Region II, while maintaining sampling frequency and intensity throughout the study area. The number of teams on 16-d trips alternated between one team (February, April, June, August, October) and two teams (January, March, May, July, September, November), with number of personnel as described for 12-d and 20-d trips, respectively.

Reports

Trip reports were completed and submitted within 10 d of the completion of each of the 36 field trips, and annual reports were completed at the end of 1990, 1991, and 1992. These reports were submitted to Reclamation and GCES, and distributed to cooperating agencies and interested individuals. A complete list of reports and publications produced from this investigation is included as Appendix A. This final report was written entirely by the B/W Grand Canyon Staff, and reviewed by GCES, Reclamation, the Senior Scientist, several independent reviewers, and the National Research Council of the National Academy of Sciences.

SAMPLING DESIGN

A stratified random sampling design was implemented to approximate uniform spatial and temporal sampling of fish assemblages and associated physical, chemical, and biological components (Schreck and Moyle 1990). The four study regions (0-III) were longitudinally divided into 11 geomorphic reaches (Schmidt and Graf 1988, 1990), each with approximately uniform channel and shoreline characteristics (Table 1-2). The 11 geomorphic reaches were subdivided into 34 sample strata that ranged from 2.0 to 12.1 mi (3.2 to 19.5 km) in length (Table 2-1). These strata were the base spatial sampling units, and were considered representative of the geomorphic reaches in which they occurred (Fig. 2-2). The five major tributary inflows in Region II (i.e., Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek, and Havasu Creek) were each treated as individual stratum to be selected and sampled at least once seasonally in order to insure adequate temporal characterization of areas where fishes aggregated seasonally. Eight to 16 strata were randomly selected for sampling during each monthly trip. Selected strata were not eliminated from consideration for selection on subsequent trips.

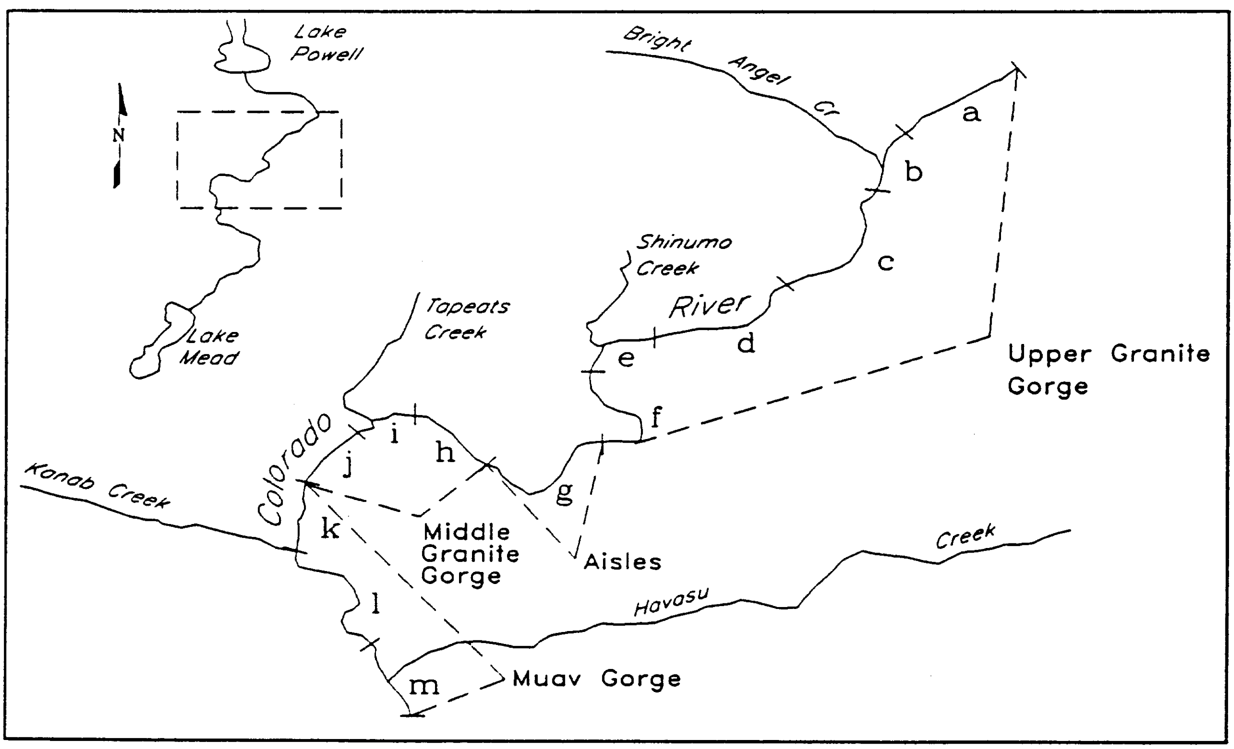


Fig. 2-2. Spatial stratified sampling design for Region II; a-m are sampling strata within geomorphic reaches, Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge.

Table 2-1. Lengths of sample strata within the 11 geomorphic reaches.

Study Region	Geomorphic Reach	Sample Strata	River Miles	Length km(mi)
0	1 - Permian Section	a. Paria - Badger Creek	1.0-8.0	11 .3 (7.0)
		b. Badger Creek - Soap Creek	8.0-11.3	5.3 (3.3)
	2 - Supai Gorge	c. Soap Creek - Sheer Wall	11.3-14.5	5.1 (3.2)
		d. Sheer Wall - House Rock	14.5-17.0	4.0 (2.5)
		e. House Rock - North Canyon	17.0-22.6	9.0 (5.6)
	3 - Redwall Gorge	f. North Canyon - Tiger Wash	22.6-26.5	6.3 (3.9)
		g. Tiger Wash - Vasey's	26.5-35.9	15.1 (9.4)
	4 - Lower Marble Canyon	h. Vasey's - President Harding Rapid	35.9-43.7	12.6 (7.8)
		i. President Harding Rapid - Nankoweep	43.7-52.0	13.4 (8.3)
		j. Nankoweep - Kwagunt	52.0-56.0	6.4 (4.0)
I	Lower Marble Canyon	a. Kwagunt - LCR	56.0-61.5	8.9 (5.5)
	5 - Furnace Flats	b. LCR - Chuar Rapid	61.5-65.5	6.4 (4.0)
		c. Chuar Rapid - Unkar Rapid	65.5-72.5	11.3 (7.0)
		d. Unkar Rapid - RM 77.4	72.5-77.4	7.9 (4.9)
II	6 - Upper Granite Gorge	a. Hance Rapid - Cremation Canyon	77.4-86.5	14.6 (9.1)
		*b. Bright Angel Creek	86.5-89.0	4.0 (2.5)
		c. Pipe Creek - Crystal Rapid	89.0-98.0	14.5 (9.0)
		d. Crystal Rapid - Bass Rapid	98.0-107.8	15.8 (9.8)
		*e. Shinumo Creek	107.8-109.8	3.2 (2.0)
		f. 110-mile Rapid - RM 117.8	109.8-117.8	12.9 (8.0)
	7 - Aisles	g. Aisles	117.8-125.5	12.4 (7.7)
	8 - Middle Granite Gorge	h. RM 125.5 - Dubendorf SSR	125.5-131.7	9.8 (6.2)
		*i. Tapeats Creek	131.7-134.5	4.5 (2.8)
		j. 134 Mile Rapid - RM 140.0	134.5-139.9	8.7 (5.4)
	9 - Muav Gorge	*k. Kanab Creek	139.9-143.8	6.3 (3.9)
		l. Kanab Rapid - Sinyala Rapid	143.8-153.5	15.6 (9.7)
		*m. Havasu Creek	153.5-159.9	10.3 (6.4)
III	10 - Lower Canyon	a. RM 160 - RM 169.9	159.9-169.9	15.8 (9.8)
		b. RM 169.9 - Lava Falls	169.9-179.4	15.3 (9.5)
		c. Lava Falls - RM 189.1	179.4-189.1	15.6 (9.7)
		d. RM 189.1 - RM 200.0	189.1-200.0	17.5 (10.9)
		e. RM 200.0 - 209-Mile Rapid	200.0-208.9	14.3 (8.9)
		f. 209-Mile Rapid - 214 Mile Cr	208.9-213.9	8.0 (5.0)
	11 - Lower Granite Gorge	g. 214-Mile Cr - Diamond Creek	213.9-226.0	19.6 (12.1)

*Tributary strata

Length of each sampling stratum was determined primarily by the distance of river between large rapids that was repeatedly accessible by research boats (See SAMPLING GEAR - Research Boats) from temporary riverside camps for setting and retrieving sampling gear and tracking radiotagged fish. Whitewater rapids too large or swift to ascend with small motorized research boats prevented repeated access to sample sites, and frequently delineated stratum boundaries.

Sampling was conducted monthly and at different times of day and night to account for temporal variation (Fig. 2-3). Effort was partitioned by season to represent winter (December-February), spring (March-May), summer (June-August), and fall (September-November), and by time of day to represent night, dawn, day, and dusk. Since day length and photoperiod varied with season, a computer program (Sun and Moon Events Worksheet, Heizer Software, Inc., Palo Alto, CA) was used to appropriately adjust time blocks.

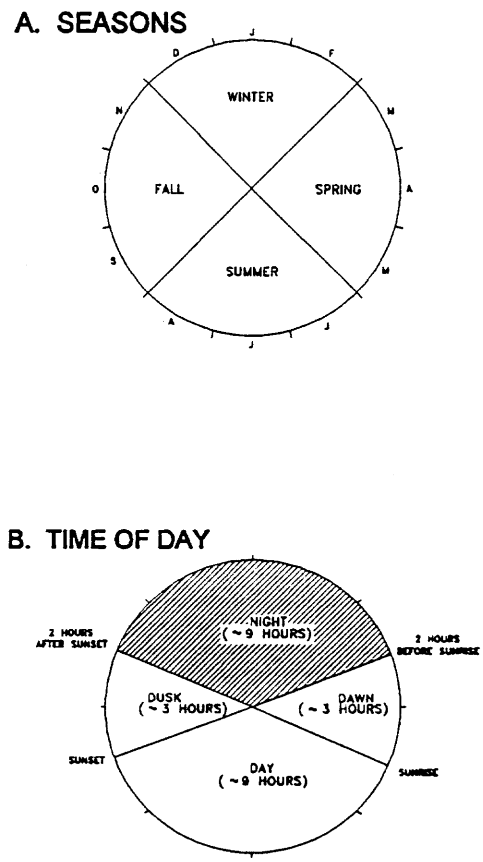


Fig. 2-3. Temporal stratfied sampling design for seasons (A) and time of day (B).

SAMPLING GEAR

Research Boats

Inflatable hypalon boats (Achilles Corp., Number 22 Daikyo-Cho, Shinjuku-Ku, Tokyo 160) were used for sampling and radiotracking. These small boats increased access to a greater variety of habitats than previously sampled, and enhanced scientific validity by allowing replication of data collection (Valdez et al. 1993). The sport utility SU-16 model (4.9 m long) was used primarily for electrofishing and radiotracking, and the sport heavy-duty SH-170 model (5.2 m long) was used primarily for netting and radiotracking (Fig. 2-4). Each model had a removable sectional aluminum floor and wooden transom, and was powered by a 40-hp Yamaha outboard motor. Frames were designed for each model to accommodate appropriate research gear (Fig. 2-5).

The research boats were usually folded and loaded on larger support boats (33 or 37-ft S-rigs, or 23-ft snouts) for transport to and from riverside camps to reduce boat activity in the canyon, and to minimize personal risk and damage to equipment in traversing large whitewater rapids. Support rafts were provided by OARS, a commercial river concessionaire from Flagstaff, Arizona, contracted by GCES to provide logistical support for research efforts in Grand Canyon.

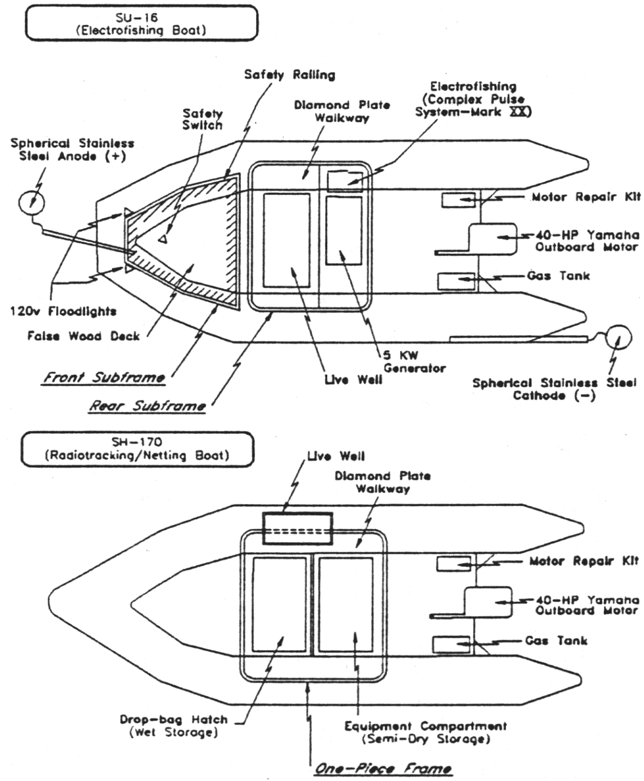


Fig. 2-4. Fishery research boats, SU-16 used for electrofishing (A) and SH-170 used for netting and radiotracking (B).

Fig. 2-5. Frame designs for model SU-16 (A) and SH-170 (B) research boats.

Fish Sampling Methods

A complete description of parameters recorded for each sample method, including field data forms and codes, is provided in Appendix B.

Gill and Trammel Nets

Gill and trammel nets were the primary sampling gear for characterizing large-fish assemblages in deep habitats, and to capture adult humpback chub for implanting radiotransmitters. Nets were used to compare fish distribution and abundance by area and time, as well as to characterize general fish habitat use in support of radiotelemetry data. These nets are commonly used to survey and monitor other populations of humpback chub in the Upper Colorado River Basin (Valdez and Clemmer 1982, McAda et al. 1994, U.S. Fish and Wildlife Service 1987).

Gill nets were 100 ft long and 6 ft deep, with 1.5 or 2-in square mesh (30.5 m x 1.8 m, 3.8 or 5.1 cm mesh). Experimental gill nets were also used with four sections of 0.5, 1, 1.5, and 2-in mesh (1.3, 2.5, 3.8, 5.1-cm). Trammel nets were 75 ft long and 6 ft deep (22.9 m x 1.8 m), with three panels of netting--two outer walls of 12-in (30.5 cm) mesh and one inner panel of 0.5, 1, or 1.5-in mesh (1.3, 2.5, or 3.8-cm). Gill and trammel nets were made of double knotted #139 multifilament twine with 0.5-in (1.3-cm) diameter braided polyfoamcore float line and 5/16-in (0.8-cm) leadcore line. White, labeled mooring boat bumpers, 5-in (12.7 cm) in diameter and 18-in (45.7-cm) long, were tied to a line at the distal end of each net to facilitate relocation and retrieval, and to alert boaters of submerged nets. Polypropylene mesh bags were filled with rocks and used as convenient net weights.

Gill and trammel nets were typically tied to shore, and stretched along the channel bed with net weights to anchor each end of the leadline, and a long line and mooring bumper to keep the net spread and marked (Fig. 2-6). Nets were also suspended in the water column to sample midwater habitat. Nets were checked at intervals of about 2 h to minimize stress and reduce mortality of entangled fish. Nets clogged with algae (Cladophora glomerata) or debris were replaced and cleaned regularly.

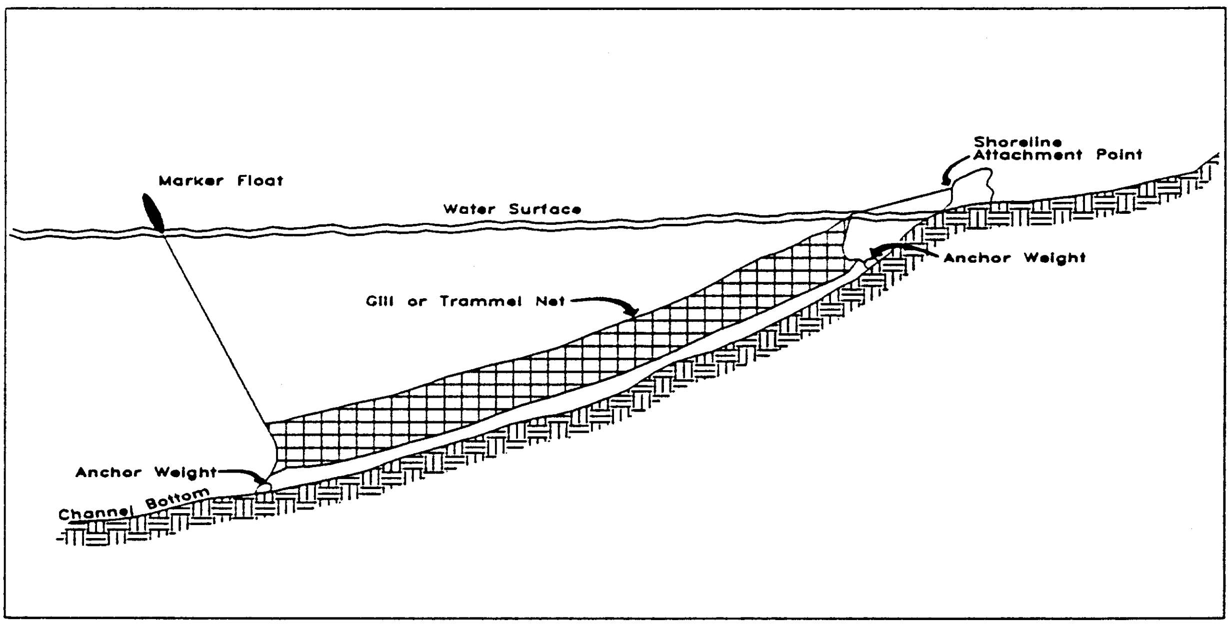


Fig. 2-6. Typical gill or trammel net set.

Hoop Nets

Three sizes of hoop nets were used in various velocity habitats including 2 ft x 10 ft x 0.5-in (0.6 m x 3.0 m x 1.3-cm), 3 ft x 13 ft x 1-in (0.9 m x 4.0 m x 2.5-cm), and 4 ft x 16 ft x 0.5-in (1.2 m x 4.9 m x 1.3-cm) (diameter x length x square mesh). Two 25-ft (7.6 m) wings made of 1-in (2.5-cm) #15 knotless nylon were attached to the opening of the hoop nets. Hoop nets were set by anchoring the rear of the net with a length of rebar and orienting the mouth in a downstream direction to capture fish moving upstream (Fig. 2-7). Nets were checked at least every 8 h to minimize stress and mortality to fish.

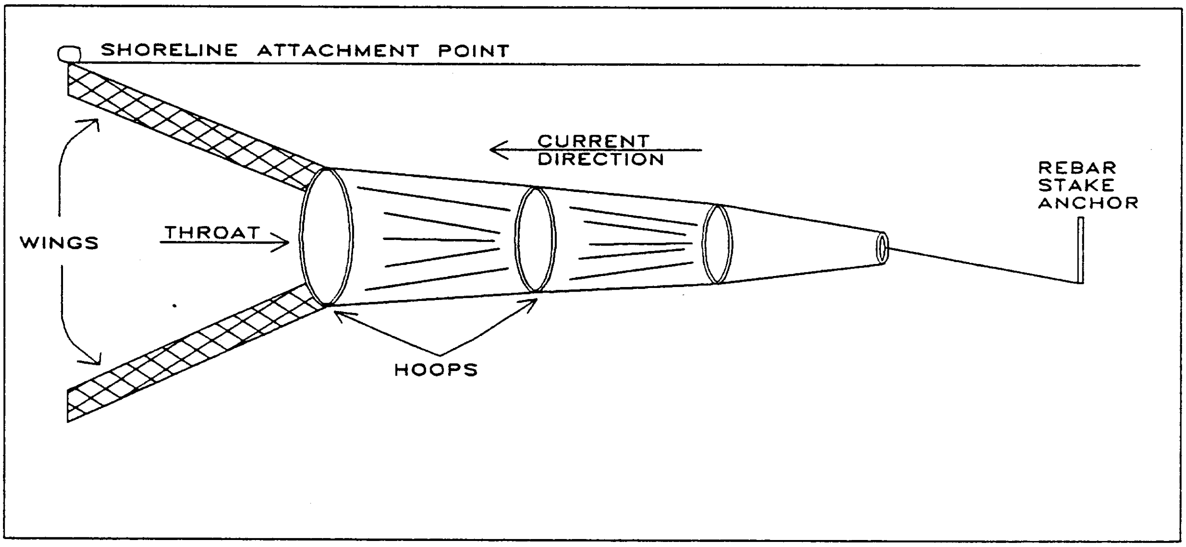


Fig. 2-7. Typical hoop net set.

Minnow Traps

Unbaited minnow traps were used to sample small fish in a variety of shoreline habitats. Minnow traps were standard Gee minnow traps--17.5 in (44.5 cm) long, 9 in (22.9 cm) diameter, and constructed of galvanized wire and steel. Funneled openings were located at each end of the trap. Traps were placed on the bottom or suspended in the water column depending on conditions. Traps were also set in pods of five as sample repititions for habitat types. Each trap was tethered to a secure anchor point and discretely flagged for easy relocation. Traps were checked at intervals of no longer than 24 h to minimize stress and mortality to fish.

Seines

Seines were used to characterize assemblages of small fish in relatively shallow habitats (up to about 1.5 m in depth). Three sizes of seines were used, including 30 ft x 4 ft x 0.25-in (9.1 m x 1.2 m x 0.6-cm), 30 ft x 5 ft x 0.25-in (9.1 m x 1.5 m x 0.6-cm), and 10 ft x 3 ft x 0.125-in (3.0 m x 0.9 m x 0.3-cm) (length x height x square mesh). The float line was constructed of 0.3125-in (0.8-cm) braided polypropylene with hard foam floats at 18-in (45-cm) intervals. The bottom line was made of braided polypropylene line with lead sinkers at 6-in (15-cm) intervals.

Length and width of each seine haul were measured and three water depths recorded; one at the deepest point of the haul, and one each midway between the deepest point and the nearest shore. Length and width of the habitat sampled were also recorded, where applicable.

Electrofishing

Electrofishing was used to sample fishes along shorelines, and to capture adult humpback chub for implanting radiotransmitters. Each electrofishing effort was conducted within a distinct geomorphic shoreline type (i.e., alluvial fan, bedrock, cobble bar, sand bar, talus slope, vegetation) in order to evaluate habitat use and reduce variability in comparing catch rates between habitats and reaches, as well as between flow levels and over time.

Electrofishing was conducted from an Achilles SU-16 research boat capable of ascending small and medium-sized rapids for increased access to sample areas (Fig. 2-4, 2-5). Each boat 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, and rubber gloves, rubber boots, and fiberglass-lined dip nets for netters and boat handler. The system was powered by a 5000-W Yamaha industrial grade generator (Model YG-500-D) or a Honda 5000-W generator (Model EB 5000X), and routed through a Mark XX Complex Pulse System (CPS) developed by Coffelt Manufacturing (Flagstaff, AZ). Stainless steel spheres, were used as electrodes with the anode (positive electrode) mounted on a boom projecting from the bow, and the cathode (negative electrode) suspended from the stern. Anode and cathode were interchanged every 45-60 min of electrofishing to allow for cleaning of the cathode surface by reversing the electroplating process.

In 1990-91, CPS output settings ranged from 15 to 20 A and 300 to 350 V, as recommended by Coffelt Manufacturing for electrofishing in the Colorado River below Glen Canyon Dam (N. Scharber, Coffelt Manufacturing, pers. comm.). In 1992, output was reduced to a range of 8-10 A and 200-250 V after "bruise marks" were observed on trout under the higher settings. The lower settings seemed to reduce the incidence of these marks (See EVALUATION OF SAMPLING DESIGN).

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). Cheese balls, commercial salmon eggs, stink bait, grasshoppers, Mormon crickets (Tyus and Minckley 1988), and artificial flies have been used with varying success. Angling was not used extensively in Grand Canyon because of the relative high efficiency and low impact of other sampling gears, and the time and commitment necessary for successful angling of this endangered species. However, angling was used to catch actively feeding rainbow trout for stomach analysis to assess predation on YOY and juvenile humpback chub in the vicinity of the LCR inflow, where concentrations of young chubs were highest.

FISH HANDLING METHODS

Care and Processing

Captured fish were placed in live wells to minimize stress and enhance recovery. Live wells consisted of 120-qt (127-L) insulated coolers located on each boat (Fig. 2-5), 5-gal (1.3-L) bail buckets carried by seining crews, and 4 ft x 6 ft, 0.5-in mesh (1.2 m x 1.8 m x 1.3-cm) holding pens placed in the river. Fresh river water was used for contained fish of each sample effort, and changed frequently when holding time was prolonged or large numbers of fish were being held. Fish showing signs of stress (e.g., increased or irregular respiration, loss of equilibrium, dramatic color change, reddened fins, excessive slime) were isolated in fresh water, carefully monitored, and treated with a salt solution to minimize electrolytic losses (Bulkley et al. 1982, Hattingh et al. 1975). Fish with extended lethargy or obvious injuries were appropriately treated (e.g., Betadine™ was applied to wounds) and released upon recovery. Dead fish were preserved in an appropriately labeled container, and transferred to the ichthyology collection at Arizona State University. Incidental mortality of humpback chub from this investigation did not exceed 10 per year, the number allowed under B/W's federal collecting permit.

From October 1990 through July 1991, all humpback chub captured were transported to a central processing station near camp, and then returned to their capture location for release--a one-way distance of up to 4 mi (6.4 km). This protocol prolonged holding time and unnecessarily stressed the fish, and was modified in August 1991, when humpback chub were processed and released near their capture location. Only adults destined for radioimplant were transported to a central processing station.

A number of fish processing procedures were used during the course of this investigation. Some were initiated by the original study design, and modified or discontinued, while others were implemented as a result of specific data needs or at the request of the ACT (Fig. 2-8). Humpback chub were measured for total length (TL), standard length (SL), and forked length (FL) in millimeters, weighed wet in grams, and gender determined. From October 1990 through July 1991, the left aspect of every humpback chub ≥200 mm TL was photographed (35-mm color slide and VHS video) on a white plasticized board marked with a 1-cm grid. Starting in August 1991, 35-mm photographs were taken of every tenth adult captured, and videography was discontinued. Primary rays of dorsal and anal fins were also counted for every tenth adult, and ten morphometric dimensions were

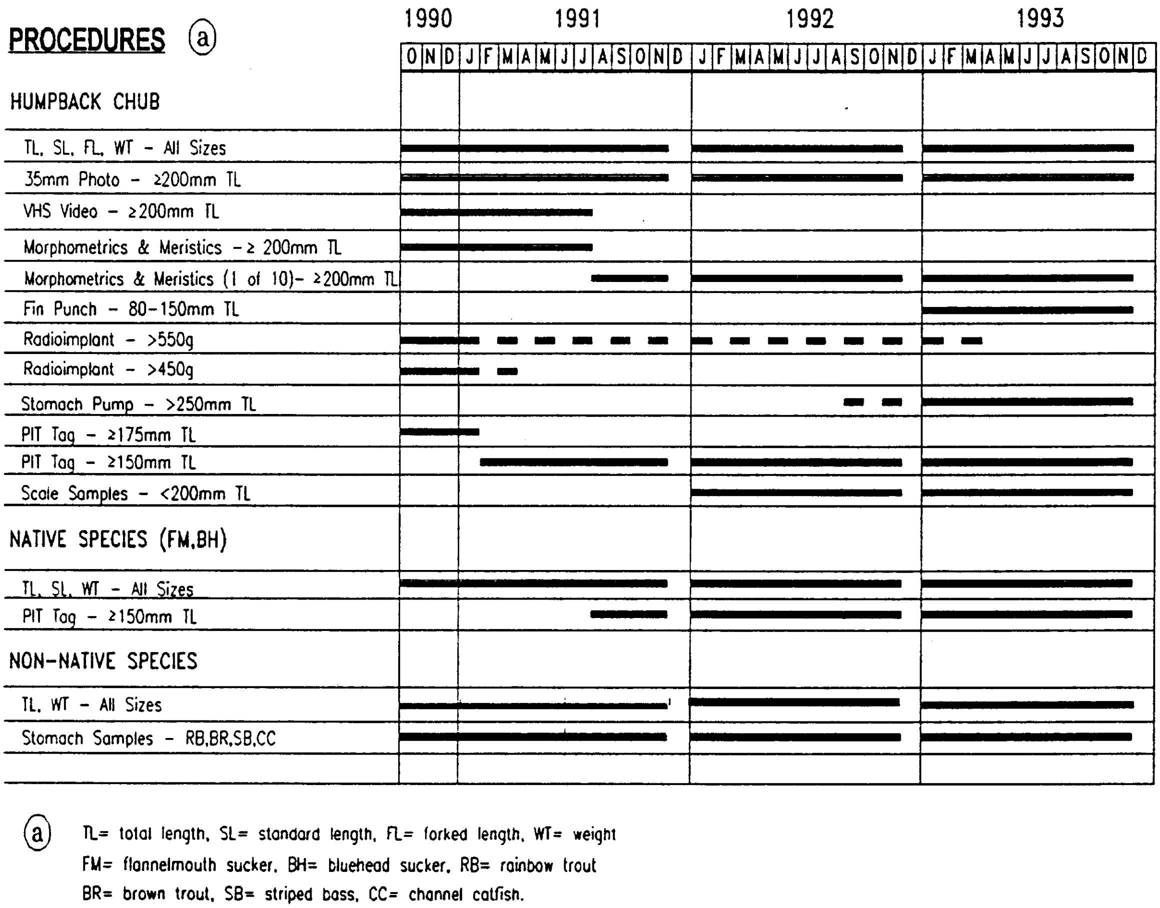


Fig. 2-8. Schedule of fish processing procedures conducted by BIO/WEST.

measured with venier calipers (Fig. 2-9), accurate to the nearest 0.01 mm, including depth of nuchal hump, head length, snout length, distance between insertion of pelvic and pectoral fins, maximum body depth, caudal peduncle length, maximum caudal peduncle depth, minimum caudal peduncle depth, length of anal fin base, and length of dorsal fin base.

Select adult humpback chub weighing more than 550 g were surgically equipped with 11-g radiotransmitters from October 1990 through January 1991, and every other month through March 1993. Use of 9-g radiotransmitters in fish 450-550 g was discontinued because of transmitter limitations. A nonlethal stomach pumping technique was implemented in September 1992, following an evaluation the technique (Wasowicz and Valdez 1994). Scales were taken from chub <200 mm TL to determine age and size at transition from the LCR to the mainstem.

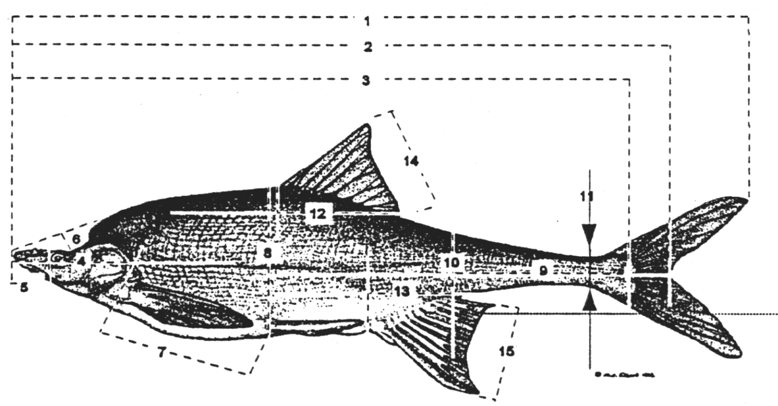


Fig. 2-9. Morphometrics and meristics recorded for adult humpback chub ≥200 mm TL.

Other native species, including flannelmouth sucker, bluehead sucker, and speckled dace were measured for total and standard length (i.e., TL, SL), weighed, and those ≥150 mm TL were PIT-tagged starting in August 1991. Non-native species were also measured for total and standard length, weighed, examined for reproductive condition and gender, and released. All channel catfish, striped bass, and selected rainbow trout and brown trout were sacrificed for removal of stomachs. Gut contents were preserved in ethanol, placed in labeled whirl-packs, and transported to Leibfried Environmental Services in Flagstaff, Arizona, for identification and quantification of food contents (See Chapter 9 - DRIFT AND FOOD HABITS).

All fish were examined for anomalous characteristics such as previous marks (e.g., fin punches, fin clips, external fish tags), parasites, wounds, or deformities. Anomalies were recorded in detail on appropriate data sheets and photographed if relevant.

Marking

A PIT tag (Passive Integrated Transponder) was injected into the parietal cavity (Fig. 2-10) of humpback chub ≥175 mm TL, and starting in February 1991 minimum size of tagging was reduced to 150 mm TL. External tags (i.e., Carlin or Floy tags placed by previous investigators) were removed from native fish and replaced with PIT tags, and both tag numbers recorded in the database for corresponding information. These old tags were replaced at the request of the ACT because PIT tags were considered more reliable, with less chance of tag loss, and greater capacity and facility for information retrieval (Burdick and Hamman 1993).

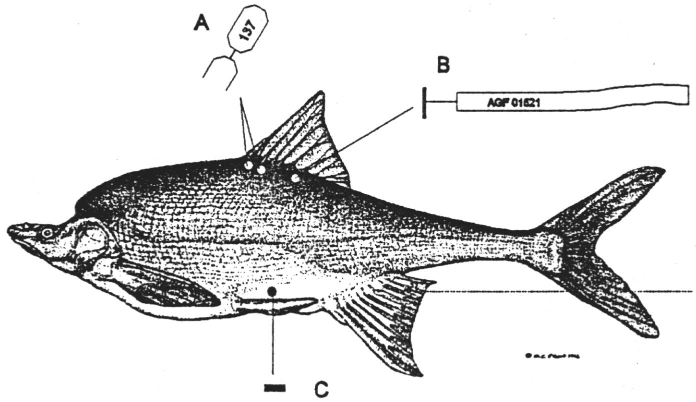


Fig. 2-10. Attachment sites for Carlin dangler tag (A) and Floy anchor tag (B) by previous investigators, and injection site for PIT tag (C) by this investigation.

Beginning in January 1993, humpback chub 60-150 mm TL (juveniles) were temporarily marked with fin punches (Fig. 2-11) to track longitudinal dispersal. A 3-mm diameter biopsy needle was used to punch various fin combinations specific to river subreaches (Wydoski and Emery 1983). Fish captured between RM 57 and RM 65.5 were marked with a dorsal fin punch; those between RM 65.5 and RM 76.5, with a lower caudal fin lobe punch; those between RM 76.5 and RM 157, with a lower caudal fin lobe punch; and those between RM 157 and RM 225, with a combination dorsal and upper caudal lobe punch.

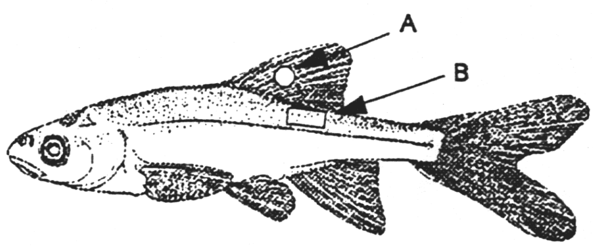


Fig. 2-11. Juvenile humpback chub with dorsal fin punch (A) and location of scale samples (B).

CHAPTER 3 - HYDROLOGY

INTRODUCTION

The Colorado River drains a basin of approximately 242,000 mi² (626,780 km²), and flows for about 1450 mi (2330 km) from the Rocky Mountains of Colorado to the Gulf of Lower California in Mexico. The river and its tributaries flow through seven arid western states (Colorado, Wyoming, Utah, Arizona, New Mexico, California, and Nevada) and Mexico, and drain approximately one-twelfth of the U.S. land area. Major tributaries include the Green, Yampa, White, Gunnison, Dolores, and San Juan rivers in the upper basin (above Lees Ferry), and the Little Colorado, Virgin, Bill Williams, and Gila rivers in the lower basin (below Lees Ferry). Although upper basin drainage area is less than half of total basin area--about 111,800 mi² (289,540 km²)--average annual historic upper basin discharge of 12.93 million acre feet (maf), measured in 1912-62 at Lees Ferry, is about 90% of average total basin volume (13.9 maf) (Boner et al. 1990). Current estimates of inflow into Lake Powell are 14.35 maf (Dawdy 1991 and literature cited therein).

The Colorado River in Grand Canyon is the longest continuous portion of river remaining in the lower basin, flowing for 250 mi (403 km) from Glen Canyon Dam to Bridge Canyon in upper Lake Mead. Major tributaries include the Paria River, Bright Angel Creek, Shinumo Creek, Tapeats Creek, and Kanab Creek flowing from the north rim, and the LCR, Havasu Creek, Diamond Creek, and Spencer Creek from the south rim. The largest tributary in Grand Canyon is the LCR with a drainage basin of about 26,964 mi² (69,832 km²).

It is estimated that the Colorado River has flowed through Grand Canyon for the last 5 million years, in which natural streamflow has decreased from an increasingly arid basin climatology and hydrology. The Colorado River is a high elevation desert stream, characterized by high spring snowmelt flows, and low summer, fall, and winter flows, with periodic and spurious short-term flows from summer rainstorms. The Colorado River through Grand Canyon has undergone many changes, greatly increasing variability in streamflow regime, sediment loads, and water quality. Also, periodic geologic phenomena have temporarily altered and reshaped the channel; Late Cenozoic lava flows in western Grand Canyon formed at least 12 major lava dams in the last 1.2 million years. The largest of these dams was approximately 2000 ft (610 m) high and backed the Colorado River for over 200 mi (322 km) for an estimated 3000 years (Hamblin ***).

Natural streamflow is now substantially modified by anthropogenic activities--irrigation withdrawals, transbasin diversions, and dam construction. Thirteen mainstem dams have variously regulated flow of the Colorado River since construction of Boulder Dam in 1935, and hundreds of smaller dams control virtually every stream in the basin (Fradkin 1984). Glen Canyon Dam, largest of the dams on the Colorado River, was authorized under the Colorado River Storage project Act of 1956 and completed in 1963 (Martin 1989). The dam is located 15.2 mi (25 km) upstream of Lees Ferry, the dividing point between upper and lower basins, as designated by the Colorado River Compact of 1922 (Compact). The dam is 730 ft (222.5 m) high, and backs water in Lake Powell for approximately 200 mi (322 km), at a maximum lake elevation of 3700 ft (1128 m). The reservoir is used to provide storage replacement for upstream irrigation development, to meet downstream requirements under the Compact, and for storing water for peaking power generation through Glen Canyon Dam.

Lake Powell has a total capacity of 27 maf, and an active useable capacity of 25 maf. Water can be released through Glen Canyon Dam in the following three ways (U.S. Department of Interior 1994):

- Powerplant releases. The powerplant has eight generators with a maximum combined discharge capacity of about 33,200 cfs, although releases during fluctuations are limited to 31,500 cfs. Powerplant releases are preferred because of electrical production and associated revenues. Penstock intakes are located 229 ft (70 m) below the water surface at maximum lake elevation.

- River outlet works releases. Capacity of the river outlet works is 15,000 cfs, providing a total release capacity of 48,200 cfs, when used in conjunction with powerplant releases. The river outlet works as "jet tubes" draw water from 20 ft (6 m) below the water surface at maximum lake elevation.

- Spillway releases. Spillway releases are made only when necessary to avoid overtopping the dam or to lower the level of Lake Powell. Combined capacity of right and left spillways is about 208,000 cfs. Spillway releases draw water from 20 ft (6 m) below the water surface at maximum lake elevation.

Although combined release capacity of the powerplant, river outlet works, and spillway is about 256,000 cfs, maximum combined releases from Glen Canyon Dam are not expected to exceed 180,000 cfs. Releases during this investigation, from October 1990 through November 1993, were entirely through the powerplant.

This chapter presents streamflow characteristics of the Colorado River and selected tributaries in Grand Canyon. An overview of the hydrology of Glen Canyon and Grand Canyon by Dawdy (1991) was used as a source for this chapter. Flow characteristics of the mainstem are presented for pre and post-dam conditions to provide a perspective of hydrology during the term of this investigation. Although tributaries contribute a relatively minor component of flow to the mainstem, flow characteristics are presented because inflows were important areas of fish concentrations, providing local habitats for holding, food resources, warming, and possibly spawning and rearing. Also, access to tributaries by adult native fishes for spawning, and subsequent dispersal of young is greatly influenced by volume and timing of tributary flow.

METHODS

Flow of the Colorado River and its tributaries in Grand Canyon was evaluated from stream gage records of the U.S. Geological Survey (USGS, Table 3-1, Fig. 3-1). Earliest records for Grand Canyon are for the Colorado River at Lees Ferry starting in 1895. Early records were typically based on single daily measurements, while most gaging stations today record streamflow at 15-min intervals. The most current records are provisional, and subject to verification and change by USGS. Some provisional records were modified for this

Table 3-1. Stream gages used for hydrology analysis.

USGS Station Number	Station Name	Location[a]	Drainage Area (mi^2)	Period of Record (water years)
9380000	Colorado River at Lees Ferry, AZ	RM 0.0	111,800	1895-present
9383100	Colorado River above LCR, AZ	RM 61.2	-	Apr 1983-present
9402500	Colorado River near Grand Canyon, AZ	RM 87.4	~141,600	1925-1988
9404120	Colorado River at National Canyon, AZ	RM 166.5	-	Apr 1983-present
9404200	Colorado River above Diamond Creek, AZ	RM 226.0	-	Apr 1983-present
9402000	Little Colorado River near Cameron, AZ	45 mi ups	26,459	1947-present
9402300	Little Colorado River near mouth, AZ	0.5 mi ups	26,964	1989-Jan 1993[bc]
9382000	Paria River at Lees Ferry, AZ	1.1 mi ups	1,410	1923-present
9403000	Bright Angel Creek near Grand Canyon, AZ	0.5 mi ups	101	1923-1974
9403780	Kanab Creek near Fredonia, AZ	31 mi ups	1,085	1963-1980

[a]RM = river miles downstream from Lees Ferry.
ups = distance upstream from Colorado River confluence.
[b]data inconsistent
[c]discharge based on stage elevations, periodically adjusted based on stream channel measures.

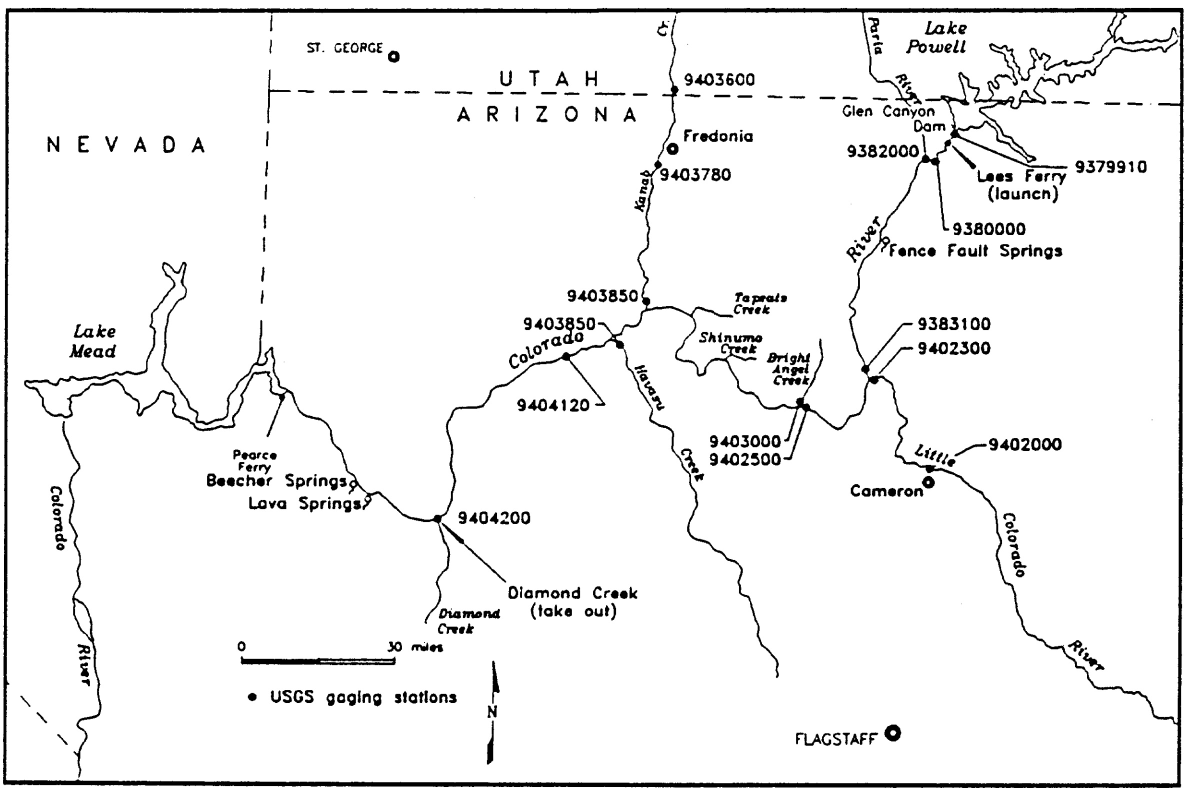


Fig. 3-1. Locations of stream gages used for hydrology analysis.

report, using data from adjacent gaging stations where obvious data irregularities existed. Final published records of the USGS are not expected to vary significantly from those presented in this report.

A streamflow routing model was developed for this study to provide time and site-specific flow for correlation with radiotelemetry observations of adult humpback chub and collection of drift material. This flow routing model was based on the flood wave theory (Lazenby 1987), using the nearest stream gages for calibration. Stage-discharge relationships were derived from USGS stream gages for determination of flow from channel bathymetry (See Chapter 7 - HABITAT).

Mainstem Colorado River

Flow data for the Colorado River in Grand Canyon were obtained from five USGS stream gages (Fig. 3-1), identified by the following gage numbers and descriptions:

- 09380000 - at Lees Ferry, AZ
- 09383100 - above Little Colorado River, AZ
- 09402500 - near Grand Canyon, AZ
- 09404120 - at National Canyon, AZ
- 09404200 - above Diamond Creek, AZ

Historic records were available from the Lees Ferry gage (1895 to present) and from the Grand Canyon gage (1922 to present), but only intermittent records were available from above the LCR, at National Canyon, and above Diamond Creek (mid-1980s to present). The gage above the LCR was used most frequently because of its proximity to many aspects of this investigation that required time and site-specific streamflow information (e.g., fish movement from radiotelemetry observations, habitat assessment, fish movement into tributaries from channel bathymetry). Missing or aberrant discharge measurements were replaced using routed flow data from the Lees Ferry gage. Because USGS discontinued gaging streamflow above the LCR in April 1993, GCES began collecting flow data in March 1993, and a correlation was developed between the two records to adjust the GCES data and provide a consistent record.

Little Colorado River

Flow data for the LCR were obtained from the following two USGS stream gages (Fig. 3-1):

- 09402000 - near Cameron, AZ
- 09402300 - near mouth, AZ

The gage near Cameron provided an historic record of flow for the LCR since 1947. However, the gage was located 45 mi (72 km) upstream of the confluence, and did not record flow from Blue Springs (21 km upstream of the confluence), which was the major source of base flow for the LCR. The gage above the confluence with the mainstem was operated from 1987 to January 1993, when it was disabled by an unusually high flood. GCES measured stage at this location with a manometer pressure sensor starting in January 1993, but no correlation with discharge was made in time for this report.

Other Tributaries

Flow data for major tributaries in Grand Canyon, other than the LCR, were obtained from the following three USGS stream gages (Fig. 3-1):

- 09382000 - Paria River at Lees Ferry, AZ
- 09403000 - Bright Angel Creek near Grand Canyon, AZ
- 09403780 - Kanab Creek near Fredonia, AZ

Of seven major tributaries identified in the study region, only four had USGS gaging streamflow data--LCR, Paria River, Bright Angel Creek, and Kanab Creek. No USGS gages were located on Shinumo Creek, Tapeats Creek, or Havasu Creek. The gages on the Paria River and Bright Angel Creek were each located within 1.2 mi (2 km) of the mouth, and were valuable for determining annual and seasonal inflow into the Colorado River. The Kanab Creek gage was located about 31 mi (50 km) upstream from the mouth, and reflected general hydrology.

FLOW CHARACTERISTICS

Mainstem Colorado River

Pre-Dam Flows

Prior to completion of Glen Canyon Dam in 1963, flow of the Colorado River through Grand Canyon was characterized by dramatic annual and seasonal variation. Year-to-year variation depended on snowpack accumulated high in the basin's headwaters. During high runoff years, annual flow volume exceeded 18 maf, while the lowest recorded annual discharge at Lees Ferry, in 1934, was only 4.4 maf (Fig. 3-2). Mean annual discharge for 51 water years (WY) prior to the dam (WY 1912-62) was 17,850 cfs and mean volume was 12.93 maf. For 26 years after initial filling of Lake Powell (WY 1965-90), mean annual discharge was 14,350 cfs and mean volume was 10.40 maf.

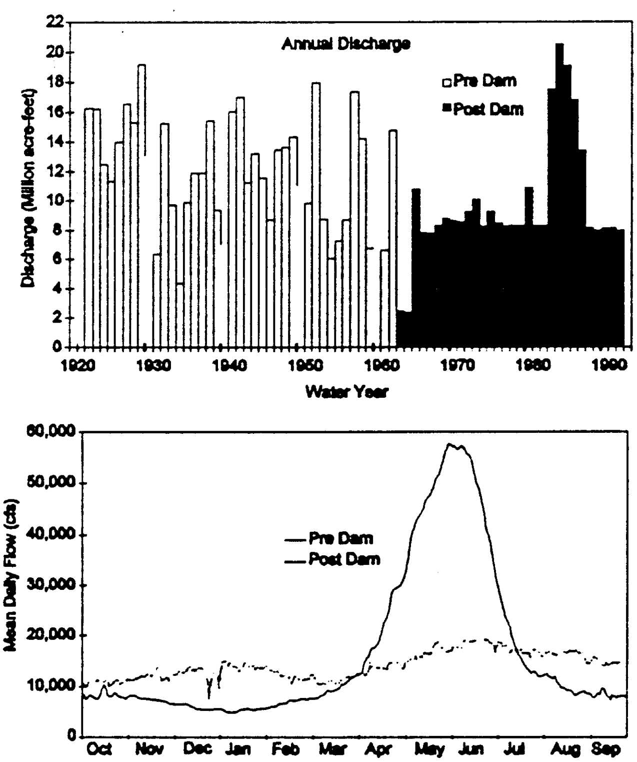


Fig. 3-2. Mean discharge (WY 1922-92) and of mean daily pre-dam (WY 1922-62) and post-dam (WY 1965-92) flow of the Colorado River at Lees Ferry, AZ.

Pre-dam seasonal discharge patterns were characterized by exceptionally high spring and early summer flows, and low fall and winter flows (Fig. 3-2). Flows typically began rising in March with low elevation snowmelt, and were generally highest in late May and early June with snowmelt runoff. Although flows in June averaged nearly 60,000 cfs, peak daily flows frequently were over 100,000 cfs. Flows typically receded in late June and July, and from August through March, averaged 5000 to 10,000 cfs. Lowest recorded flow at Lees Ferry, since the USGS gage was installed in 1895, was 750 cfs on December 27, 1924, and highest was 220,000 cfs on June 18, 1921 (Boner et al. 1990). Maximum discharge since at least 1868 was about 300,000 cfs on July 7, 1884, and climatological evidence from tree rings indicates that a flow of about 500,000 cfs occurred in the 1600's (Webb *****).

Post-Dam Flows

Annual and seasonal flow variation dramatically decreased, and daily fluctuations dramatically increased when Glen Canyon Dam was closed on March 13, 1963. Except in years of high-runoff (WY 1983-87), year-to-year variation in total annual discharge has been maintained between 8 and 9 maf (Fig. 3-2). Average daily post-dam flows have exceeded 30,000 cfs only about 3% of the time, and have been less than 5000 cfs about 10% of the time. Seasonal streamflow regime has also been modified, with mean daily springtime flows reduced from about 60,000 cfs to less than 20,000 cfs. Conversely, mean daily flows during late summer and winter have increased from a range of 5000-10,000 cfs to 10,000-15,000 cfs (Fig. 3-2). Fluctuations within the day have varied dramatically for peaking power generation, with a range in median (equalled or exceeded 50% of the time) daily fluctuations (difference between minimum and maximum daily releases) of about 12,000 cfs in October to about 16,000 cfs in January and August. Minimum flows during peaking power operations ranged from 1000 to 4000 cfs prior to August 1, 1991.

Hydroelectric power generation is one of the more significant operational aspects affecting the character of Glen Canyon Dam releases through Grand Canyon. Since hydroelectric power is used primarily for "peaking power" (power needs above base loads brought about by daily changes in demand), water is held in the reservoir at night when demand for power is low, and released at higher volume during high daytime demand. Weekends and holidays are often extended periods of low flow. This daily fluctuation in releases generates long waves which travel downriver with a characteristic pattern (Fig. 3-3). Discharge and river flow velocities are substantially greater at wave peaks than at wave troughs. As the waves move downriver, wave peaks travel faster and tend to overtake wave troughs, but because of flow hydraulics, wave peaks maintain similar magnitude and wave troughs increase. High tributary inflows may disrupt this pattern by increasing discharge for both wave peaks and wave troughs.

Six distinct, and sometimes overlapping, operational scenarios were evident for post-dam flows of the Colorado River in Grand Canyon for WY 1963-93 (Fig. 3-4):

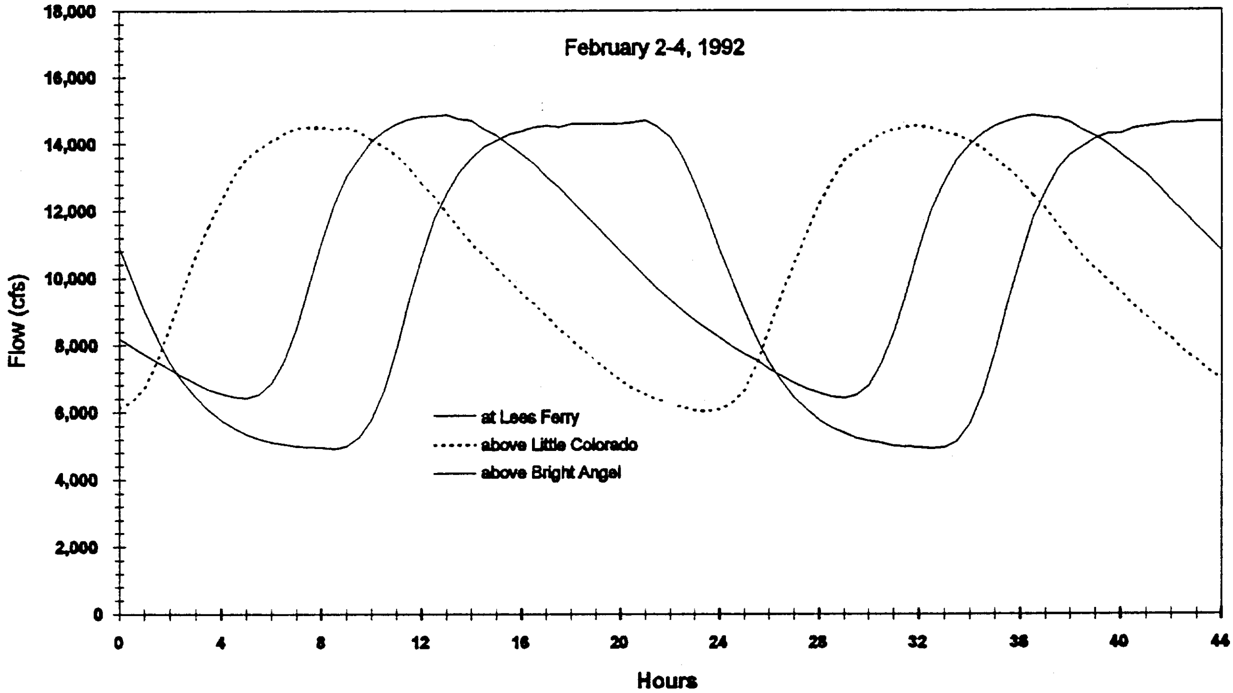


Fig. 3-3. Characteristic wave patterns generated by daily fluctuating releases over a 44-h period, as measured simultaneously at Lees Ferry, above LCR, and above Bright Angel.

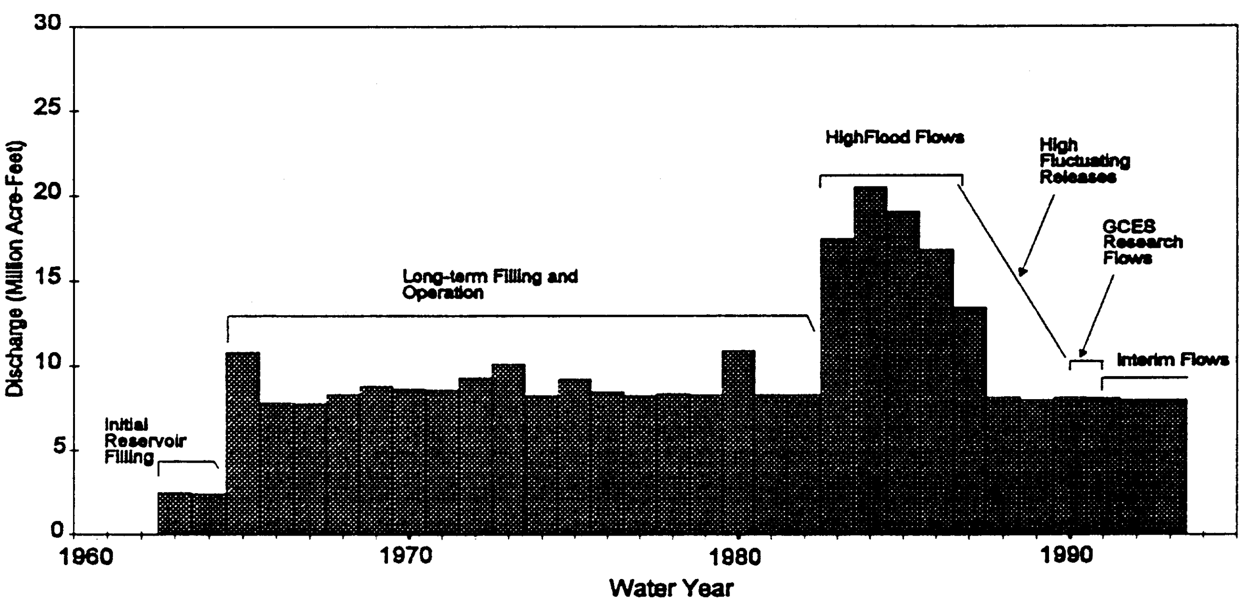


Fig. 3-4. Six operational scenarios during post-dam discharges (WY 1963-93), as measured at Lees Ferry, AZ.

- Initial reservoir filling from March 1963 through WY 1964
- Long-term filling and operation from WY 1965 to WY 1982
- High floods flows from WY 1983 through WY 1986
- High fluctuating releases from WY 1987 to June 1, 1990
- GCES Research flows from June 1, 1990 through July 29, 1991
- Interim flows beginning August 1, 1991

For the first 2 years following closure of Glen Canyon Dam in 1963, releases were low to allow for initial filling of the reservoir. Minimum daily flow on January 23 and 24, 1963 was 700 cfs, as a result of closing the coffer dam, and annual discharge in 1963 and 1964 was less than 2.5 maf. Water released through the dam was of similar chemical and thermal nature to upstream river water through the late 1960's, but became increasingly cold and clear as the reservoir filled and impounded sediments, eventually stratifying to trap cold water in the lowermost hypolimnion. Lake Powell reached maximum capacity of 26.373 maf on July 14, 1983, at 3708 ft (1130 m) elevation (Boner 1990).

The third operational scenario resulted from heavy snowfall in winter 1982-83 and 1983-84 which produced an unusually high runoff, and a maximum discharge of 97,300 cfs on June 29, 1983. Over 20 maf were released through the dam in WY 1984 (October 1, 1983 through September 30, 1984), more than any year since WY 1922. Annual releases from WY 1983 through WY 1987 averaged 12 maf, as a result of this wet period.

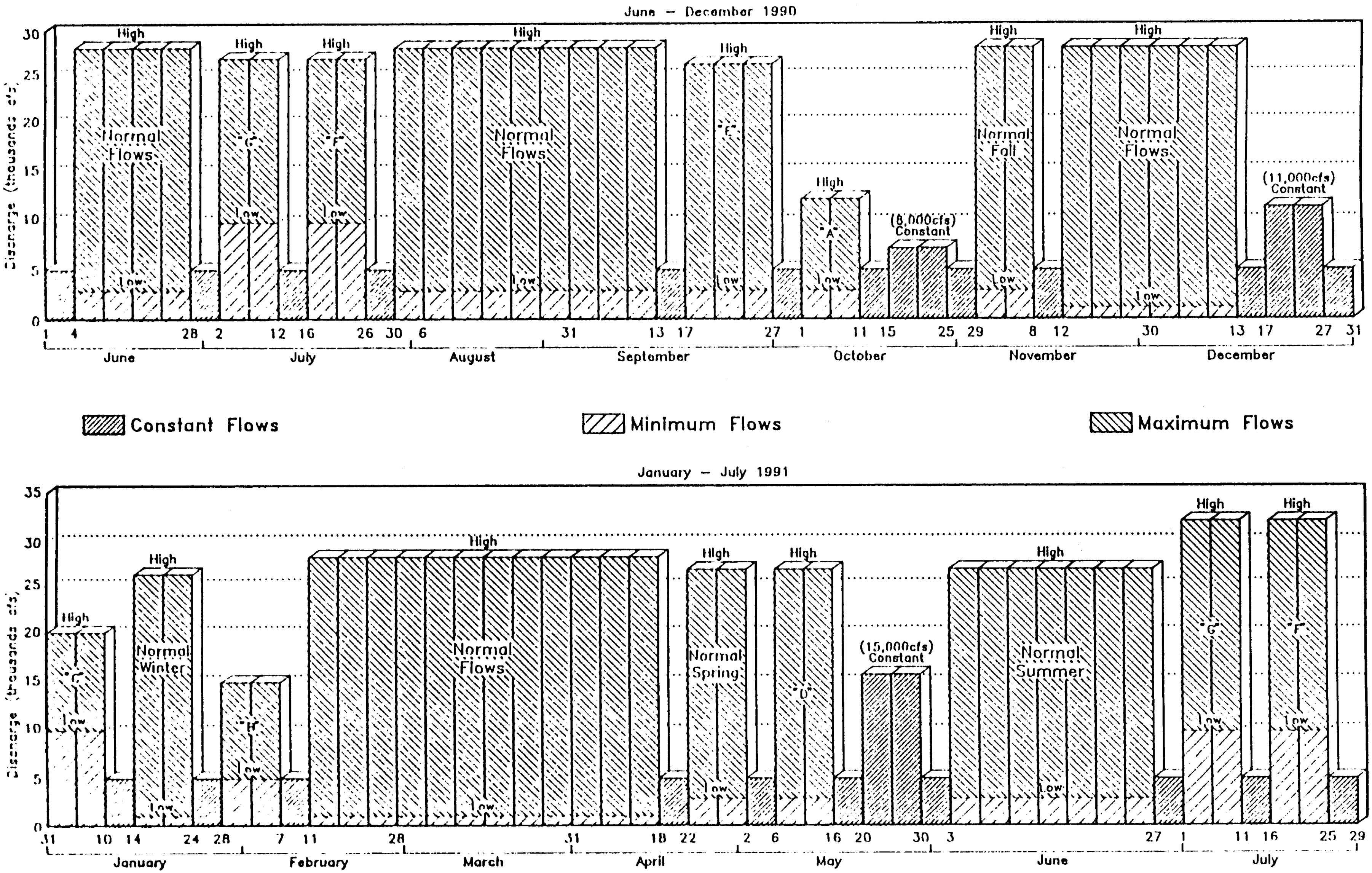
The period from WY 1987 to June 1, 1990, was characterized by low annual runoff, and high daily fluctuating releases, as a result of increased regional peaking power demands. Typical daily release patterns (Fig. 3-5) for a low-release year (WY 1989), moderate release year (WY 1987), and high release year (WY 1984) (U.S. Department of Interior 1994) illustrate the wide variation of operational scenarios caused by local weather patterns and peaking power demands. The magnitude of daily fluctuations was greater for low to moderate release years than for high release years.

Releases from June 1, 1990 through July 29, 1991 were identified as research flows--releases requested by GCES to evaluate the effects of controlled releases on canyon resources (Fig. 3-6). These releases were characterized by normal flow for periods of 10-30 d with:

- minimum daily releases of 1000 cfs from Labor Day to Easter, and 3000 cfs from Easter to Labor Day
- maximum release of 31,500 cfs
- daily fluctuations of 30,500 cfs/24 h from Labor Day to Easter, and 28,500 cfs/24 h from Easter to Labor Day
- unrestricted ramping rate

Fig. 3-5. Low, moderate, and high release water years for Glen Canyon Dam. Used with permission of Bureau of Reclamation, Colorado River Studies Office, Salt Lake City, UT.

Fig. 3-6. Research flow schedule for releases from Glen Canyon Dam. The 3-d 5000 cfs constant flows were scheduled to begin at 12:01 a.m. on Friday and conclude at 12:01 a.m. on Monday. The 8000 cfs, 11,000 cfs, and 15,000 cfs constant flows each lasted 11 d.


June – December 1990
Discharge (thousands cfs)
High
Normal Flows
"G"
"F"
"E"
"A"
Low
(8,000cfs) Constant
Normal Fall
(11,000cfs) Constant
June
July
August
September
October
November
December
Constant Flows
Minimum Flows
Maximum Flows
January – July 1991
Normal Winter
"C"
"H"
Normal Spring
"D"
(15,000cfs) Constant
Normal Summer
January
February
March
April
May

The research flows also consisted of constant flow of:

- 5000 cfs for 3 d at least once monthly, except for March 1991
- 8000, 11,000, and 15,000 cfs in October and December 1991, and May 1992, respectively.

Beginning August 1, 1991, Secretary of Interior Manuel Lujan issued a decree to operate Glen Canyon Dam under "interim operating criteria" until the Record of Decision for the Glen Canyon Dam Environmental Impact Statement, expected in October 1995. Interim criteria were characterized by:

- Flows limited to a maximum of 20,000 cfs
- Daytime minimum of 8000 cfs, and a nighttime minimum of 5000 cfs
- Maximum allowable daily flow variation of 5000 cfs for low (<600,000 af), 6000 cfs for medium (600,000-800,000 af), and 8000 cfs for high (>800,000 af) volume months
- Maximum allowable rate of release change for rising flows (up ramp) no greater than 2500 cfs/h, with a maximum of 8000 cfs change during any 4-h period
- Maximum allowable rate of release change for falling flows (down ramp), of 1500 cfs/h.

This investigation spanned from October 1990 through November 1993, and covered three complete water years (WY 1991-93), plus the first two months of WY 1994 (i.e., October and November 1993). Hydrographs showing daily high and low flows for this period for the Colorado River above the LCR are presented in Fig. 3-7. Except for "normal flow" periods during research flows, daily and hourly flow variations were generally less during the 3-year study period than prior to inception of research flows on June 1, 1990.

Little Colorado River

The LCR is the largest tributary to the Colorado River in Grand Canyon, with a drainage area of about 26,964 mi^2 (69,832 km^2) and an average annual discharge of 170,000 af. Although the LCR drainage comprises nearly 23% of the area of the Colorado River Basin, it contributes less than 2% of flow volume. The LCRoriginates on Mount Baldy in the White Mountains and flows north for about 256 mi (412 km) through northeastern Arizona, entering the Colorado River at RM 61.3 (61.3 mi below Lees Ferry, 76.8 mi below Glen Canyon Dam). Stream gradient in the last 2 km is low with an average change of about 12 m/km.
originates on Mount Baldy in the White Mountains and flows north for about 256 mi (412 km) through northeastern Arizona, entering the Colorado River at RM 61.3 (61.3 mi below Lees Ferry, 76.8 mi below Glen Canyon Dam). Stream gradient in the last 2 km is low with an average change of about 12 m/km.

The LCR, unlike the upper Colorado River, does not drain a large mountainous region, and does not produce large snowmelt runoffs. Although greatest annual flows generally originate from snowmelt in March and April, high flows often occur from late summer to winter (Fig. 3-8), as a result of l ocal high-intensity rainstorms. The LCR is often dry at the Highway 89A bridge near Cameron, but a series of springs located 3-13 mi (5-21 km) upstream from the mouth provide a relatively constant baseflow of 200-300 cfs. The largest spring, Blue Springs, is located 13 mi (21 km) from the mouth, and imparts the characteristic aqua-blue color to the LCR.

Flows of the LCR during the study period (WY 1991-93) displayed the erratic variability in streamflow, characteristic of this stream (Fig. 3-9). Volume discharged in WY 1991 was below normal from low snowmelt runoff, and only three major flood events occurred--peaks of about 2200 cfs in early January and March, and about 2700 cfs in mid April. Above normal runoff occurred in WY 1992 and WY 1993. In WY 1992, an extended spring runoff occurred from February through April, and unlike WY 1991, several spike

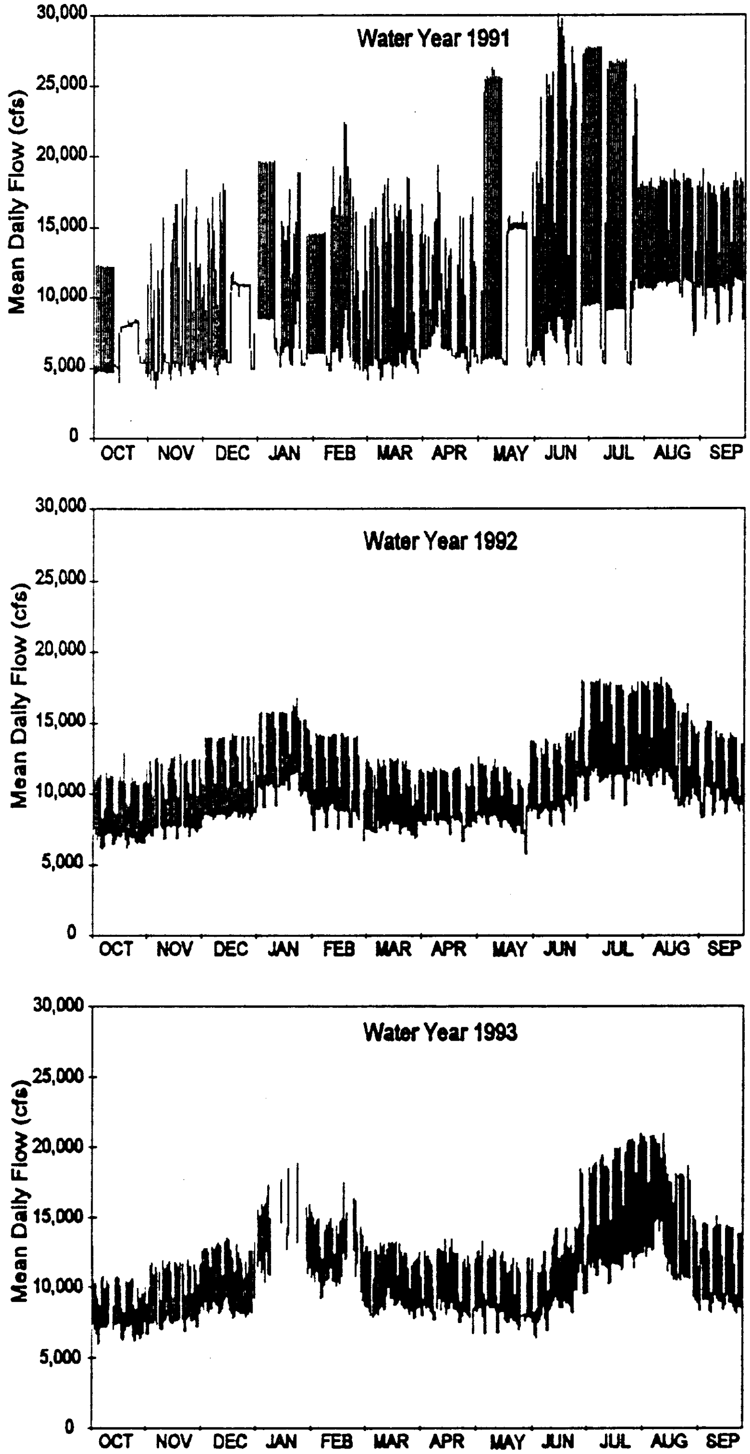


Fig. 3-7. Mean daily flow of the Colorado River for WY 1991-93 as measured above the Little Colorado River, AZ.

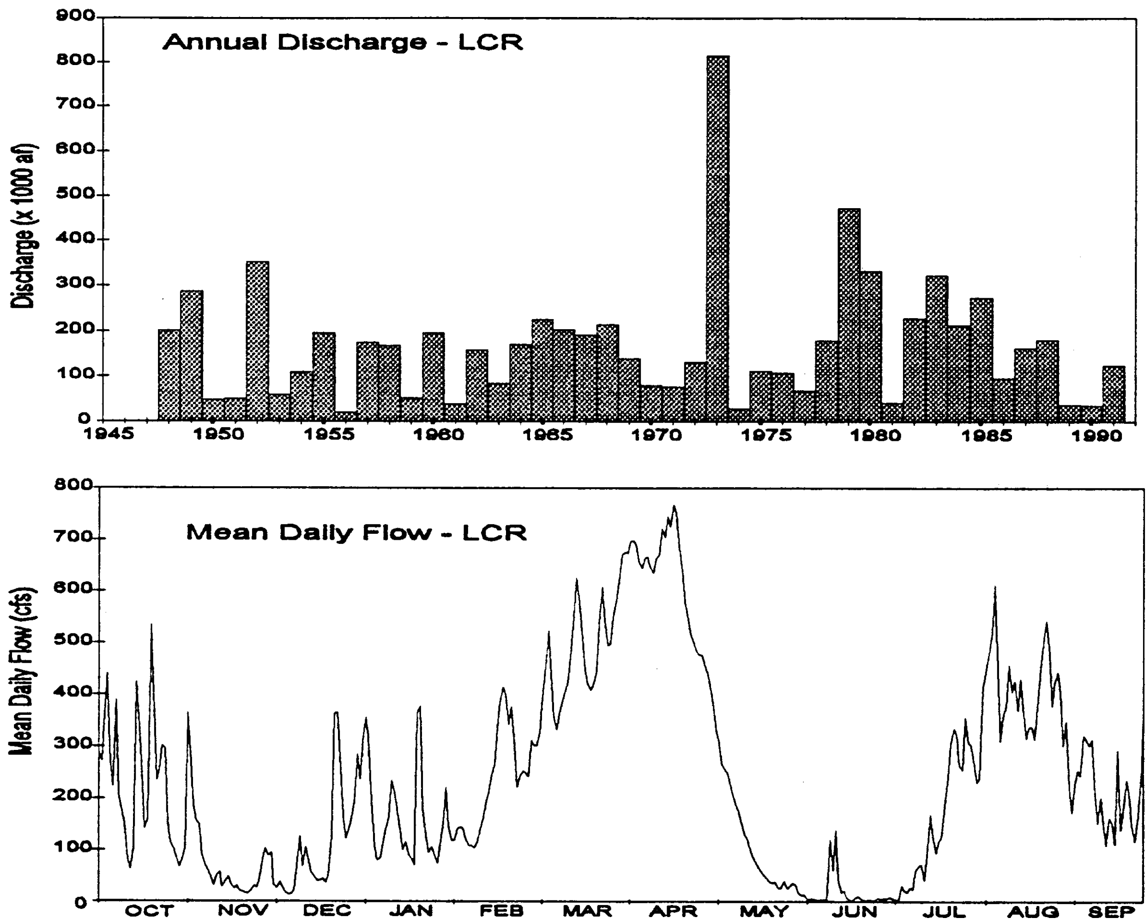


Fig. 3-8. Annual discharge and mean daily flow for WY 1948-91 of the Little Colorado River at Cameron, AZ.

flows of about 2200-2500 cfs occurred throughout summer. The high rainfall-induced flow in June 1992 was unusual, since high intensity rainstorms on the Colorado Plateau usually occur in late summer (late July to mid September). WY 1993 was marked by an unusually high winter flood event that peaked at about 17,000 cfs on January 13, 1993, and a second event of about 14,000 cfs in late January 1993. The first event disabled the stream gage near the mouth, and precluded continued streamflow data for the lower LCR.

Other Tributaries

Paria River

The Paria River enters the Colorado River about 1 mi (1.6 km) downstream from Lees Ferry (Fig. 3-1). It originates in the Escalante Mountains and the Paria Plateau of southern Utah, and flows south for 55 mi (88 km), draining an area of approximately 1409 mi^2 (3650 km^2). The lower 2 km of the channel has a low gradient of about 12 m/km. Unlike the Colorado River and LCR, the Paria River does not originate in high mountainous areas (highest elevation in the watershed is less than 6560 ft, 2000 m), and springtime snowmelt runoff is not a large contributor to streamflow. The largest flows typically occur in late summer and fall following high-intensity rainstorms. This irregular and unpredictable streamflow pattern, caused by heavy rainfall on relatively barren and unvegetated ground, produces large sediment loads that flow into the Colorado River (See Chapter 4 - WATER QUALITY).

Mean annual discharge of the Paria River was about 21,000 af, with average streamflow of 29 cfs that varied widely (Fig. 3-10). Minimum annual flows typically occurred from mid May to mid July, when flow was often less than 10 cfs. Beginning about mid July, summer storm activity often produced flash floods with discharges >1000 cfs. However, without such runoff, low flows were likely. The probability of storm-generated runoff typically decreased in November.

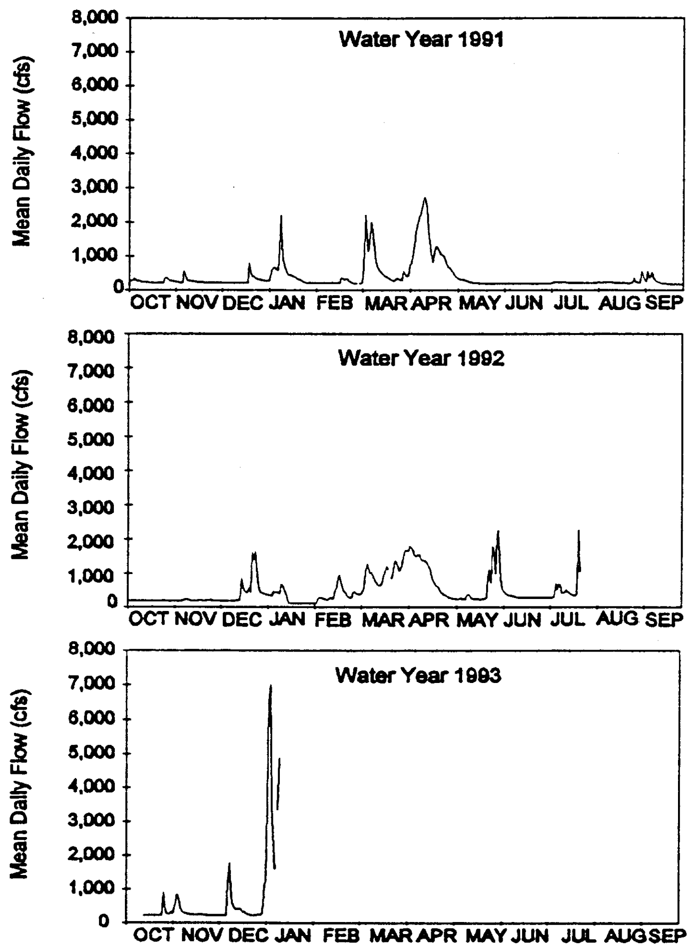


Fig. 3-9. Mean daily flow of the Little Colorado River for WY 1991-93 at Cameron, AZ, and near the mouth. Discontinuous line indicates missing data.

Bright Angel Creek

Bright Angel Creek originates near Greenland Lake in the southern part of the Kaibab Plateau in northern Arizona. It flows south for about 12.5 mi (20 km), and enters the Colorado River at RM 87.6, near Phantom Ranch. The watershed of Bright Angel Creek is small, and encompasses an area of about 100 mi² (260 km²). The stream drains a karstic ground water system, with numerous springs providing a relatively constant baseflow of about 20 cfs. For the period of record, discharge typically increased with local snowmelt, between April and early June, when flows often reached several hundred cubic feet per second (Fig. 3-10). However, in drought years, flows never exceeded 50 cfs.

Shinumo Creek

Shinumo Creek originates at South Big Springs within the Shinumo Amphitheater, and drains about 85 mi² (220 km²) of the southern Kaibab Plateau in northern Arizona--similar to terrain drained by Bright Angel Creek.

The stream flows south for about 12.5 mi (20 km), and enters the Colorado River at RM 108.5. Stream gradient is high, with an average elevational change of about 46 m/km in the last 2 km. Numerous springs support a year-round base flow, and annual streamflow regime is probably similar to that of Bright Angel Creek. A USGS stream gage has never been installed in Shinumo Creek, and discharge information is based on individual measurements by different investigators. Johnson and Sanderson (1968) measured a range of flow near the mouth of 3.5-16 cfs. Maddux et al. (1986) reported a range of 10.5-108.0 cfs during a study from April 1, 1984 to May 30, 1986.

Tapeats Creek

Tapeats Creek originates in the Tapeats Amphitheater and drains about 40 mi² (100 km²) of the southern Kaibab Plateau in northern Arizona. It is formed by a number of springs, the largest of which is Tapeats Spring, and flows south for about 6 mi (10 km) to enter the Colorado River at RM 133.7. Springs originating from Monument and Crazy Jug points, as well as Thunder Springs, which feeds Thunder River and enters Tapeats Creek about 2 mi (3 km) above the Colorado River, also provide water to Tapeats Creek. Although a USGS stream gage has not been installed in Tapeats Creek, it is estimated that this stream has the highest discharge of any tributary originating from the north rim of Grand Canyon (Huntoon 1968). Maddux et al. (1986) reported a flow range of 78.4-281.9 cfs from April 1, 1984 to May 30, 1986. Stream gradient in the last 2 km is among the steepest of tributaries in Grand Canyon, with an average change of about 49 m/km. Seasonal flow pattern of Tapeats Creek is probably similar to that of Bright Angel Creek (Fig. 3-10).

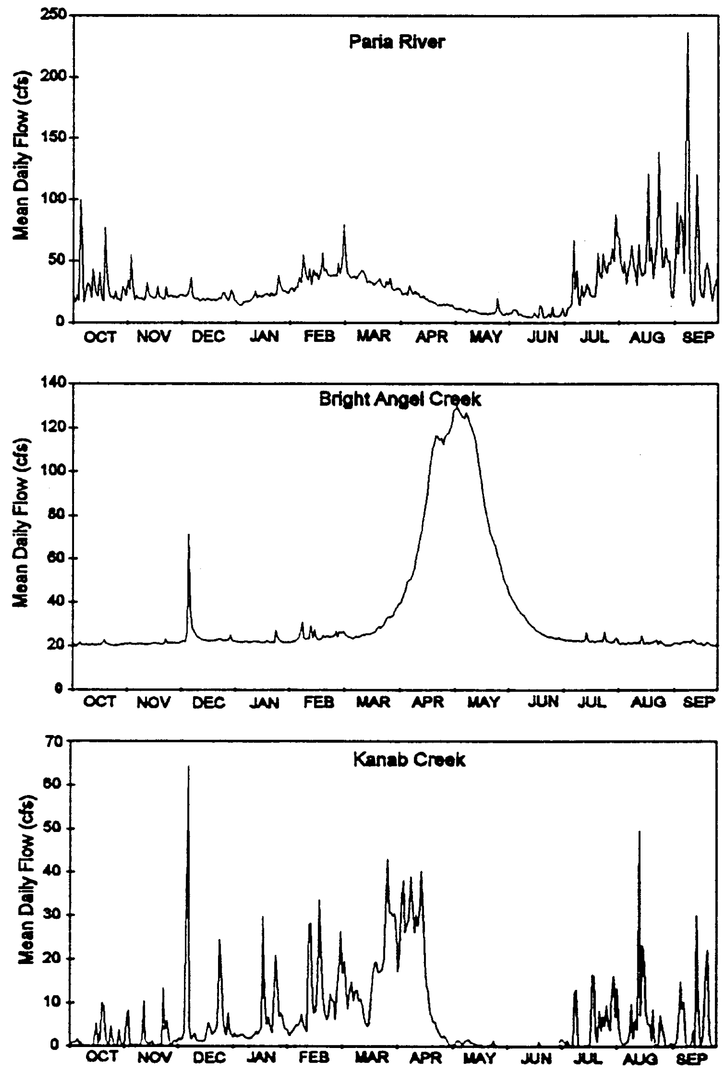


Fig. 3-10. Mean daily flow of the Paria River near Lees Ferry, AZ (WY 1923-93), Bright Angel Creek near Phantom Ranch, AZ (WY 1923-74), and Kanab Creek near Fredonia, AZ (WY 1963-80). Discontinuous line indicates missing data.

Kanab Creek

Kanab Creek originates in the Pausagunt Plateau of southern Utah, and flows south for over 62 mi (100 km) to enter the Colorado River at RM 143.5. The stream drains a watershed area of approximately 2200 mi^2 (5700 km^2), and like the Paria River and LCR, has an irregular and unpredictable flow, characterized by high, short-term floods following severe rainstorms in late summer. Mean daily flow, recorded at the USGS gage near Fredonia, Arizona (about 31 mi, 50 km, upstream from the mouth), varied dramatically from over 60 cfs in December to periods of no flow in June and July (Fig. 3-10). Maddux et al. (1986) reported a flow range of 2.8-38.0 cfs between April 1, 1984 and May 30, 1986. Stream gradient in the lower 2 km is low with an average change of about 12 m/km.

Havasu Creek

Havasu Creek is the major tributary draining the Coconino Plateau south of the Colorado River. A constant baseflow of about 70 cfs is provided by Havasu Springs, which is located about 10 mi (16 km) above the confluence with the Colorado River (Johnson and Sanderson, 1968). Havasu Creek enters the Colorado River at RM 156.7, and is the only major perennial tributary for 69 mi (111 km) to Diamond Creek (RM 225.7). Maddux et al. (1986) reported a flow range of 60.6-207.4 cfs between April 1, 1984 and May 30, 1986. Seasonal flow regime for Havasu Creek is similar to the other tributaries in Grand Canyon, with high snowmelt flows in spring, and low summer, fall, and winter baseflows, marked by high, short-term rainstorm floods. Gradient over the last 2 km of stream is moderate with an average elevational change of about 25 m/km.

DISCUSSION

Historic hydrology of the Colorado River in Grand Canyon illustrates the great annual and seasonal variability in flow, characteristic of this southwestern river. Highest annual flow volume (18 maf) from WY 1922 to WY 1962 was four times higher than lowest volume (4.4 maf), and highest mean daily flow in June (75,000 cfs) was more than one order of magnitude (10 times) greater than lowest mean daily flow in January (5000 cfs). The most dramatic illustration of system variability was the difference of nearly three orders of magnitude between record lowest (750 cfs) and estimated highest (500,000 cfs) flow. Daily variation in summer, fall, and winter was low, except for periodic rainstorm floods that, at times, dramatically increased river volume and subsided over a period of days.

Since completion of Glen Canyon Dam in 1963, annual and seasonal variability was greatly reduced, and daily variation was increased. Except for high flood flows in WY 1983-87, highest annual flow volume (11 maf) from WY 1965-WY 1990 was only 50% higher than lowest volume (7 maf), and highest mean daily flow (20,000 cfs) was only four times greater than lowest mean daily flow (5000 cfs). The difference between lowest (1000 cfs) and highest (31,500 cfs) flow was greatly reduced from pre-dam conditions, but represented daily variation through some of the post-dam period that greatly exceeded pre-dam conditions.

Release patterns from during this investigation (October 1990-November 1993), were unlike those of any comparable period of time, and unlike those witnessed by previous investigators on the Colorado River in Grand Canyon (Fig. 3-11). Flow of the Colorado River, during the first 10 months of this study (October 1990-July 1991), was characterized by intervening periods of high fluctuating flows and constant releases--the research flows. The last 28 months of the study (August 1991-November 1993) were marked by dramatically higher minimums, lower maximums, and less range in daily fluctuations--the interim flows.

Although high fluctuating releases of 1000 or 3000 cfs to 31,500 cfs, with unlimited ramping rates, were similar to previous maximum peaking power operations (e.g., WY 1987-89), the intervening monthly constant flows of 5000, 8000, 11,000, and 15,000 cfs, during research flows (June 1990-July 1991), were uncharacteristic of previous operations. Also, the elements of interim flows (starting August 1991) had not been integrated into any previous operation, i.e., minimum of 5000 or 8000 cfs, maximum of 20,000 cfs, and maximum daily variation of 5000, 6000, or 8000 cfs, with limited ramping rates.

Flows during this investigation lacked the high spring floods of pre-dam years (WY 1949-62), some exceeding 120,000 cfs, (Fig. 3-11). They also lacked the characteristic high daily fluctuating releases and periodic low flows of post-dam years (WY 1964-93). The most dramatic contrast, for this investigation, was with the period WY 1983-86, during the time of the last major mainstem investigation by AGF (Maddux et al. 1987). Researchers during that period witnessed three monthly maximums of over 40,000 cfs, and many monthly minimums of over 20,000 cfs (based on mean daily flows).

Stage-discharge relationships for the Colorado River above the LCR inflow illustrated the differences in flow magnitude and flow change rate observed in the principal humpback chub habitat. River stage varied up to ** m during research flows of 3000 to 4\31,500 cfs, and up to ** m during interim flows of 8000 to 20,000 cfs. Average ramping rate observed during research flows was 886 cfs/h (s.d.=1230), and 378 cfs/h (s.d.-379) during interim flows, while magnitude of daily flow change decreased from an average of 5643 cfs (s.d.=5144) during research flows to an average of 4014 cfs (s.d.=1991) during interim flows.

Flows of seven principal tributaries in Grand Canyon (LCR, Paria, Bright Angel, Shinumo, Tapeats, Kanab, Havasu creeks) were characteristically variable with high spring runoff, low summer flows, and erratic late summer and winter floods. Large floods of about 20,000 cfs in Havasu Creek in January 1990 and 1991, and in the LCR in January 1993 of about 17,000 cfs were dramatic and notable to this investigation. The Havasu Creek flood scoured much of in-channel travertine and most of the streamside riparian vegetation, and transported large volumes of woody debris, sand, and silt to form a temporary dam across the Colorado River. This flood occurred early in this investigation, and its effects on fish and fish habitat were largely undocumented.

The LCR flood also scoured much of the in-channel travertine (Gorman et al. (1993), and transported large volumes of sand and silt into the Colorado River. This flood occurred immediately before a scheduled B/W trip, and was the important aspect of several analyses in this report including dispersal of fish (See Chapter 5 - DISTRIBUTION AND ABUNDANCE) and reformation of channel morphology (Chapter 7 - HABITAT). Sand beaches, formed primarily from reattachment bars in large recirculating eddies, received substantial deposits of sand downstream of the LCR.

Fig. 3-11. Monthly maximum, mean and minimum flow of the Colorado River at Lees Ferry for WY 1949-1993, with fishery investigation periods indicated.

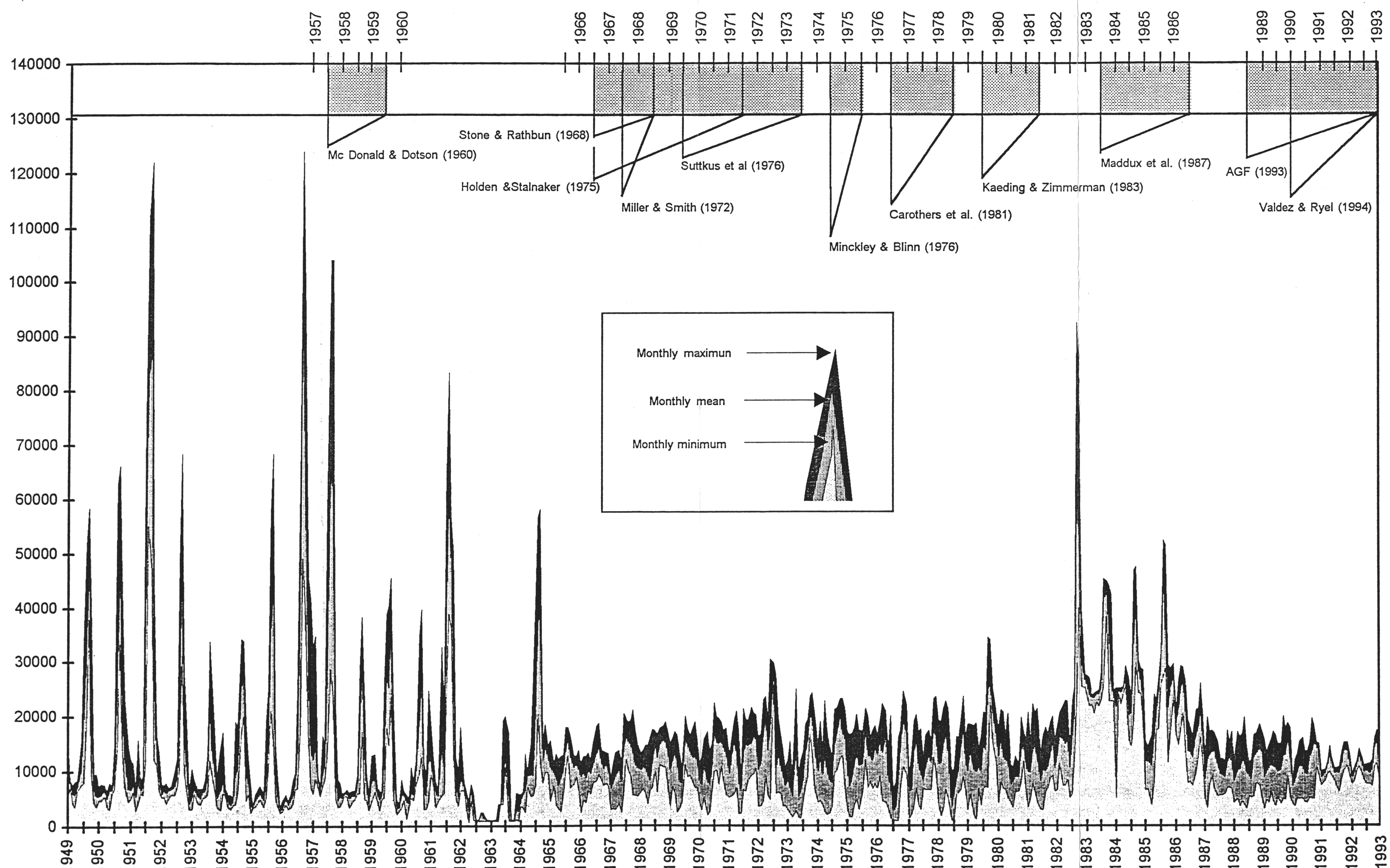
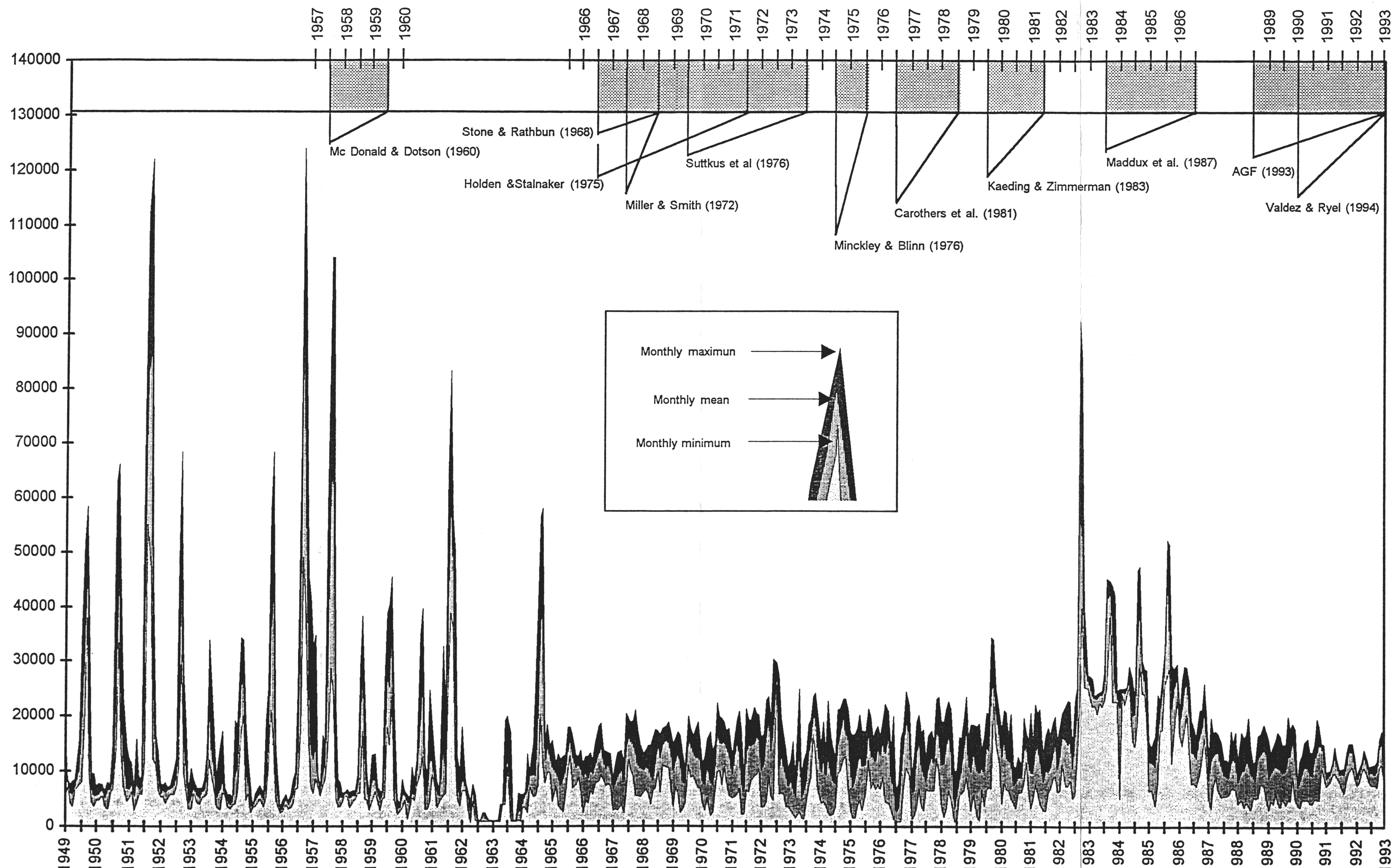
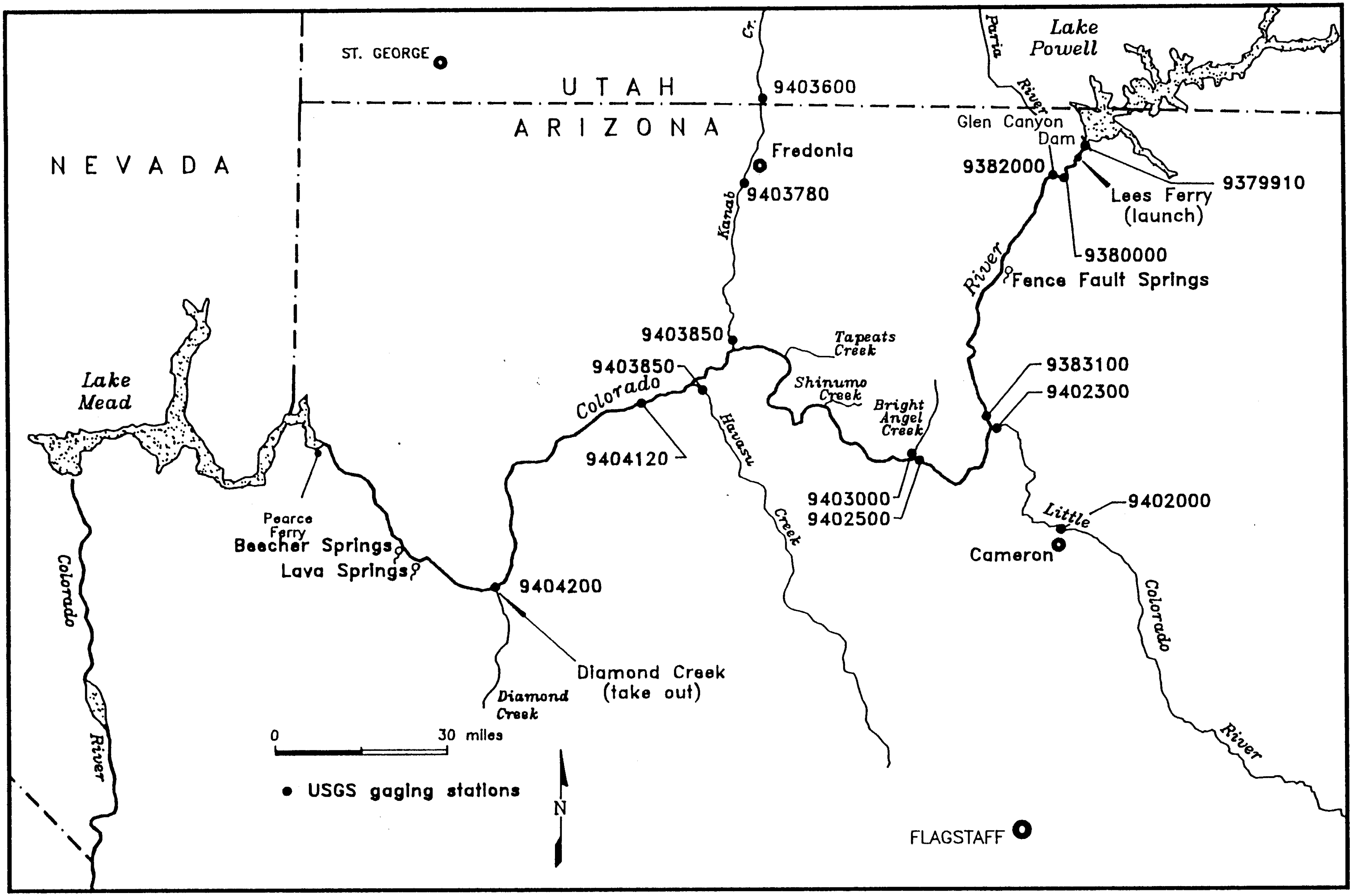

CFS
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
140000
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Mc Donald & Dotson (1960)
Stone & Rathbun (1968)
Holden &Stalnaker (1975)
Miller & Smith (1972)
Suttkus et al (1976)
Minckley & Blinn (1976)
Carothers et al. (1981)
Kaeding & Zimmerman (1983)
Maddux et al. (1987)
AGF (1993)
Valdez & Ryel (1994)
Monthly maximun
Monthly mean
Monthly minimum

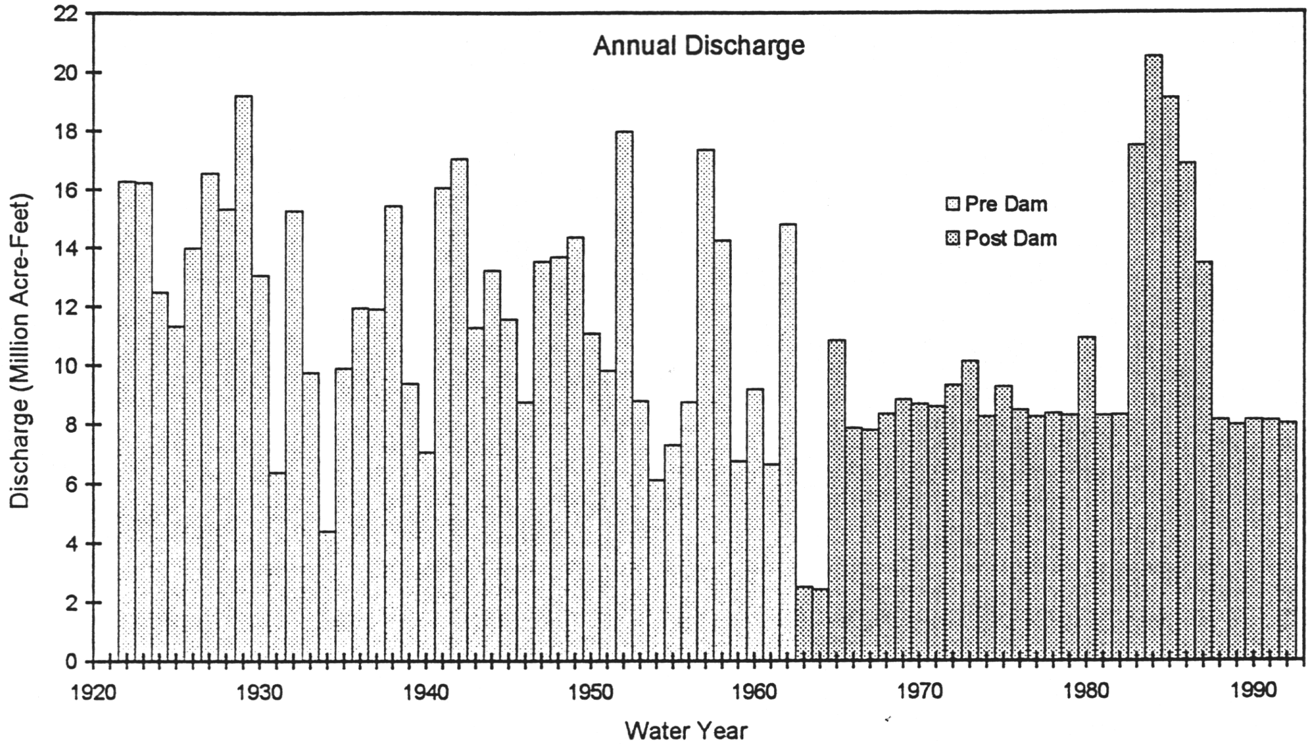
Figure 3-11


CFS
Mc Donald & Dotson (1960)
Stone & Rathbun (1968)
Holden &Stalnaker (1975)
Miller & Smith (1972)
Suttkus et al (1976)
Minckley & Blinn (1976)
Carothers et al. (1981)
Kaeding & Zimmerman (1983)
Maddux et al. (1987)
AGF (1993)
Valdez & Ryel (1994)
Monthly maximun
Monthly mean
Monthly minimum

gur 3-11



ST. GEORGE
UTAH
ARIZONA
NEVADA
9403600
Fredonia
9403780
Kanab
Cr.
Paria
River
Lake Powell
Glen Canyon Dam
9382000
9379910
Lees Ferry (launch)
9380000
Fence Fault Springs
River
9403850
Tapeats Creek
9403850
Colorado
Shinumo Creek
Bright Angel Creek
9383100
9402300
9404120
Havasu
Creek
9403000
9402500
Little
9402000
Cameron
Colorado
River
Lake Mead
Pearce Ferry
Beecher Springs
Lava Springs
9404200
Diamond Creek (take out)
Diamond Creek
Colorado
River
0
30 miles
• USGS gaging stations
N
FLAGSTAFF


Annual Discharge
Discharge (Million Acre-Feet)
Pre Dam
Post Dam
Water Year
0
2
4
6
8
10
12
14
16
18
20
22
1920
1930
1940
1950
1960
1970
1980
1990

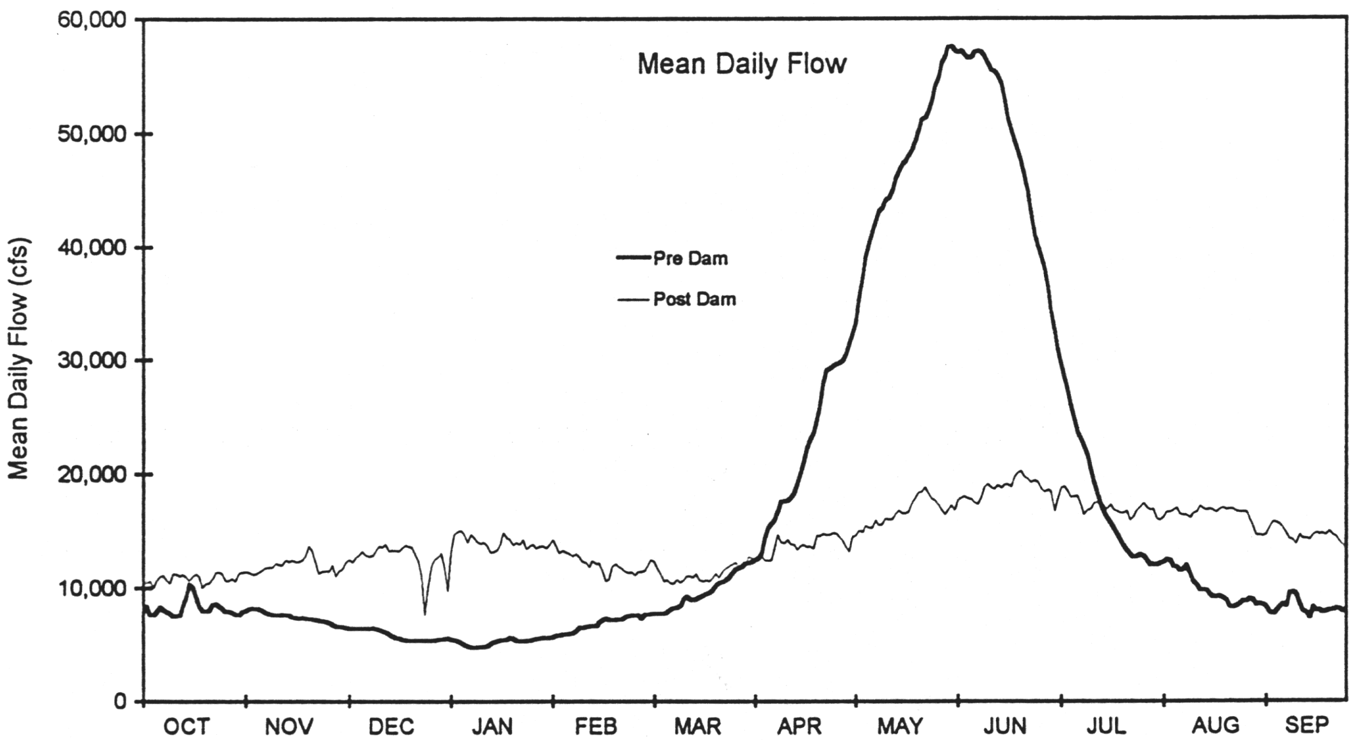

Mean Daily Flow
Mean Daily Flow (cfs)
Pre Dam
Post Dam
0
10,000
20,000
30,000
40,000
50,000
60,000
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

fIGURE 3-2

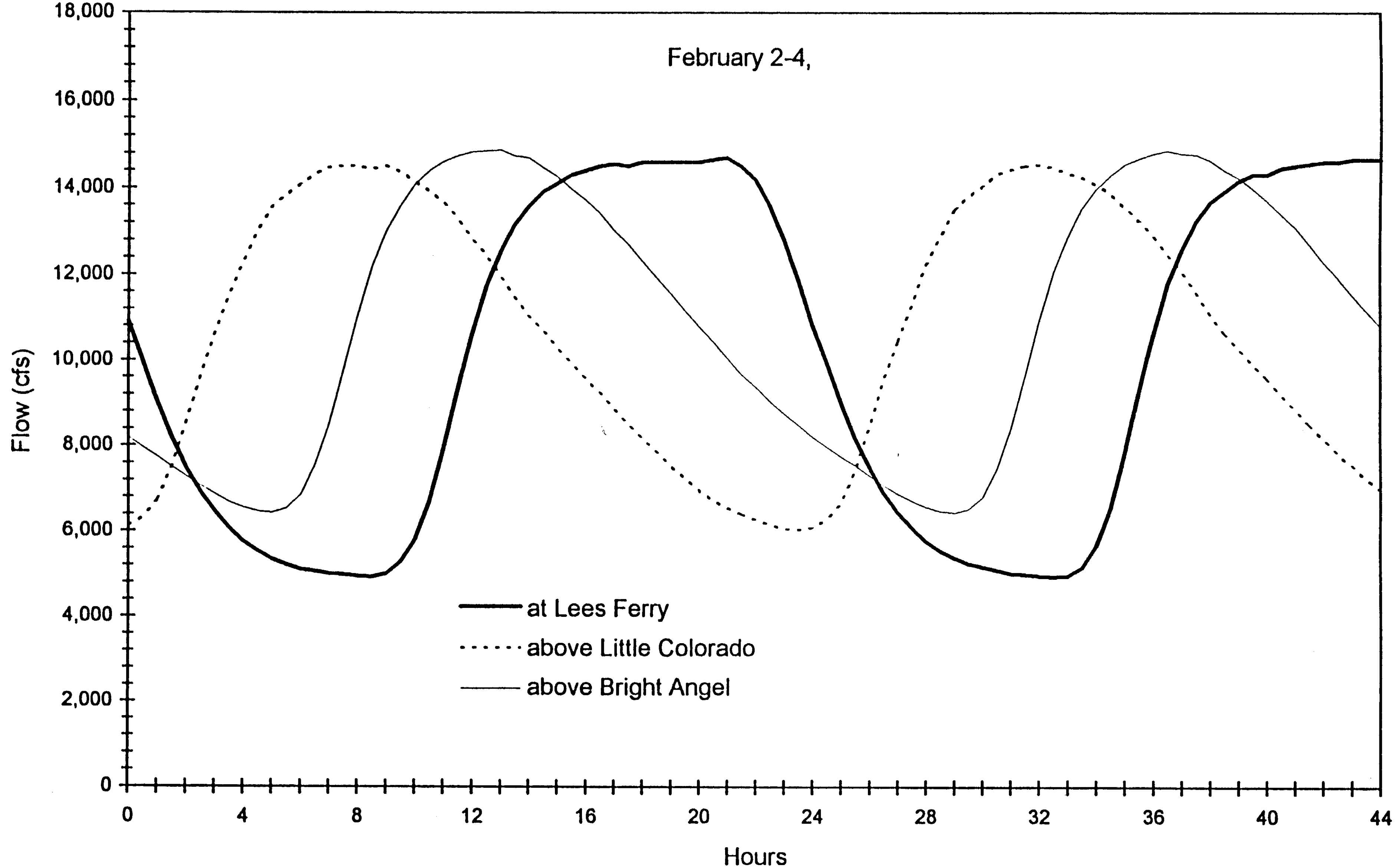

February 2-4,
Flow (cfs)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
4
8
12
16
20
24
28
32
36
40
44
Hours
at Lees Ferry
above Little Colorado
above Bright Angel

Figure 3-3

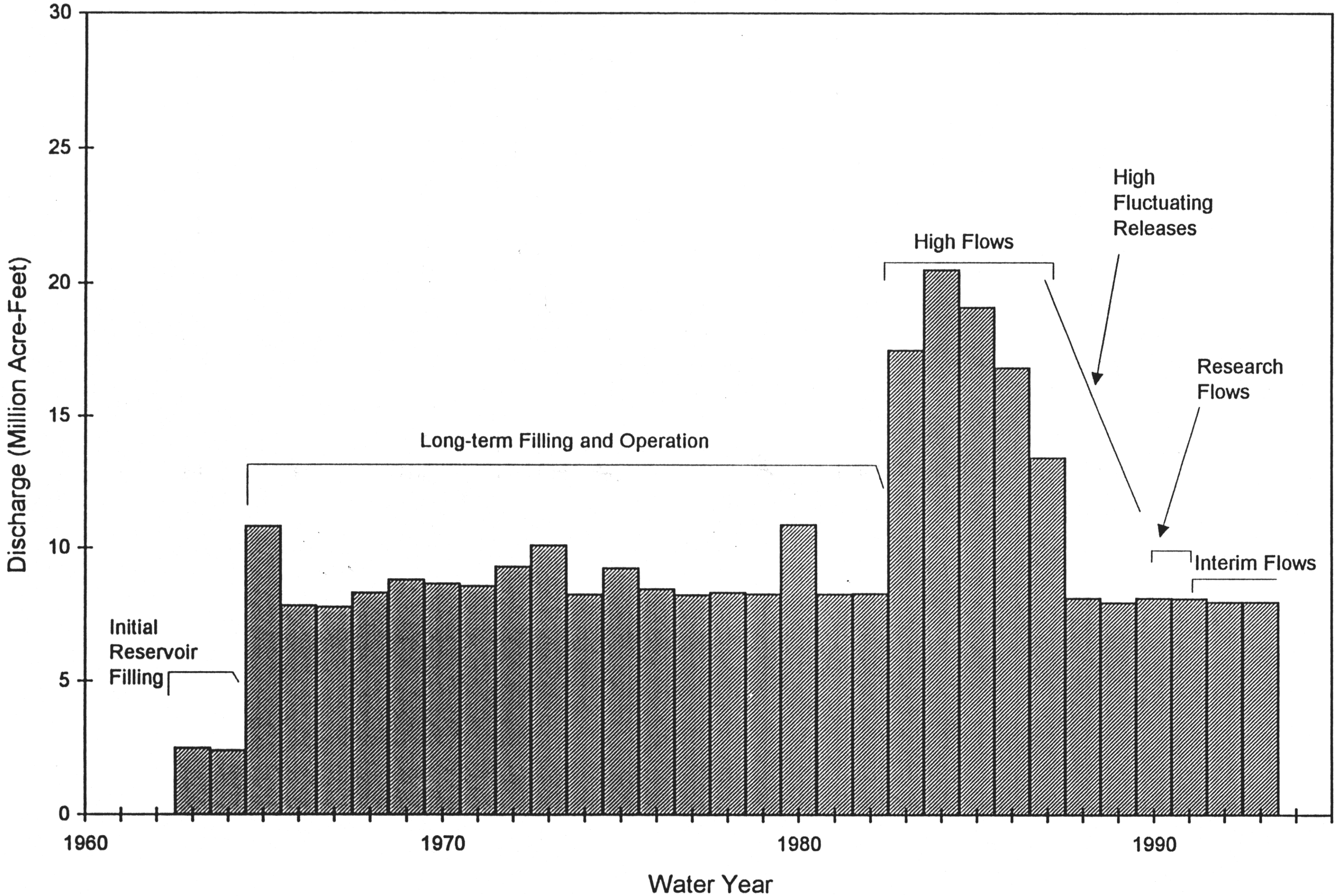
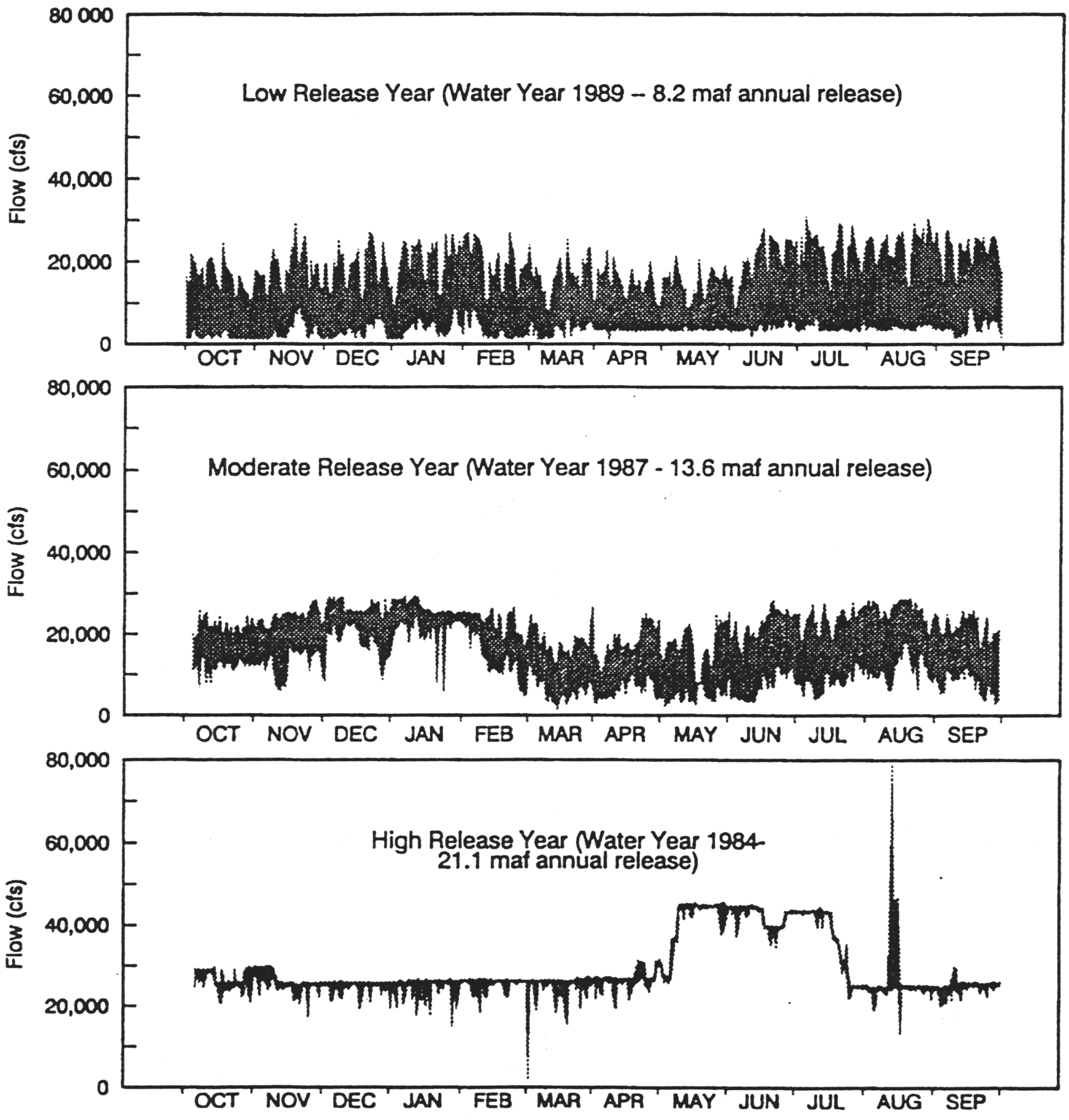
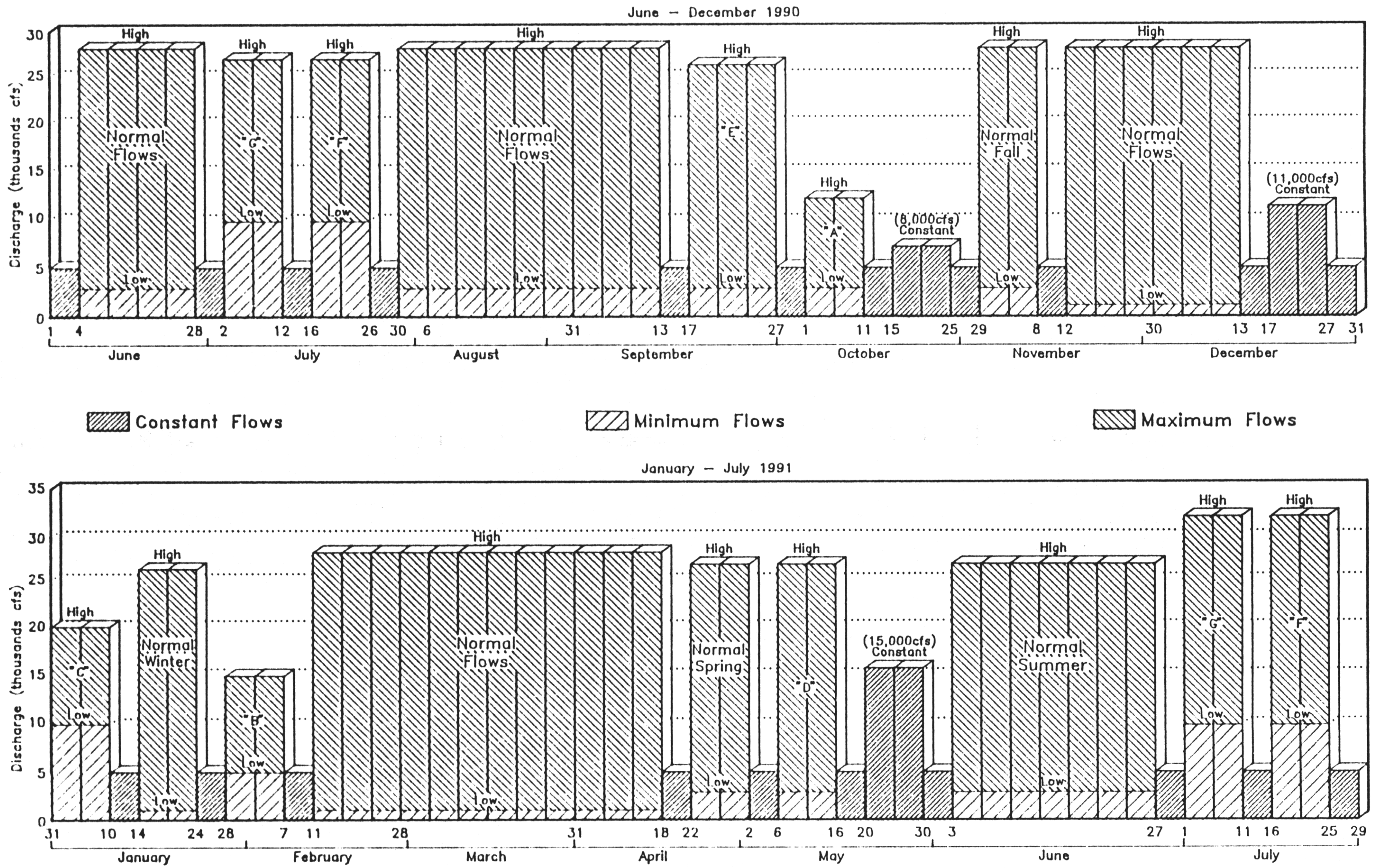

30
25
20
15
10
5
0
Discharge (Million Acre-Feet)
1960
1970
1980
1990
Water Year
Initial
Reservoir
Filling
Long-term Filling and Operation
High Flows
High
Fluctuating
Releases
Research
Flows
Interim Flows

Figure 3-4


Low Release Year (Water Year 1989 -- 8.2 maf annual release)
Moderate Release Year (Water Year 1987 - 13.6 maf annual release)
High Release Year (Water Year 1984-
21.1 maf annual release)
Flow (cfs)
80,000
60,000
40,000
20,000
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP


June – December 1990
Discharge (thousands cfs)
High
Low
Normal Flows
"G"
"F"
"E"
"A"
(8,000cfs) Constant
Normal Fall
(11,000cfs) Constant
June
July
August
September
October
November
December
Constant Flows
Minimum Flows
Maximum Flows
January – July 1991
"C"
Normal Winter
"B"
Normal Spring
"D"
(15,000cfs) Constant
Normal Summer
January
February
March
April
May

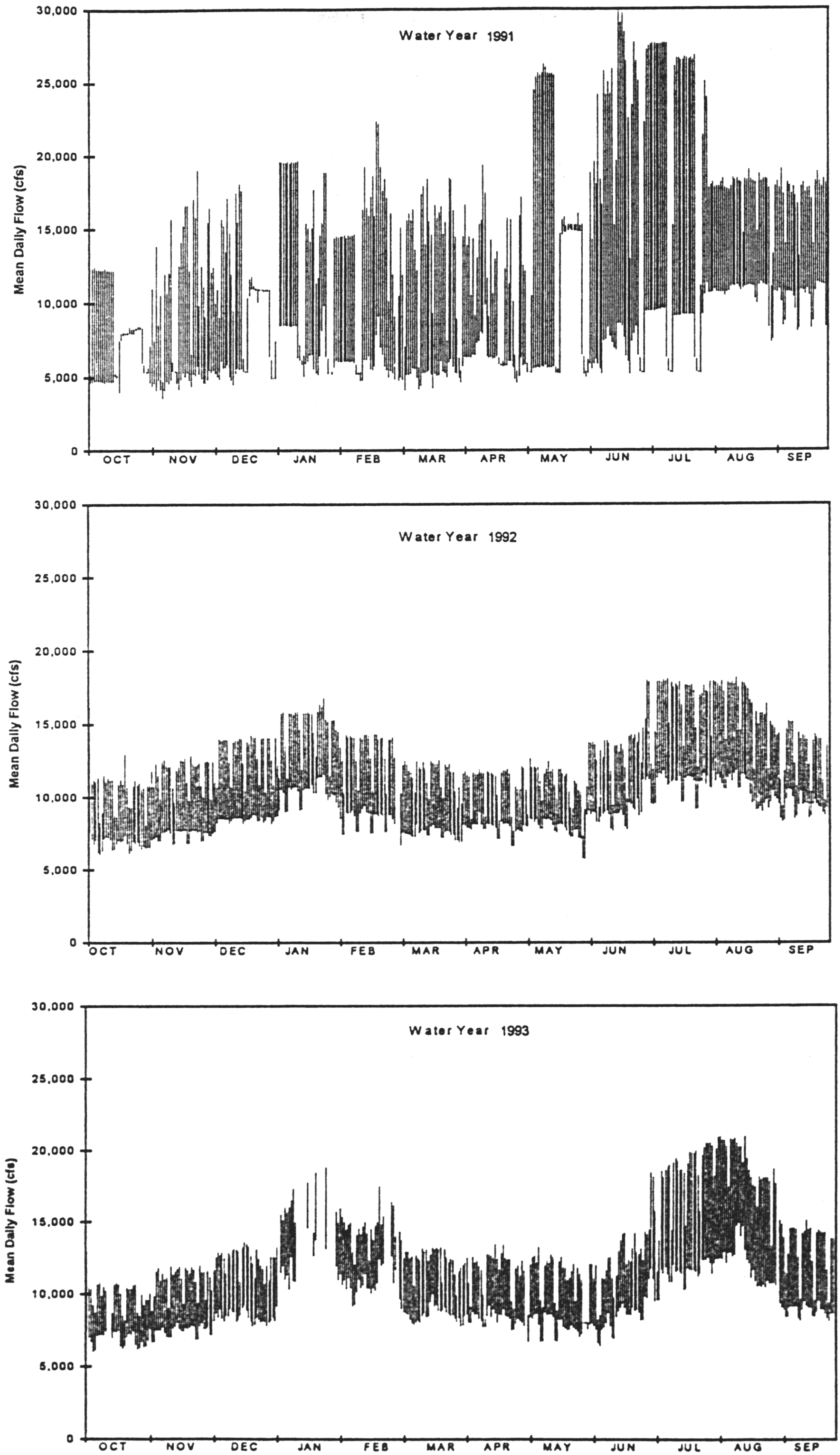
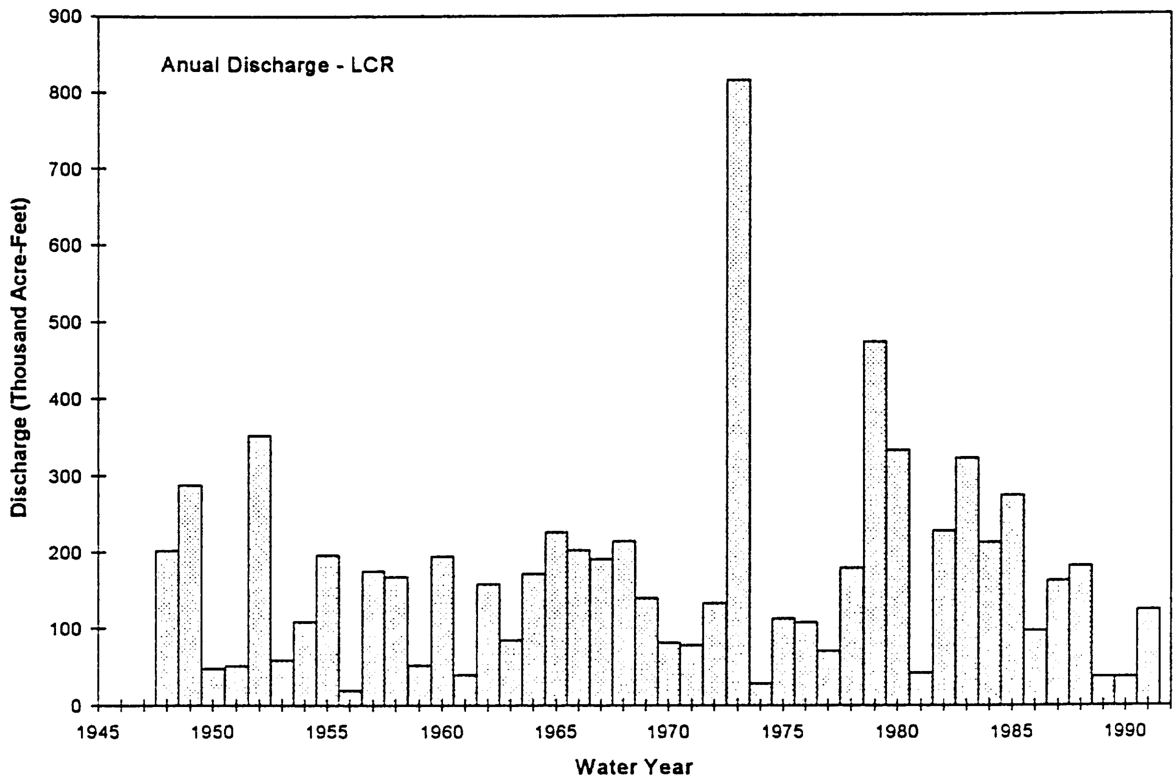

Water Year 1991
Water Year 1992
Water Year 1993
Mean Daily Flow (cfs)
30,000
25,000
20,000
15,000
10,000
5,000
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

Figure 3-7


Anual Discharge - LCR
Discharge (Thousand Acre-Feet)
0
100
200
300
400
500
600
700
800
900
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
Water Year

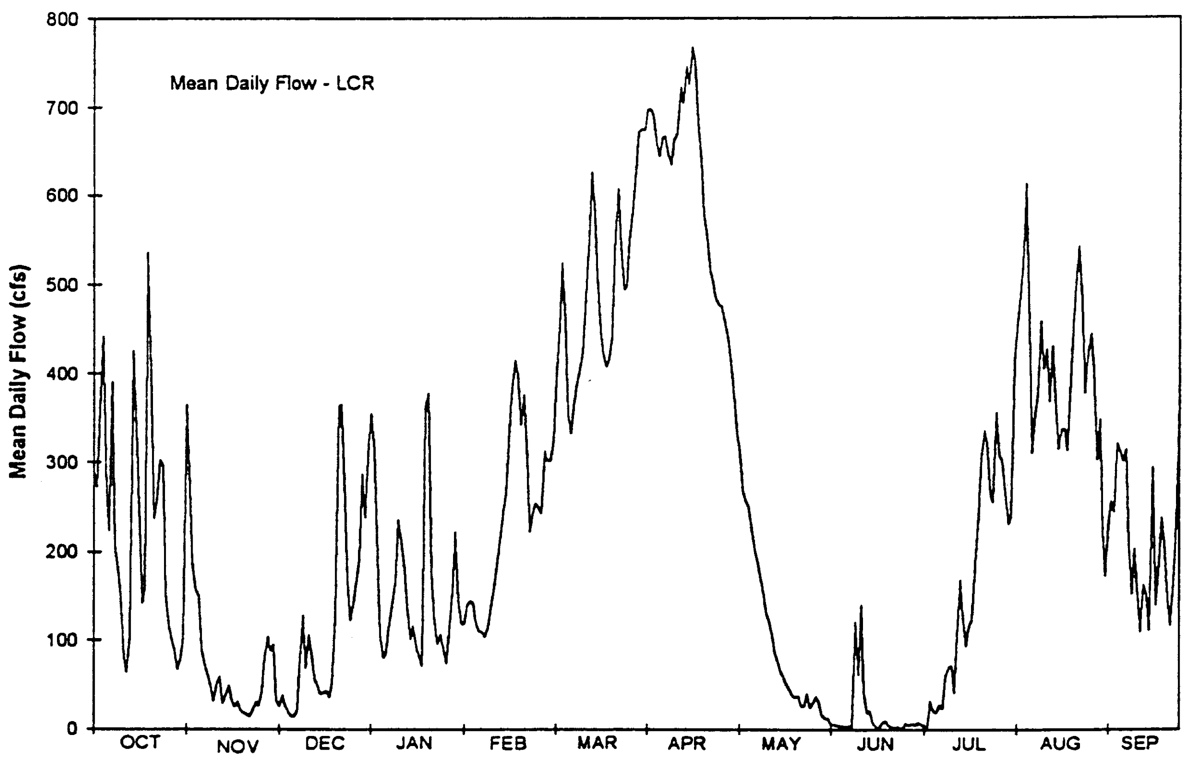

Mean Daily Flow - LCR
Mean Daily Flow (cfs)
0
100
200
300
400
500
600
700
800
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

Figure 3-8

CHAPTER 4 - WATER QUALITY

INTRODUCTION

Water quality of the Colorado River in Grand Canyon has been substantially altered by reduced variation in seasonal streamflow and temperature, increased daily fluctuations, and reduced sediment load. Before Glen Canyon Dam, water temperature ranged widely, from winter lows near freezing to highs of near 30° C in late summer (Table 4-1). After the dam, hypolimnetic releases from Lake Powell have ranged from about 7.5° C to 10° C. Average pre-dam sediment load through Grand Canyon was about 140 million tons per year, with a range of 50-500 million tons. Average post-dam sediment load has been about 15 million tons per year (Cole and Kubley 1976, Marzolf et al. 1987). Sediment deposits in Lake Powell in 1986 ranged from a depth of 36 ft (11 m) near the base of the dam to a maximum depth of 182 ft (55.5 m) near the mouth of Dark Canyon, in the Colorado River inflow about 180 mi (290 km) upstream of the dam (Ferrari 1988). Deposition of sediment and lacustrine chemical dynamics in Lake Powell have also altered other water quality parameters, including inorganic and organic components (Stanford and Ward 1991).

Table 4-1. Summary of pre- and post-dam sediment transport and thermal characteristics of the Colorado River below Glen Canyon Dam.

Measurement	Lees Ferry		Grand Canyon	
	Pre-dam	Post-dam	Pre-dam	Post-dam
		Temperature(° C)[a]		
Range in mean daily	0 - 29.5	7.5 - 10	2 - 25	6 - 13
Mean annual	10	10	11	12
		Total Sediment (tons/year)[b]		
Mean annual load (years of record)	76.3 x 10^6 (1948-58)	8.6 x 10^6	138.7 x 10^6	14.6 x 10^6
		Suspended Sediment (mg/l)[c]		
Range in mean daily (years of record)	-	-	1000-19,000 mg/l (1947-57)	500-7000 mg/l (1967-71)

Sources: [a]Cole and Kubly 1976; USGS Water Supply Papers
[b]Schmidt and Graf 1991 - Lees Ferry
[b]Carothers and Brown 1991 - Grand Canyon
[c]USGS data from Earth Info on CD-Rom

Water quality parameters presented in this report include temperature, turbidity, specific conductance, dissolved oxygen, and hydrogen ion concentration (pH). These parameters were used as chemical descriptors, together with physical and biological components, to characterize dynamics of the ichthyofaunal environment resulting from dam operations. Conductivity, dissolved oxygen and pH remained within known acceptable levels for the warmwater native fishes. Bulkley et al. (1982) reported that juvenile humpback chub preferred a TDS range of 1.3-3.0 microsemens per centimeter (µS/cm), which is slightly higher than normally reported in Grand Canyon, and avoided levels greater than 8.5 µS/cm, which is reported only from local springs in the basin. Dissolved oxygen and pH do not appear to be significantly different from pre-dam levels.

Lowered water temperature and decreased turbidity have contributed substantially to a new set of environmental conditions for the riverine ecosystem in Grand Canyon. Relatively constant post-dam temperatures have remained below-optimum for warmwater fish species (Hamman 1982, Marsh 1985, Bulkley et al 1982), and disrupted life cycles of many species of diatoms, algae, (Hardwick et al. 1992) and macroinvertebrates essential to the pre-dam ecosystem (Carothers and Brown 1991). Reduced sediment has resulted in reduced organic levels and suspended food supplies, and increased water clarity, which may reduce cover for feeding and escape from predators.

METHODS

Water quality parameters, analyzed for the mainstem Colorado River, LCR, other tributaries, and special habitats (i.e., riverside springs, tributary inflows, shallow embayments, areas of local fish abundance), included temperature, turbidity, specific conductance, dissolved oxygen, and hydrogen ion concentration (pH). Water quality data were procured from three sources, including portable Hydrolab water quality instruments (Hydrolab Corp, Austin, TX), USGS stream gaging stations, and Ryan Tempmentors (Ryan Instruments, Redmond, WA) deployed and maintained by GCES. Water quality data were collected during monthly field trips to characterize local habitats and supplement other data. Hydrolab data were usually collected hourly for 10-20 d/month, and discontinuous between field trips, since instruments were not left in the field between trips. BIO/WEST used the following Hydrolab water quality instruments:

- Surveyor 2: With Field Data Logger (Model 5100A)
- Surveyor 2: Display Unit (Model: SVR2-SU)
- Surveyor 3: 1100 Surveyor Data Logger (Model SVR3-DL)
- DataSonde 2: (Model 2270 H)

Water temperature was recorded in degrees Celsius (° C), and turbidity (as light transmisivity) was recorded in nephelometric turbidity units (NTUs) with a Hach Model 2100P turbidimeter, and as depth of water clarity with a standard 20-cm diameter Secchi disk. Specific conductance was measured in microSemens per centimeter (µS/cm), adjusted to 25° C. Dissolved oxygen was expressed as milligrams per liter (mg/l), and hydrogen ion concentration in pH units (0-14).

Each Hydrolab instrument was calibrated before and after each field trip. Water quality data were downloaded from dataloggers using a laptop or desktop computer and Procomm Plus Version 1.1B communications program (Datastrom Technologies, Inc., Columbia, MO). Water quality parameters (except turbidity) were recorded at camp locations, sample sites, tributary inflows, and special habitats. Turbidity was measured daily at camp, or with dramatic changes, usually from tributary inflow. A summary of water quality instruments used by river mile and month for 1991, 1992, and 1993 is presented in Appendix Table D-1.

Data from six mainstem gages and six tributary USGS gages were used to provide historic and present overviews of water quality in the mainstem Colorado River and its tributaries (Table 4-2, Fig. 3-1). Pre-dam water quality and sediment data were obtained from two mainstem gages (Colorado River at Lees Ferry and Colorado River near Grand Canyon, AZ) and three tributary gages (Paria River at Lees Ferry, LCR near Cameron, and Bright Angel Creek near Grand Canyon). Post-dam data were from gages on the Colorado River below Glen Canyon Dam, above the LCR, at National Canyon, and at Diamond Creek, which were installed in 1983, as part of GCES Phase I to evaluate sediment transport and provide data for a flow routing model. Post-dam data were also obtained from gages (minimonitors) installed in 1989 on the lower LCR, Bright Angel Creek, Kanab Creek, and Havasu Creek. These minimonitors recorded water temperature, DO, and conductivity, and included pressure transducers for use with flow-rating curves to yield stream discharge estimates.

Table 4-2. Stream gages used for water quality analysis.

USGS Station Number	Station Name	Location[a]	Period of Record (water years)
09379910	Colorado River below Glen Canyon Dam, AZ	RM +14.5	Oct 1989-Sep 1990
09380000	Colorado River at Lees Ferry, AZ	RM 0.2	1895-present
09383100	Colorado River above LCR, AZ	RM 61.2	Apr 1983-present[b]
09402500	Colorado River near Grand Canyon, AZ	RM 87.4	1925-1988
09404120	Colorado River at National Canyon, AZ	RM 166.5	Apr 1983-present
09404200	Colorado River at Diamond Creek, AZ	RM 226.0	Apr 1983-present
09382000	Paria River at Lees Ferry, AZ	1.1 mi ups	1923-present
09402000	Little Colorado River near Cameron, AZ	45 mi ups	1947-present
09402300	Little Colorado River near mouth, AZ	0.5 mi ups	1989-Jan 1993[bc]
09403000	Bright Angel Creek near Grand Canyon, AZ	0.5 mi ups	1923-1974
09403850	Kanab Creek near mouth, AZ	1.0 mi ups	1989-present
09404115	Havasu Creek near mouth, AZ	0.3 mi ups	1989-present

[a]RM = river miles downstream from Lees Ferry.
ups = distance upstream from Colorado River confluence.
[b]data inconsistent
[c]discharge based on stage elevations, periodically adjusted to stream channel measurements.

Ryan Tempmentors were installed by GCES in several tributaries and mainstem locations to supplement USGS gaging data and to provide data for a temperature model for the Colorado River in Grand Canyon. Tempmentors were located in lower Nankoweap Creek, LCR, Shinumo Creek, Kanab Creek, Tapeats Creek, and Havasu Creek, as well as select locations on the mainstem, such as RM 127 (Middle Granite Gorge).

Methods for gathering water quality parameters were adjusted for particular locations and conditions in this investigation. Water quality parameters in the mainstem were measured with a Hydrolab DataSonde deployed from a 37-ft (11.3-m) raft at each temporary campsite. Parameters were recorded electronically at 1-h intervals, and manual readings were recorded from a Hydrolab Surveyor 2, to supplement the electronic data in case of battery failure. Water temperature associated with fish and drift sampling was recorded with handheld thermometers, calibrated with a Surveyor 2 at the beginning of each trip. Water quality in the LCR was also recorded electronically at 15-min intervals with a Hydrolab DataSonde. Datasondes were deployed only when teams were in the vicinity--about 10 d/month--and temperature data were supplemented with Ryan Tempmentors and CR10 dataloggers (Campbell Scientific, Inc., Logan, UT), and USGS ADAPs (Data Collection Platforms). Hydrolab Datasondes or Surveyors were also used to record water quality data in various tributary inflows, which were supplemented with data from Tempmentors or USGS gaging stations, to provide a continuous record of tributary temperature. Water quality parameters of special habitats were measured opportunistacally with a Surveyor 2 and results recorded manually.

WATER QUALITY CHARACTERISTICS

Colorado River

Water Temperature

Pre-Dam. Mean monthly temperature of the Colorado River at Lees Ferry and near Grand Canyon (Phantom Ranch) before Glen Canyon Dam (1959 used as a representative year) ranged from about 2° C in winter to 26° C in late summer (Fig. 4-1), with daily extremes of 0° C in December-January, and 29.5° C in July-August (Cole and Kubly 1976). Although warming usually began in February, peak snowmelt from late May through early July maintained relatively cool water temperature through spring and early summer. As flow decreased in mid-summer, water temperature reached 23-26° C in July and August, and by September, water temperature began cooling. Little longitudinal difference was seen in mean monthly temperature between these two stations, approximately 87 mi apart, indicating little warming or cooling through the canyon in pre-dam flows.

Post-Dam. Following construction of Glen Canyon Dam, the Colorado River in Grand Canyon was transformed into a cold, clear river. The same seasonal pattern of coldest water temperatures in December or January, and warmest temperatures in June or July occurred after the dam, but the difference between winter lows

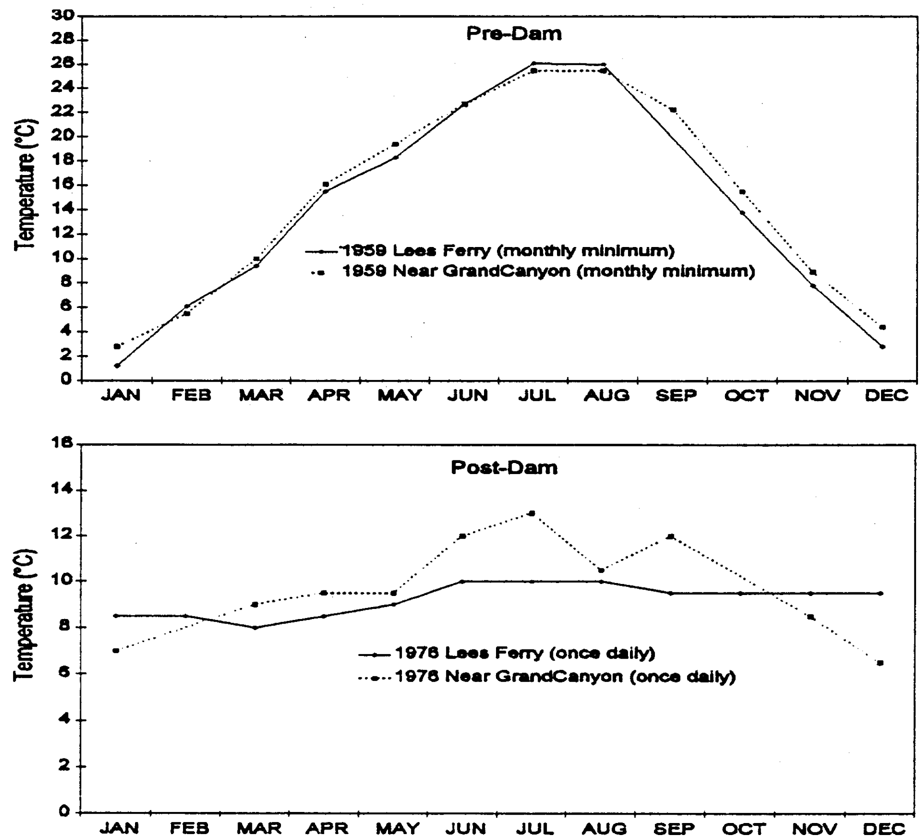


Fig. 4-1. Pre-dam (1959) and post-dam (1976) mean monthly temperatures of the Colorado River at Lees Ferry, AZ and near Grand Canyon, AZ (Phantom Ranch). USGS Water Resources Data.

and summer highs was only a few degrees Celsius. Mean daily post-dam water temperature at Lees Ferry (1976 used as a representative year) ranged annually from 8.0 to 10° C (Fig. 4-1), while mean temperature near Grand Canyon (Phantom Ranch) ranged from 6.5 to 13° C.

Longitudinal warming of the Colorado River through Grand Canyon is an important aspect of the aquatic ecosystem that can affect trophic levels spatially and temporally. Averages of mean daily temperatures for representative months of the four seasons for WY 1992 (i.e., spring=April, summer=July, fall=October, winter=January) showed greatest longitudinal increase in temperature in July (Fig. 4-2), of 8° C at the dam to 15.5° C at Diamond Creek, or about 7.5° C for 240 mi (1° C/32 mi). Comparable warming during selected months were 1° C/37 mi in spring, 1° C/60 mi in fall, and no longitudinal warming or cooling was observed in winter. Similar longitudinal warming was seen when temperature was averaged for the entire season for WY 1991, 1992, and 1993 (Fig. 4-3). This comparison also revealed differences between water years, e.g., spring temperatures in WY 1992 were higher than WY 1991 or WY 1993, and similar to summer temperatures, particularly at Diamond Creek (i.e., 15.5° C)

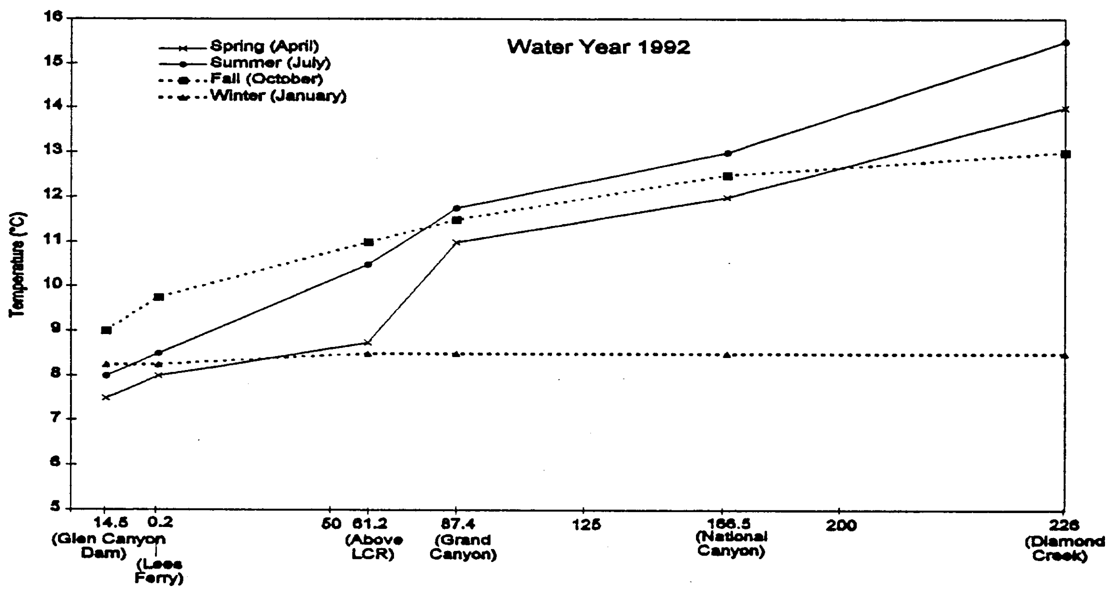


Fig. 4-2. Seasonal longitudinal warming of the Colorado River from Glen Canyon Dam to Diamond Creek, as mean daily temperatures at six stations for WY 1992.

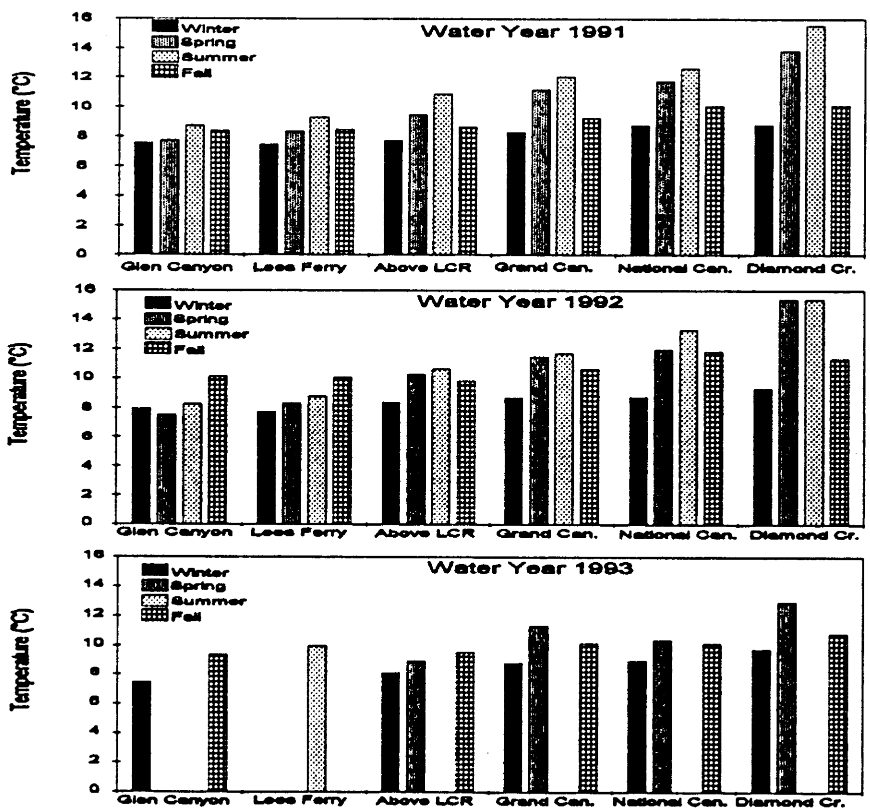


Fig. 4-3. Mean seasonal temperature of the Colorado River for WY 1991-93 at six stations (Glen Canyon Dam, Lees Ferry, Above LCR, Grand Canyon, National Canyon, Diamond Creek). USGS ADAPS data.

Mean daily water temperatures for the mainstem Colorado River during research flows in 1991 were compared for constant flows of 5000 cfs (May 16-20, May 31-June 3), 15,000 cfs (May 21-30), and normal summer fluctuating flows (June 4-27) to evaluate the effect of flow volume on temperature (Fig. 4-4). Although time span for this analysis was short and precluded distinction of diurnal and seasonal influences, specific patterns are indicated. Assuming a travel time at 5000 cfs of about 15 h from the dam to the LCR, about 19 h to Bright Angel Creek (gage at Grand Canyon) (Dawdy 1991), and about 60 h to Diamond Creek, a relationship of water mass and temperature was evident longitudinally. The river warmed 2-2.5° C under the combined influence of longitudinal warming and constant 5000 cfs, but remained cooler and more isothermal under constant 15,000 cfs. These gage data were confirmed through field measurements near Diamond Creek, which showed an increase of up to 3° C during the 3-d constant 5000 cfs release, and a decrease of up to 3° C with return to normal operation or high fluctuating releases. It also appears that normal summer fluctuating flows resulted in a higher average water temperature at downstream stations (i.e., Grand Canyon and Diamond Creek) than under constant 15,000 cfs. Some of this increase in water temperature was probably attributed to seasonal warming, but the analysis suggests a need to better understand the relationship between volume and temperature, particularly when considering high spring releases or late summer constant low releases.

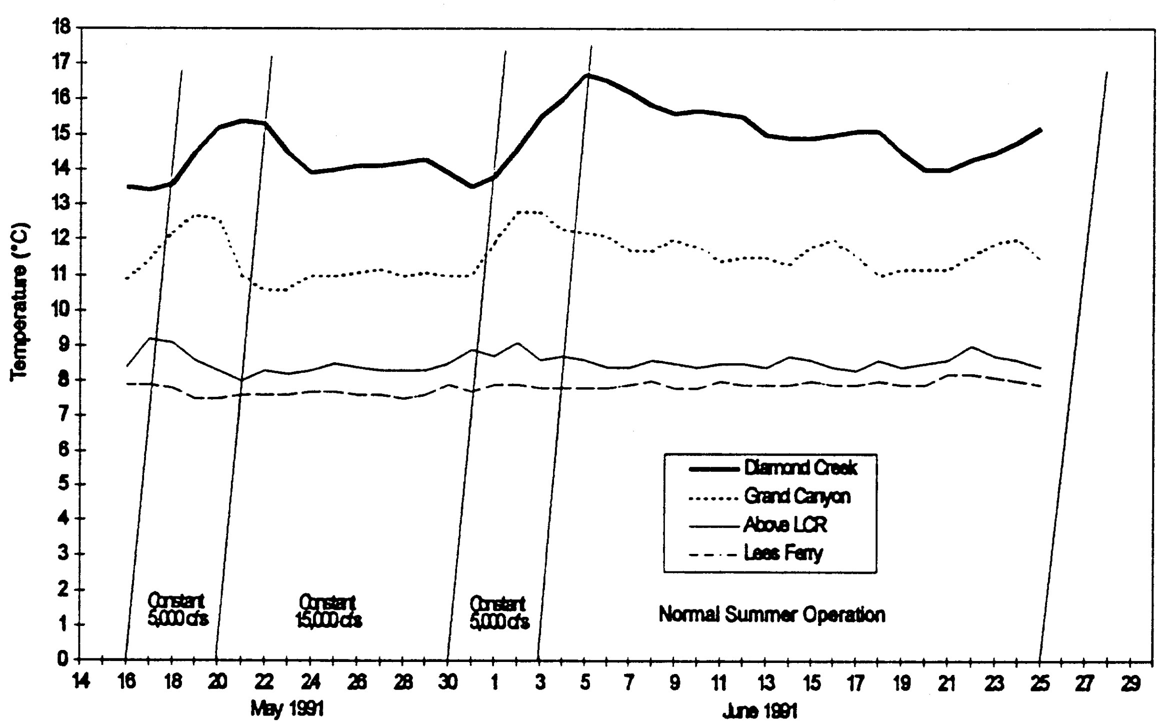


Fig. 4-4. Mean daily temperature of the Colorado River at four USGS stations (Lees Ferry, Above LCR, Grand Canyon, Diamond Creek) during 1991 research flows of constant 5000 cfs (May 16-20, May 31-June 3), constant 15,000 cfs (May 21-30), and normal summer fluctuating flows (June 4-27). Diagonal dashed lines represent approximate travel time for flow to reach each of the four designated stations. USGS ADAPS data.

While mean monthly temperature patterns provided an understanding of ambient seasonal conditions, mean daily temperatures revealed variation within and between months at various distances downstream of Glen Canyon Dam. Annual water temperature patterns, using mean daily values from six mainstem USGS gages (Glen Canyon Dam, Lees Ferry, Above LCR, Grand Canyon, National Canyon, and Diamond Creek) for WY 1991(Fig. 4-5), WY 1992 (Fig. 4-6), and WY 1993 (Fig. 4-7) revealed the phenomena of seasonal longitudinal warming and cooling, and increasingly greater downstream daily and monthly variation. In WY 1991, dam releases ranged from about 7.5° C to 9.5° C, while water temperature at Diamond Creek (240 mi from the dam) ranged from about 5.5° C to 18° C. In WY 1992, dam releases ranged from about 7° C to 11° C, and water temperature at Diamond Creek ranged from about 8.5° C to 17° C; warmer dam releases were probably the result of lower levels in Lake Powell, and withdrawal of warmer near-surface water. Dam releases in WY 1993 also ranged from about 7° C to 11° C, and recorded temperature at Diamond Creek was 7.5° C to nearly 14° C, although the gage record was incomplete for the warmest part of the year.

Sediment

Suspended sediment is the primary cause of turbidity in the Colorado River. It originates as particles of disintegrated or eroded rocks that are suspended and transported by water. Suspended sediment is discussed separately from turbidity in this chapter, because sediment load as milligrams/liter was a standard measurement prior to Glen Canyon Dam, and few pre-dam turbidity measurements exist. Suspended sediment in the Colorado River originates from two distinct sources. Mountainous headwater areas contribute about 31% of suspended sediment, the remainder comes locally from tributaries draining the Colorado Plateau (Andrews 1991). In Grand Canyon, the main sources of sediment are the Paria River and LCR. Sediments carried by the Colorado River during spring runoff consist primarily of coarse sand from headwaters, while local summer floods transport primarily silts and clays (Carothers and Brown 1991). Intermittent winter rains over the plateau may result in tributary flooding and additional sediment input.

Pre-Dam. The pre-dam Colorado River was a sediment-rich system, undergoing an annual cycle of erosion, transport, and deposition that. Mean annual suspended sediment load at Lees Ferry was 76.3 million tons per year during 10 years (WY 1947-57) prior to dam construction (Laursen et al. 1976 in Schmidt and Graf 1991). Mean daily suspended sediment at the Grand Canyon gage near Phantom Ranch varied from about 1000 to 19,000 mg/l over the 10-year period (Fig. 4-8).

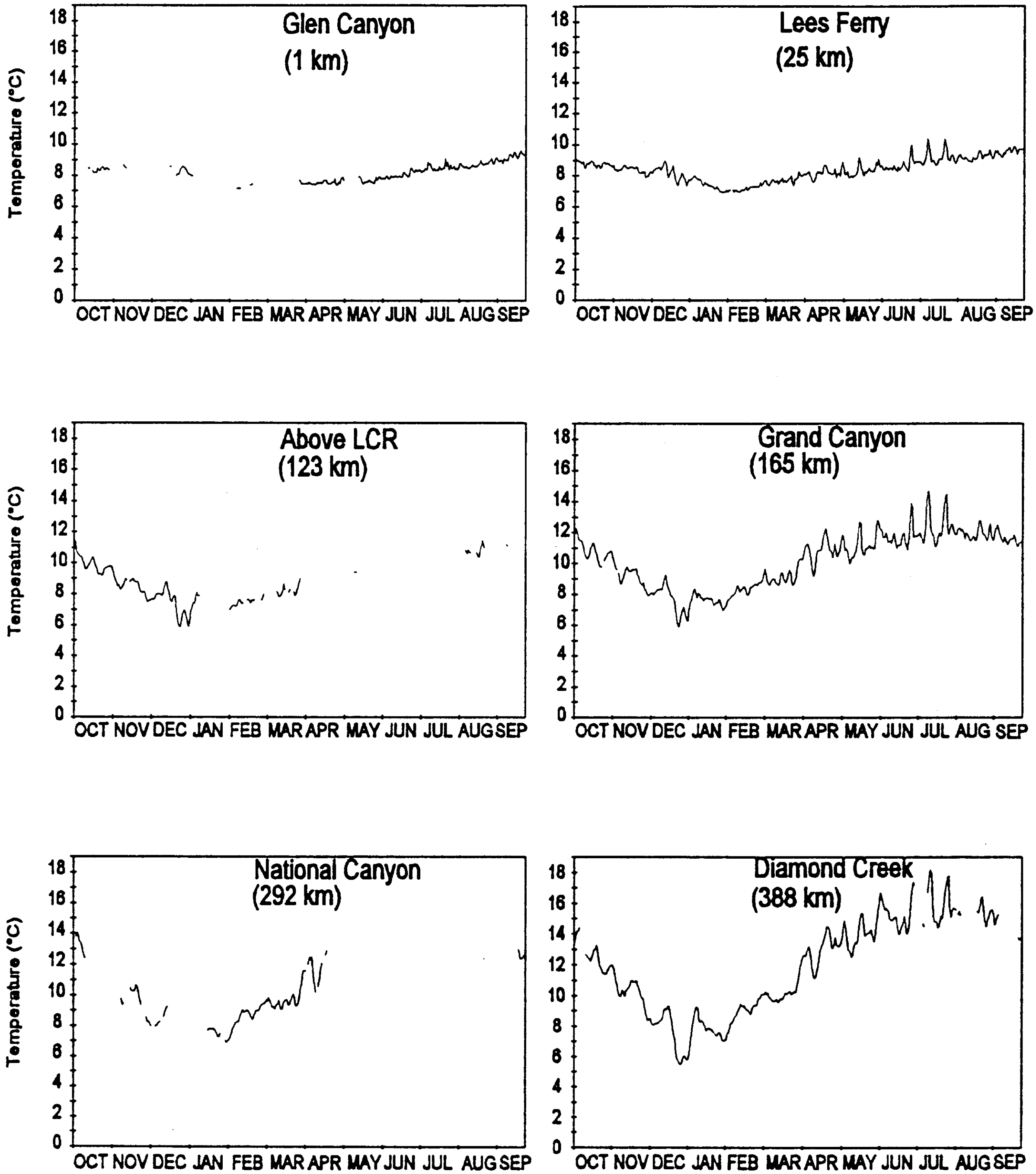


Fig. 4-5. Mean daily temperature of the Colorado River for WY 1991 at six stations (Glen Canyon Dam, Lees Ferry, Above LCR, Grand Canyon, National Canyon, Diamond Creek). Distance in kilometers downstream from Glen Canyon Dam is indicated in parentheses. Discontinuous line indicates missing data. USGS ADAPS data.

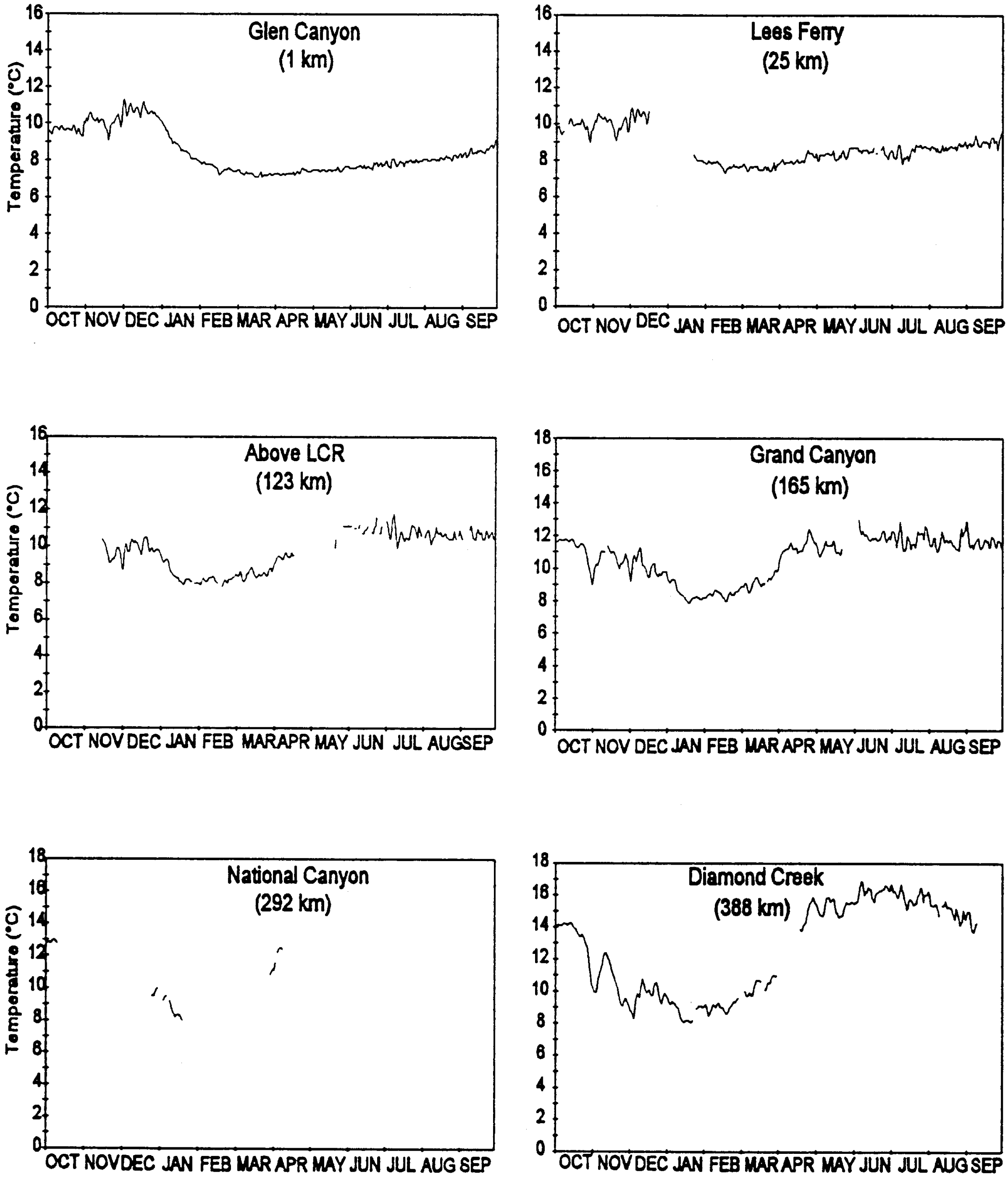


Fig. 4-6. Mean daily temperature of the Colorado River for WY 1992 at six stations (Glen Canyon Dam, Lees Ferry, Above LCR, Grand Canyon, National Canyon, Diamond Creek). Distance in kilometers downstream from Glen Canyon Dam is indicated in parentheses. Discontinuous line indicates missing data. USGS ADAPS data.

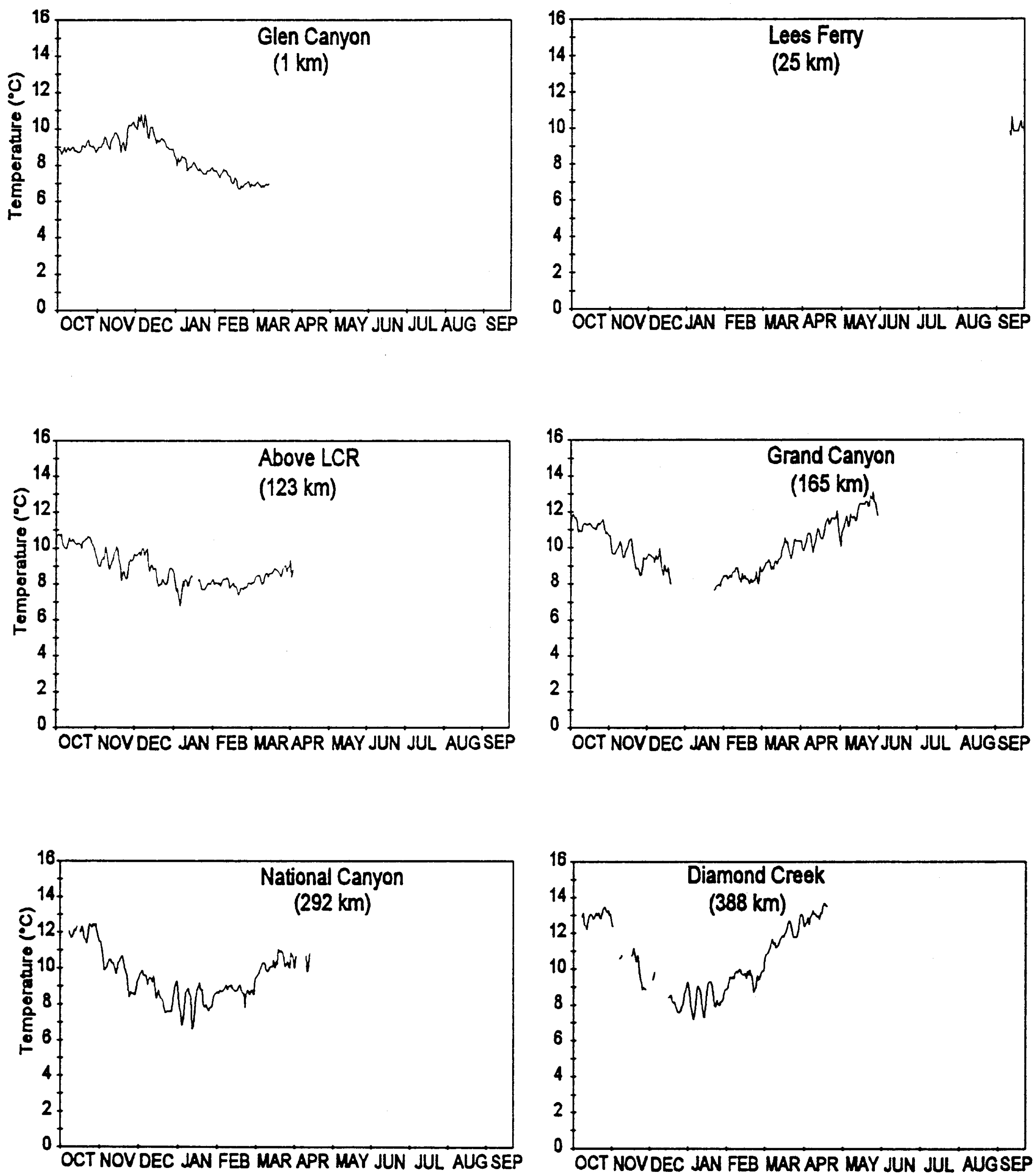


Fig. 4-7. Mean daily temperature of the Colorado River for WY 1993 at six stations (Glen Canyon Dam, Lees Ferry, Above LCR, Grand Canyon, National Canyon, Diamond Creek). Distance in kilometers downstream from Glen Canyon Dam is indicated in parentheses. Discontinuous line indicates missing data. USGS ADAPS data.

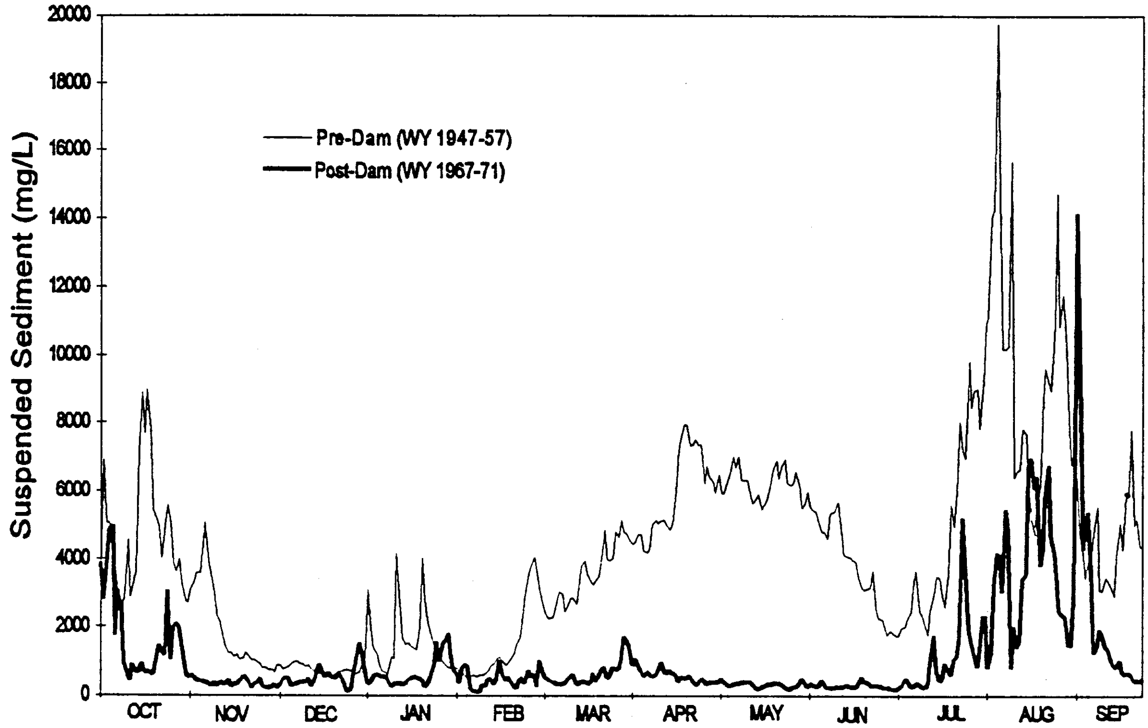


Fig. 4-8. Pre-dam (WY 1947-1957) and post-dam (WY 1967-1971) average daily sediment concentrations (mg/l) near Grand Canyon. USGS data from EarthInfo on CD ROM.

Historically, suspended sediment was highest during three distinct periods. Spring runoff produced a consistent period of moderate sediment from late February through June, while summer rainstorms produced short, spurious, and sometimes high sediment loads. The third period was marked to minor peaks in sediment from mid-winter rainstorms or intermittent snow melt.

Post-Dam. Today, sediment originating from the headwaters of the Colorado River is deposited in a series of reservoirs, primarily in Lake Powell. Sediment passing Lees Ferry decreased by almost 90% (76.3 to 8.6 million tons/year) in WY 1963-65 just after dam construction (Laursen et al. 1976 in Schmidt and Graf 1991). The annual sustained sediment load during runoff (i.e., February-June) was eliminated by Glen Canyon Dam and Lake Powell, and peaks in sediment load from summer rainstorms (i.e., July-November) and winter rains (January) in major tributaries were still apparent, but reduced in magnitude (Fig. 4-8). Thus, the main volume of sediment into Grand Canyon now occurs in late summer from local rainstorms, instead of in spring and early summer from high elevation snowmelt.

Sediment load of the post-dam Colorado River in Grand Canyon is derived primarily from two tributaries--Paria River and LCR. Mean annual sediment discharge of the Paria River for WY 1941-57 was 3.02 million tons, and sediment discharge for the same time period for the LCR near Cameron was 9.27 million tons (Andrews 1991). Other tributaries, such as Kanab Creek, and many ephemeral drainages, also contribute sediment intermittently.

Suspended sediment load in the post-dam Colorado River increases with discharge and distance from Glen Canyon Dam (M. Yard, GCES, pers. comm.). This increase in suspended sediment load is attributed to tributary input, and to the greater capacity of clear, cold water to transport sediment. Thus, phototrophic productivity of the Colorado River between the dam and the Paria River (39 km) is much higher than historic levels, but quickly decreases with distance from Glen Canyon Dam as suspended sediment increases.

Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted through a water sample. Turbidity in water may be caused by suspended matter, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, or other microscopic organisms (Greenburg et al. 1992). The current standard method for quantifying turbidity is the nephelometric method (expressed as nephelometric turbidity units, NTU's), which measures light scattered at right angles to an incident light source.

High spring snowmelt flows and spurious, intense late summer rainstorms was a sparsely-vegetated and arid drainage basin to produce a history of high sediment loads and low water clarity. The relationship between light attenuation and turbidity is not the same for all aquatic systems, because of variation in characteristic size, shape, and refractive index of suspended material (Roos and Pieterse 1994, Yard 1994). The unique characteristics of sediment from tributaries throughout Grand Canyon preclude direct correlation of turbidity with weight concentration of suspended matter (milligrams per liter), without concurrent sampling. Thus, a power regression curve (Fig. 4-9), describing the relationship between concurrent field measurements of Secchi depth and turbidity (NTUs), was developed for a practical assessment of turbidity during this investigation. This relationship revealed that a Secchi depth of 0.5 m equates to about 30 NTU's, and enabled researchers to use either technique for assessing water clarity relative to fish catch information and movement (See Chapter 5 - DISTRIBUTION AND ABUNDANCE; Chapter 8 - MOVEMENT).

Conductivity

Conductivity is a measure of the ability of an aqueous solution to carry an electric current, and is dependent on concentrations of total dissolved solids (ions). Post-dam conductivity of the Colorado River in Grand Canyon has varied slightly with volume of flow entering Lake Powell. Years with above-average flows have diluted the lake water and reduced conductivity of releases, while below-average flows, combined

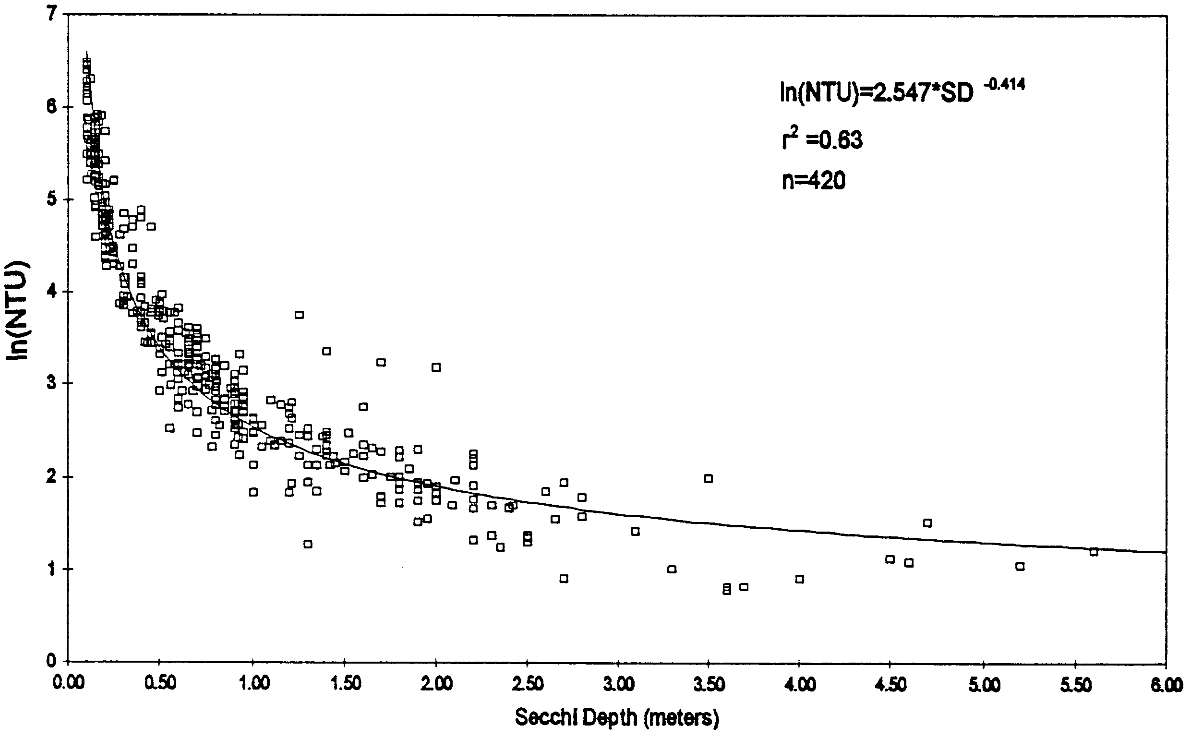


Fig. 4-9. Relationship between Secchi depth (m) and turbidity (NTU) for the Colorado River in Grand Canyon.

with evaporation, have produced higher conductivities. Although tributary input within Grand Canyon has a minor influence on local conductivity, collectively these add to constituents from many other streams in the drainage to produce high salinity in downstream reaches.

During WY 1992 (October 1, 1991 - September 30, 1992), mean daily conductivity of the Colorado River at Lees Ferry ranged from 874 to 981 µS/cm (USGS 1992), and mean daily conductivity above the LCR (RM 61.2) varied from 880 µS/cm in September to 1030 µS/cm in April (Table 4-3). Mainstem conductivity varied slightly with season and distance from Glen Canyon Dam.

Dissolved Oxygen

Mean daily dissolved oxygen (DO) concentrations from the mainstem ranged from 10.35 mg/l in February to 11.03 mg/l in July (Table 4-3). This relatively constant and high DO was attributed to cool water temperatures and constant aeration by current. A slight seasonal trend in DO resulted from seasonal changes in water temperature and associated saturation levels. All DO values recorded during the investigation approximated saturation for the elevation of Grand Canyon.

Table 4-3. Minimum (min), maximum (max), and mean (ave) water quality parameters of the Colorado River and selected tributaries at 10 or 15-min intervals during monthly trips in 1992. BIO/WEST Hydrolab data.

		Temperature (°C)			Conductivity (us/cm)			Dissolved Oxygen (mg/l)			pH		
Month	No. Days	min	max	ave	min	max	ave	min	max	ave	min	max	ave
					Colorado River Above LCR (RM 61.2)								
Jan	-	-	-	-	-	-	-	-	-	-	-	-	-
Feb	7	7.76	8.57	8.22	910	950	930	9.76	10.63	10.35	7.79	7.88	7.84
Mar	6	7.78	9.14	8.36	970	1000	990	10.14	10.67	10.51	7.71	7.81	7.77
Apr	7	9.21	10.38	9.75	990	1030	1010	9.51	10.92	10.78	7.71	7.84	7.77
May	6	9.85	11.39	10.49	930	1010	980	-	-	-	7.83	8.00	7.93
Jun	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul	5	9.64	11.22	10.58	920	950	930	10.73	11.34	11.03	7.84	7.92	7.88
Aug	3	10.16	11.11	10.74	910	950	930	-	-	-	6.92	7.76	7.72
Sep	6	10.40	11.45	10.84	890	920	910	-	-	-	7.85	7.98	7.92
Oct	7	10.15	19.99	10.63	880	910	890	8.88	10.76	10.46	7.44	7.72	7.66
Nov	-	-	-	-	-	-	-	-	-		-	-	-
					Little Colorado River								
Jan	12	6.56	14.18	11.36	262	395	362	9.08	11.36	9.71	7.57	8.08	7.72
Feb	7	7.31	15.33	11.53	990	3080	1700	8.53	11.19	9.93	7.59	8.01	7.84
Mar	10	8.65	14.80	11.77	1220	1980	1520	8.90	10.69	9.78	8.01	8.24	8.09
Apr	7	15.03	20.30	17.15	560	1240	940	5.92	9.87	8.87	8.07	8.20	8.11
May	9	16.86	24.16	20.47	1770	4170	3190	5.02	9.12	8.12	7.50	7.85	7.73
Jun	6	16.83	26.00	21.17	4340	4590	4480	7.76	9.26	8.48	7.76	7.90	7.82
Jul	10	20.45	26.14	22.79	1770	4240	3470	7.56	9.19	8.33	6.39	8.04	7.67
Aug	8	21.73	26.19	23.83	1800	2990	2470	7.26	8.00	7.66	8.00	8.00	8.00

Month	No. Days	Temperature (°C) min	max	ave	Conductivity (us/cm) min	max	ave	Dissolved Oxygen (mg/l) min	max	ave	pH min	max	ave
Sep	10	18.06	24.78	21.24	930	4610	3270	6.13	8.74	7.94	7.50	8.05	7.80
Oct	7	16.63	21.48	18.89	4340	4510	4450	8.38	9.37	8.89	6.05	7.80	7.64
Nov	11	9.84	18.13	14.19	1500	4110	2680	8.38	10.66	9.38	7.58	8.02	7.79
Bright Angel													
Nov	2	10.07	12.65	11.43	390	390	390	8.50	10.46	10.08	8.26	8.30	8.27
Shinumo													
Jan	2	2.69	5.77	4.60	340	380	370	12.74	13.88	13.31	7.61	8.57	8.49
May	3	11.37	17.00	13.20	1800	1900	1900	9.52	10.76	10.34	7.96	8.08	8.00
Nov	3	8.31	13.70	10.57	380	390	390	9.30	11.42	10.68	8.25	8.37	8.29
Kanab													
May	4	18.05	26.52	21.55	1190	1230	1220	7.68	9.26	8.52	7.98	8.20	8.07
Nov	2	11.96	12.82	12.22	1260	1260	1260	9.15	10.45	10.17	8.04	8.08	8.05
Havasu													
May	3	18.69	20.81	19.19	710	740	720	7.87	9.41	8.93	7.93	8.23	8.06
Nov	3	11.83	14.53	12.65	700	740	720	9.91	10.68	10.46	7.87	8.14	7.98
Crystal													
Jan	2	1.42	6.68	3.11	2000	2020	2010	11.86	14.97	13.81	7.06	8.62	8.55
Tapeats													
May	2	11.99	14.86	12.50	2300	2400	2400	8.83	10.43	10.26	8.09	8.21	8.11
Nov	2	10.90	12.46	11.41	340	340	340	10.02	10.55	10.39	8.23	8.32	8.25
Deer Creek													
May	2	13.67	14.87	14.11	3300	3300	3300	9.50	9.85	9.71	8.22	8.25	8.23

pH

Mean daily pH of the Colorado River above the LCR (RM 61.2) varied slightly and ranged from 7.66 in October to 7.93 in May. No longitudinal trends in pH were apparent, and only slightly higher pH values were recorded in summer months.

Little Colorado River

Water Temperature

Seasonal variation in water temperatures of the lower LCR during this investigation (WY 1991-93) approximated the range of the pre-dam Colorado River (Fig. 4-10). A low winter temperature of about 2° C was recorded in January, with a maximum of 23-25° C in June and July. The effect of water temperature from the LCR on the mainstem was localized, with a characteristic downstream plume that varied with flow of both rivers and time of year (See Chapter 7 - HABITAT).

Conductivity

Conductivity of the LCR varied with runoff. At base flow in June, conductivity was about 4480 µS/cm, and during floods and runoff in January, dilution decreased conductivity to less than 362 µS/cm (Table 4-3). Like temperature, conductivity of the LCR had only a localized effect on mainstem conductivity.

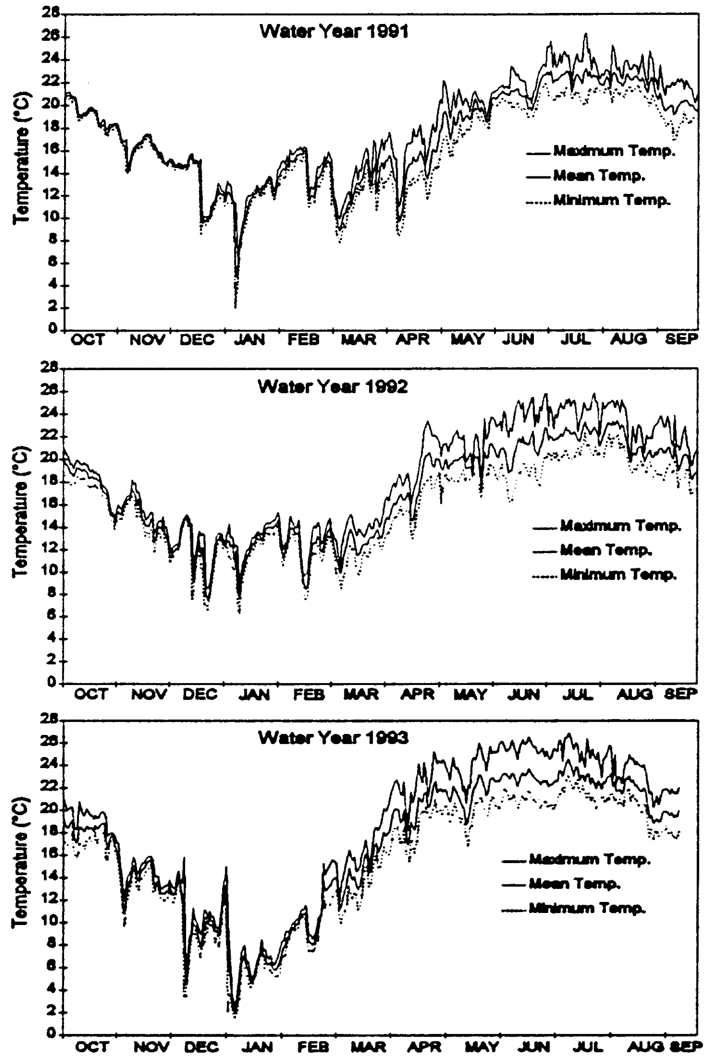


Fig. 4-10. Daily mean, minimum, and maximum temperature of the LCR for WY 1991-93. GCES Ryan Tempmentor data.

Dissolved Oxygen

Dissolved oxygen in the LCR was generally lower than the mainstem and other tributaries, possibly because of warm LCR temperatures. Variation in DO levels in the LCR was caused by temperature fluxes and periodic flood events. In 1992, mean daily DO values in the LCR varied from 7.66 mg/l in August to 9.93 mg/l in February (Table 4-3).

pH

Mean daily pH in the LCR, during 1992, ranged from 7.72 in January to 8.11 in April (Table 4-3). These values were similar to those in the mainstem Colorado River.

Other Tributaries

A cursory examination of water quality for Bright Angel, Shinumo, Kanab, Havasu, Crystal, Tapeats, and Deer creeks was conducted to determine if water quality at tributary inflows was related to occurrence of fish species. Sources of water temperature data for the four major tributaries (Bright Angel, Shinumo, Kanab, Havasu) are indicated on corresponding figures (Fig. 4-11, 4-12, 4-13, 4-14), and the remaining parameters (conductivity, DO, pH) are daily means for 1992 (Table 4-3).

Bright Angel Creek

Water temperature of Bright Angel Creek ranged from a low of 1°C in December 1990, to a high of 24°C in August 1992 (Fig. 4-11). Conductivity measured in November 1992, was 390 μS/cm, while DO ranged from 8.50 to 10.46 mg/l, and pH from 8.26 to 8.30 (Table 4-3).

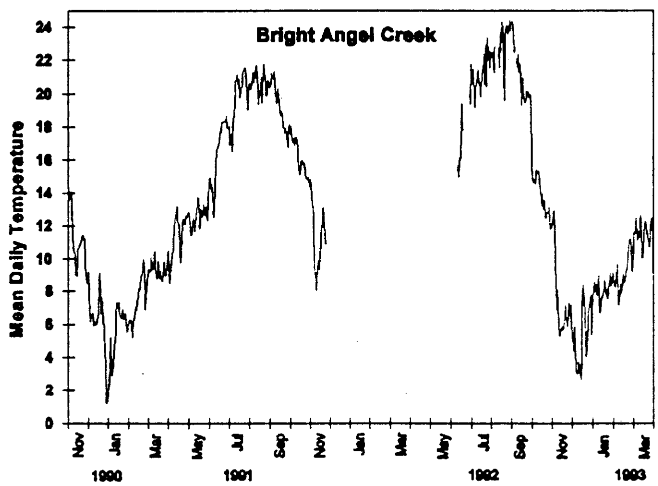


Fig. 4-11. Mean daily temperature of Bright Angel Creek from October 1990 through March 1993. USGS ADAPS data. Discontinuous line indicates missing data.

Shinumo Creek

The seasonal temperature pattern for Shinumo Creek was similar to that of Bright Angel Creek, with a minimum of 1°C in December 1990, and a maximum of 23°C in July-August 1991 and 1992 (Fig. 4-12). Mean conductivity in January, May, and November 1992, ranged from 370 to 1900 μS/cm, mean DO ranged from 10.34 to 13.31 mg/l, and pH ranged from 8.00 to 8.49 (Table 4-3).

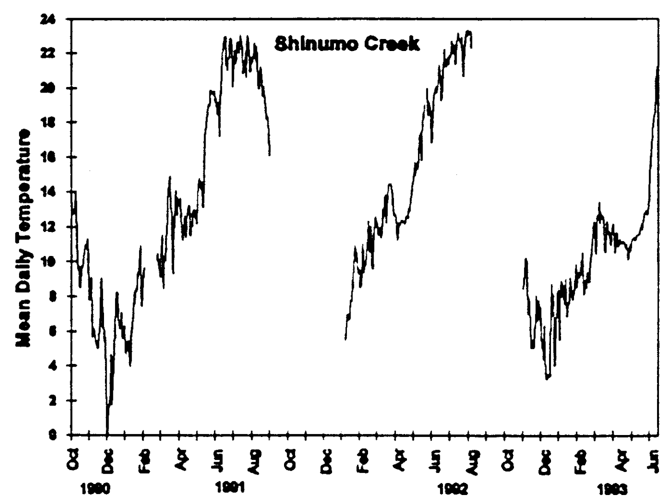


Fig. 4-12. Mean daily temperature of Shinumo Creek from October 1990 through June 1993. GCES Ryan Tempmentor data. Discontinuous line indicates missing data.

Kanab Creek

Kanab Creek was the warmest tributary sampled during this investigation, with a maximum of 35° C in August 1991 (Fig. 4-13). A minimum of 0° C was recorded in December 1990, during lowest flow. Mean conductivity in May and November 1992 ranged from 1220 to 1260 µS/cm, DO ranged from 8.52 to 10.17 mg/l, and pH from 8.05 to 8.07 (Table 4-3).

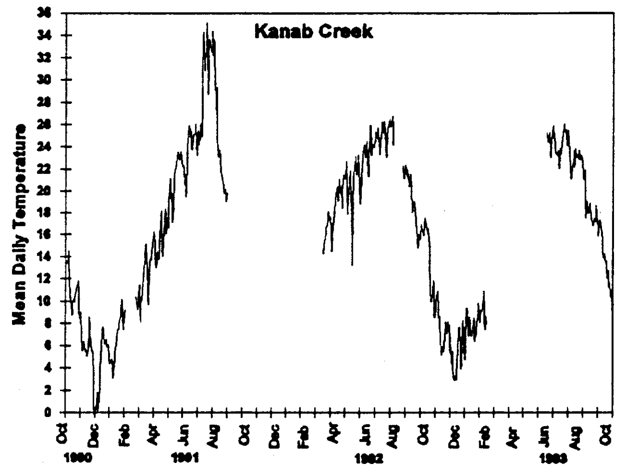


Fig. 4-13. Mean daily temperature of Kanab Creek from April 1992 through October 1993. GCES Ryan Tempmentor data. Discontinuous line indicates missing data.

Havasu Creek

Maximum water temperature of Havasu Creek was 22.5° C in July 1992, and minimum mean daily temperature was 9.5° C in December 1992 and January 1993 (Fig. 4-14). The seasonal temperature pattern of Havasu Creek, unlike that of the other tributaries examined, was moderated by the warm temperature of Havasu Springs, resulting in relatively warm winter temperatures. Mean conductivity in March, May, and November 1992 was 720 µS/cm, while mean DO ranged from 8.93 to 10.46 mg/l, and mean pH from 7.98 to 8.06 (Table 4-3).

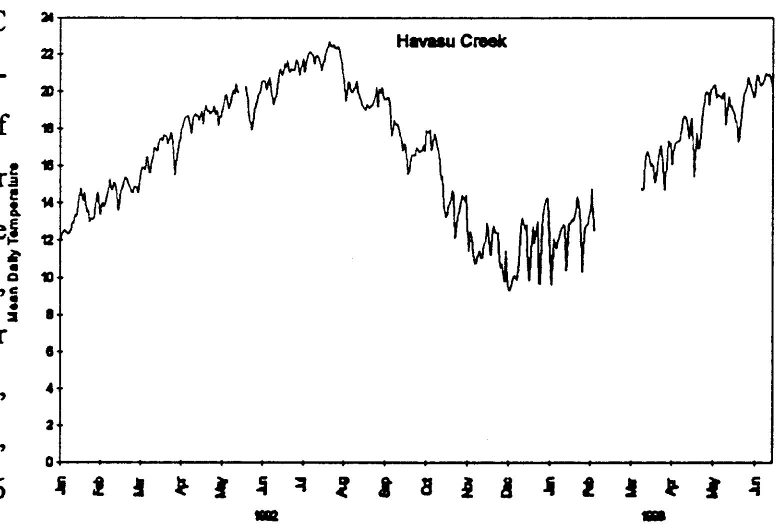


Fig. 4-14. Mean daily temperature of Havasu Creek from February 1992 through June 1993. GCES Ryan Tempmentor and USGS ADAPS data. Discontinuous line indicates missing data.

Additional Tributaries

Daily means for water quality parameters from Crystal, Tapeats and Deer creeks were similar to those of other tributaries examined for comparable periods, during this investigation (Table 4-3). Temperature for these tributaries could not be adequately characterized from periodic monthly samples. Limited measurements indicated high conductivity in Crystal Creek (2000-2010 µS/cm), Tapeats Creek (340-2400 µS/cm) and Deer Creek (3300 µS/cm). Dissolved oxygen was relatively high in all three tributaries; Crystal Creek (11.86-14.97 mg/l), Tapeats Creek (8.83-10.55 mg/l), and Deer Creek (9.50-9.85 mg/l).

Special Habitats

Water quality parameters were collected from four locations identified as special habitats, including three spring areas and one mainstem area used by an aggregation of humpback chub. The spring areas included Fence Fault Springs (RM 30.1-31.8), Lava Springs (RM 179.5), and Beecher Springs (RM 183.5). The fourth special habitat was in Middle Granite Gorge (RM 126.0-129.0).

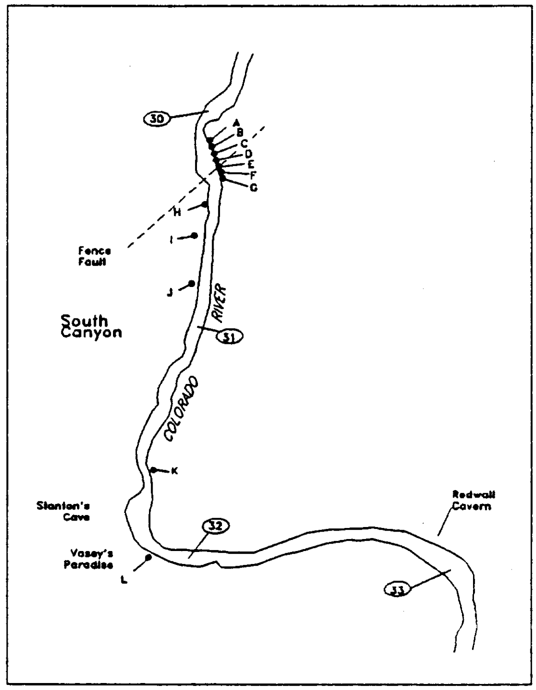


Fig. 4-15. Locations of 12 springs (A-L) in the Fence Fault area.

Fence Fault Springs

Twelve springs were identified in a 2-mi stretch of river near South Canyon (RM 30-32) (Fig. 4-15). Seven springs were closely spaced at Fence Fault and five additional springs were located downstream to Vasey's Paradise. These springs were collectively named the Fence Fault Springs.

The spring identified as "Spring J" in Fig. 4-15 was the most intensively sampled. In January, 1992 the undiluted spring temperature was 21.5° C, with a plume extending into the mainstem that measured 2 m x 2 m at 17.5° C, while mainstem temperature was 9° C. When the spring was revisited on July 14, 1994, spring temperature remained 21.5° C. Plume temperature was approximately 15° C, 2 m from the source, 12° C, at 3 m from the source and was not perceptibly different than the mainstem at 10 m from the source (Fig. 4-16). Approximate area of the plume was 3 m wide and 10 m long. The mouth of the spring was located in a limestone shelf along the shoreline. Substrates in the plume were composed of bedrock limestone, boulders and sand. Estimated discharge on July 14, 1994 was 2-4 cfs.

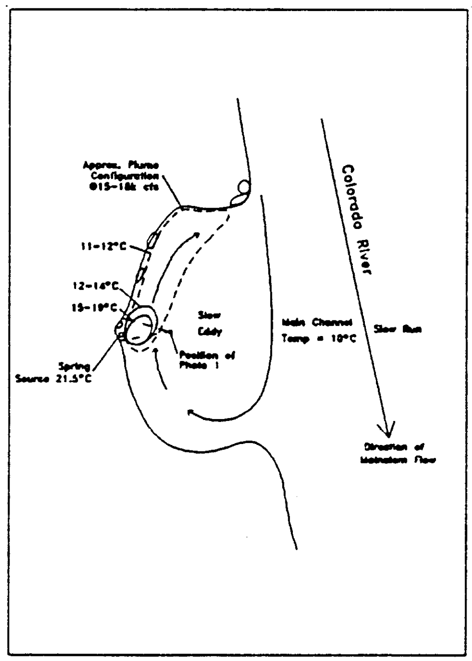


Fig. 4-16. Approximate plume shape and thermal characteristics of Spring J at RM 30.8. Data collected July 14, 1994, with a Hydrolab Surveyor 3.

Locations, estimated discharges, plume areas, and source temperatures for the 12 Fence Fault Springs indicated variable flow and plume areas, but relatively constant source temperatures of 21.0-21.5° C (Table 4-4), except for Spring A (20.9° C) and Spring L (17° C). Spring L (Vasey's Paradise) emanated above the river level, and possibly from a different groundwater source than the other springs. Estimated discharge of eight springs ranged from less than 0.1 cfs (seeps) to about 10 cfs. Discharge from some springs (e.g., Spring H) varied daily, perhaps with river stage. All springs in the Fence Fault area except for Spring L, emanated at river level between the 10,000 and 15,000 cfs. Other springs may be present below this level, but were not detected or observed. Most springs in this area, entered the river in the proximity of Fence Fault, emanating from fractures in the Redwall limestone between RM 30.3 and RM 30.4.

Table 4-4. Physical and chemical characteristics of springs in the Fence Fault area, between RM 30.3 and RM 31.8.

Spring	RM	Estimated Discharge (cfs)	Estimate Area of Plume (m^2)	Temperature at source (°C)
A	30.3	0.5-5.0	15	20.9
B	30.3	-	-	-
C	30.3	<0.1	<1	-
D	30.4	-	-	-
E	30.4	< 0.1	-	-
F	30.4	1-3	20	21
G	30.4	5-10	30-40	21
H	30.5	Variable	10-40	21
I	30.7	0.5	1-10	-
J	30.8	2-4	10-30	21.54
K	31.6	-	-	-
L	31.8	10-15	200	17

Lava Springs

Lava Springs were located just downstream of Lava Falls on the left bank (RM 179.5). These springs flowed into the river from low travertine rims at a temperature of 16° C, while mainstem temperature was 14° C.

Beecher Springs

Beecher Springs were located near river level at RM 183.5 on the left bank. Temperature of the main spring at its source was 23.5° C, and temperature of the mixed plume was 17.5° C, while mainstem temperature was 14° C.

Middle Granite Gorge

The largest downstream aggregation of humpback chub in Grand Canyon was found in Middle Granite Gorge, RM 126.0-129.0 (See Chapter 5 - DISTRIBUTION AND ABUNDANCE). Mean daily temperature from late May to mid-December 1993 reached a high of 14.2° C in late June and early July, while concurrent maximum daily temperature was about 14.6° C (Fig. 4-17). Water temperature measured near debris fans in the area showed no evidence of warm shoreline springs, although the presence of midchannel, subsurface springs could not be discounted. Data from two sites sampled in July 1992, showed only slight warming (about 0.1° C) in slack surface water and in pockets of quiet water next to schist cliffs--a localized effect probably caused by heating from shoreline rocks and cliffs.

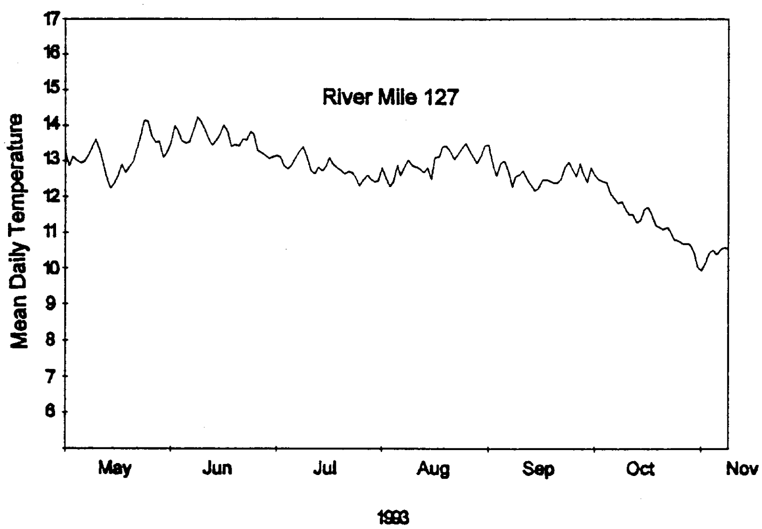


Fig. 4-17. Daily mean, minimum, and maximum temperature of the Colorado River, May-December, 1993, near RM 127. GCES Ryan Tempmentor data.

DISCUSSION

Water quality of the Colorado River in Grand Canyon is largely influenced by Lake Powell (Stanford and Ward 1991). Many water quality parameters have changed since the reservoir was created by Glen Canyon Dam in 1963. Changes in some parameters have had a direct and marked effect on fish populations, while others have indirectly affected fish, or had no affect at all.

This investigation examined the water quality parameters of temperature, turbidity, dissolved oxygen, conductivity, and pH. Other water quality parameters were the subject of other GCES investigations (GCES 1990). The most significant changes from pre-dam conditions were for temperature and turbidity. Pre-dam temperature extremes of 0-29.5° C were replaced by dam releases with annual variation of 7-11° C. Greatest longitudinal warming in summer (1° C/32 miles) produced mean daily temperatures of 10-11° C at the confluence of the LCR (RM 61), 13-14° C in Middle Granite Gorge (RM 127), and 15-16° C at Diamond Creek (RM 226).

The maximum temperature range for the Colorado River in Grand Canyon observed for interim flows was about 10° C below the temperature preferenda of 21-24.4° C for juvenile humpback chub under laboratory conditions (Bulkley et al. 1982). This preferred range was based on juveniles that selected 21° C, 23.5° C, and

24.4° C at acclimation temperatures of 14° C, 26° C, and 20° C, respectively. Mean temperatures selected for the three acclimation temperatures were not significantly different.

Also, maximum temperature range observed under interim flows was marginally suitable for spawning, incubation, and larval survival of humpback chub, with a reported optimum of 16-22° C (Marsh 1985). Hamman (1982) found 79%, 84%, 62%, and 12% hatching success at 21-22° C, 19-20° C, 16-17° C, and 12-13° C, respectively. He also found 99%, 95%, 91%, and 15% survival of swim-up larvae at 21-22° C, 19-20° C, 16-17° C, and 12-13° C, respectively.

Under interim flow temperature regimes, special habitats such as tributary inflows, warm springs, and backwaters provide special attraction to fish because of their thermal properties. Major tributaries, such as the Paria River, LCR, Bright Angel Creek, Shinumo Creek, Kanab Creek, Havasu Creek, Crystal Creek, Tapeats Creek, and Deer Creek, exhibited seasonal warming with temperatures higher than mainstem levels from about April through September. However, during base tributary flows, thermal influence on the mainstem was insignificant, and typically extended as a warm plume less than 200 m from the outflow (See Chapter 7 - HABITAT).

Warm springs were also identified as important because of their thermal properties, but like tributary inflows, their influence on the mainstem was insignificant, and their size and duration was dependent on mainstem flows. Of 14 springs located in three areas (Fence Fault, RM 30.2; Lava Falls, RM 179.5; Beecher Springs, RM 183.5), source temperature was typically ≥21° C, and plume diameter was highly variable with spring volume and mainstem flow. One spring with a source temperature of 21.5° C had a plume of 3 m x 10 m that was warmer than the mainstem (See Chapter 7 - HABITAT).

The other water quality parameter that has been significantly altered in Grand Canyon is turbidity. Since turbidity is a product of suspended sediment, it is reduced sediment concentrations from retention of spring runoff in Lake Powell that has resulted in lower year-around turbidity, and reduced frequency of turbid conditions. The average annual sediment load reduction of 140 million tons to 15 million tons is not a quantifiable relationship to turbidity because of additional considerations, but provides a perspective of relative magnitude of change. The effect of reduced turbidity on humpback chub and other Colorado River native fishes has not been evaluated, and is further discussed in Chapter 8 (MOVEMENT AND ACTIVITY) of this report. However, it is known that turbidity >30 NTUs significantly reduces feeding efforts by rainbow trout (Barrett et al. 1992), and likely affects other sight feeders such as brown trout.

Dissolved oxygen, conductivity, and pH were not significantly different in post-dam conditions, and were not likely to have the direct affect on fishes hypothesized for temperature and turbidity. Also, levels of these parameters did not exceed tolerance ranges for the Colorado River native fishes. Bulkley and Pimental (1982) determined that TDS avoidance levels for juvenile humpback chub, bonytail, and Colorado squawfish were 8500, 5100, and 5000 umhos/cm, respectively, with preferred levels of 1300-3000, 3400-3800, and 1000-1400 umhos/cm, respectively. Average mainstem conductivity, and most monthly maximums were below the preferred range for humpback chub, while most monthly averages in the LCR were within or just above the preferred range.

Minimum observed dissolved oxygen in the mainstem (not including backwater habitats) was ≥8.88 mg/L, while average DO was above 10.35 mg/L. Although preferred and tolerance levels of DO for the Colorado River native fishes is unknown, other fish species require 5 mg/L or more for health, and 1 mg/L is usually lethal (Whitmore et al. 1960, Moss and Scott 1961, Bonn et al. 1976, Piper et al. 1982, Stickney 1986). Dissolved oxygen levels in the LCR in April and May were 5.92 and 5.02, respectively, during spring runoff.

Observed levels of pH were also not perceived as problematic for the native fishes, with a range of 6.92 to 8.00 in the mainstem, and 6.05 to 8.24 in the LCR.

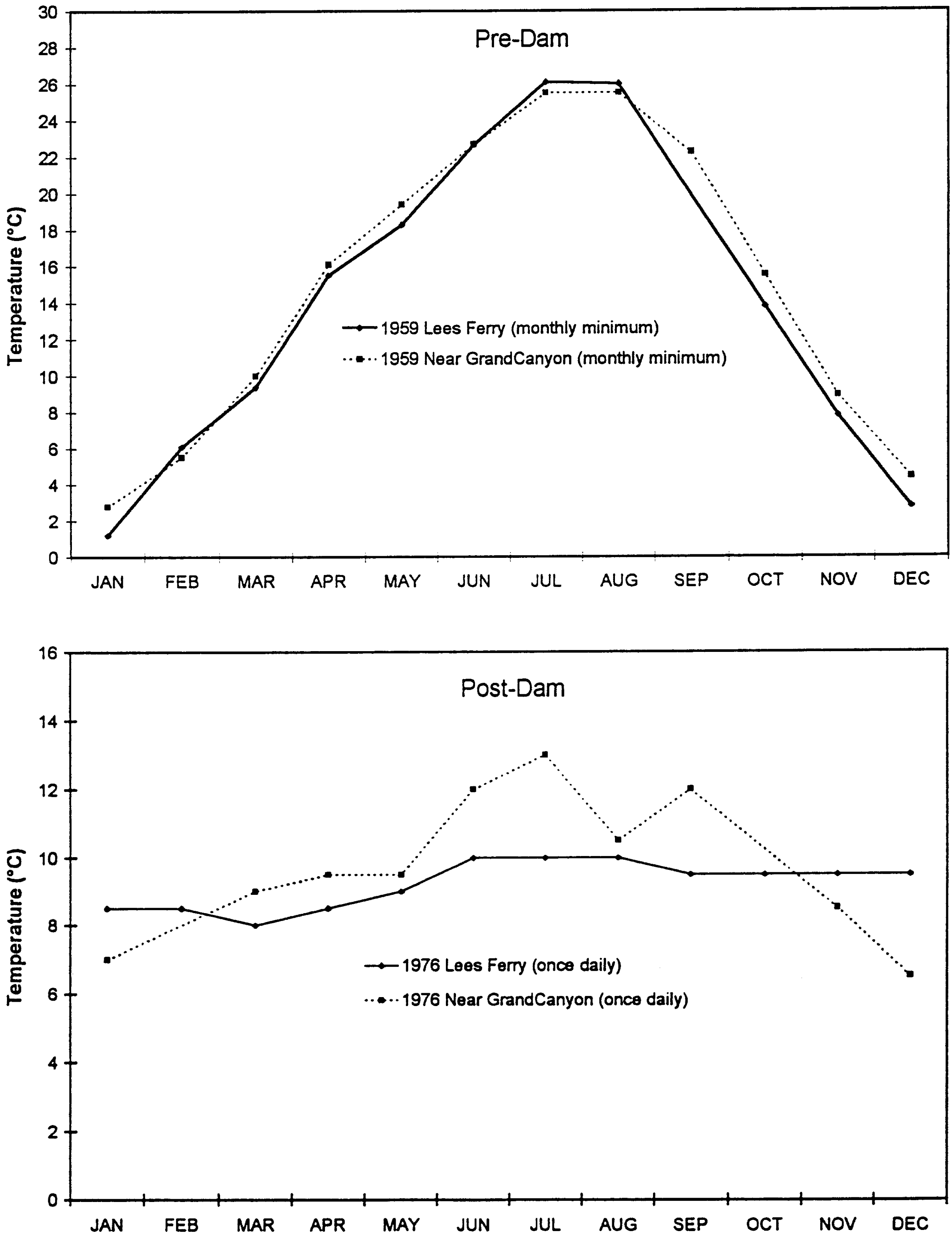
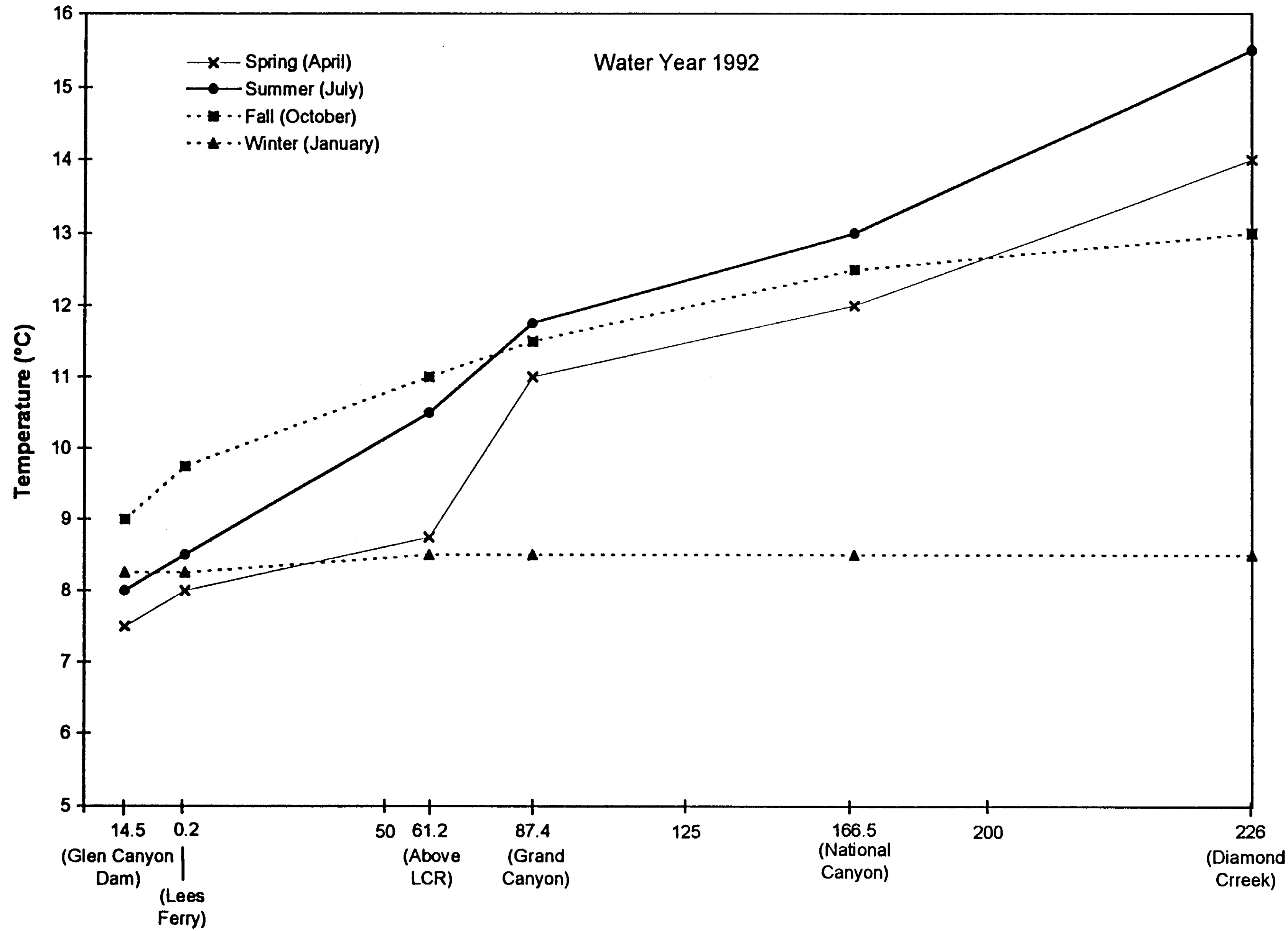

Pre-Dam
Temperature (°C)
1959 Lees Ferry (monthly minimum)
1959 Near GrandCanyon (monthly minimum)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Post-Dam
Temperature (°C)
1976 Lees Ferry (once daily)
1976 Near GrandCanyon (once daily)

Figure 4-1



Water Year 1992
Spring (April)
Summer (July)
Fall (October)
Winter (January)
Temperature (°C)
16
15
14
13
12
11
10
9
8
7
6
5
14.5
(Glen Canyon
Dam)
0.2
(Lees
Ferry)
50
61.2
(Above
LCR)
87.4
(Grand
Canyon)
125
166.5
(National
Canyon)
200
226
(Diamond
Crreek)

Figure 4-2.

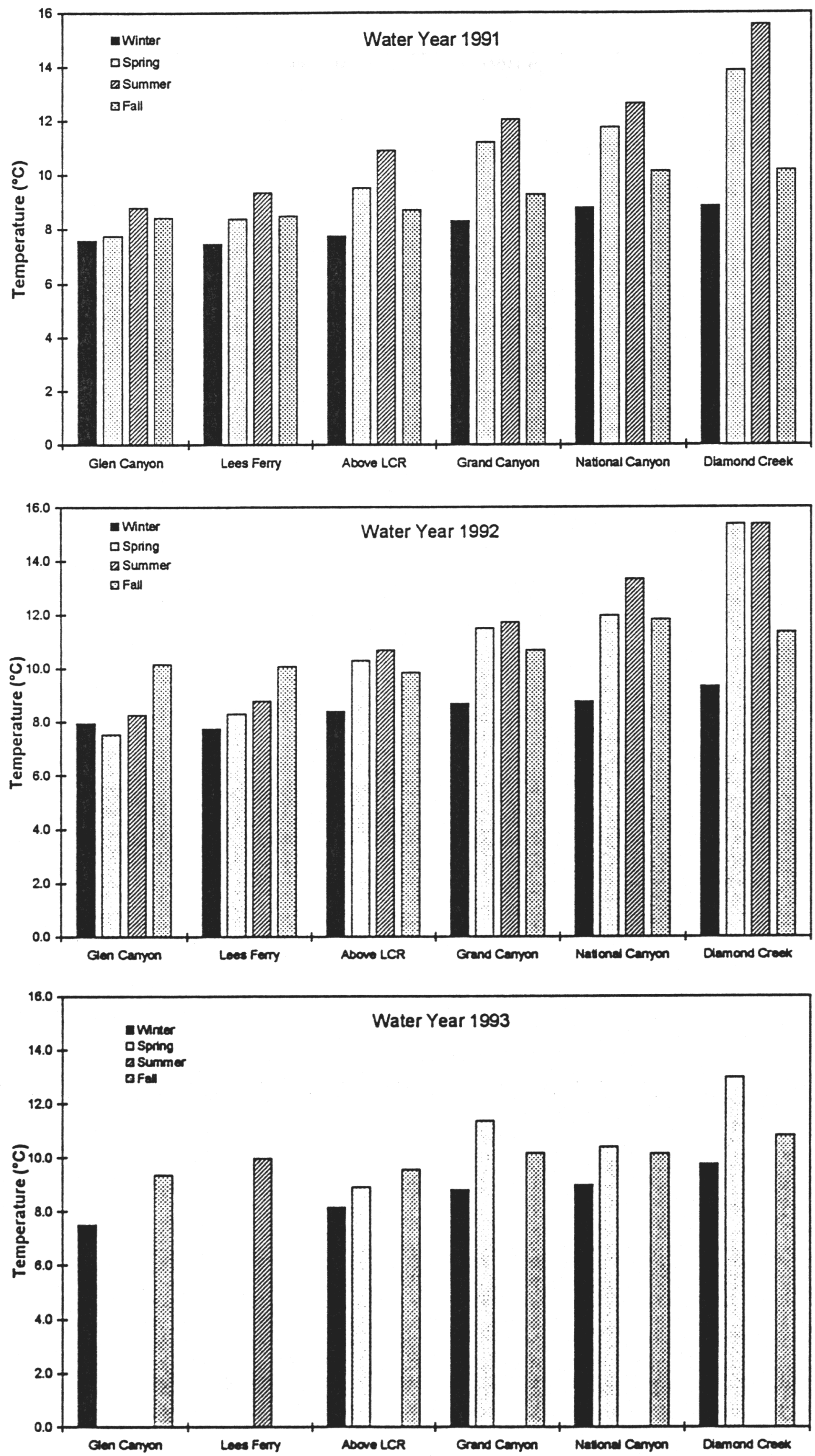

Water Year 1991
Winter
Spring
Summer
Fall
Temperature (°C)
0
2
4
6
8
10
12
14
16
Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek
Water Year 1992
Winter
Spring
Summer
Fall
Temperature (°C)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek
Water Year 1993
Winter
Spring
Summer
Fall
Temperature (°C)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek

Figure 4-3

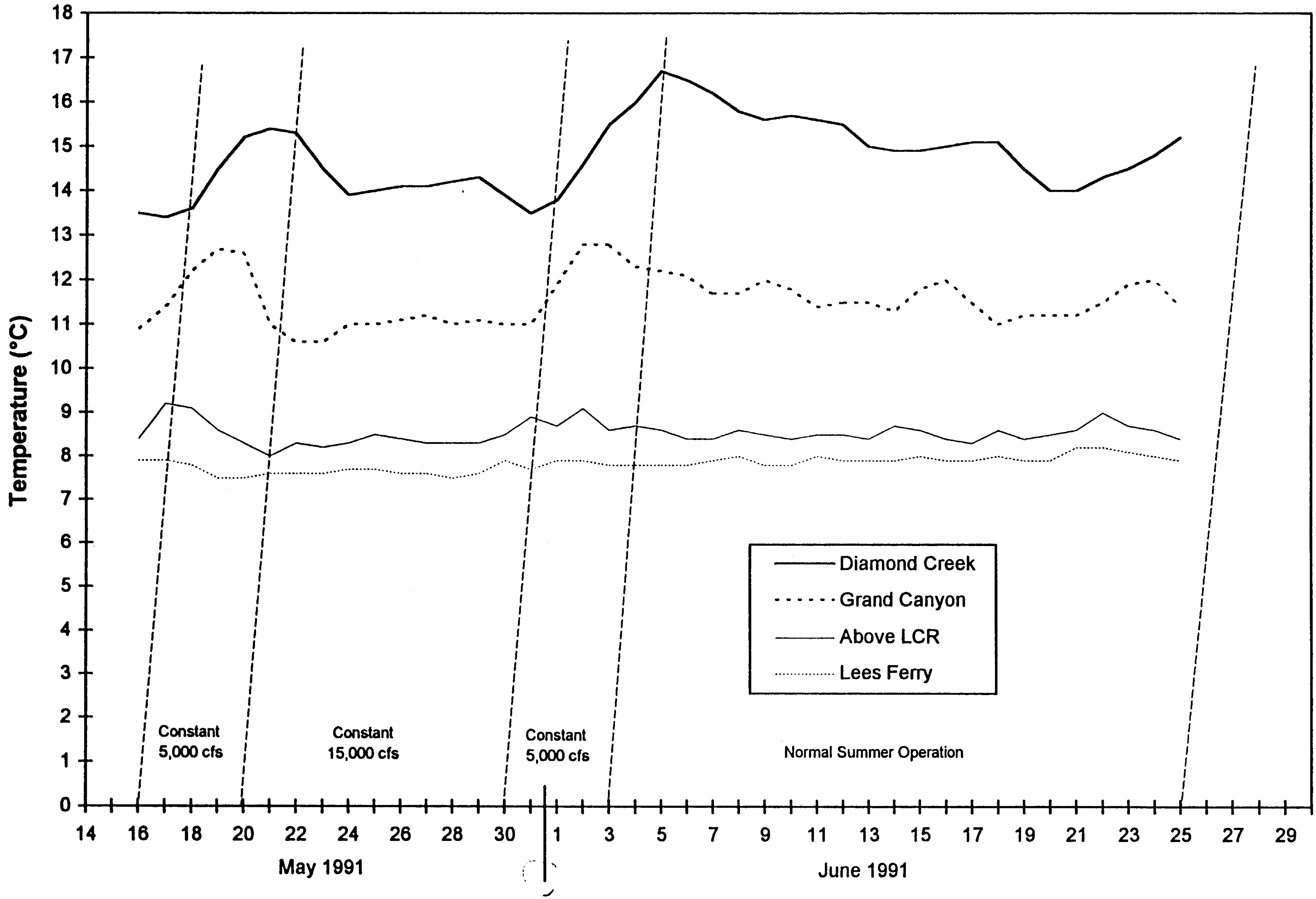
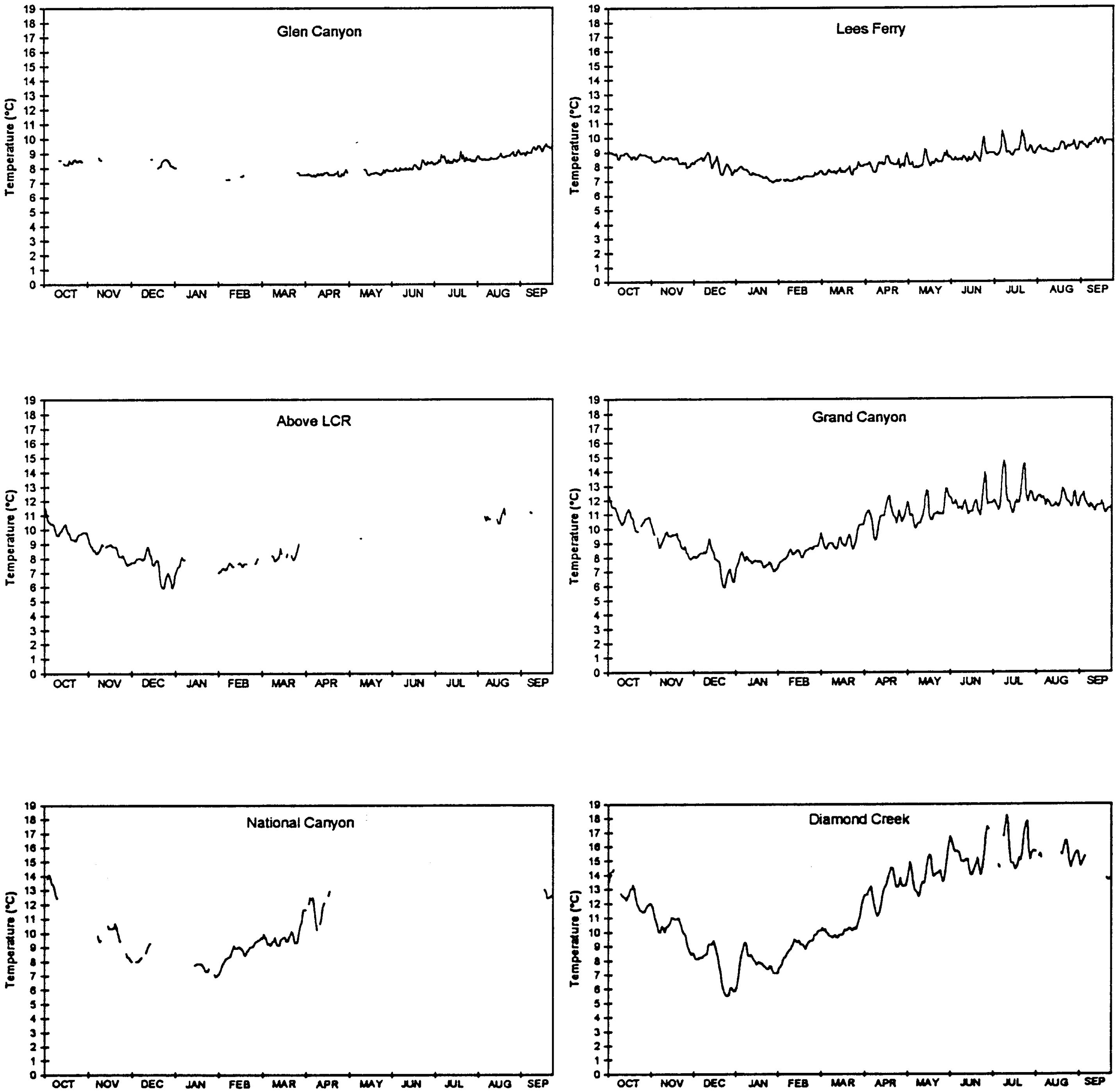

Temperature (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
14
16
18
20
22
24
26
28
30
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
May 1991
June 1991
Constant
5,000 cfs
Constant
15,000 cfs
Constant
5,000 cfs
Normal Summer Operation
Diamond Creek
Grand Canyon
Above LCR
Lees Ferry

Figure 4-4.



Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek
Temperature (°C)
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

Figure 4-5

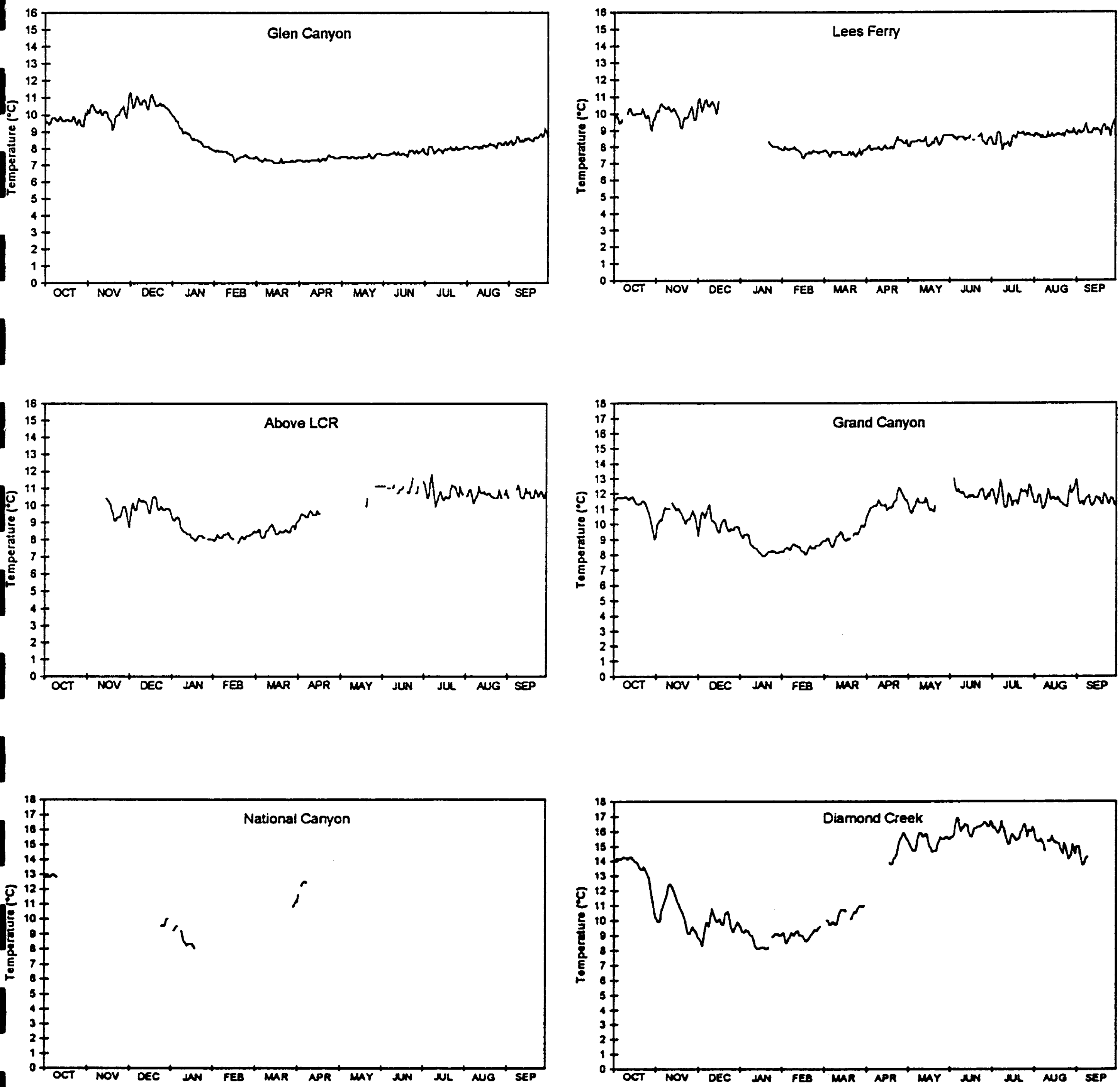
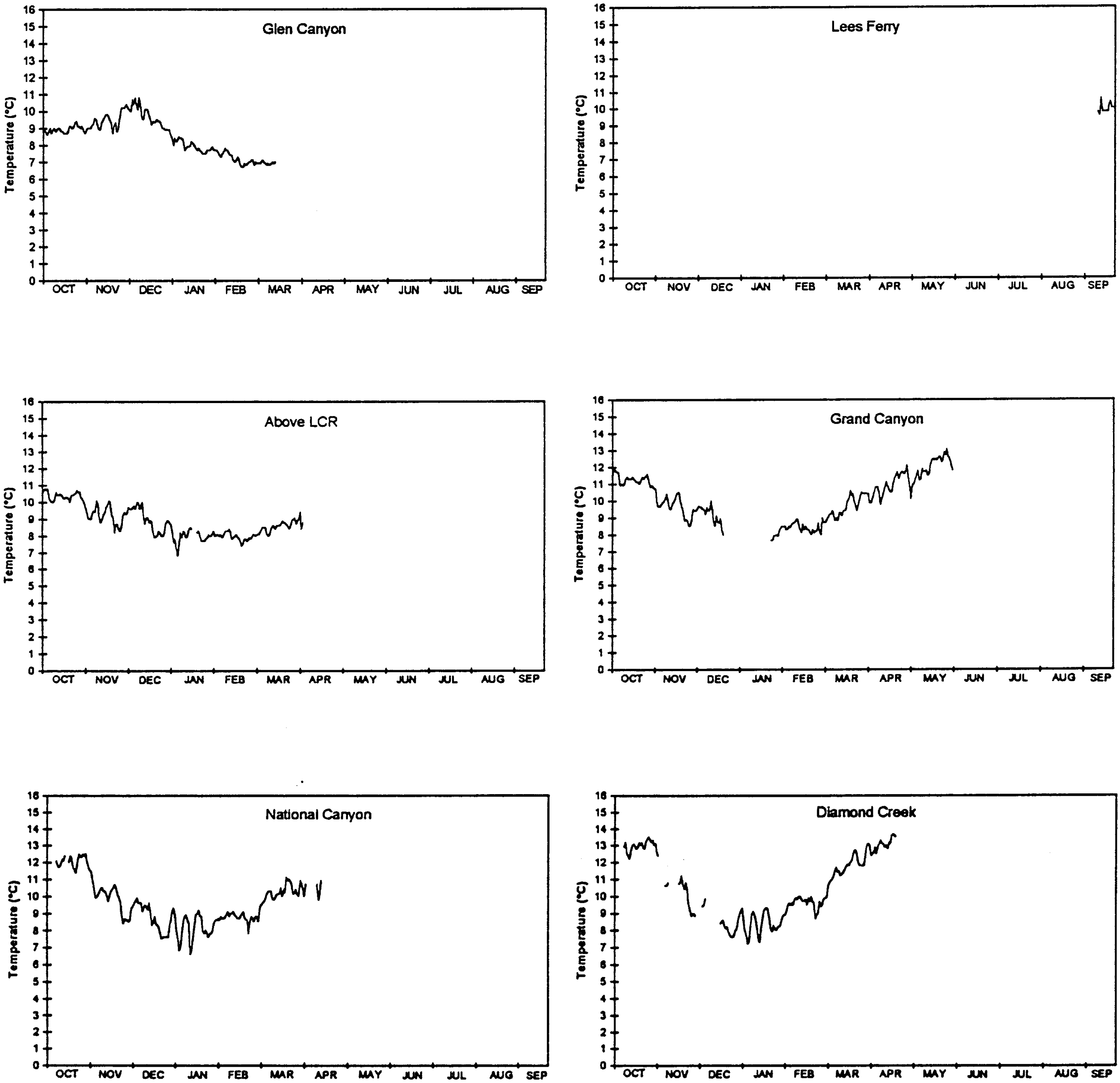
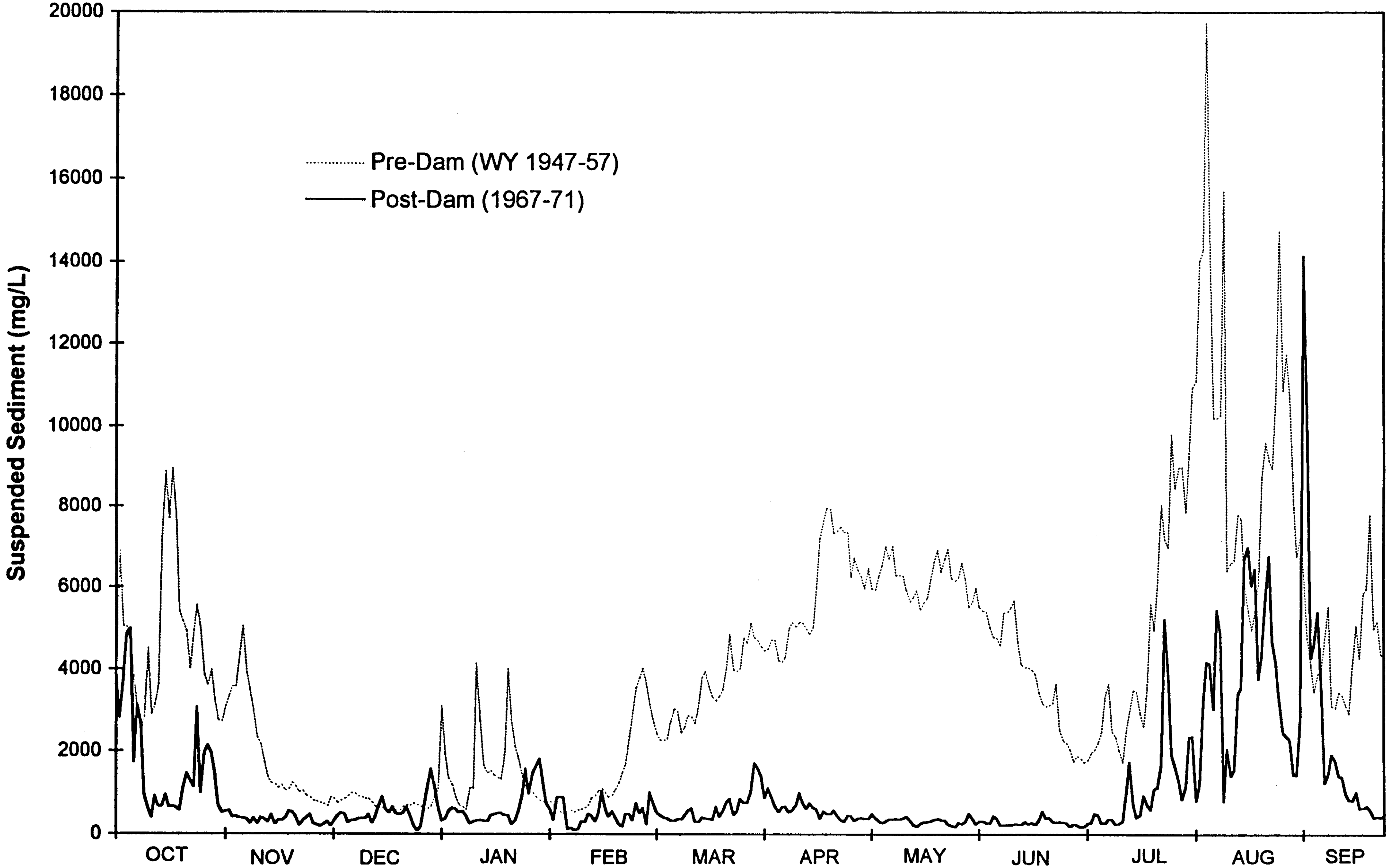

Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek
Temperature (°C)
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Figure 4-6



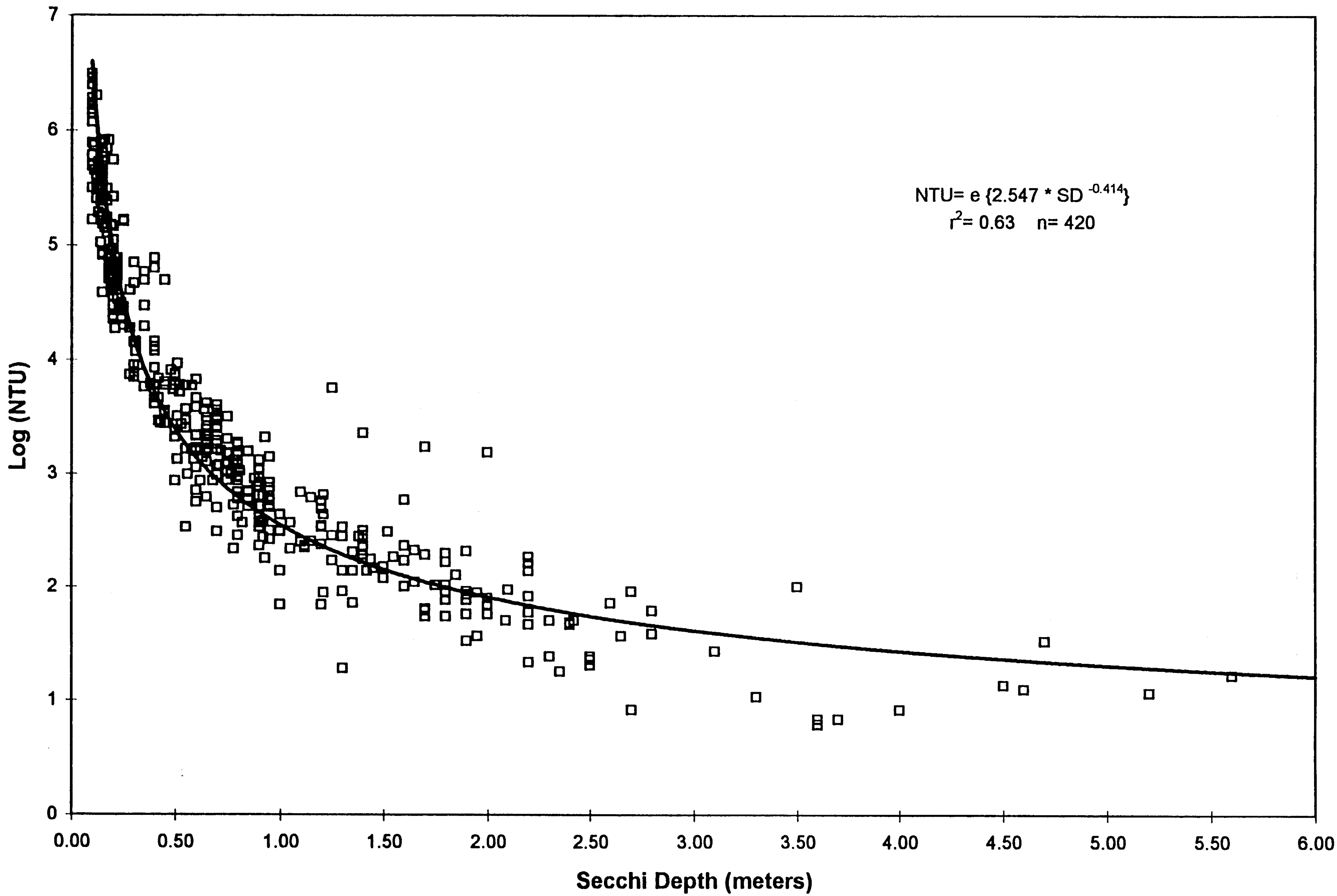
Glen Canyon
Lees Ferry
Above LCR
Grand Canyon
National Canyon
Diamond Creek
Temperature (°C)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Figure4-7



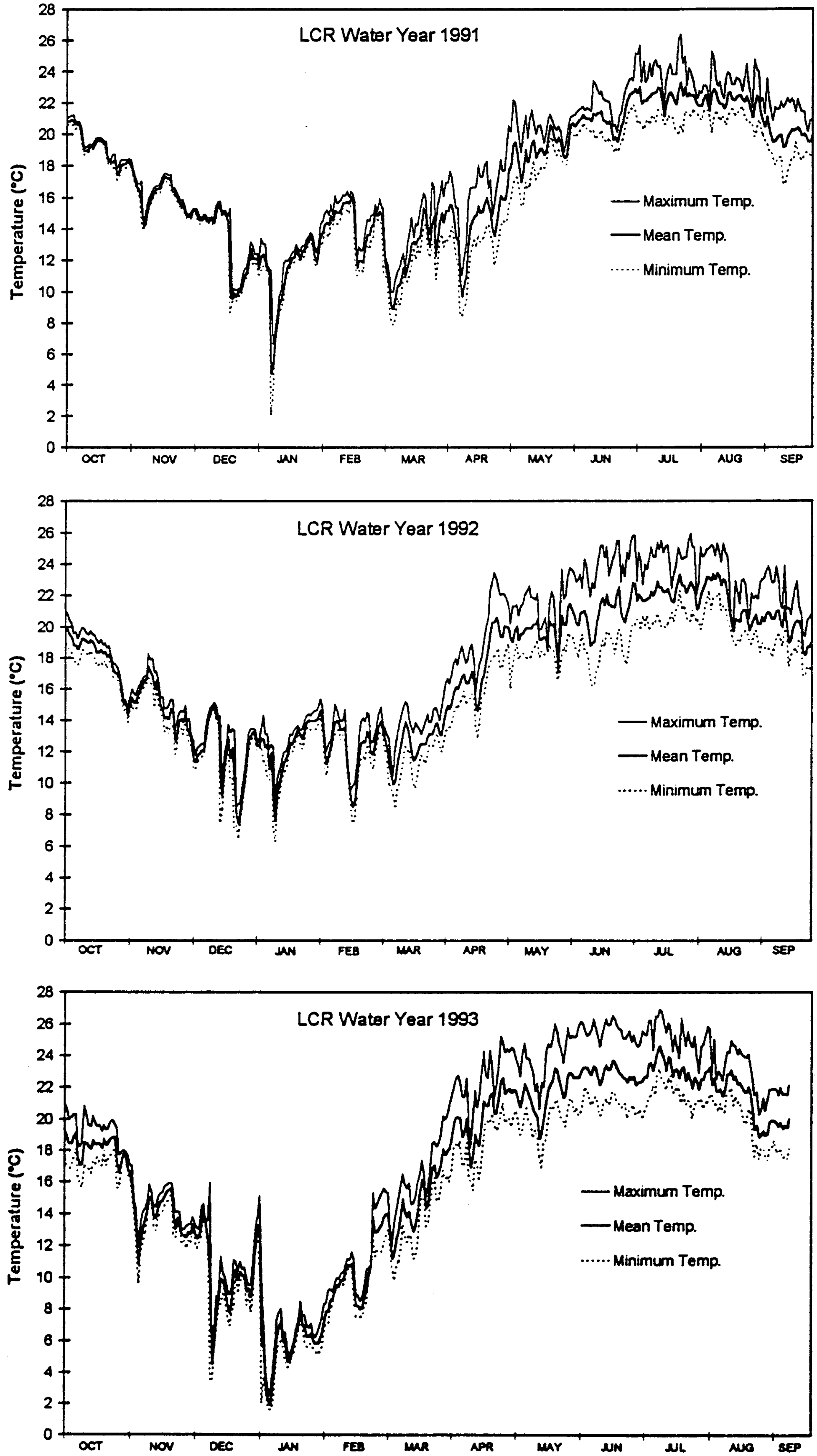
Pre-Dam (WY 1947-57)
Post-Dam (1967-71)
Suspended Sediment (mg/L)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

Figure 4-8



Log (NTU)
7
6
5
4
3
2
1
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
Secchi Depth (meters)
NTU= e {2.547 * SD -0.414}
r2= 0.63 n= 420

Figure 4-14.



LCR Water Year 1991
Temperature (°C)
Maximum Temp.
Mean Temp.
Minimum Temp.
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
LCR Water Year 1992
Temperature (°C)
Maximum Temp.
Mean Temp.
Minimum Temp.
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
LCR Water Year 1993
Temperature (°C)
Maximum Temp.
Mean Temp.
Minimum Temp.
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Figure 4-10

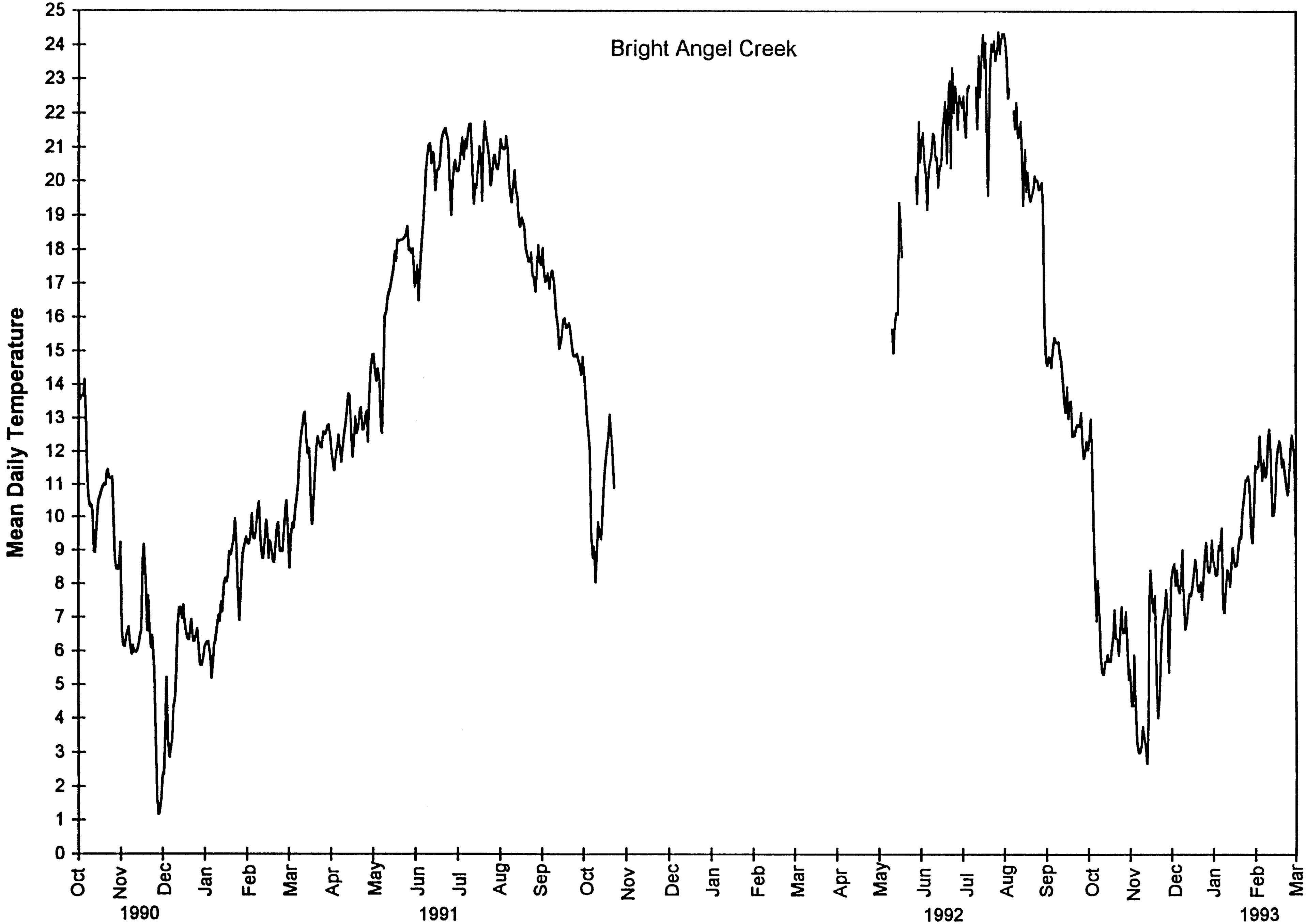

Bright Angel Creek
Mean Daily Temperature
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
1990
1991
1992
1993

Figure 4-11.

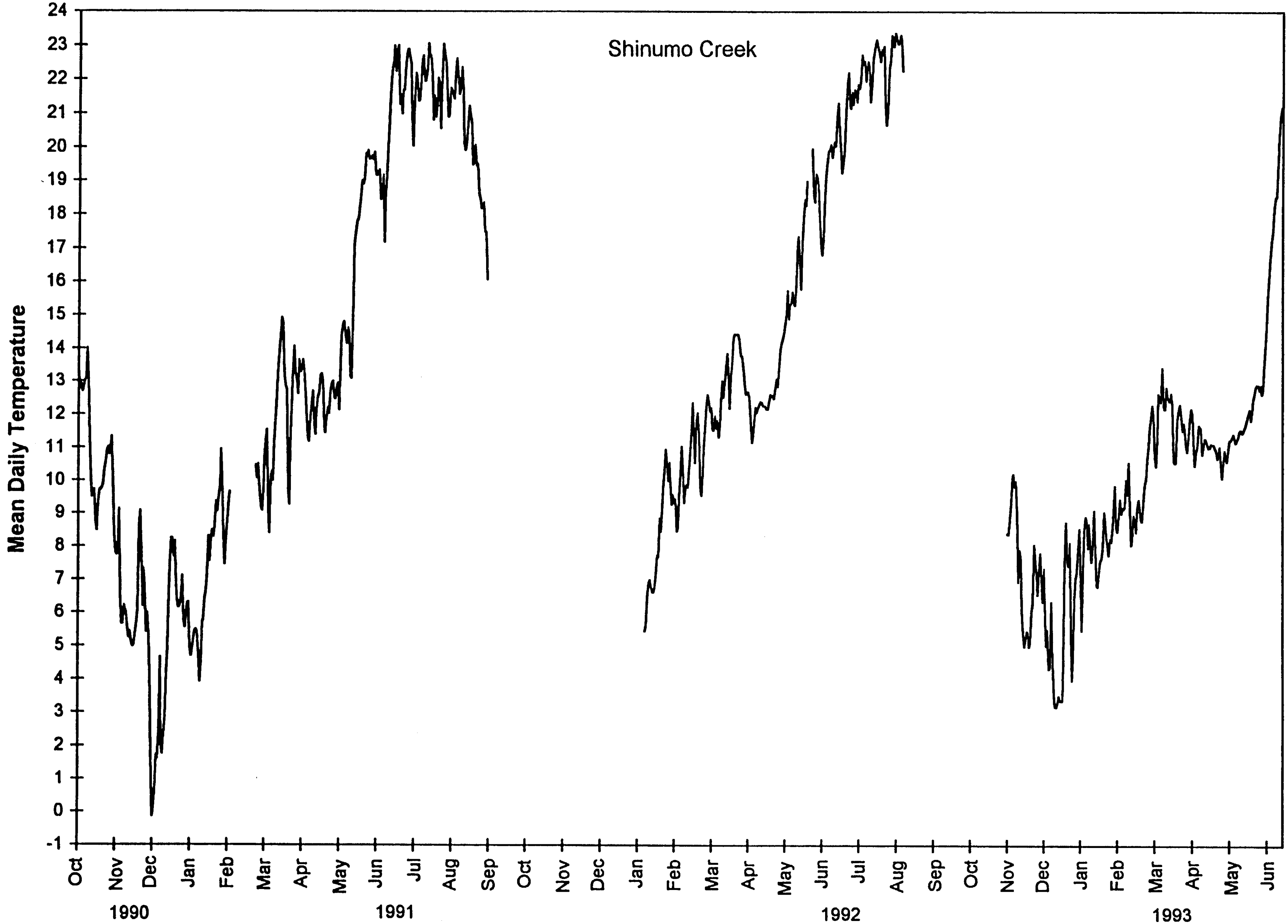

Shinumo Creek
Mean Daily Temperature
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1990
1991
1992
1993

Figure 4-12.

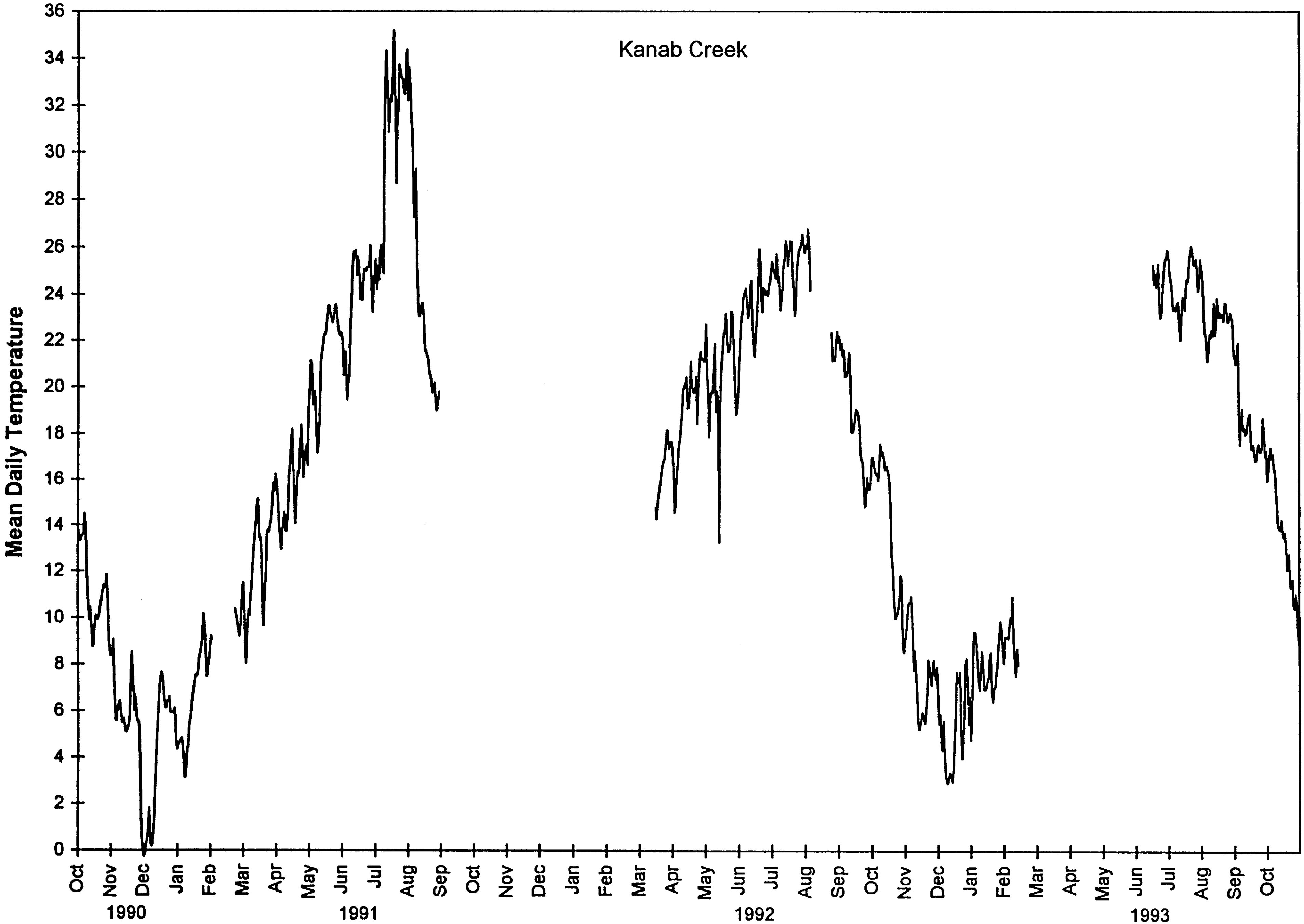
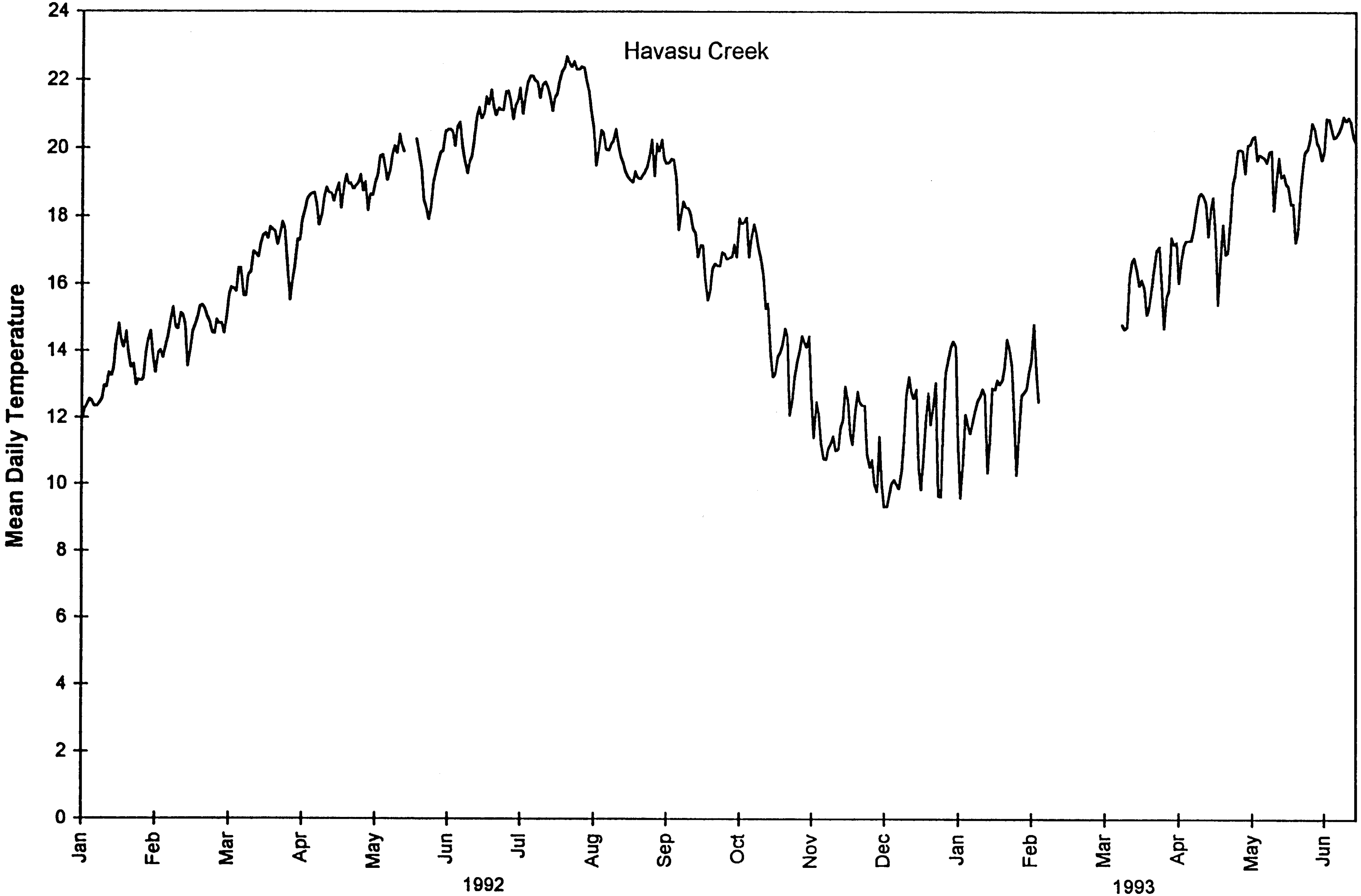
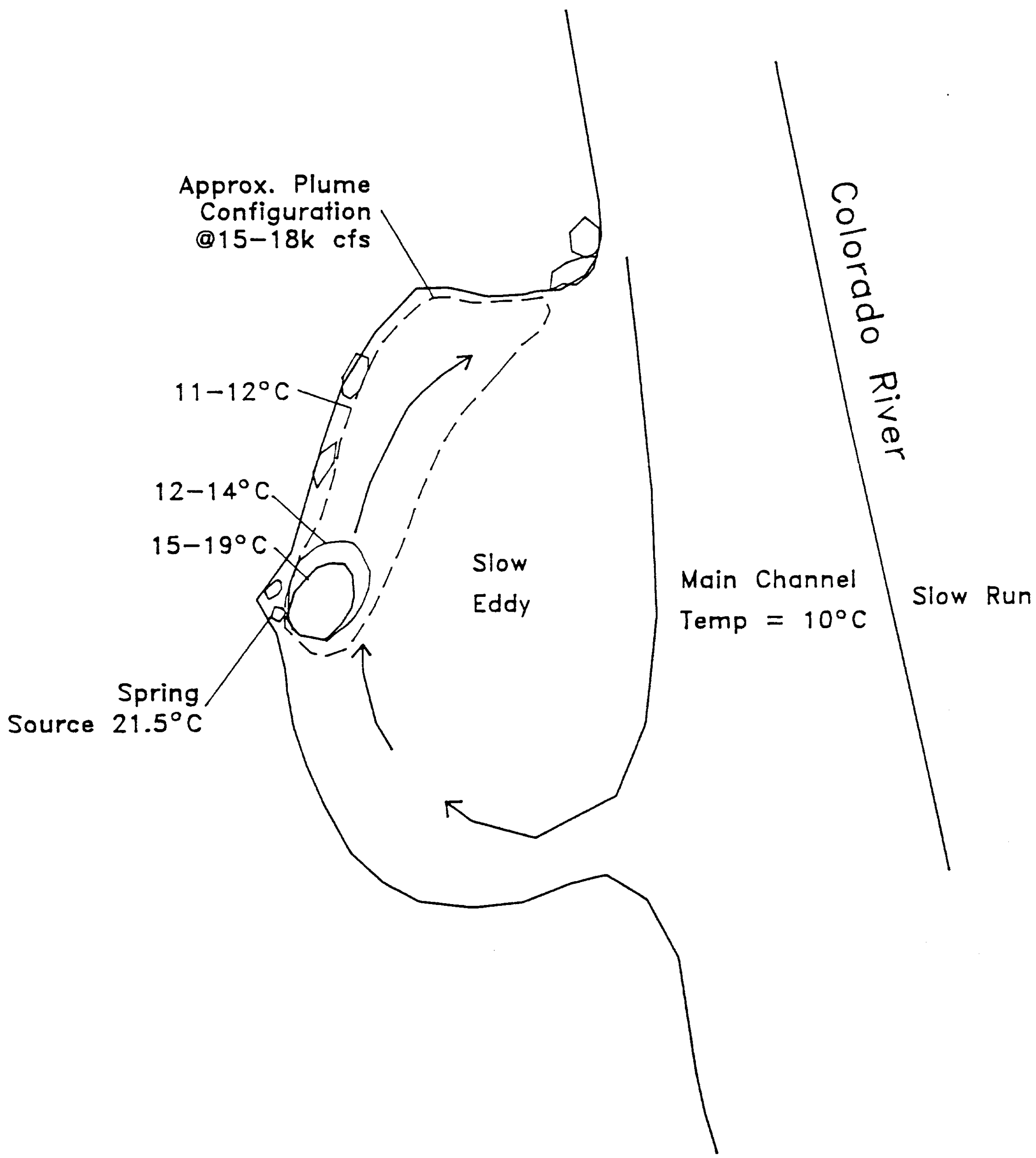

Kanab Creek
Mean Daily Temperature
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
1990
1991
1992
1993

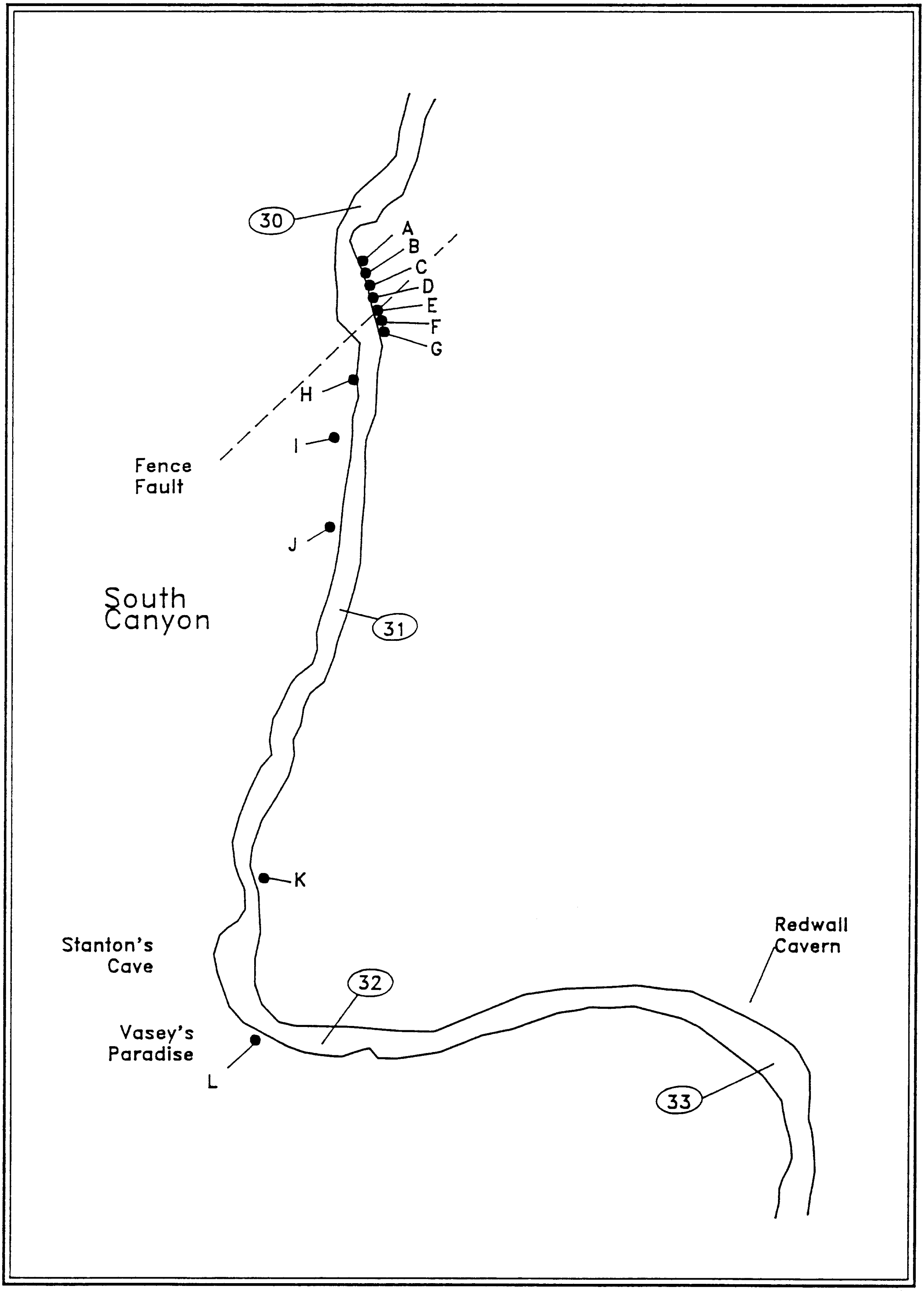
Figure 4-13.



Havasu Creek
Mean Daily Temperature
0
2
4
6
8
10
12
14
16
18
20
22
24
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
1992
1993

Figure 4-14


Approx. Plume Configuration @15-18k cfs
11-12°C
12-14°C
15-19°C
Spring Source 21.5°C
Slow Eddy
Main Channel Temp = 10°C
Colorado River
Slow Run



30
A
B
C
D
E
F
G
H
I
Fence Fault
J
South Canyon
31
K
Redwall Cavern
Stanton's Cave
32
Vasey's Paradise
L
33

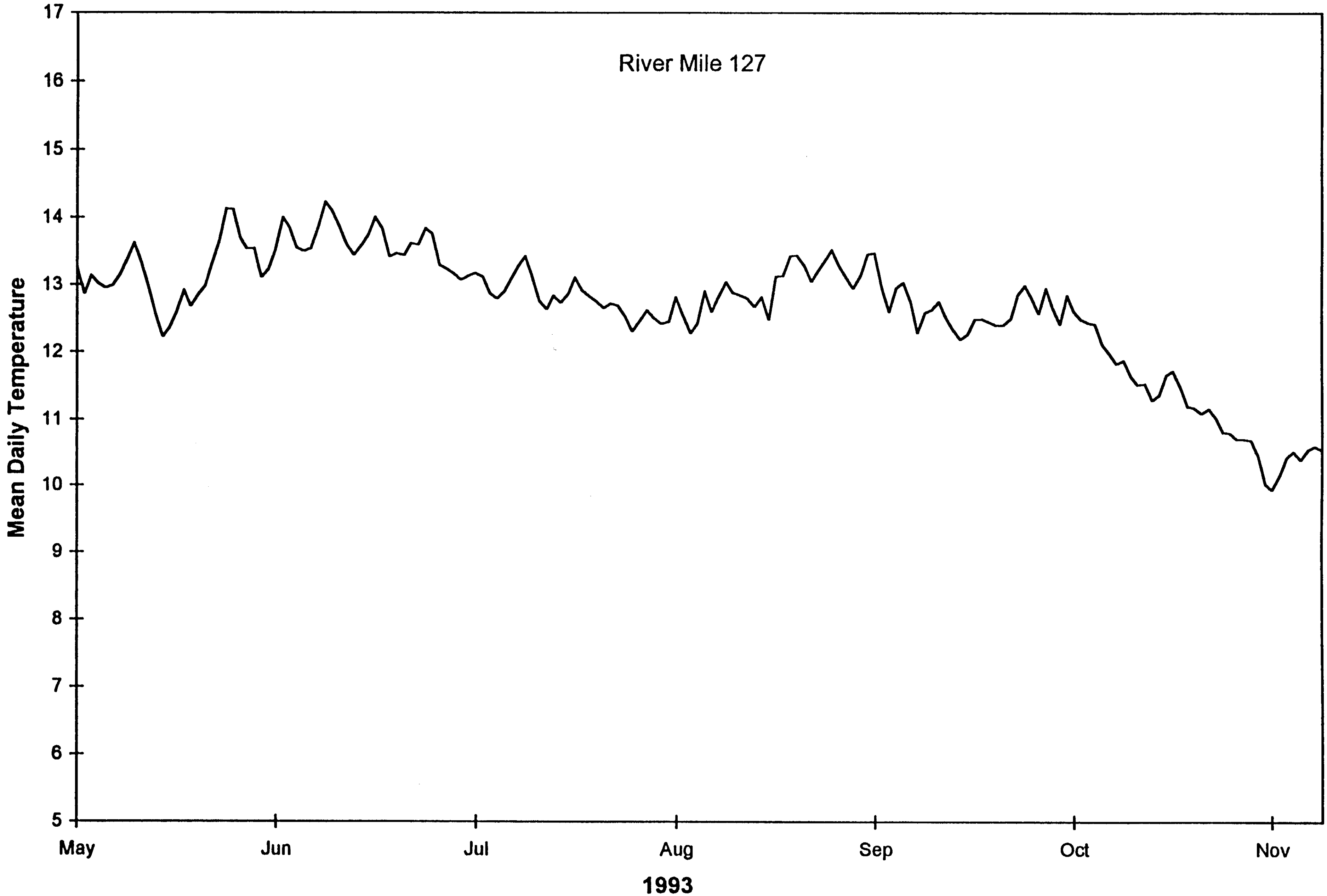

River Mile 127
Mean Daily Temperature
17
16
15
14
13
12
11
10
9
8
7
6
5
May
Jun
Jul
Aug
Sep
Oct
Nov
1993

Figure 4-16./7

CHAPTER 5 - DISTRIBUTION AND ABUNDANCE

INTRODUCTION

Distribution and abundance of fishes in the Colorado River in Grand Canyon are not well understood inspite of numerous surveys and studies over the last 35 years (McDonald and Dotson 1960, Stone and Rathbun 1968, Miller and Smith 1972, Holden and Stalnaker 1975, Minckley and Blinn 1976, Suttkus et al. 1976, Carothers et al. 1981, Kaeding and Zimmerman 1983, Maddux et al. 1987, Arizona Game and Fish Department 1993). The present investigation adds to an increasing wealth of knowledge that will continue to grow as historic and present data become integrated, sampling methodologies are refined, and monitoring programs are implemented. Describing fish assemblages in Grand Canyon will continue to be challenged by logistical difficulties of accessing and sampling the deep and swift river, and by relatively inefficient gears that sample but a fraction of the river corridor. Implementation of new methodologies, such as radiotelemetry, timed sampling strategies, and small, maneuverable research boats to reoccupy sample sites, will enhance opportunities for collecting information vital to understanding the fishes in canyon regions (Valdez et al. 1993).

This chapter integrates pre- and post-dam information with data from this investigation to characterize fish assemblages in the Colorado River in Grand Canyon. Composition, distribution, and abundance are presented for all species, and in detail for humpback chub, together with a discussion of causative effects of Glen Canyon Dam operations on distribution and abundance.

METHODS

Species Composition, Distribution, Abundance

Historic species composition, distribution, and abundance of fishes in the Colorado River in Grand Canyon were described from a search of agency and university reports (i.e., gray literature) and published manuscripts. Present distribution and abundance were determined from the pool of spatial and temporal information gathered from a variety of sampling gears and radiotelemetry used in this investigation, and fish species composition was determined from the sum of fish species captured. Distribution was determined from occurrence of specimens throughout the study area, and abundance was computed as catch-rate statistics and mark-recapture population estimates (see Chapter 6 - DEMOGRAPHICS).

Catch Rates

Catch per effort (CPE) statistics were used as indices of abundance, and to compare relative abundances, temporally and spatially. Problems inherent to catch rate statistics are magnified when dealing with endangered species, such as humpback chub, because low numbers of a target species yield a preponderance of samples with no individuals and a skewed or non-normal catch distribution. Non-normal catch distributions limit parametric tests (Cryer and Maclean 1991), which are based on normality, and distort nonparametric tests, which are based on measures of central tendency, i.e., use of simple non-parametric tests, such as the Mann-Whitney 'U', provides lower statistical power than parametric tests (Zar 1984), and results can be distorted by the large number of zero values.

Two methods were used to compute catch per effort statistics for this investigation: arithmetic mean (AM_{CPE}) and geometric mean (GM_{CPE}) (Sokal and Rohlf 1987). Arithmetic mean was used to estimate relative fish abundance, for comparison with previous investigations, or where comparative statistical tests were not used. Geometric mean was used for comparative parametric tests. Use of catch rate statistics was limited to those datasets with robust sampling regimes and sufficient sample sizes, and for comparisons with identifiable and consistent external variables.

Arithmetic mean catch per effort was calculated as the number of fish captured in each sample, divided by respective effort, and averaged for a given set of samples (Equation 1). This statistic was used to perform comparative tests for samples with normal catch distributions, or where sample efforts were similar. Where sample efforts were dissimilar and catch was zero, this statistic eliminated variable effort from consideration through the catch rate calculation; e.g., two electrofishing efforts of 0.5 h and 2.0 h with no fish each yielded zero catch rates, but difference in effort was not reflected in the averaging statistic.

$$AM_{CPE} = \sum (f/e)/n \qquad \text{(Equation 1)}$$

where: AM_{CPE} = arithmetic mean CPE,
f/e = number of fish divided by effort for each sample
n = number of samples

Geometric mean catch per effort was calculated as shown in Equation 2, with the catch rate for each sample (number of fish divided by effort) transformed to natural logarithms. Samples were averaged, and geometric mean was calculated as the antilog of the average. An adjustment for zero catches was made by adding '1' to each untransformed sample (Sokal and Rohlf 1987). Standard deviation was computed from log-transformed values, and the antilog taken to provide bounds around the geometric mean. The main advantage of GM_{CPE} was reduced dependence of the variance on the mean (Sokal and Rohlf 1987), and reduced influence of single samples with exceptionally high CPE. Disadvantages included loss of individual effort from samples with no fish, and a tendency for log transformations to underweight samples with higher CPE. Because of the reduced dependence of the variance on the mean, GM_{CPE} was used to compare datasets with variable efforts, numerous zero catches, and non-normal AM_{CPE} distributions. This statistic was used as an index of abundance and was not considered to yield realistic catch rates for comparison with AM_{CPE}, which more accurately repleated true fish density.

GM_{CPE} is used by the Service to estimate densities of age-0 Colorado squawfish in the Interagency Standardized Monitoring Program for the Upper Colorado River Basin (McAda et al. 1994).

$$GM_{CPE} = \exp\left[(1/n) \sum \ln (f/e + 1)\right] - 1 \qquad \text{(Equation 2)}$$

where: GM_{CPE} = geometric mean CPE,
f/e = number of fish divided by effort for each sample,
n = number of samples

Biomass

Biomass of native and non-native fish species was estimated by geomorphic reach, using electrofishing and seine catch information for three age categories--young-of-year (YOY), juveniles, and adults. Numbers of individuals per mile of each species and age category were estimated from a regression relating electrofishing catch rate to numbers of fish (Coble 1992). A relationship was developed for humpback chub, in which a mark-recapture estimate was compared with catch rate for each mile sampled. This relationship was applied to other large species (e.g., flannelmouth sucker, bluehead sucker, rainbow trout, brown trout, carp, channel catfish, etc.), for which mark-recapture data were insufficient for population estimates. Numbers per mile of small species (e.g., fathead minnow, plains killifish, green sunfish, etc.) were estimated from seine haul catch rates as numbers of fish/100 m^2. Numbers of fish per mile were converted to numbers per hectare for a 10-m strip along each shoreline--the approximate area effectively sampled with electrofishing and seines. It was assumed, and supported with radiotelemetry and other sampling gears, that the majority of large fish frequented the shoreline during nighttime electrofishing runs, and most small fish resided along shorelines, so that catch rate was a reasonable indicator of minimum fish density. Average total length and weight were determined for each fish species by age category from field measurements and literature (Carlander 1969), and weight was multiplied by total number of fish by species and age category to determine biomass per hectare.

Species Diversity

Species diversity indices were computed for fish assemblages in geomorphic reaches using a measure of information developed by Shannon and Weaver (1949) and applied to ecological situations by Margalef (1958, 1963, 1968). Species richness (i.e., number of fish species present) and evenness (number of individuals per species) were also presented and discussed. Species diversity was computed according to Equation 3.

$$H = - \sum (p_i \ln p_i) \qquad \text{(Equation 3)}$$

where: H = species diversity index,
p = n/N, or number of individuals of a given species/sum of individuals of all species.

RESULTS

Composition, Distribution, And Abundance Of All Species

Pre-Dam (Before 1964)

Fishery data for the Colorado River in Grand Canyon, prior to 1850, are nonexistent. Earliest documentation of native fish species in the area was recovered from 4000-year old flood deposits in Stanton's Cave at RM 31.5 (Euler 1978, Miller 1971, Miller and Smith 1984), which included skeletal remains of bonytail, humpback chub, Colorado squawfish, flannelmouth sucker, and bluehead sucker. Bones of Gila species were also discovered at an archeological site at RM 136 (Jones 1985) and in Catclaw Cave, now an inundated archeological site in Lake Mead (Miller 1955). The original complement of fishes in Grand Canyon was also surmised from early explorers to the region (Powell 1875, Stanton 1892, Dellenbaugh 1904, Kolb and Kolb 1914), and from initial fish surveys (Jordan 1891, Everman and Rutter 1895).

Establishment of Grand Canyon as a National Park in 1919 brought renewed attention to the area, but initial efforts in fish management were toward establishment of a recreational fishery, with non-native trout in clear water tributaries (Williamson and Tyler 1932). A preliminary checklist of fishes of Grand Canyon National Park was assimilated by Miller (1944), and the first comprehensive portrayal of historic fish assemblages of the Colorado River complex and tributaries was from paleontological records of Tertiary and Quaternary deposits (Miller 1959). The list consisted of 11 families, 22 genera, and 35 species, with 27% and 74% level of genus and species endemism, respectively. The primary (mainstem) ichthyofauna consisted of 2 families (Cyprinidae and Catostomidae), 12 genera, and 23 species, with 50% and 87% level of genus and species endemism, respectively. The records and archaeological findings indicate that the primary ichthyofauna in Grand Canyon consisted of 2 families, 5 genera, and 8 species--humpback chub, bonytail, roundtail chub, Colorado squawfish, speckled dace, bluehead sucker, flannelmouth sucker, and razorback sucker. Secondary or tributary-dwelling species, rarely found in the mainstem in Grand Canyon, included 2 Cyprinidae--Virgin spinedace and woundfin.

The first ichthyofaunal survey of the Colorado River in Glen Canyon in 1958-59 (McDonald and Dotson 1960) reported 17 species of fish (6 native, 11 non-native) from the mainstem and various tributaries (Table 5-1). By this time, several non-native fishes had been introduced into the region, including carp in 1881 (Cooper 1987, Sigler and Miller 1963), fathead minnows in the early 1900's, channel catfish in 1939 (Popov 1949), and rainbow trout in the 1920's (Miller 1944). Of the eight primary native species, speckled dace were the most common shoreline inhabitant, flannelmouth suckers were common in the mainstem, and bluehead suckers were restricted to tributaries, while only two immature razorback suckers and one Colorado squawfish were reported. Humpback chub were not reported, probably because the survey was concentrated in Glen Canyon, an intervening alluvial reach not usually considered habitat for the species. Roundtail chub were rare and bonytail were not found.

Table 5-1. Historic and present relative abundance of fish species in the Colorado River, Glen Canyon to Separation Canyon. P = present, abundance unknown, A = abundant, C = common, LC = locally common, R = rare, - = not encountered.

Species	Pre-1850[a]	1958-59[b]	1967-68[c]	1968[d]	1896[e]	1897[f]	1975[g]	1977-78[h]	1980-81[i]	1984-86[j]	1990-93[k]
Family: Cluperdae (herrings)											
threadfin shad (Dorosoma petenense)	-	-	-	-	-	R	-	-	-	-	C[l]
Family: Cyprinidae (minnows)											
red shiner (Cyprinella lutrensis)	-	-	-	C	-	R	-	-	-	-	A[l]
common carp (Cyprinus carpio)	-	C	A	C	C	A	C	A	LC	A	A
Utah chub (Gila atraria)	-	R	-	-	-	-	-	-	-	R	-
humpback chub (Gila cypha)	P	-	C	R	R	R	R[m]	LC	LC	R	LC
bonytail (Gila elegans)	P	-	-	-	-	-	-	-	-	-	-
roundtail chub (Gila robusta)	P	R	C	-	-	-	-	-	-	-	-
Virgin spinedace (Lepidomeda mollispinnis)	P	-	-	-	-	R	-	-	-	-	-
golden shiner (Notemigonus crysoleucas)	-	-	-	-	-	R	-	R	-	R	R[l]
fathead minnow (Pimephales promelas)	-	A	-	A	R	C	A	C	A	A	C
woundfin (Plagopterus argentissimus)	P	-	-	-	-	-	-	-	-	-	-
Colorado squawfish (Ptychocheilus lucius)	P	R	R	-	-	-	-	-	-	-	-
speckled dace (Rhinichthys osculus)	P	A	-	C	A	A	A	C	C	A	C
redside shiner (Richardsonius balteatus)	-	-	-	-	-	-	-	-	R	-	-
Family: Catostomidae (suckers)											
bluehead sucker (Catostomus discobolus)	P	C	C	C	C	C	A	C	C	C	C
flannelmouth sucker (Catostomus latipinnis)	P	C	A	C	C	C	A	C	C	C	C
razorback sucker (Xyrauchen texanus)	P	R	-	-	-	-	-	R	-	R	-
Family: Ictaluridae (catfishes, bullheads)											
black bullhead (Ameiurus melas)	-	C	R	R	-	-	R	-	R	R	R
yellow bullhead (Ameiurus natalis)	-	-	-	-	-	-	-	-	-	R	-
channel catfish (Ictalurus punctatus)	-	A	A	A	R	C	R	C	LC	R	LC
Family: Salmonidae (trout)											

Table 5-1. Continued.

Species	Pre-1850[a]	1958-59[b]	1967-68[c]	1968[d]	1896[e]	1897[f]	1975[g]	1977-78[h]	1980-81[i]	1984-86[j]	1990-93[k]
cutthroat trout (Oncorhynchus clarki)	-	-	-	-	-	-	-	-	R	R	-
coho salmon (Oncorhynchus kisutch)	-	-	-	-	-	R	-	-	-	-	-
rainbow trout (Oncorhynchus mykiss)	-	-	A	C	C	C	C	A	A	A	A
kokanee (Oncorhynchus nerka kennerlii)	-	-	R	-	-	-	-	-	-	-	-
brown trout (Salmo trutta)	-	-	R	-	-	-	-	C	C	C	C
brook trout (Salvelinus fontinalis)	-	-	-	-	-	-	-	C	C	C	R
Family: Cyprinodontidae (killifishes)											
plains killifish (Fundulus zebrinus)	-	R	-	-	-	C	C	C	C	R	LC
Family: Poeciliidae (livebearers)											
mosquitofish (Gambusia affinis)	-	R	-	-	-	R	-	-	-	-	LC[l]
Family: Percichthyidae (temperate basses)											
striped bass (Morone saxatilis)	-	-	-	-	-	-	-	R	-	R	R
Family: Centrarchidae (sunfish)											
green sunfish (Lepomis cyanellus)	-	C	C	-	-	R	-	R	-	R	R
bluegill (Lepomis macrochirus)	-	R	-	-	-	R	-	R	-	-	R[l]
largemouth bass (Micropterus salmonides)	-	R	C	-	-	R	-	R	-	R	R[l]
black crapple (Pomoxis nigromaculatus)	-	-	R	-	-	-	-	-	-	-	R[l]
Family: Percidae (perches)											
yellow perch (Perca flavescens)	-	R	-	-	-	-	-	-	-	-	-
walleye (Stizostedion vitreum)	-	-	R	-	-	-	-	-	-	-	R
Total Number of Species	10	17	15	10	8	18	10	21	14	20	22

[a]Miller (1959)
[b]McDonald and Dotson (1960)
[c]Stone and Rathburn (1968)
[d]Miller and Smith (1972)
[e]Holden and Stalnaker (1975)
[f]Suttkus et al. (1976)
[g]Minckley and Blinn (1976)
[h]Carothers et al. (1981)
[i]Kaeding and Zimmerman (1983)
[j]Maddux et al. (1987)
[k]Valdez and Ryel (1994)
[l]Valdez (1994), reported only below Diamond Creek
[m]reported as "Gila elegans"

Even before completion of Glen Canyon Dam, the decline of much of the native ichthyofauna of the lower Colorado River basin was being documented (Miller 1961).

The earliest catalogued collections of the Gila complex from the Grand Canyon were by R.R. Miller for specimens held at the University of Michigan (M. Douglas, ASU, pers. comm.). Sixteen bonytail (11 from LCR, 3 from Lava Cliff Rapids, 1 from Lees Ferry, 1 from Marble Canyon), six roundtail chub (G. robusta), and five humpback chub (G. cypha) were reported in the 1940's. Morphometrics and meristics from these specimens were used in a paper by Bookstein et al. (1985).

Post-Dam (1964-90)

Following completion of Glen Canyon Dam in 1963, Stone and Rathbun (1968) reported 15 species of fish (5 native, 10 non-native) from the tailwater of Glen Canyon Dam in 1967-68 (Table 5-1), and continued to show the advance of non-native species and decline of natives species. Flannelmouth sucker, rainbow trout, and channel catfish were the most abundant species, and carp were observed in large schools. Razorback sucker were not reported, and "bonytail" were common (probably roundtail chub since specific epithet Gila robusta was used). Colorado squawfish were "rare" in 1968, as the last report of the species from Grand Canyon. This survey also report an abundance of coldwater salmonids introduced by resource agencies, including rainbow trout, brown trout, and kokanee salmon.

In August 1968, Miller and Smith (1972) reported 10 species of fish (4 native, 6 non-native) between Lees Ferry and Diamond Creek, noting that introduced fishes outnumbered native fishes. Channel catfish were particularly abundant, as well as carp, fathead minnow, and red shiners (first reported from this area). Holden and Stalnaker (1975) reported only 8 species (4 native, 4 non-native) from Glen, Marble, and Grand canyons in 1967-71, and Minckley and Blinn (1976) reported 10 species (4 native, 6 non-native). These investigations continued to show the decline of native species, and increase in non-natives.

In 1970-73, Suttkus et al. (1976) reported 18 species (5 native, 13 non-native) between Glen Canyon Dam and Pearce Ferry, including one Virgin spinedace from the mouth of the Paria River, humpback chub from various mainstem locations and the LCR, and flannelmouth sucker, bluehead sucker, and speckled dace from numerous tributary inflows. They also reported red shiner from five different sites, including five fish from RM 194.5, one from RM 212.5, and unspecified numbers from three sites in Lake Mead (Spencer Creek, Scorpion Island, Pearce Ferry).

Carothers et al. (1981), in a comprehensive treatise of fishes of Grand Canyon, identified 17 species (5 native, 12 non-native), with 6 (carp-42%, speckled dace-16%, flannelmouth sucker-14%, rainbow trout-13%, bluehead sucker-9%, humpback chub-6%) comprising nearly 100% of the total number. Razorback suckers were also reported during this investigation.

Kaeding and Zimmerman (1983), as part of the Service's Colorado River Fishery Project in 1980-81, reported 14 species of fish from 32 km of the Colorado River (16 km above and 16 km below the LCR inflow). Fathead minnows, speckled dace, and plains killifish were common to abundant along shorelines; flannelmouth sucker and bluehead sucker were found primarily downstream of the LCR inflow; and rainbow trout were abundant. This study also reported 10 redside shiners from RM 61.4 to RM 71.7, as the only record of the species from the mainstem Colorado River in Grand Canyon.

As part of GCES Phase I, AGF conducted a complete fishery investigation of the Colorado River and tributaries between Glen Canyon Dam and Diamond Creek from April 1984 to June 1986 (Maddux et al. 1987). Twenty fish species (5 native, 15 non-native) were reported, and rainbow trout dominated total catch with 78%, 85%, 59%, 77%, and 42% of composition by number in five reaches sampled progressively downstream. The second most common species was carp with 5%, 13%, 18%, and 37% composition in the lower four reaches. Brown trout were the second most common fish between the LCR and Bright Angel Creek, with 19% of composition. Native species were 17%, 8%, 8%, 2%, and 19% of fish composition in the five reaches. AGF also reported five (TL=68-167 mm) golden shiners from 1985 to 1988, from RM 66.0 to RM 165.0, and one (TL=124 mm) from the lower LCR. Red shiners were not reported from the mainstem, but two specimens (TL=50, 70 mm) were collected in May 1989 from the lower LCR, about 100 m upstream from the confluence (Minckley 1989).

Present (1990-93)

Present fish composition, distribution, and abundance were based on findings of this investigation. Some preliminary findings from a concurrent mainstem investigation by AGF were available from progress reports and personal communications, and data were used where available and applicable to this report.

Fifteen species of fish (4 native and 11 non-native) and one hybrid form were captured in the Colorado River (not including tributaries) between Lees Ferry and Diamond Creek during this investigation in 1990-93 (Table 5-2), and an additional 7 non-native species (Table 5-1) were captured between Diamond Creek and Pearce Ferry (including tributaries) in a separate study for the Hualapai Indian Tribe in 1992-94 (Valdez 1993, 1994, 1995). Of the eight primary native species, only four were found--humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace. Razorback sucker were not captured, although five specimens were classified as flannelmouth sucker x razorback sucker hybrids, based on external morphological characters (McAda and Wydoski 1980). Colorado squawfish, roundtail chub and bonytail were also not captured. Morphologic variation (e.g., nuchal hump depth, caudal peduncle length and depth) and meristic variation (e.g., fin ray counts) of humpback chub handled in Grand Canyon suggest historic introgressive hybridization between the three forms of Colorado River Gila (Gilbert 1961, Kaeding and Zimmerman 1983, Dowling and DeMarais 1993).

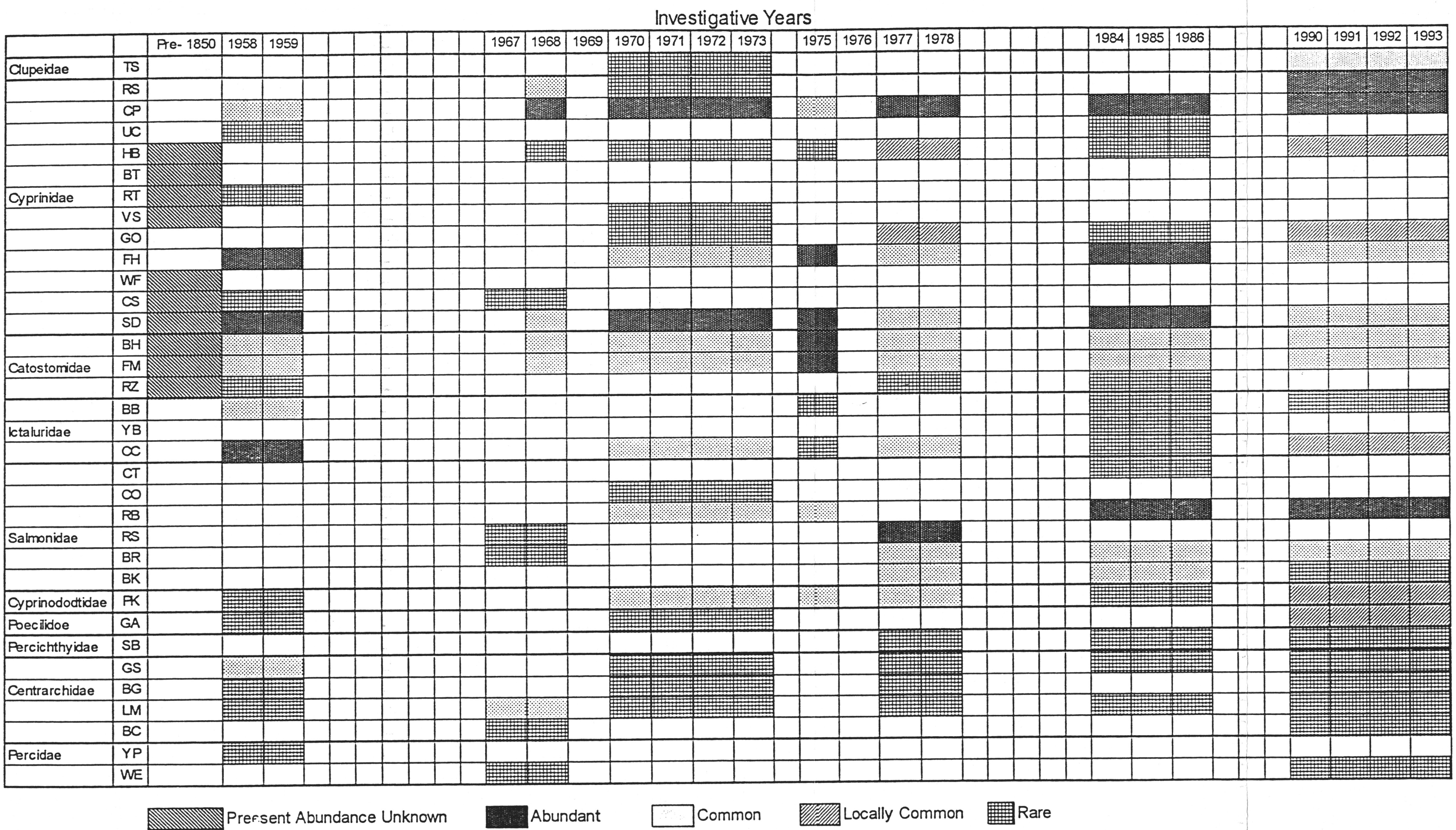
Table 5-2. Fish species captured during this investigation in the Colorado River from Lees Ferry to Diamond Creek, October 1990 - November 1993. See Table 5-1 for species names.

Common Name	Species Code	Status[a]	YOY	JUV	ADU	Total	Percent
Family: Cyprinidae (minnows)							
common carp	CP	EX	4	44	2375	2423	8.6
humpback chub	HB	EN	2865	1638	1791	6294	22.3
fathead minnow	FH	NN	44	12	1074	1130	4.0
speckled dace	SD	NA	4	92	1395	1491	5.3
Family: Catostomidae (suckers)							
bluehead sucker	BH	NA	101	250	689	1040	3.7
flannelmouth sucker	FM	EN	183	395	2197	2775	9.8
flannelmouth x razorback sucker	FR	-	0	0	5	5	<0.1
unidentified sucker	SU	-	32	0	0	32	0.1
Family: Ictaluridae (catfishes, bullheads)							
black bullhead	BB	NN	0	3	3	6	<0.1
channel catfish	CC	NN	4	5	104	113	0.4
Family: Salmonidae (trout)							
rainbow trout	RB	NN	169	1152	9800	11121	39.4
brown trout	BR	EX	2	107	1564	1673	5.9
brook trout	BK	NN	0	0	6	6	<0.1
Family: Cyprinodontidae (killifishes)							
plains killifish	PK[b]	NN	1	0	75	76	0.3
Family: Percichthyidae (temperate basses)							
striped bass	SB	NN	0	0	39	39	0.1
Family: Centrarchidae (sunfish)							
green sunfish	GS	NN	1	1	1	3	<0.1
Family: Percidae (perches)							
walleye	WE	NN	0	0	1	1	<0.1
Totals			**3,410**	**3,699**	**21,119**	**28,228**	**100**

[a]NA = native to the drainage
EN = endemic to the drainage
EX = exotic, introduced from another continent
NN = non-native, introduced from another drainage in North America

[b]Former synonym Rio Grande killifish

Fig. 5-1. Historic and present abundance of fishes in the Colorado River, Glen Canyon to Separation Canyon.



Species Codes:

TS= Threadfin shad
RS= Red shiner
CP= Common carp
UC= Utah chub
HB= Humpback chub
BT= Bonytail
RT= Roundtail chub
VS= Virgin spinedace
GO= Golden shiner
FH= Fathead minnow

WF= Woundfin
CS= Colorado squafish
SD= Speckled dace
BH= Bluehead sucker
FM= Flannelmouth sucker
RZ= Razorback sucker
BB= Black bullhead
YB= Yellow bullhead
CC= Channel catfish
CT= Cutthroat trout

CO= Coho salmon
RB= Rainbow trout
KS= Kokane salmon
BR= Brown trout
BK= Brook trout
PK= Plains killifish
GA= Mosquitofish
SB= Striped bass
GS= Green sunfish
BG= Bluegill

LM= Largemouth bass
BC= Black crappie
YP= Yellow pearch
WE= Walleye

Fig. 5-1. Historic and present abundance of fishes in the Colorado River, Glen Canyon to Separation Canyon.

The 11 non-native species found between Lees Ferry and Diamond Creek were previously reported by other investigators (Table 5-1; Fig. 5-1), and included carp, fathead minnow, black bullhead, channel catfish, rainbow trout, brown trout, brook trout, plains killifish, striped bass, green sunfish, and walleye. Carp and channel catfish were common throughout the study area, rainbow trout and brown trout were abundant to common in upstream reaches, and fathead minnow and plains killifish were locally common in backwaters and shorelines. A total of 39 striped bass and 1 walleye were caught in July and August of 1991-93, and were believed to be summer spawning migrants from Lake Mead. Utah chub, yellow bullhead, and cutthroat trout, previously reported as rare, were not captured in this investigation. Red shiners were not found upstream of Bridge Canyon (RM 235, 14 km below Diamond Creek), but were abruptly abundant in tributaries and tributary inflows downstream of that point. Lacustrine species--threadfin shad, bluegill, largemouth bass, black crappie, and walleye--were common transients from Lake Mead to below Bridge Canyon, and one golden shiner was captured near Lost Creek (RM 249, 37 km below Diamond Creek)(Valdez 1994). The only red shiners reported between Glen Canyon Dam and Bridge Canyon since 1973 was a single specimen (TL = 38 mm) captured by AGF on June 26, 1992 at RM 117.4 (T. Hoffnagle, AGF, pers. comm).

Nine species of fish were captured every year of the investigation, and were considered common residents of the mainstem between Lees Ferry and Diamond Creek, including rainbow trout, humpback chub, flannelmouth sucker, carp, brown trout, speckled dace, fathead minnow, bluehead sucker, and channel catfish. The remaining six species were uncommon or transient, i.e., plains killifish, black bullhead, and green sunfish were uncommon in sheltered shoreline habitats; brook trout were infrequently captured; and striped bass and walleye were midsummer upstream spawning migrants from Lake Mead. Annual changes in relative numbers of individuals of a given species and age category (Table 5-3) were attributed primarily to changes in sampling effort, sampling variation caused by temporal and spatial distribution of fishes, or gear efficiency relative to river condition, and not necessarily to changes in total numbers. Increased numbers of YOY humpback chub in 1993 were attributed to increased sampling of shorelines near the LCR and to a strong 1993 year class (See Chapter 6 - DEMOGRAPHICS).

A longitudinal trend of the 15 species of fish found between Lees Ferry and Diamond Creek was indicated from a regional comparison (Table 5-4. Fig. 5-2). Species richness by geomorphic reach increased in a downstream direction (Fig. 5-3), from a low of 3 in reach 2 (RM 11.0-22.5) to a high of 14 in reach 10 (RM 160.0-213.9). The four native species--humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace--were present in all reaches, except for reach 1 (bluehead sucker, flannelmouth sucker, and speckled dace were present) and reach 2 (flannelmouth sucker were present). Numbers of non-native species increased downstream from a low of 1 in reach 2 to a high of 10 in reach 10. Non-native species in reaches 1-3 were

Table 5-3. Fish species captured by year and age category (in order of abundance) in the Colorado River in Grand Canyon, October 1990 - November 1993. See Table 5-2 for description of species codes. YOY = young-of-year, JUV = juvenile, ADU = adult.

Species Code	1990-91				1992				1993				TOTAL			
	YOY	JUV	ADU	Total	YOY	JUV	ADU	Total	YOY	JUV	ADU	Total	YOY	JUV	ADU	Total
RB	45	382	4309	4736	42	257	2257	2556	82	513	3234	3829	169	1152	9800	11121
HB	117	241	608	966	119	527	422	1068	2629	870	761	4260	2865	1638	1791	6294
FM	4	53	798	855	57	140	550	747	122	202	849	1173	183	395	2197	2775
CP	2	15	1168	1185	2	9	787	798	0	20	420	440	4	44	2375	2423
BR	0	24	703	728	2	62	579	643	0	20	282	302	2	107	1564	1672
SD	1	0	163	164	1	0	385	386	2	92	847	941	4	92	1395	1491
FH	0	0	18	18	11	0	549	560	33	12	507	552	44	12	1074	1130
BH	1	14	198	213	8	48	179	235	92	188	312	592	101	250	689	1040
CC	1	1	59	61	2	2	22	26	1	2	23	26	4	5	104	113
PK	0	0	5	5	1	0	65	66	0	0	5	5	1	0	75	76
SB	0	0	17	17	0	0	3	3	0	0	19	19	0	0	39	39
SU	0	0	0	0	28	0	0	28	4	0	0	4	32	0	0	32
FR	0	0	3	3	0	0	2	2	0	0	0	0	0	0	5	5
BB	0	0	1	1	0	2	0	2	0	1	2	3	0	3	3	6
BK	0	0	4	4	0	0	1	1	0	0	1	1	0	0	6	6
GS	0	0	0	0	0	1	0	1	1	0	1	2	1	1	1	3
WE	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Totals:	171	730	8055	8957	273	1048	5801	7122	2966	1920	7263	12149	3410	3699	21119	28227

Table 5-4. Number and percentage of fish species by age category in the four study reaches. See Table 5-2 for description of species codes. YOY = young-of-year, JUV = juvenile, ADU = adult.

	Region 0					Region I					Region II					Region III				
Species	YOY	JUV	ADU	Total	%	YOY	JUV	ADU	Total	%	YOY	JUV	ADU	Total	%	YOY	JUV	ADU	Total	%
RB	34	291	2012	2337	94.3	56	412	5152	5620	37.0	72	385	2527	2984	37.6	7	64	112	183	6.9
HB	0	0	26	26	1.0	2885	1537	1569	5991	39.4	37	45	181	263	3.3	0	2	12	14	0.5
FM	0	0	64	64	2.6	117	147	990	1254	8.3	27	131	834	992	12.5	39	117	309	465	17.6
CP	0	0	37	37	1.5	2	25	203	230	1.5	0	7	1292	1299	16.4	2	12	843	857	32.4
BR	0	1	4	5	0.2	0	1	67	68	0.4	2	100	1480	1582	20.0	0	4	13	17	0.6
SD	0	0	4	4	0.2	2	0	712	714	4.7	2	0	279	281	3.5	0	92	400	492	18.6
FH	0	0	0	0	0.0	26	8	878	912	6.0	5	0	132	137	1.7	13	4	64	81	3.1
BH	0	0	2	2	0.1	79	108	157	344	2.3	9	49	242	300	3.8	13	93	288	394	14.9
CC	0	0	0	0	0.0	3	3	27	33	0.2	1	1	3	5	0.1	0	1	74	75	2.8
PK	0	0	0	0	0.0	0	0	10	10	0.1	0	0	56	56	0.7	1	0	9	10	0.4
SB	0	0	0	0	0.0	0	0	0	0	0.0	0	0	8	8	0.1	0	0	32	32	1.2
SU	0	0	0	0	0.0	1	0	0	1	<0.1	16	0	0	16	0.2	15	0	0	15	0.6
FR	0	0	0	0	0.0	0	0	4	4	<0.1	0	0	1	1	<0.1	0	0	0	0	0.0
BB	0	0	0	0	0.0	0	2	3	5	<0.1	0	1	0	1	<0.1	0	0	0	0	0.0
BK	0	0	2	2	0.1	0	0	1	1	<0.1	0	0	0	0	<0.1	0	0	3	3	0.1
GS	0	0	0	0	0.0	0	1	1	2	<0.1	0	0	0	0	0.0	1	0	0	1	<0.1
WE	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0.0	0	0	1	1	<0.1
Total	**34**	**292**	**2151**	**2477**	**100**	**3171**	**2244**	**9780**	**15195**	**100**	**171**	**719**	**7038**	**7928**	**100**	**91**	**389**	**2169**	**2649**	**100**

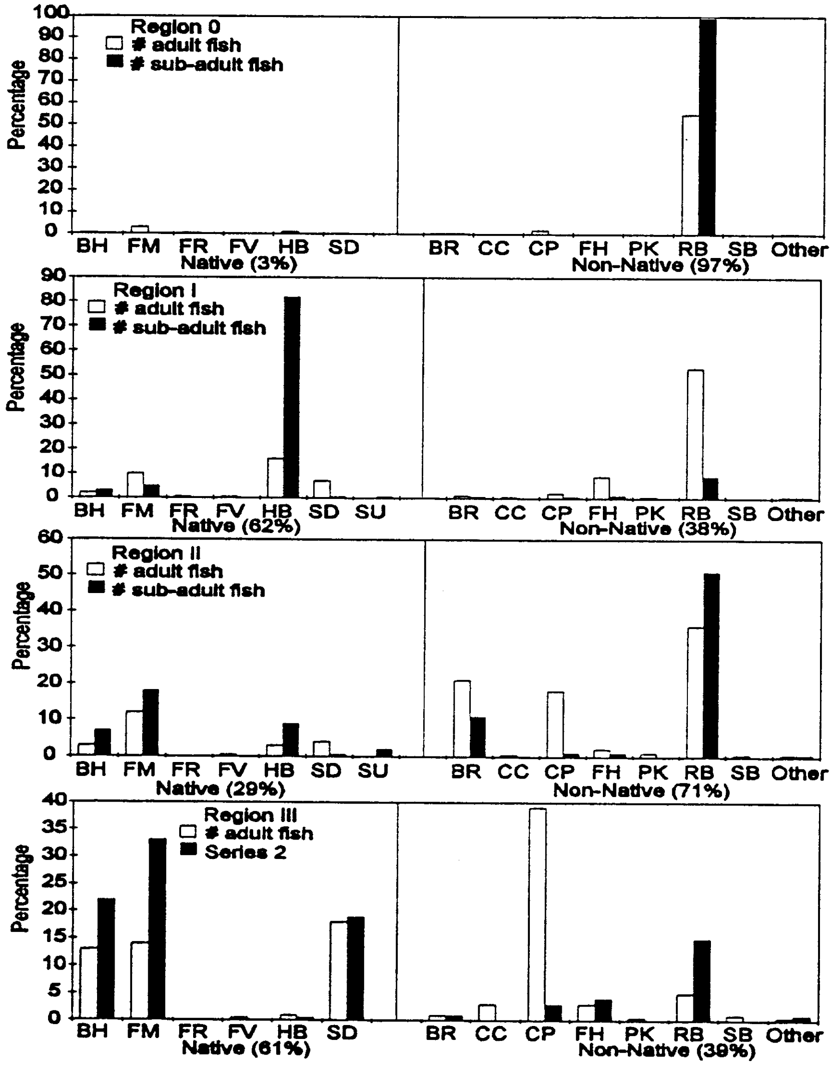


Fig. 5-2. Percentage of adults and subadults of common fish species by study region, 1990-1993. See Table 5-2 for description of species codes.

primarily coldwater salmonids, while non-native species in reaches 4-11 were primarily warmwater cyprinids, ictalurids, and centrarchids. Numbers of non-native species increased dramatically, from 3 in reach 3 (RM 22.6-35.9) to 9 in reach 4 (RM 40.0-61.5), a possible influence of the warm and productive LCR inflow at RM 61.3. Similarly, the increase in non-native species from 5 in reach 8 (RM 125.6-139.9) to 9 in reach 9 (RM 140.0-159.9) could also be attributed to warm inflows from Kanab Creek (RM 143.5) and Havasu Creek (RM 156.6).

Fish species diversity also increased dramatically downstream, with a low Shannon-Weaver index (H) of 0.022 in reach 2 to a high of 1.728 in reach 11 (Fig. 5-3). Maddux et al. (1986) reported lowest diversity of 0.20

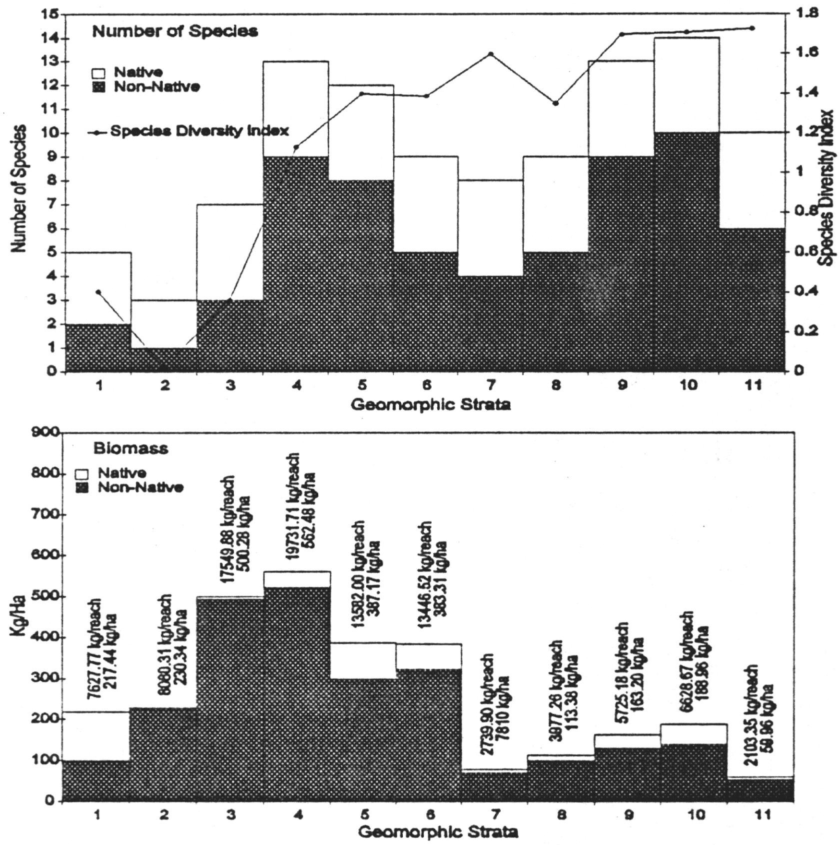


Fig. 5-3. Number of species, species diversity, and biomass of native and non-native fish species by geomorphic reach from Lees Ferry to Diamond Creek.

in reach 20 (RM 0-61.5), and higher diversities of 0.77 and 0.63 in reaches 30 (RM 61.5-88.0) and 50 (RM 166.5-226.0). AGF reach 30 approximately corresponded to reach 5 of this study (H=1.400), and reach 50 corresponded to reach 10 (H=1.708) and reach 11 (H=1.728).

Estimated fish biomass (wet weight) followed a different longitudinal pattern than either species richness or species diversity (Fig. 5-3). Biomass varied from a high of 562.48 kg/ha in reach 4 (RM 40.0-61.5) to a low of 59.96 kg/ha in reach 11 (RM 213.9-225.0). Highest biomass occurred in reaches 3-6, where species richness and diversity were high, possibly as an influence of the LCR inflow, while lowest biomass occurred in reaches 7-11, where richness and diversity were highest for the study area.

Longitudinal distribution and abundance of the six most common fish species were portrayed by AM_{CPE} for netting (Fig. 5-4) and electrofishing (Fig. 5-5) in each of the 11 geomorphic reaches. Catch rates of adults for both gears decreased downstream of reach 2, while AM_{CPE} for subadults was variable. Netting and electrofishing catch rates of adult rainbow trout exceeded those of all other species in each of the first eight reaches, except for reach 5 (Furnace Flats, RM 61.5-77.4), where AM_{CPE} for humpback chub was higher near the LCR inflow.

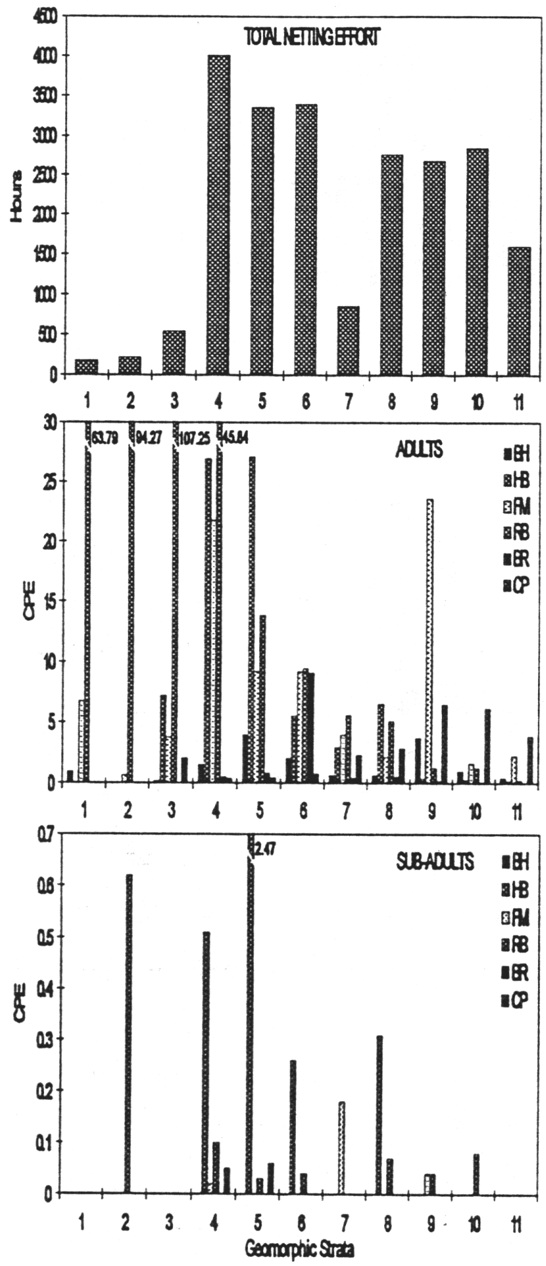


Fig. 5-4. Gill and trammel netting effort (hours) and AM_{CPE} (#/100 ft/100 h) for adult and subadult humpback chub (HB), flannelmouth sucker (FM), bluehead sucker (BH), rainbow trout (RB), carp (CP), and brown trout (BR) in 11 geomorphic reaches. See Table 2-1 for description of geomorphic reaches.

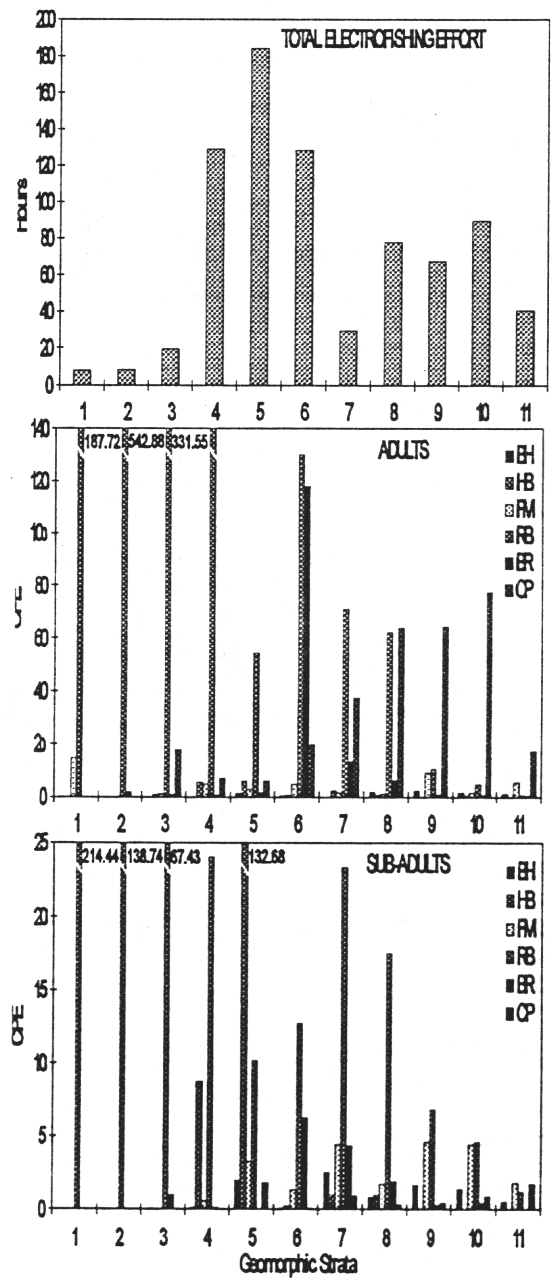


Fig. 5-5. Electrofishing effort (hours) and AM_{CPE} (#/10 h) for adult and subadult humpback chub (HB), flannelmouth sucker (FM), bluehead sucker (BH), rainbow trout (RB), carp (CP), and brown trout (BR) in 11 geomorphic reaches. See Table 2-1 for description of geomorphic reaches.

Netting catch rates of adult flannelmouth sucker and bluehead sucker decreased downstream, except for an increase in reach 9 (Muav Gorge, RM 140.0-160.0), in association with the Havasu Creek inflow.

The association of high catch rates with tributary inflows was further examined by comparing species composition and AM_{CPE} between 1-mi subreaches at six major tributary flows with randomly-selected 1-mi subreaches within the same geomorphic reach, for nets (Table 5-5) and electrofishing (Table 5-6). Numbers of species and fish were higher near tributary inflows than disjunct areas for each tributary, except Tapeats Creek. Numbers and catch rates of fish of all ages captured with nets at inflows of the LCR, Shinumo Creek, Kanab Creek and Havasu Creek were dominated by native species, i.e., humpback chub at the LCR and Shinumo Creek, and flannelmouth sucker at Kanab Creek and Havasu Creek. Brown trout and rainbow trout were dominant at inflows of the other two major tributaries--Bright Angel Creek and Tapeats Creek, respectively.

Non-natives were dominant in electrofishing catches at inflows of all six major tributaries (Table 5-6). Carp were the most abundant species at Kanab Creek and Havasu Creek, rainbow trout at the LCR and Shinumo Creek, brown trout at Bright Angel Creek, and carp and rainbow trout at Tapeats Creek. Total fish numbers were higher at tributary inflows than disjunct areas for each tributary except the LCR, and numbers of species were higher at all inflows, except for Tapeats Creek. Discrepancies in species composition and numbers of fish captured with nets and electrofishing were attributed to inherent gear selectivity for species and habitat.

Distribution And Abundance Of Humpback Chub

Pre-Dam (Before 1964)

Pre-dam records are too few to accurately characterize historic distribution or abundance of humpback chub in Grand Canyon (Fig. 5-6). Emery and Ellsworth Kolb (Kolb 1914, Kolb and Kolb 1914), in 1908, provided the first description and photographic documentation of humpback chub ("bony tail") from the Little Colorado River near Beamer's Cabin, about 200 m upstream from the outflow:

> "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 "bony tail" were spawning. We had hooks and lines in our packs, and caught all we cared to use that evening."

The species was described in 1945 by R.R. Miller (1946) from a specimen collected in 1942 by N.N. Dodge near Phantom Ranch, a second specimen of unknown origin, and the head, nape, and pectoral fins of a third specimen of unknown origin (Miller 1946). The specimens of unknown origin were probably from the Grand Canyon area.

Before Glen Canyon Dam was completed in 1963, humpback chub were captured at four locations, including near Phantom Ranch (Miller 1946), Lees Ferry (National Park Service 1944), LCR (Kolb and Kolb 1914), and

Table 5-5. Arithmetic mean catch rate (AM_{CPE}) and percentage (in parentheses) captured by gill and trammel nets in 1-mi subreaches of tributary inflows (I) and adjacent main channel areas (A) in the same geomorphic reach of the Colorado River. See Table 5-2 for description of species codes.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	767	483	381	55	762	30	186	532	473	29	414	29
Effort (hrs)	1629.5	1019.1	795.0	121.5	1556.1	57.5	366.1	1138.8	986.1	62.4	845.7	62.4
Number of Fish	1556	322	372	3	204	8	30	163	322	2	222	1
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	116-117	133.2-134.2	127-128	143-144	147-148	156.2-157.2	147-148
Species												
BH	6.4 (4.2)	1.8 (3.7)	2.7 (4.3)	0	2.5 (11.8)	0	0.2 (3.3)	0.4 (2.5)	3.5 (7.8)	0	5.6 (13.5)	0
BR	0.7 (0.5)	0.9 (2.8)	27.0 (40.6)	0	1.2 (5.4)	4.2 (12.5)	0	0.5 (1.8)	0.3 (0.6)	0	0	0
CC	1.1 (0.6)	0.2 (0.6)	0	0	0	0	0	0	0.4 (0.9)	0	0	0
CP	0.8 (0.6)	0.6 (1.2)	1.0 (1.1)	0	0.8 (3.4)	3.7 (12.5)	1.4 (13.3)	3.2 (13.5)	8.9 (19.9)	1.6 (50.0)	2.4 (5.4)	1.6 (100.0)
FM	48.7 (37.7)	2.0 (5.0)	26.7 (37.6)	0	3.9 (18.1)	0	0.3 (3.3)	2.8 (14.1)	29.4 (65.8)	0	30.8 (73.4)	0
FR	0.3 (0.2)	0	0	0	0	0	0	0	0	0	0	0
HB	54.0 (38.3)	21.5 (52.2)	0.7 (0.8)	0	11.4 (13.7)	0	0	13.6 (60.7)	0.1 (0.3)	0	1.0 (2.7)	0
RB	23.1 (17.7)	14.0 (34.5)	11.0 (15.6)	3.2 (100.0)	8.5 (47.5)	18.4 (75.0)	10.2 (80.0)	1.7 (7.4)	1.5 (3.1)	0	1.7 (5.0)	0
SB	0	0	0	0	0	0	0	0	0.7 (1.6)	0.2 (50.0)	0	0

Table 5-6. Arithmetic mean catch rate (AM_{CPE}) and percentage (in parenthesis) captured by electrofishing in 1-mi subreaches of tributary inflows (I) and adjacent main channel areas (A) in the same geomorphic reach of the Colorado River. See Table 5-2 for description of species codes.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	163	154	72	15	144	4	27	47	45	3	32	3
Effort (hrs)	34.5	60.7	17.4	7.5	43.7	2.3	8.9	16.7	16.1	0.5	8.5	0.5
No. of Fish	732	822	822	153	912	26	154	98	191	3	100	3
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	116-117	133.2-134.2	127-128	143-144	147-148	156.2-157.2	147-148
Species												
BH	0.3 (0.3)	0.8 (0.5)	0.5 (0.1)	0	0.5 (0.2)	0	4.9 (1.3)	2.0 (3.1)	2.3 (2.1)	0	7.2 (60.0)	0
BR	0.3 (0.1)	0.6 (0.5)	499.6 (73.6)	50.4 (22.2)	42.2 (16.1)	22.1 (19.2)	10.5 (4.5)	5.9 (13.3)	0	0	2.5 (2.0)	0
CC	1.2 (0.5)	0.2 (0.1)	0	0	0	0	0	0	0	0	0	0
CP	8.3 (4.1)	13.2 (4.9)	6.0 (1.2)	34.8 (15.0)	36.9 (18.0)	39.3 (34.6)	140.2 (32.5)	15.9 (34.7)	59.0 (51.8)	35.2 (66.7)	47.4 (41.0)	35.2 (66.7)
FM	10.8 (4.6)	2.7 (1.1)	15.0 (1.9)	0	7.7 (2.0)	4.5 (3.8)	0	1.3 (3.1)	15.7 (11.0)	0	41.6 (27.0)	0
FH	11.3 (5.6)	18.7 (6.7)	0	0	0	0	0	0	10.1 (9.9)	0	1.4 (1.0)	0
HB	41.7 (21.6)	123.8 (48.5)	0	0	1.2 (0.2)	0	0	2.9 (4.1)	0	0	0	0
RB	106.2 (50.5)	68.7 (30.7)	191.4 (22.4)	156.4 (62.7)	167.3 (62.4)	48.0 (42.3)	141.0 (61.7)	20.6 (40.8)	15.2 (15.7)	11.9 (33.3)	18.5 (16.0)	11.9 (33.3)
SD	32.4 (12.2)	21.4 (6.8)	8.8 (0.7)	0	16.9 (1.1)	0	0	0.3 (1.0)	10.3 (9.4)	0	1.4 (2.0)	0

Table 5-6. Continued.

	LCR		Bright Angel		Shinumo		Tapeats		Kanab		Havasu	
	I	A	I	A	I	A	I	A	I	A	I	A
Samples	163	154	72	15	144	4	27	47	45	3	32	3
Effort (hrs)	34.5	60.7	17.4	7.5	43.7	2.3	8.9	16.7	16.1	0.5	8.5	0.5
No. of Fish	732	822	822	153	912	26	154	98	191	3	100	3
River mile	60.9-61.9	64-65	87.2-88.2	97-98	108-109	116-117	133.2-134.2	127-128	143-144	147-148	156.2-157.2	147-148
PK	0.3 (0.1)	0.2 (0.1)	0	0	0	0	0	0	0	0	2.8 (1.0)	0
BB	0.5 (0.3)	0.6 (0.1)	0	0	0	0	0	0	0	0	0	0
SB	0	0	0	0	0	0	0	0	0	0	8.3 (3.0)	0
BK	0	0	0	0	0	0	0	0	0	0	1.3 (1.0)	0

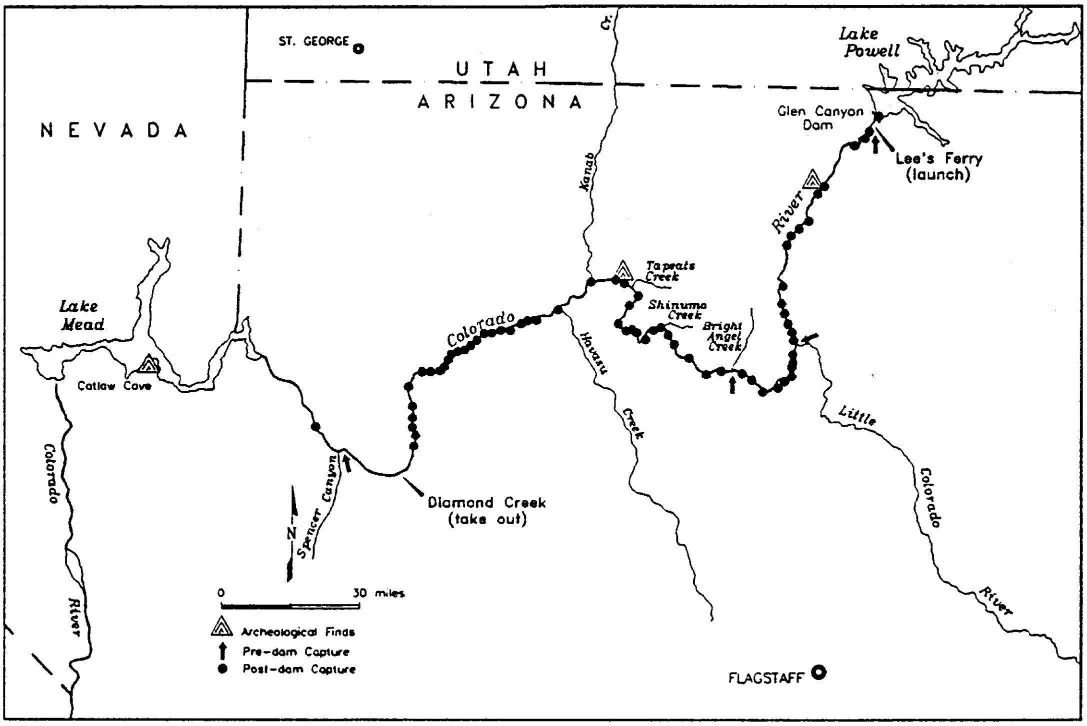


Fig. 5-6. Archaeological finds and pre and post-dam capture locations of humpback chub in the Colorado River, Grand Canyon.

Spencer Creek (O.L. Wallis reported eight juvenile humpback chub from Spencer Creek in 1950, in Kubley 1990). Although these records fail to discern the historic distribution of the species in Grand Canyon, knowledge of life history requirements and present distributions of other humpback chub populations suggest that the species was historically distributed through most of Grand Canyon, with local concentrations. Similarity in historic flow regimes and water quality with areas occupied by other populations (i.e., Westwater Canyon, Cataract Canyon, Desolation Canyon) indicates mainstem reproduction and maintenance without dependance on tributaries.

Post-Dam (1964-90)

Completion of Glen Canyon Dam in 1963 prompted a renewed interest in the ichthyofauna of the Colorado River in Glen and Grand canyons. Humpback chub were consistently reported in AGF creel census from Lees Ferry in 1963-68, although use of an ichthyocyde in the lower 300 m of the Paria River in 1965 and 1967 yielded no humpback chub (Stone 1964, 1966; Stone and Queenan 1967; Stone and Rathbun 1968). Stone and Rathbun (1968) also sampled seven tributaries (excluding the LCR) between Lees Ferry and Lake Mead in 1968, and reported no humpback chub. Holden (1973) collected 15 humpback chub in July 1967 and 1 in August 1970, all within a few hundred meters downstream of Glen Canyon Dam. Humpback chub have not been captured in this area since 1970, when a tailwater trout fishery supported large rainbow trout of up to 7 kg (Carothers and Brown 1991). Holden and Stalnaker (1970, 1975) reported humpback chub from Lake Powell in the early to mid

1960's, suggesting that the species was variously distributed throughout the region now inundated by the reservoir.

Humpback chub were captured during 15 scientific collecting trips through Grand Canyon from 1970 to 1976 (Suttkus et al. 1976, Suttkus and Clemmer 1977). Most were YOY or juveniles (SL<165 mm) captured between RM 44 (just below President Harding Rapid) and RM 108.7 (Shinumo Creek). Four adults were also caught at the mouth of the LCR in June 1976.

Researchers from the Museum of Northern Arizona captured humpback chub during six river trips in 1977-79 (Carothers and Minckley 1981), including adults between RM 19.5 (above North Canyon) and RM 194 (below Boulder Wash), and one juvenile (TL<100 mm) at RM 93.5 (just above Granite Rapid). Of 19 tributaries sampled from the Paria River to Travertine Creek (RM 229.1), humpback chub were captured only in the LCR.

In 1980-81, biologists from the Service captured 504 adult humpback chub (TL>200 mm) between RM 52.2 (Nankoweep Canyon) and RM 72.3 (Unkar Rapid) (Kaeding and Zimmerman 1981, 1983). Fish abundance was reported to assume a normal or "bell-shaped" distribution with greatest numbers at the LCR inflow. Humpback chub smaller than 145 mm TL were not caught from the Colorado River above the LCR confluence, although many small specimens were caught in spring and fall below the confluence.

AGF sampled the Colorado River annually from 1984 through 1989 (Maddux et al. 1987; Kubly 1990), and reported humpback chub from RM 32 to RM 217, mostly in or around the LCR. Ninety-six percent of humpback chub were captured in reaches 20 (RM 0.0-61.5) and 30 (RM 61.5-88.0). No humpback chub were electrofished from the tailwaters of the dam. AGF captured humpback chub with trammel nets in reaches 30 and 40, with little difference in CPE between the two reaches. Humpback chub were also captured in lower reaches of Bright Angel, Shinumo, Kanab and Havasu creeks.

Present (1990-93)

Present distribution of humpback chub in the mainstem were based on findings of this investigation. Preliminary findings from a concurrent mainstem study by AGF were integrated into this report where applicable.

A total of 6294 humpback chub, including 2865 YOY, 1638 juveniles, and 1791 adults, were captured during 36 trips from October 1990 through November 1993 (Table 5-7). Subadults (YOY and juveniles) were caught primarily in late summer and fall (July - October) following descent from the LCR to the mainstem. Adults were captured all months of the year. Humpback chub were captured in 53 of 226 (23%) river miles between Lees Ferry and Diamond Creek (Table 5-8, Fig. 5-7); 72% were between RM 60 and RM 65. River mile 62 (RM 62.0-62.9) yielded the largest number of YOY (555), while RM 63 yielded the largest number of juveniles (410) and RM 61 yielded the largest number of adults (590).

Table 5-7. Total numbers of young-of-year, juvenile, and adult humpback chub captured by trip, October 1990 - November 1993[a].

Trip	Trip	YOY	JUV	ADU	Total
1990					
1	October	0	1	45	46
2	November	0	2	48	50
3	December	-	-	-	-
1991					
4	January	0	2	83	85
5	February	0	0	3	3
6	March	0	3	127	130
7	April	0	0	7	7
8	May	0	34	33	67
9	June	0	16	35	51
10	July	6	46	81	133
11	August	-	-	-	-
12	September	63	116	100	279
13	October	-	-	-	-
14	November	48	21	46	115
1992					
15	January	23	11	27	61
16	February	0	0	6	6
17	March	22	10	44	76
18	April	3	3	38	44
19	May	0	151	54	205
20	June	0	2	38	40
21	July	3	137	102	242
22	August	2	60	6	68
23	September	4	68	48	120
24	October	3	0	0	3
25	November	59	85	59	203
1993					
26	January	97	52	111	260
27	February	18	18	79	115
28	March	35	25	58	118
29	April	56	42	45	143

Table 5-7. Continued.

Trip	Trip	YOY	JUV	ADU	Total
30	May	0	141	93	234
31	June	0	49	71	120
32	July	247	89	94	430
33	August	590	99	40	729
34	September	713	288	87	1,088
35	October	646	63	44	753
36	November	227	4	39	270
	Total	**2,865**	**1,638**	**1,791**	**6,294**

[a]Fish were not sampled on trips 3, 11, and 13 when only radiotracking was conducted.

Table 5-8. Ranking of river miles, according to total numbers of humpback chub captured by age category in the mainstem Colorado River, October 1990-November 1993.

Ranking	River Mile[a]	YOY	JUV	ADU	Total	Percent
1	61	235	188	590	1013	16.10
2	63	479	410	119	1008	16.02
3	62	555	215	132	902	14.33
4	64	413	320	137	870	13.82
5	60	25	31	346	402	6.39
6	65	141	134	88	363	5.77
7	76	257	76	4	337	5.36
8	68	242	36	3	281	4.47
9	75	104	64	3	171	2.72
10	67	119	24	0	143	2.27
11	58	0	2	123	125	1.99
12	127	0	7	97	104	1.65
13	72	72	20	0	92	1.46
14	71	64	19	1	84	1.33
15	70	65	17	0	82	1.30
16	108	4	13	27	44	0.70
17	74	20	14	0	34	0.54
18	73	17	10	0	27	0.43
19	66	12	10	3	25	0.40
20	30	0	0	24	24	0.38
21	126	1	5	18	24	0.38
22	119	0	7	13	20	0.32
23	78	13	2	0	15	0.24
24	59	0	1	13	14	0.22
25	69	9	1	0	10	0.16
26	128	0	3	7	10	0.16
27	87	5	1	2	8	0.13
28	57	0	0	7	7	0.11
29	156	0	0	6	6	0.10
30	83	1	0	4	5	0.08
31	213	0	0	5	5	0.08
32	86	4	0	0	4	0.06
33	122	1	3	0	4	0.06

Table 5-8. Continued.

Ranking	River Mile[a]	YOY	JUV	ADU	Total	Percent
34	82	3	0	0	3	0.05
35	85	3	0	0	3	0.05
36	92	1	0	2	3	0.05
37	91	0	1	1	2	0.03
38	114	0	0	2	2	0.03
39	120	0	1	1	2	0.03
40	129	0	0	2	2	0.03
41	187	0	2	0	2	0.03
42	0	0	0	1	1	0.02
43	29	0	0	1	1	0.02
44	31	0	0	1	1	0.02
45	118	0	0	1	1	0.02
46	125	0	1	0	1	0.02
47	142	0	0	1	1	0.02
48	143	0	0	1	1	0.02
49	155	0	0	1	1	0.02
50	195	0	0	1	1	0.02
51	212	0	0	1	1	0.02
52	219	0	0	1	1	0.02
53	221	0	0	1	1	0.02
Total		**2865**	**1638**	**1791**	**6294**	**100**

[a]Includes all fractions to next highest river mile, e.g. 29 = 29.00 to 29.99.
Excludes 10 from LCR, 13 with no age category, 9 with no designated mile of capture, for a total of 2,635 + 32 = 2,667.

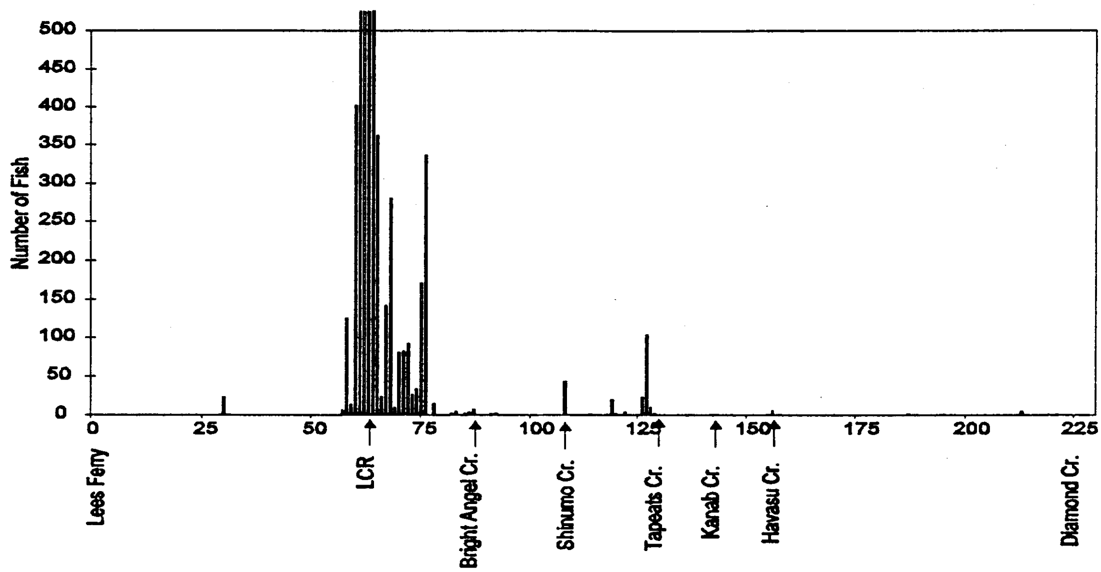


Fig. 5-7. Numbers of humpback chub captured by river mile from Lees Ferry to Diamond Creek, October 1990 - November 1993.

Netting and electrofishing catch rates by linear mile (Appendix Fig. E-1, E-2) further illustrate the clumped distribution for humpback chub in Grand Canyon. All humpback chub captured in Region 0 between RM 29.0 and RM 31.9, while 99% of adults captured in Region I were between RM 58.0 and RM 65.9 (Awatubi Canyon to Lava Canyon). Pooled netting catch rate (AM_{CPE}) for adults were highest at 56 fish/100 ft/100 h (FPN) at the LCR inflow, RM 61.0-61.9. Pooled netting AM_{CPE} for humpback chub in Region II did not exceed 15 FPN for any 1-mi block--the highest was in RM 114.0-114.9 (Garnet Canyon), where effort was relatively low. Within Region II, adults were also captured with nets in RM 83.0-83.9 (above Clear Creek), RM 87.0-87.9 (Bright Angel Creek inflow), RM 92.0-92.9 (around Salt Creek), RM 108.0-108.9 (Shinumo Creek inflow), RM 119.0-119.9 (upper end of Middle Granite Gorge), RM 126.0-129.9 (below Fossil Canyon), RM 142.0-143.9 (Kanab Creek inflow), and RM 155.0-156.9 (Havasu Creek inflow). In Region III, adults were collected from RM 212.0-212.9 (Pumpkin Spring), RM 219.0-219.9 (Trail Canyon), and RM 221.0-221.9 (222 Mile Canyon). In a separate investigation (Valdez 1994), one adult female humpback chub (TL=329 mm, WT=293 g), was netted on October 5, 1993 near Maxon Canyon (RM 253.2), about 44 km downstream of Diamond Creek.

Highest electrofishing AM_{CPE} for adult humpback chub in Region 0 was 2 fish/10 h (FPH) in RM 30.0-30.9 (Fig. E-2). Within Region I, AM_{CPE} exceeded 16 FPH in RM 62.0-62.9 (Crash Canyon), but no adults were caught above RM 58.0 or below RM 69.0. In Region II, electrofishing AM_{CPE} was over 7 FPH in RM 118.0-118.9 (Stephen Aisle). Adults were also collected in RM 90.0-90.9 (near Horn Creek), RM 108.0-108.9

(Shinumo Creek inflow), RM 120.0-120.9 (near Blacktail Canyon), and RM 126.0-128.9 (upper end of Middle Granite Gorge). One adult was captured in Region III, at RM 195.6.

Of 4503 subadult humpback chub captured in 1990-93, 2865 were designated as YOY and 1638 as juveniles (Table 5-2); 99% and 1% of YOY were caught in Regions I and II, respectively, while none were captured in Regions 0 or III. In a subsequent field trip in July 1994, 14 YOY (TL=18-31 mm) were captured in a warm spring near RM 30 (See Chapter 6 - DEMOGRAPHICS). Of 1638 juveniles, 97%, 3%, and <1% were caught in Regions I, II, and III, respectively, but none were caught in Regions 0.

Distribution of subadult humpback chub was associated with distinct aggregations of adults (Table 5-8). Ninety-nine percent of subadults (2859 YOY, 1596 juveniles) were captured between RM 58.8 and RM 92.1 (above LCR to Salt Creek). Of these, only 2% were above the LCR confluence, 68% were between the LCR (RM 61.3) and Lava Canyon (RM 65.4), and 30% were between Lava Canyon and Salt Creek. Numbers of subadults captured were dramatically lower downstream of Salt Creek, with only 4 YOY and 13 juveniles near Shinumo Creek (RM 108.1-108.6), 2 YOY and 27 juveniles from Blacktail Canyon to Specter Rapid (RM 119.0-128.9), and 2 juveniles at Whitmore Wash (RM 187.6).

Pooled monthly AM_{CPE} for subadult humpback chub (<200 mm TL) captured with electrofishing, minnow traps, and seines along shorelines (excluding backwaters), between RM 61.3 (LCR inflow) and RM 65.4 (Lava Canyon), illustrates monthly and seasonal patterns of abundance (Fig. 5-8). This area of river provided the best index to year class

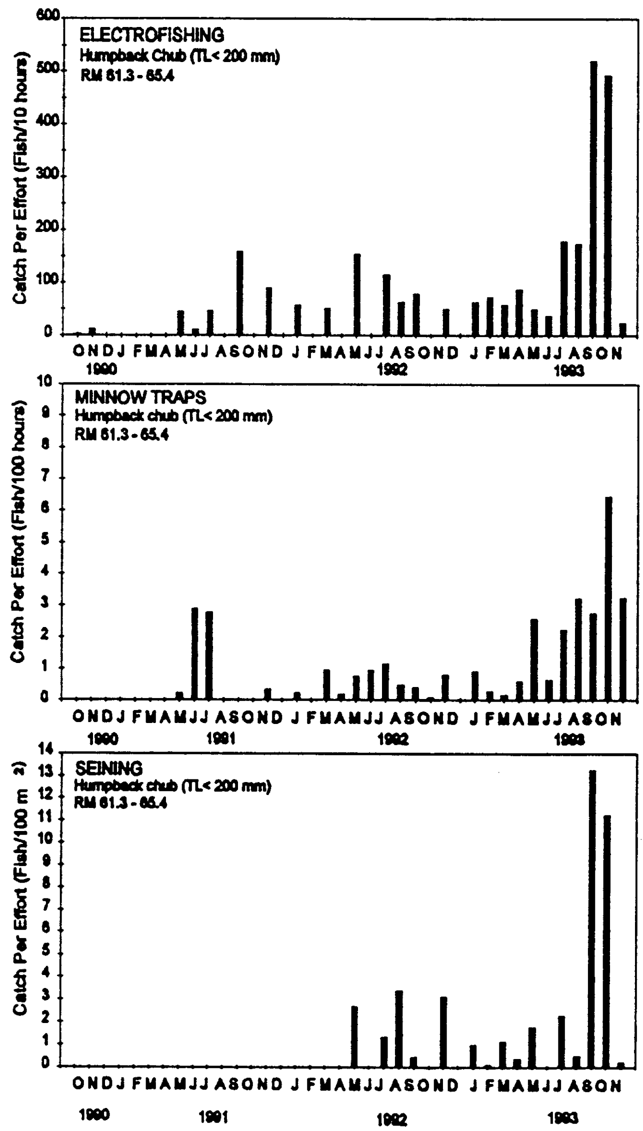


Fig. 5-8. Arithmetic mean catch per unit effort (AM_{CPE}) for subadult humpback chub (TL <200 mm) captured with electrofishing, minnow traps, and seines along shorelines between RM 61.3 and RM 65.4.

strength of humpback chub from the LCR because it was the first area occupied by fish dispersing into the mainstem. Annual peaks in electrofishing AM_{CPE} occurred in September 1991 (159.7 FPH), May 1992 (154.7 FPH), and September 1993 (521.7 FPH_{10}). Typically, numbers of subadult humpback chub were highest in late summer and early fall, following dispersal of young from the LCR.

Distribution and relative abundance of subadult humpback chub in the mainstem indicates that more young were produced in 1993 than either 1991 or 1992. Over 22 times as many fish classified as YOY were captured in 1993 than in 1991 or 1992, and maximum electrofishing catch rates for subadults were over three times higher (Fig. 5-8).

Mainstem Aggregations. Nine aggregations of humpback chub were identified in the mainstem as a result of the previous longitudinal analysis of distribution (Table 5-9, Fig. 5-9). An aggregation was a consistent and disjunct group of fish having no significant exchange of individuals with other aggregations, as indicated by recapture of PIT-tagged juveniles and adults, or movement of radiotagged adults (See Chapter 8 - MOVEMENT), These aggregations also had a high adult recapture rate, indicating long-term residence by individuals. These nine aggregations accounted for 94% of all humpback chub captured in the mainstem, or 92% of YOY (2640 of 2879), 94% of juveniles (1545 of 1638), and 98% of adults (1755 of 1791). Estimated numbers of adults comprising these nine aggregations ranged from 4 to 3446. The following is a description of each aggregation and characteristic attributes of associated habitat.

Table 5-9. Location and numbers of humpback chub in aggregations in the Colorado River in Grand Canyon.

Aggregations	Location (RM)	Number Captured			Number Recaptured	Estimated Total[a]	% of Total Numbers
		YOY	Juv	Adu			
A-1 (30-Mile)	29.8 - 31.3	14[b]	0	26	6	39	0.4
A-2 (LCR Inflow)	56.0 - 65.4	1830	1293	1524	280	3446	73.8
A-3 (Lava to Hance)	65.7 - 76.3	778	226	15	3	22	16.2
A-4 (Bright Angel Inflow)	83.8 - 92.2	13	2	9	1	30	0.4
A-5 (Shinumo Inflow)	108.1 - 108.6	4	13	27	6	44	0.7
A-6 (Stephen Aisle)	114.9 - 120.1	0	7	17	2	35	0.4
A-7 (Middle Granite Gorge)	126.1 - 129.0	1	4	124	48	103	2.0
A-8 (Havasu Inflow)	155.8 - 156.7	0	0	7	1	16	0.1
A-9 (Pumpkin Spring)	212.5 - 213.2	0	0	6	2	4	0.1
Total		**2640**	**1545**	**1755**	**349**		**94.1**

[a]Mark-recapture estimate for adults (See Chapter 6)
[b]Captured from a school of about 100 YOY in a spring plume, July 14, 1994, not included in totals for October 1990-November 1993.

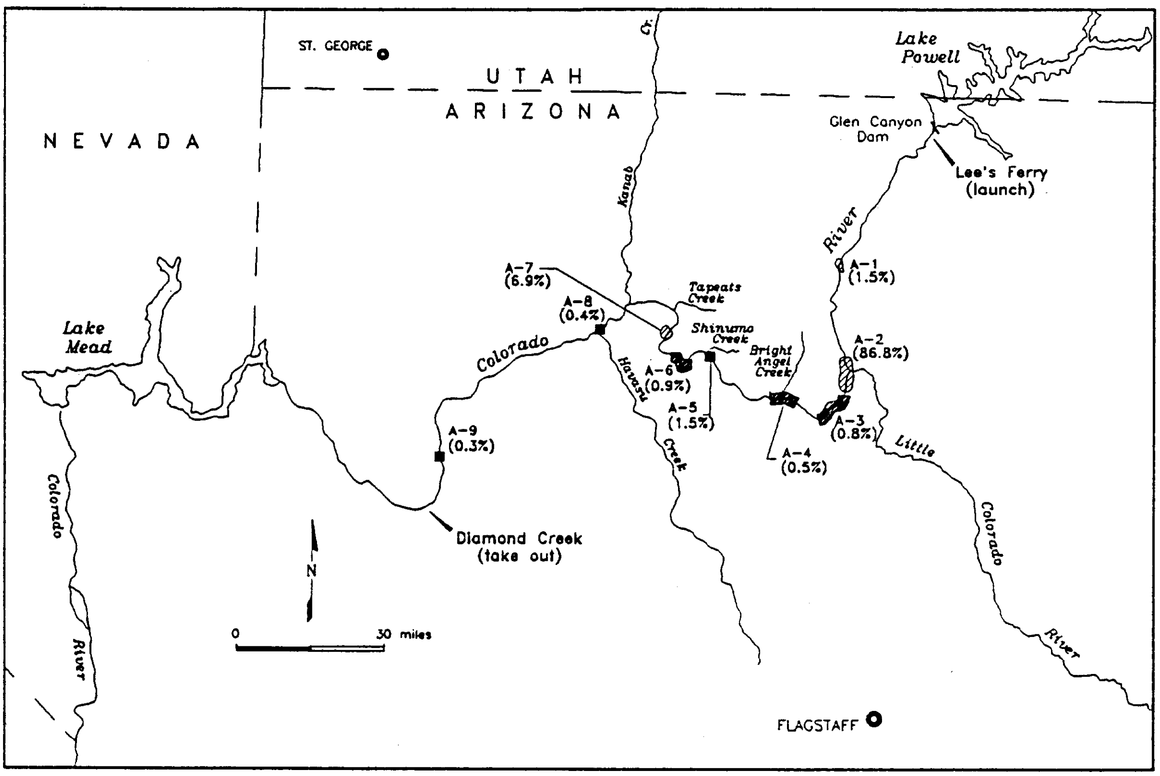


Fig. 5-9. Locations (percentage of total numbers)of nine aggregations of humpback chub in the Colorado River in Grand Canyon.

1. 30-Mile Aggregation

The 30-Mile aggregation of humpback chub was distributed from RM 29.8 to RM 31.3. A total of 26 adults were captured and released in this area during eight sampling trips in 1993, the only year this region was sampled (See Chapter 2 - STUDY DESIGN). Six of these fish were recaptured in the area, and none were encountered outside of this area. The 30-Mile aggregation was composed of an estimated 39 adults, based on mark-recapture estimates (see Chapter 6 - DEMOGRAPHICS).

Twenty of 26 humpback chub (77%) were captured in the plume of a warmwater shoreline spring above South Canyon, designated as 'Spring J' (See Chapter 4 - WATER QUALITY, Fig. 4-15, 4-16). Six of these fish were recaptured in the warm plume of the spring in the same net location. With few exceptions, three nets yielded two to six chubs from the spring nightly, and two of four adult humpback chub observed in the plume during electrofishing in September 1993 were captured. Elsewhere in Region 0, three humpback chub were caught at the upstream edge of a large eddy just above the South Canyon riffle, two were captured in the plume of a small spring ('Spring I') above Spring J, and one was captured in a return channel adjacent to Fence Fault. All chubs were captured in the immediate vicinity of springs, indicating an attraction to the warmer spring water.

Spring 'J' was resampled July 12-14, 1994, and an estimated 100 YOY humpback chub were sighted among boulders in the warm plume. Fourteen specimens (18-31 mm TL) were captured with a dip net and preserved to verify identification. Water temperature at the source of Spring J was relatively constant at 21.5° C, compared to 9° C in the adjacent mainchannel. These young were presumed to belong to the 1994 year class, and probably hatched from eggs deposited in the warm spring plume, since mainstem water temperature was too cold for survival of eggs or larvae (Hammon 1982, Marsh 1985). The fish were about 30 d old, based on age to length relationships developed by Muth (19**) for young humpback chub. It is unlikely that these young originated from upstream locations, because of the thermal restriction and large numbers of predators (i.e., rainbow trout) in the area. Spawning by humpback chub in this area is further discussed in Chapter 6 - DEMOGRAPHICS, and Chapter 7 - HABITAT.

In 1993, AGF (Persons et al. 1994) captured 20 YOY humpback chub, 20-50 mm TL (3 in July, 3 in September, and 14 in October) in a backwater at RM 44.3 (Eminence Fault just below President Harding Rapid). These fish probably emerged from eggs deposited in one of three areas--springs in the vicinity of Fence Fault (30-Mile aggregation), the Paria River, or an undiscovered warm spring below the river surface and near the subject backwater. It is unlikely that these young fish originated from the Paria River, since adult humpback chub have not been reported in that tributary, and a large number of young would be necessary to supply a distant backwater with 20 individuals, under normal dispersal. It is also unlikely that these fish originated from the 30-Mile aggregation because of the thermal barrier, transport distance (RM 30 to RM 44), and the presence of large numbers of predators. The potential for humpback chub spawning in the Eminence Fault area was difficult to assess, because little was known about the area, and it was sampled only twice during this investigation. Warm springs are commonly associated with geologic fault, but none were visible along the shoreline. At least one juvenile humpback chub was captured at RM 44 between 1970 and 1976, but no lengths were reported (Carothers and Minckley 1981, Suttkus et al. 1976).

2. LCR Inflow Aggregation

The LCR aggregation was considered a component of the LCR population of humpback chub. The relationship between the mainstem and LCR components of this population are further discussed in Chapter 8 - MOVEMENT and Chapter 11 - INTEGRATION. Eighty-seven percent of 1791 adults in this mainstem aggregation were captured between RM 56.0 (Kwagunt Rapid) and RM 65.4 (Lava Canyon). This area contained an estimated 3446 adult humpback chub, based on a mark-recapture estimate (See Chapter 6 -DEMOGRAPHICS), but no estimate was available for subadults. Lava Canyon was a relatively distinct lower boundary for this aggregation, i.e., from 1990 to 1993, 134 adult humpback chub were captured within 1 mi upstream, but only 1 adult was captured within 1 mi downstream. The upper boundary was also distinct, with 106 humpback chub captured within 2 mi downstream of Kwagunt Rapid, and none upstream for

25 mi, to RM 31. These distinct boundaries may be related to habitat distribution and quality (See Chapter 7 - HABITAT).

The majority of adults from this aggregation congregated annually prior to ascending the LCR for spawning. Numbers and catch rates of humpback chub in the LCR inflow varied dramatically by season in 1991, 1992, and 1993. This variation in numbers of adults in the inflow probably accounts for variable catch results reported by past investigators (Table 5-1). Timing and magnitude of these seasonal congregations are illustrated by netting catch rates in a 1-mi subreach at the LCR inflow, RM 60.9-61.9 (Fig. 5-10) and from radiotelemetry (See Chapter 9 - ACTIVITY AND MOVEMENT). Significantly higher mean monthly catch rates (GM_{CPE}) in March 1991 and February 1992 (Fisher's LSD, $P \le 0.05$), and higher catch rates in January and February of 1993, resulted from movement to and staging at the mouth of the LCR during these months. Possibly, early floods from the LCR in January 1993 prompted an early ascent. Slightly higher catch rates in June and July indicate that post-spawning descent and little or no congregation by adults before redispersing into the mainstem.

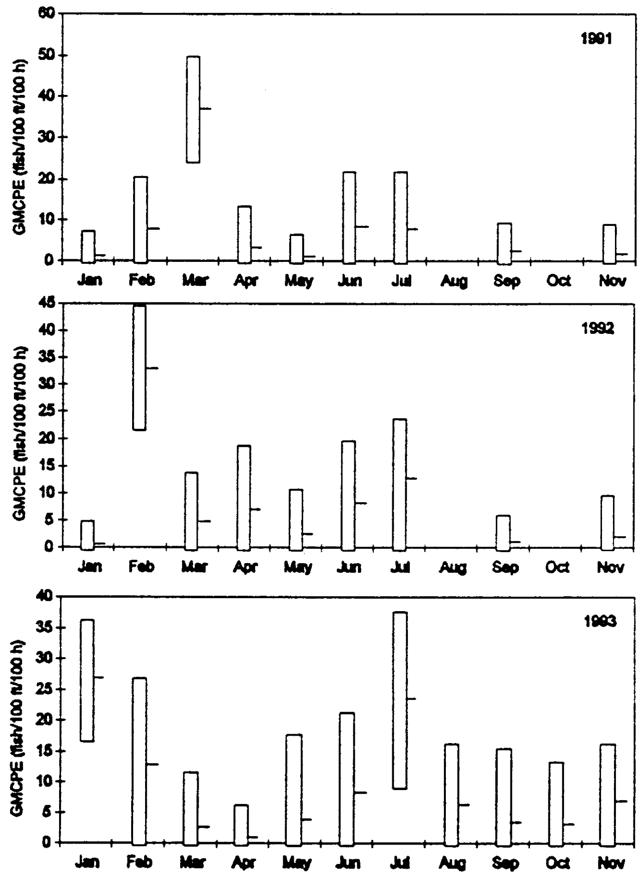


Fig. 5-10. Monthly geometric mean catch per effort (GM_{CPE}) for adult humpback chub captured in nets within RM 60.0-61.9 (LCR inflow), 1990-91.

3. Lava to Hance Aggregation

Although this aggregation was immediately downstream of the LCR inflow aggregation, no exchange of marked adults was recorded from October 1990 through November 1993. Increased densities indicate that subadults from the LCR dispersed downstream into both aggregations, providing a unidirectional link that was partly impeded upstream by Lava Canyon Rapid. Fifteen adults captured between RM 65.7 (below Lava Canyon Rapid) and RM 76.3 (below Papago Creek) occurred with no apparent pattern of distribution. Four chub were captured within 0.3 mi of seasonal tributaries (i.e., 3 below Papago Creek, 1 below Cardenas Creek); and the remaining 11 were captured within 0.3 mi above major rapids (i.e., 3 above Tanner Rapid, 3 above Nevills Rapid, 5 above Hance Rapid).

4. <u>Bright Angel Creek Inflow</u>

This aggregation was distributed from RM 83.8 to RM 92.2, or about 4 mi upstream and 4 mi downstream of the Bright Angel Creek inflow. Of 9 adult humpback chub captured in this aggregation, 2 were within 0.2 mi above the Bright Angel Creek inflow, and 4 were within 0.3 mi of the Clear Creek inflow. This aggregation had an estimated 30 adults, based on a mark-recapture estimate. The presence of this aggregation was attributed to Bright Angel Creek and Clear Creek, warm productive tributaries.

5. <u>Shinumo Creek Inflow</u>

This aggregation extended only 0.5 mi above the Shinumo Creek inflow, from RM 108.1 to RM 108.6. The area yielded 4 YOY, 13 juveniles, and 27 adults, or an estimated 44 adults, based on a mark-recapture estimate. This aggregation contained the highest density (fish/mile) of humpback chub downstream of the LCR aggregation. The occurrence of this aggregation was attributed to the warm, productive inflow of Shinumo Creek.

6. <u>Stephen Aisle</u>

The aggregation in Stephen Aisle was distributed from RM 114.9 to RM 120.1. Although 7 juveniles and 17 adults were captured in this area, there were no perennial tributaries present. This aggregation was associated with tapeats sandstone, a shoreline type which provided the fish with abundant lateral and overhead cover (See Chapter 7 - HABITAT). This aggregation had an estimated 35 adults, based on a mark-recapture estimate.

7. <u>Middle Granite Gorge Aggregation</u>

The Middle Granite Gorge aggregation (MGG) of humpback chub was distributed between RM 126.1 (below Fossil Rapid) and RM 129.0 (Specter Rapid). Of 181 adults captured in Region II, 129 (71%) were found in this aggregation. This aggregation had a high recapture rate of 48 of 124 adults (39%). The MGG aggregation was composed of an estimated 103 adults, based on a mark-recapture estimate.

The MGG aggregation occupied an area with high diversity of fish habitat, including deep eddy complexes, and various shoreline types such as talus slopes, debris fan, and cobble bars. Of 124 humpback chub captured from the MGG aggregation, 106 (86%) were found below the first exposure of Vishnu schist (RM 127), where convoluted walls and rooms enhanced shoreline complexity. Warm springs were not detected in this area, and the only perennial stream was 128-Mile Creek, which had low discharge and a confluence morphology that seemed unsuitable for humpback chub.

8. <u>Havasu Creek Inflow Aggregation</u>

This aggregation occupied the area between RM 155.8 and RM 156.7. All 7 adults captured in this area were within 0.9 mi upstream of the Havasu Creek inflow. Estimated number of adults for this aggregation was 16, and it is believed these fish were associated with this warm productive tributary, but occurred in more suitable habitat upstream of the inflow. Access to Havasu Creek was blocked by a series of natural falls, and only the lower 400 m was accessible to mainstem fish.

9. Pumpkin Spring Aggregation

This aggregation extended from RM 212.5 to RM 213.2. Although 6 adult humpback chub were captured within 0.7 mi of Pumpkin Spring (1 above, and 5 below), a warm shoreline spring, field measurements revealed no detectable plume or increase in mainstem temperature near the spring. Two of the 6 fish were recaptured several times, and the estimated number of adults was 4, based on a mark-recapture estimate.

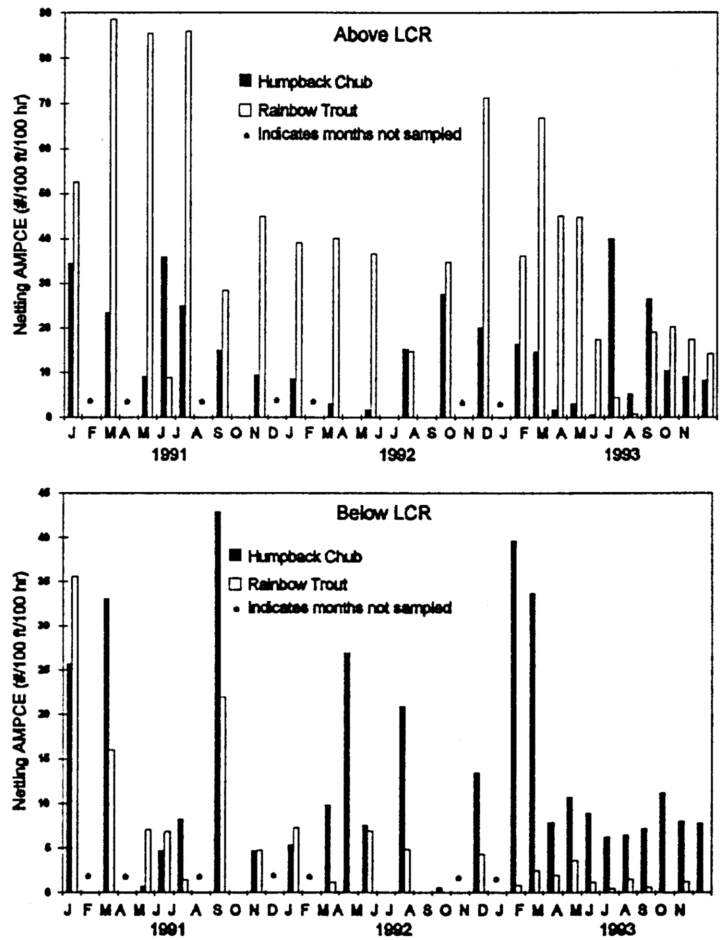


Fig. 5-11. Monthly arithmetic mean catch per effort (AM_{CPE}) for adult humpback chub and rainbow trout captured in nets above the LCR (RM 52.85-60.85) and below the LCR (RM 61.85-65.55). Months not sampled are indicated by an asterisk.

Effect of Turbidity on Distribution and Abundance. The effect of turbidity on distribution of the two most common fish species in the mainstem--humpback chub and rainbow trout--was evaluated by comparing monthly netting AM_{CPE} between two sub-reaches: above LCR (RM 52.85-60.85) and below LCR (RM 61.85-65.55) (Fig. 5-11). From January 1991 to November 1993, turbidity above the LCR was 'high' (>30 NTU's) during 29% of monthly trips, while turbidity below the LCR was 'high' during 62% of trips. Humpback chub AM_{CPE} was higher below the LCR in 13 of 25 months sampled (52%), while rainbow trout AM_{CPE} was higher above the LCR in 23 of 24 months (96%). Pooled AM_{CPE} for adult rainbow trout was significantly greater above the LCR than below (Student's T-Test; $P \leq 0.05$), although AM_{CPE} for adult humpback chub above the LCR was not significantly different from catch rate below the LCR.

Species Accounts - Native Species

Flannelmouth Sucker

Flannelmouth suckers were caught throughout the study area, from Lees Ferry to Diamond Creek. Greatest numbers were found in Region I, with declining abundance downstream to Region III, although catch rates were sporadically high at or near major tributary inflows (i.e., LCR, Bright Angel Creek, Kanab Creek, and Havasu Creek). Pooled netting catch rate (AM_{CPE}) for adults was highest at 60 FPN between RM 61.0 and RM 61.9 (LCR inflow area) (Fig. E-3), the same 1-mi subreach with highest netting catch rate for adult humpback chub (Fig. E-1). Catch rates for adults in Region 0 were highest within the first 6 river miles, because of the proximity to the Paria River as a spawning tributary (Weiss 1994), i.e., seasonal congregations of adult flannelmouth suckers in the vicinity of this tributary inflated catch rates.

Highest electrofishing AM_{CPE} for adult flannelmouth sucker was over 1700 FPH between RM 0 and RM 0.9 (Fig. E-4). This catch rate was based on four electrofishing efforts in the inflow of the Paria River in April 1993, when adults were staging to spawn. Catch rates through Regions I to III were approximately uniform, but highest near major tributaries, as with net catches.

The majority of PIT-tagged adult flannelmouth suckers (190 of 202 = 94%) were recaptured less than 10 mi from their capture locations in the Colorado River (Fig. 5-12) over periods of up to 790 d. Some adults moved long distances, but no distinct pattern was evident for seasonal movement or direction, although inflated catches of adults at tributary inflows in spring (April-May) confirmed seasonal spawning congregations. Greatest displacement (distance from capture to recapture) was 153.5 mi upstream from RM 214.0 to RM 60.5 over 79 d (July 26 to October 13, 1993). Other long-distance displacements were often associated with one or more tributary inflows, e.g., two fish were captured near the LCR inflow (RM 61.3) and recaptured near the Havasu Creek inflow (RM 156.6), and one was captured near Havasu Creek and recaptured near the LCR. Weiss (1991) also reported long-distance displacement by adults captured in spawning areas in the Paria River. Of 77 fish recaptured spawning in the Paria River in 1992-93, 15 were originally tagged in the LCR (up to 6 km above the mouth), and one originated in Kanab Creek, 141.7 mi downstream.

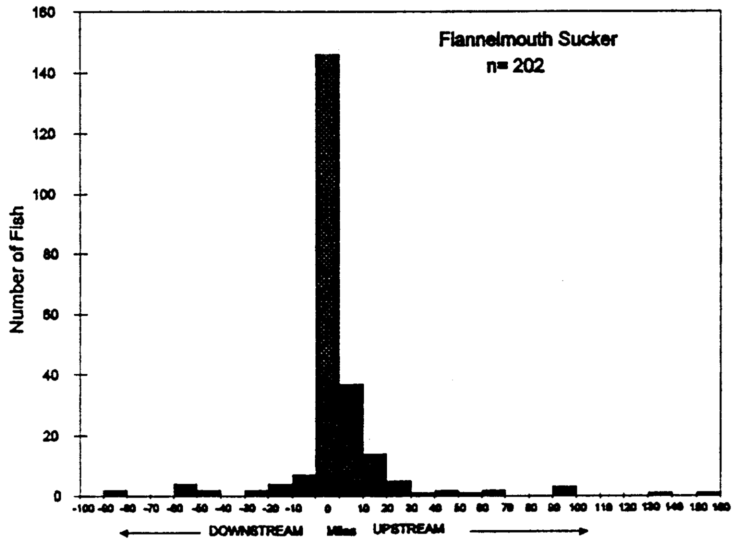


Fig. 5-12. Displacement of 202 PIT-tagged flannelmouth suckers (TL >200 mm) from capture locations in the Colorado River, Grand Canyon.

Five specimens captured in this 1990-93 investigation were classified as flannelmouth sucker x razorback sucker hybrids (Table 5-2). These fish averaged 497 mm TL (range, TL=332-631 mm), and were typically larger than adult flannelmouth suckers, with average total length of 430 mm. These presumed hybrids were distinguished by the presence of a small but distinct keel, dark olive back fading to yellow belly, and 13 or fewer anal fin rays (McAda and Wydoski 1980). Four of these presumed hybrids were captured in Region I, near the LCR, and one was found in Region II (Table 5-4).

Subadult flannelmouth suckers (TL=21-198 mm) were captured in return channels and other quiet shoreline habitats. Subadults were distributed from RM 55.7 to RM 222.0, with concentrations in the inflows of the LCR, Bright Angel

Creek, Shinumo Creek, Kanab Creek, and Havasu Creek. A summary of flannelmouth sucker catch rates by gear type and reach is presented in Appendix E.

Bluehead Sucker

Bluehead suckers were caught throughout the study area, but in smaller numbers and more infrequently than flannelmouth suckers. Greatest numbers were found in Region II, with declining abundance downstream to Region III, and like flannelmouth suckers, catch rates were sporadically high at or near major tributary inflows (i.e., LCR, Bright Angel Creek, Kanab Creek, and Havasu Creek). Pooled netting catch rates (AM_{CPE}) for adult bluehead sucker were highest at about 60 FPN between RM 88.0 and RM 88.9 (below Bright Angel Creek) (Fig. E-5). With few exceptions, relatively low catch rates (<5 FPN) occurred throughout the lower three reaches. Few bluehead suckers were captured with nets in Region 0.

Pooled electrofishing AM_{CPE} for adult bluehead sucker peaked at over 50 FPE between RM 146.0 and RM 146.9 (below Olo Canyon) (Fig. E-6). No bluehead suckers were captured electrofishing in Region 0, and catch rates throughout Regions I-III were low, except for tributary inflows.

Movement of adult bluehead sucker was inconclusive because of the small number of recaptured PIT-tagged fish. Of 12 recaptured adults at large up to 431 d, 9 were captured and recaptured near Havasu Creek, 2 were near the LCR, and only two moved more than 0.1 mi from the original capture location (Table E-4). The greatest displacement was 29.7 mi downstream from Havasu Creek.

Subadult bluehead sucker (TL=28-150 mm) were captured in return channels and other quiet shoreline habitats. Their distribution was similar to that of subadult flannelmouth sucker, extending from RM 61.4 to RM 184.1, with concentrations below the LCR, and in the inflows of Bright Angel Creek, Shinumo Creek, Kanab Creek, and Havasu Creek. A summary of bluehead sucker catch rates by gear type and reach is presented in Appendix E.

Speckled Dace

A total of 1185 speckled dace (TL=17-86 mm) were captured and processed in 1990-93. Of these, four (<1%) were captured in Region 0, 705 (60%) in Region I, 259 (22%) in Region II, and 217 (18%) in Region III. Speckled dace in Regions 0 and II were concentrated around thermal inputs, including the Fence Fault spring complex, and Clear Creek, Bright Angel Creek, Shinumo Creek, and Kanab Creek. Most speckled dace in Region III were captured near the Havasu Creek inflow, but low numbers were found consistently in the mainstem to Diamond Creek.

Species Accounts - Non-Native Species

Black Bullhead

Six black bullheads (TL=70-232 mm) were captured and processed in 1990-93; 5 adults between RM 61.3 and RM 70.9, and 1 juvenile at RM 143.5 (mouth of Kanab Creek). Bullheads have been considered rare in Grand Canyon since completion of Glen Canyon Dam in 1963 (Maddux et al. 1987), probably because mainstem temperatures limited their distribution and abundance.

Black bullheads are omnivorous, voracious feeders and can be a threat locally to young fish in enclosed habitats, such as backwaters (Valdez 1990, Sigler and Sigler 1987). Although currently not a recognized serious threat to native fishes in the mainstem Colorado River, black bullheads have successfully spawned in the LCR (Haden 1992), and proliferation of this species could have a serious impact on native fishes in that tributary. Black bullheads are present in the warm water of the upper basin, but are reported in large numbers only from riverside ponds and gravel pits (Valdez and Wick 1982, Valdez et al. 1982, Valdez 1990).

Brook Trout

Six brook trout (TL=318-436 mm, WT=342-657 g) were collected in the mainstem; 3 in 1990, and 1 each in 1991, 1992, and 1993. These fish were captured at RM 30.3, RM 32.5, RM 60.1, RM 156.7 (two fish), and RM 165.1. Brook trout have not been stocked into the mainstem or its tributaries since 1979, and their status below Lee's Ferry is currently considered rare (Haden 1992). Unless stocking is resumed, brook trout are not numerous enough to represent a significant predator threat to humpback chub or other native species in Grand Canyon.

Brown Trout

A total of 1578 brown trout (TL=69-730 mm, WT=3-4423 g) were captured in 1990-93. The longitudinal distribution of brown trout was 5 (<1%), 66 (4%), 1490 (94%), and 17 (1%) in Regions 0, I, II, and III, respectively. Within Region II, most brown trout were captured near tributaries -- 1091 of 1490 (73%) were within 6 mi of Bright Angel Creek, and 173 (12%) were within 2 mi of Shinumo Creek. In Region 0, 3 of 5 brown trout were captured in the vicinity of the Fence Fault Spring complex, and one was captured 0.3 mi upstream of Nankoweap Creek.

Although brown trout have not been stocked in the mainstem or its tributaries since 1934, they remain locally common in Grand Canyon, with reproduction in Bright Angel Creek and probably in other tributaries (Haden 1992). Numerous ripe fish were captured near the mouths of Bright Angel Creek, Shinumo Creek, and Kanab Creek during this investigation.

Brown trout are aggressive predators, consuming fish at an earlier age than most trout (Sigler and Sigler 1987), and must be considered a serious threat to native fish populations in Grand Canyon, including humpback chub. Otis (1994) observed congregations of rainbow trout and brown trout behind groups of spawning suckers in Bright Angel Creek, and found over 100 flannelmouth suckers eggs in one sacrificed brown trout. Predation by brown trout on humpback chub is further discussed in Chapter 6 -DEMOGRAPHICS).

Common Carp

A total of 2423 common carp (TL=23-827 mm, WT=2-9440 g) were captured in the mainstem Colorado River in 1990-93. Carp were abundant in Regions I-III, and captured consistently from RM 56.8 (below Kwagunt Canyon) to RM

226.0 (Diamond Creek). Within Region 0, carp were captured only between RM 26.9 and RM 32.9, where they were congregated in large schools, sympatric with humpback chub, in warm spring plumes of the Fence Fault spring complex. Carp are omnivorous and opportunistic feeders (Sigler and Sigler 1987, Cooper 1987), and suspected of preying on eggs and larvae of native fishes in the LCR (Minckley 1990). Carp could be a serious threat to the viability of the 30-Mile aggregation of humpback chub by competing for limited space and food, and preying on young within the spring plumes. Carp may reproduce in several warm Grand Canyon tributaries or in warm local springs that satisfy the temperature requirement of 14 - 19° C (Sigler and Sigler 1987).

Four of 2243 carp captured in 1990-93 were previously marked by other researchers with Floy tags or Carlin tags (Table 5-10). Of these, two were identifiable and traced to their original capture location (B. Persons, AGF, pers. comm.). Both fish were originally tagged by AGF in 1985; one at RM 182 and the other at RM 204; BIO/WEST recaptured the first at RM 208 in 1991, and the other at RM 208.6 in 1992. One fish had moved 26 mi (downstream) in 6 years and 2 months, and the other moved 4.6 mi (upstream) in 5 years and 10 months, respectively. The size of both carp remained relatively unchanged between captures.

Channel Catfish

A total of 112 channel catfish (TL=39-712 mm, WT=2-5500 g) were captured in 1990-93, including 32 (29%) in Region I, 5 (4%) in Region II, and 75 (67%) in Region III. Seventy-nine percent of all catfish captured in Region III were in the lower 13 mi. Channel catfish were not captured in Region 0.

Channel catfish are known to spawn in both the LCR and Kanab Creek (Carothers and Minckley 1981). Numerous large (up to 5 kg) channel catfish were seen in the LCR inflow during unusually clear water in July 1993. BIO/WEST biologists observed and photographed a congregation of 30-40 large catfish under a boulder along the mixing zone at the mouth of the LCR. Subadult humpback chub and unidentified suckers were occupying the same deep, boulder/ledge habitat, and often swam in close proximity to the large catfish.

Kaeding and Zimmerman (1983) observed humpback chub with apparent catfish bite marks, and suggested that catfish may be an important predator to humpback chub in the LCR. Stomach analyses were performed on channel catfish from the mainstem to determine extent of predation by this species (See Chapter 9 - DEMOGRAPHICS).

Fathead Minnow

A total of 1130 fathead minnows (TL=13-84 mm) were captured in 1990-93, including 912 (81%) in Region I, 137 (12%) in Region II, and 81 (7%) in Region III. Fathead minnows were notably absent in the mainstem Colorado River above the LCR. This distribution was explained as dispersal of individuals from a large population in the LCR (Clarkson 1993), and absence of spawning in at least the uppermost colder mainstem reaches.

Numbers of fathead minnows captured in the mainstem increased dramatically after 1991, e.g., 18 (2%) in 1990-91, 560 (50%) in 1992, and 552 (48%) in 1993. Greater numbers in 1992 and 1993 were attributed to more stable shoreline

Table 5-10. Fish species captured, tagged and recaptured during this investigation in the Colorado River from Lees Ferry to Diamond Creek, October 1990 - November 1993.

		B/W PIT Tags		Recapture - Other Tags			
Common Name	Total Captured	Tagged	Recaptured	PIT	Carlin	Floy	Coded Wire
Family: Cyprinidae (minnows)							
common carp	2423	0	-	0	1	3	
humpback chub	6294	1827	279	565	50	27	
fathead minnow	1130	0	-	-	-	?	
speckled dace	1491	0	-	-	-	?	
Family: Catostomidae (suckers)							
bluehead sucker	1040	394	13	12	-	-	
flannelmouth sucker	2775	1071	176	219	1	18	
flannelmouth x razorback sucker	5						
unidentified sucker	32	0	-	-	-	-	
Family: Ictaluridae (catfishes, bullheads)							
black bullhead	6	0	-	-	-	-	
channel catfish	113	0	-	0	-	-	
Family: Salmonidae (trout)							
rainbow trout	11121	0	-	0	-	6	3
brown trout	1673	0	-	0	-	-	
brook trout	6	0	-	0	-	-	
Family: Cyprinodontidae (killifishes)							
plains killifish	76	0	-	-	-	-	
Family: Percichthyidae (temperate basses)							
striped bass	40	0	-	-	-	-	
Family: Centrarchidae (sunfish)							
green sunfish	3	0	-	-	-	-	
Family: Percidae (perches)							
walleye	1	0	-	-	-	-	
Totals	**28229**	**3292**	**3760**	**796**	**52**	**54**	**3**

habitats, as a result of interim flows starting in August 1991, and to transport of fish from the LCR by floods in May-June 1992 and January-February 1993. Approximately even electrofishing effort of 196.5, 172.7, and 183.2 h for 1990-91, 1992, and 1993, respectively, yielded significantly higher GM_{CPE} for 1992 and 1993, compared to 1990-91.

Fathead minnows are known to act aggressively toward young native species in backwaters (Haden 1992), although it is not known if present densities in Grand Canyon are high enough to represent a threat. Fathead minnows spawn at or above a temperature of 15.6° C (Haden 1992), which probably restricts spawning to warm tributaries or local warm shoreline habitats or springs. Specimens from the mainstem included tubercled males and egg-laden females, suggesting that mainstem temperatures were sufficiently warm for maturation of gametes, but prevented survival of eggs and larvae.

Green Sunfish

Three green sunfish were captured in 1990-93, including 1 adult (TL=120 mm) at RM 60.12 in January 1993, 1 juvenile (TL=60 mm) at RM 62.45 in September 1992, and 1 juvenile (TL=28 mm) at RM 173.85 in September 1993. Small numbers of green sunfish were reported below Glen Canyon Dam in the mid-1980's, and collections near the LCR inflow have always been incidental (Maddux et al. 1987). Green sunfish are opportunistic predators and can be a local threat to young fish in enclosed habitats such as backwaters (Valdez 1990, Sigler and Sigler 1987). Currently, green sunfish do not represent a significant threat to humpback chub or other native species in Grand Canyon, because of low numbers.

Plains Killifish

Fifty-two plains killifish (TL=39-70 mm) were captured in the mainstem in 1990-93, including 10 in Region I, 33 in Region II, and 9 in Region III. All killifish captured in Region II were in tributary inflows; 3 (9%) were near Deer Creek, and 30 (91%) near Kanab Creek. Distribution in Regions I and III appeared relatively random. Although killifish may compete with juvenile native species in backwaters, their limited abundance and distribution precludes a serious threat. The former synonym for this species is Rio Grande killifish (citation***).

Rainbow Trout

A total of 11,121 rainbow trout (TL=24-708 mm, WT=1-6641 g) were captured in the mainstem Colorado River in 1990-93. Netting catch rates peaked at over 185 FPN between RM 12.0 and RM 12.9, while electrofishing catch rates in the same mile were highest at over 1300 FPE (Fig. E-7, E-8). Both netting and electrofishing catch rates generally decreased with downstream direction, although adult, juvenile, and YOY rainbow trout were captured from all four study regions. A summary of rainbow trout catch rates by gear type and region is presented in Appendix E.

Nine of 11,121 rainbow trout captured had been previously marked by other researchers with Floy tags (6) or coded wire tags (3) (Table 5-10). According to the AGF database (B. Persons, AGF, pers. comm.), four were initially Floy-tagged in the Nankoweap Creek inflow (RM 52.1) in January and February 1991 by bald eagle researchers, and were recaptured from June through September 1991, between RM 56.7 and RM 61.8. Furthest individual movement was 9.7 mi downstream in 107 d. Two fish were initially Floy-tagged by AGF at RM 105 in 1984, and at RM 5.7 in 1992. The first was recaptured at RM 56.7 in 1990, and had moved 48.3 mi upstream in just over 5 years and 11 months. The other was recaptured at RM 60.2 in 1992, and moved 54.5 mi downstream in 75 d. The three rainbow trout (TL=112, 131, 265 mm) with coded wire tags were recaptured by B/W in July 1993 at RM 3.2, RM 3.2, and RM 2.9, respectively, and were part of a lot of fish tagged and released by AGF between Glen Canyon Dam and Lees Ferry in spring 1993.

Three of four rainbow trout initially tagged at Nankoweap in January and February had lost weight (up to 215 g) when recaptured in June through September, possibly because of spawning activity. Of the two AGF Floy-tagged fish, one grew 166 mm TL and gained 27 g in 5 years and 11 months, and the other grew 27 mm TL and lost 169 g in 75 d.

Striped Bass

A total of 39 striped bass (TL=315-857 mm, WT=229-5829 g) were captured in the mainstem Colorado River, including 17 in 1991, 3 in 1992, and 19 in 1993. All striped bass were captured between May and July at river temperatures of 12.7-17.0° C, presumably during upstream spawning-related migrations from Lake Mead. The apparent reduction in abundance and upstream occurrence of striped bass from 1991 to 1992 was unexplained, but took place during a dramatic reduction in water level of Lake Mead.

Most striped bass were captured in the lower end of Region III; 16 (41%) were between RM 212 and RM 220, 4 were near Havasu Creek, and 6 were near Kanab Creek. Also, 4 striped bass were captured in one day just below Lava Falls Rapid, indicating that this rapid may be a temporary impediment to migration. The furthest upstream capture during this study was at RM 142.3, although other investigators reported striped bass in the LCR at RM 61.3 (C.O. Minckley, AGF, pers. comm.). Weiss (1993) reported a single moribund striped bass (stomach empty) at the mouth of the Paria River in September 1992, which may be the furthest upstream record for the species in Grand Canyon since completion of Glen Canyon Dam.

Walleye

One adult walleye (TL=426 mm) was captured in July 1991 at RM 179.7 (base of Lava Falls Rapid). Few walleye have been collected in Grand Canyon, and their present status is considered rare (Haden 1992). Walleye do not represent a significant threat to humpback chub or other native species in Grand Canyon, because of their low numbers.

DISCUSSION

Historic status and trends in fish species composition, distribution, and abundance in the Colorado River in Grand Canyon were difficult to characterize, because of a lack of past quantitative data. The biotic and abiotic factors that control native fish distribution and abundance, particularly humpback chub, are not well understood. Elimination of high spring floods and seasonal variability, reduced sediment loads, stable year-around cold releases, high daily flow fluctuations, and introduction of large numbers of non-native species greatly altered the riverine ecosystem. These changes have impacted habitat, food web dynamics, and fish physiology, including growth and reproductive capability, but specific causal factors, linkages, and mechanisms of effect remain uncertain.

While fish assemblages from tributaries and tributary inflows were known as early as the 1940's, information on mainstem distributions and abundances was fragmented until the late 1970's, largely because of logistical difficulties of accessing and sampling the deep, swift mainstem.

By the time of the first survey in Glen Canyon, in 1958-59, many non-native fishes had already invaded the area, and most native species were declining, with causal factors unidentified and undescribed. When Glen Canyon Dam was completed in 1963, many changes had already taken place in the riverine ichthyofauna that remained unquantified, and inseparable from effects of dam construction and some aspects of operation. Pre- and post-impoundment fishery surveys focused on developing a recreational sport fishery in Lake Powell and a cold tailwater fishery below the dam, and were primarily descriptive. Little attention was given to detailed analyses of dam construction or operational effects.

Mainstem and tributary investigations in the 1970's refined species composition, distribution, and abundance information, but infrequent sampling and dynamic fish populations precluded accurate assessments. The first fishery investigations with repeated trips and intensive mainstem sampling were conducted in the late 1970's and early 1980's, providing comprehensive accounts of mainstem ichthyofauna, and establishing a foundation for hypothesis development to address causal factors for species composition, distribution, and abundance.

Comparisons of present fish assemblages with pre-dam assemblages must be inferred, based on existing life history information for the native species, and known distributions from other similar areas. The effects of dam construction and impoundment of the Colorado River in Glen and Grand canyons cannot be fully known for lack of comparative data, and because of pre-existing anthropogenic changes (e.g., non-native fishes, watershed practices, etc,; Miller 1956) that confound comparisons. Similarly, evaluation of dam operations is confounded by lack of quantitative data for comparative flow regimes, and a plethora of pre-existing conditions that continue to confound comparisons. Nevertheless, the present investigation, together with the other ongoing GCES investigations, provide quantitative information for limited past comparisons, but more importantly, for future comparisons.

Of 34 fish species reported in Grand Canyon since 1958, only 10 were native to the Colorado River Basin. Most of the 24 non-native species were already present in the region by the time Glen Canyon Dam was built in 1963, their invasion attributed to bait fish releases, coincidental releases, dispersal from other introduction sites, and establishment of sport fisheries. Carp, fathead minnow, and channel catfish have remained common to abundant for 35 years, while plains killifish, black bullhead, yellow bullhead, mosquitofish, and green sunfish have remained low in numbers or only locally common. The other warmwater species are lacustrine in Lake Powell and Lake Mead, and occur incidentally in the canyon or commonly in the Lake Mead inflow, including threadfin shad, red shiner, striped bass, bluegill, largemouth bass, black crappie, yellow perch, and walleye. Although red shiner were common to abundant before Glen Canyon Dam was built, they were rare by the early 1970's, and except for one specimen from RM 117.4, were not reported upstream of Diamond Creek after 1973. Other cyprinids that were reported only incidentally included non-native Utah chub and golden shiner.

Of six coldwater species introduced since 1967, only rainbow trout have remained common to abundant in the upper reaches of the canyon, and brown trout have increased in relative abundance in the middle reach (near Bright Angel Creek) since about 1976. Brook trout are rare and cutthroat trout are rare or absent, but coho salmon and kokanee salmon have not been reported since the 1960's and 1970's.

Native humpback chub continue to be reported as rare or locally common, speckled dace as abundant, and bluehead sucker and flannelmouth sucker as common. The only species that have been extirpated are three natives, including bonytail, roundtail chub, and Colorado squawfish, and the razorback sucker is extremely rare.

Non-native warmwater and coldwater species dominated fish composition and biomass (Fig. 5-13) in Grand Canyon during this investigation. Approximately 81% of fish biomass was attributed to rainbow trout (53%) and carp (28%). Although cold hypolimnetic releases from Glen Canyon Dam were a dominating influence on fish assemblages, coldwater species were dominant for 140 mi below the dam and warmwater species were dominant in the lower 110 mi to the Lake Mead inflow. Rainbow trout comprised about 90% of biomass between Glen Canyon Dam and Lees Ferry (estimates from Arizona Game and Fish Department 1993), and over 63% (47-98% by reach) of biomass from Lees Ferry to Middle Granite Gorge (140 mi below the dam), where a dramatic shift occurred from coldwater to warmwater forms. While carp comprised only 18% of biomass from Lees Ferry to Middle Granite Gorge, this warmwater species dominated with over 70% of biomass from Middle Granite Gorge to Diamond Creek, and rainbow trout biomass decreased dramatically from over 63% to only 7%.

The majority of fish biomass, and thus a principal component of energy in the riverine ecosystem between Glen Canyon Dam and the Lake Mead inflow was stored as rainbow trout and carp biomass. Native fish biomass

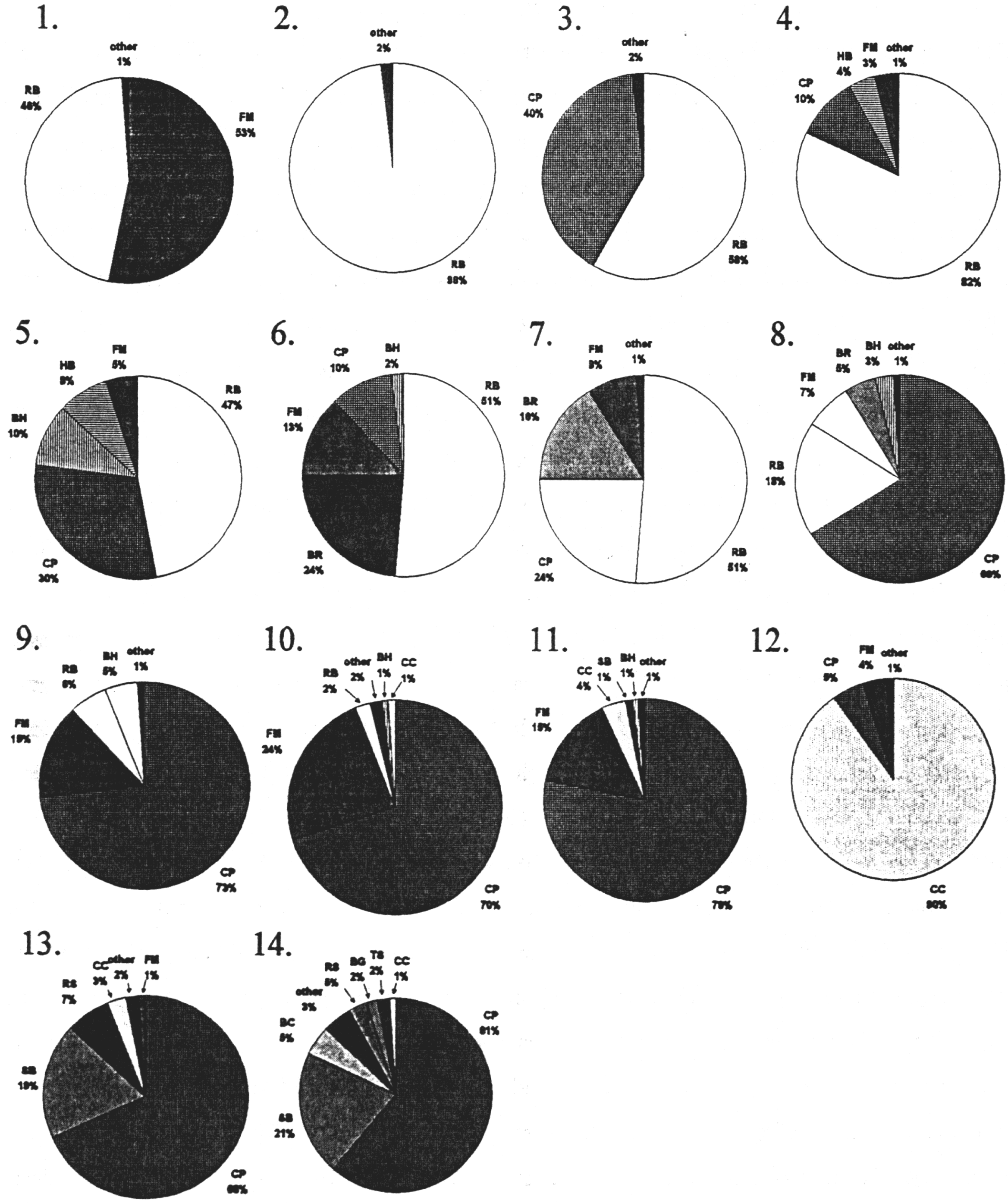


Fig. 5-13. Percentage biomass for fish species in 14 geomorphic reaches of the Colorado River from Lees Ferry to Pearce Ferry, Lake Mead. See Table 5-2 for species codes and Table 2-1 for geomorphic reach descriptions.

was associated primarily with warm tributary inflows, but was 25% or less in each of the 11 study reaches. Greatest biomass of native forms was 23% (bluehead sucker, humpback chub, and flannelmouth sucker) in Reach 5 (area immediately downstream of LCR inflow), 20% (flannelmouth sucker, bluehead sucker) in Reach 9 (Kanab Creek to Havasu Creek), and 25% (flannelmouth sucker, bluehead sucker) in Reach 10 (below Havasu Creek).

Cold hypolimnetic releases from Glen Canyon Dam have left few habitats suitable for reproduction, survival, and growth of the warmwater fishes. Tributary inflows consistently had highest catch rates, and aggregations of fish were frequently found in and near tepid springs. Mainstem temperatures appear sufficient for maturation of gametes of warmwater species, but too cold for survival of eggs and larvae. Eggs deposited in inflows or tepid springs are not likely to survive when fluctuating flows bathe gametes and larvae in sublethal temperatures. While an abundance of spawning activity was not seen in these habitats, their use may be increased under more stable thermal regimes from lower fluctuations. This propensity was demonstrated by the discovery of about 100 YOY humpback chub from a warm spring near Fence Fault in July 1994 that probably hatched and survived in a warm plume that sustained suitable conditions for at least 30 d under interim flows. This finding also confirmed that mainstem humpback chub not spawning in the LCR reached spawning readiness nearly 2 months later (May) than the LCR fish (March).

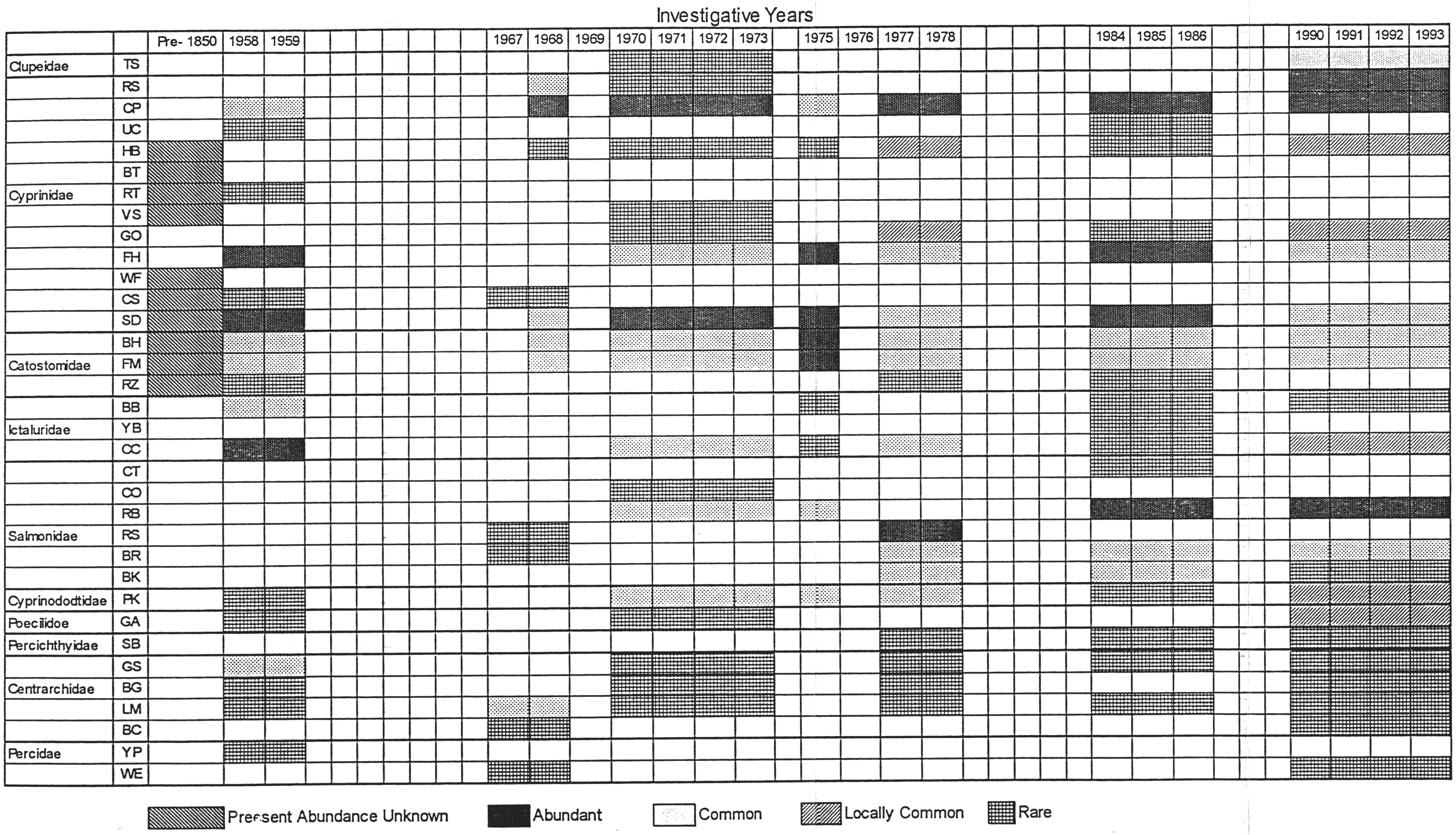
While pre-dam status of humpback chub in Glen and Grand canyons remains unknown, it is reasonable to surmise distribution and possibly abundance from known life history requirements and current distribution. Based on a present affinity for whitewater canyon regions, humpback chub were probably throughout the 41 mi (62 rapids) of Cataract Canyon, described by Dellenbaugh (1908) as ending at the Dirty Devil River. A small population of humpback chub in the remaining 11 mi (26 rapids) above Lake Powell (Valdez 1990), and specimens from the lake during filling in 1962-67 (Holden and Stalnaker 1975) support this contention. However, humpback chub were probably not common in Glen Canyon (Dirty Devil River to the Paria River), described as a gentle meandering river cut through sandstone (Dellenbaugh 1908), with photographs (Stephens and Shoemaker 1987) showing an alluvial region not commonly used by the species. Based on present distributional patterns in the upper Colorado River basin, humpback chub were probably distributed through most of Marble and Grand Canyons, as far downstream as Grand Wash Cliffs, a distance of about 443 km (275 mi). While the species in Grand Canyon was probably common near tributary inflows, and possibly ascended these to spawn, it is noted that upper basin populations are not associated with tributaries, and spawn in main channel habitats (Valdez and Clemmer 1982, Valdez 1990).

Post-dam distribution certainly suggests the demise of the species from 41 mi of Cataract Canyon, now inundated by Lake Powell. In Marble and Grand canyons, distribution has been reduced by 98 km, or 24% of the original estimated distribution since Glen Canyon Dam was completed in 1963. Post-dam capture locations spanned 412 km, from the base of Glen Canyon Dam to Separation Rapid (RM 241), while the most recent distribution is 314 km, from above South Canyon (RM 30) to Diamond Creek (RM 225). Except for a specimen near Maxson Canyon (RM 253.7), humpback chub have not been captured recently downstream of Diamond Creek, and researchers have consistently found the majority of the post-dam population within a small area around the confluence of the LCR (RM 61.3).

Reduction in abundance of humpback chub in Marble and Grand canyons has been at least as great as the reduction in distribution. Of nine distinct aggregations of humpback chub identified in this study, 74% of total catch was from the LCR aggregation (RM 56.0-65.4), an area of about 15 km. The LCR aggregation was a component of the LCR population, the only known self-sustaining population in Grand Canyon. Size structure of eight other disjunct aggregations indicated a lack of reproductive success, and only limited recruitment from downstream dispersal from the LCR population. Lack of mainstem recruitment and absence of humpback chub from large intervening reaches between aggregations provided substantial evidence of reduced abundance of the species since 1963. While recruitment in seven aggregations downstream of the LCR is probably supplemented by the LCR population, and possibly some local reproduction in warm springs or tributary inflows, an aggregation of adults near RM 30 (50 km above LCR) may be remnants of fish produced about the time of dam construction in 1963. Post-larvae in a warm spring near RM 30 shows successful reproduction, but the lack of subadults in the aggregation indicated no survival and recruitment.

Aside from these distinct aggregations, small numbers of humpback chub were found in tributary inflows, including 4 within 0.3 miles above Clear Creek, 2 within 0.2 miles above Bright Angel Creek, 27 within 0.6 miles above Shinumo Creek, 2 within 0.9 miles above Kanab Creek, and 7 within 0.9 miles above Havasu Creek. The remaining 20 outliers in Reach 2 were not captured in proximity to a major tributary or rapid; 13 were captured between RM 118.5 and RM 119.8 (Stephen Isle) in frequent association with tapeats sandstone, shoreline habitat similar to that associated with three other aggregations (LCR, A-6 and MGG). Adults in these aggregations were usually captured in deep, tapeats-bounded eddies and return channels, and in deep eddies adjacent to talus debris fans.

Although mainstem temperature has had a dominating influence on fish species composition, distribution, and abundance in Grand Canyon, water clarity or turbidity has also affected species distribution and composition for given river reaches. Turbidity was a main deterrent to rainbow trout below the LCR, and probably limited downstream distribution and abundance by reducing sight feeding opportunities. Conversely, humpback chub were more abundant downstream of the LCR, and possibly used turbidity as a cover element for feeding and to escape predation.



Species Codes:

TS= Threadfin shad
RS= Red shiner
CP= Common carp
UC= Utah chub
HB= Humpback chub
BT= Bonytail
RT= Roundtail chub
VS= Virgin spinedace
GO= Golden shiner
FH= Fathead minnow

WF= Woundfin
CS= Colorado squafish
SD= Speckled dace
BH= Bluehead sucker
FM= Flannelmouth sucker
RZ= Razorback sucker
BB= Black bullhead
YB= Yellow bullhead
CC= Channel catfish
CT= Cutthroat trout

CO= Coho salmon
RB= Rainbow trout
KS= Kokane salmon
BR= Brown trout
BK= Brook trout
PK= Plains killifish
GA= Mosquitofish
SB= Striped bass
GS= Green sunfish
BG= Bluegill

LM= Largemouth bass
BC= Black crappie
YP= Yellow pearch
WE= Walleye

Fig. 5-1. Historic and present abundance of fishes in the Colorado River, Glen Canyon to Separation Canyon.

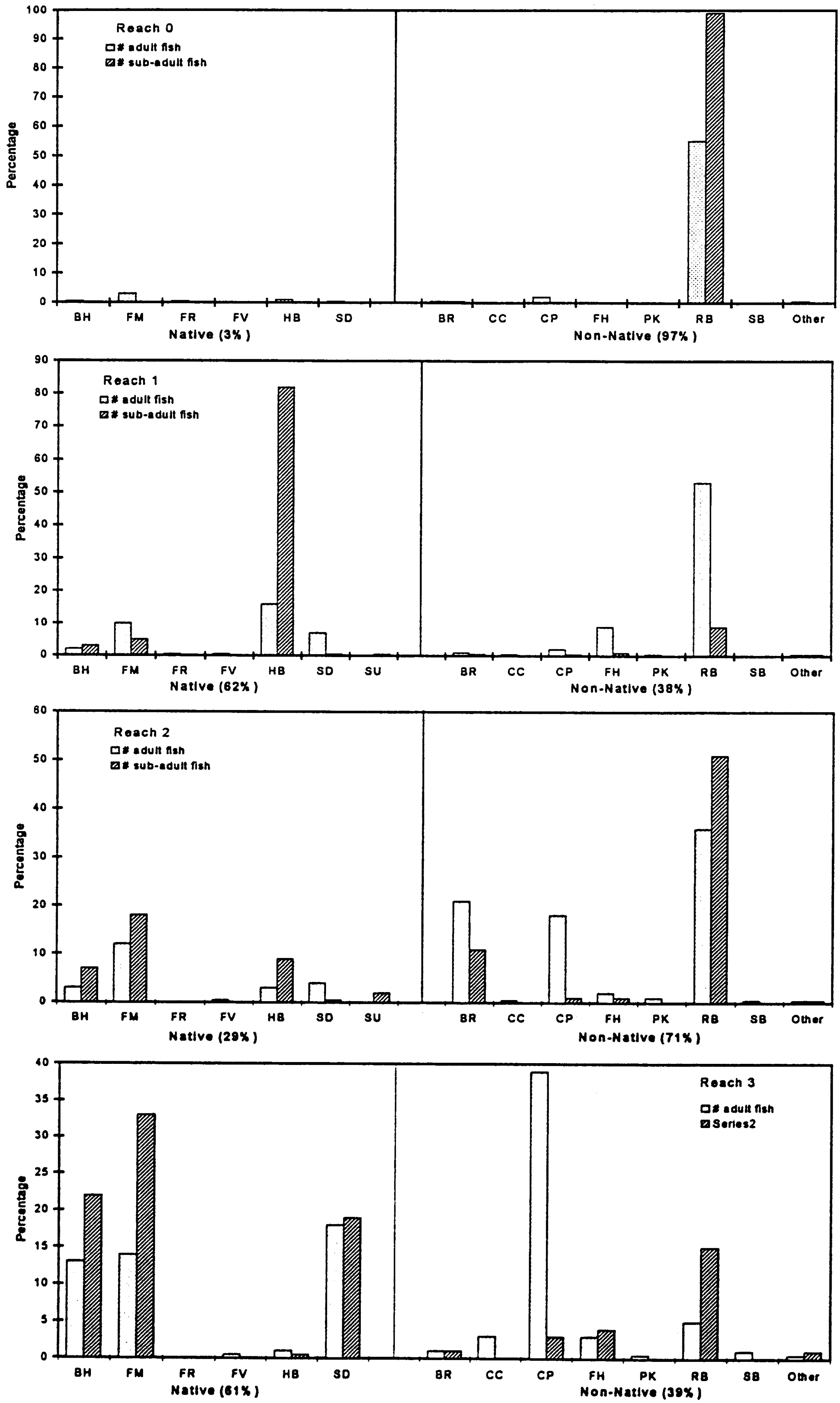
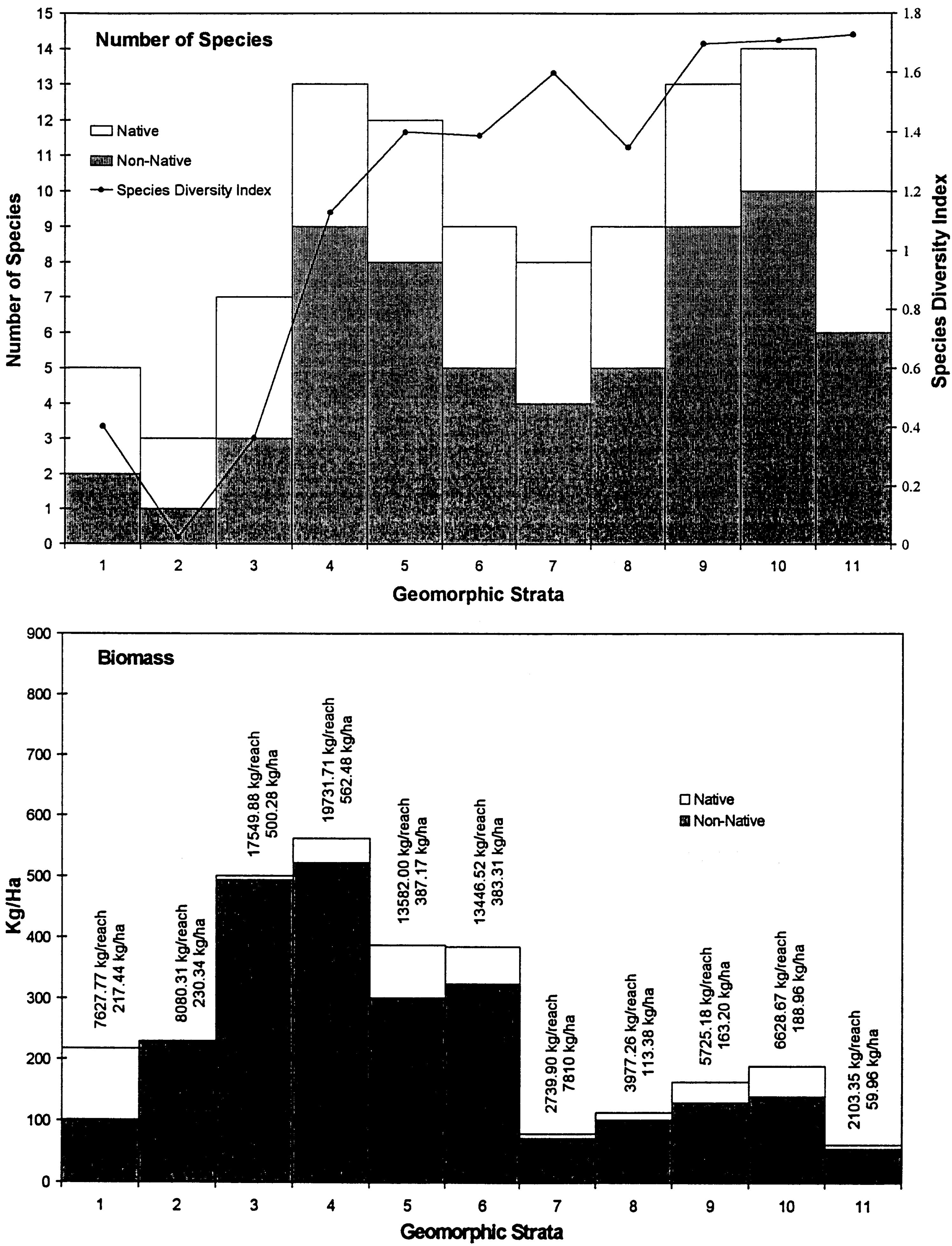
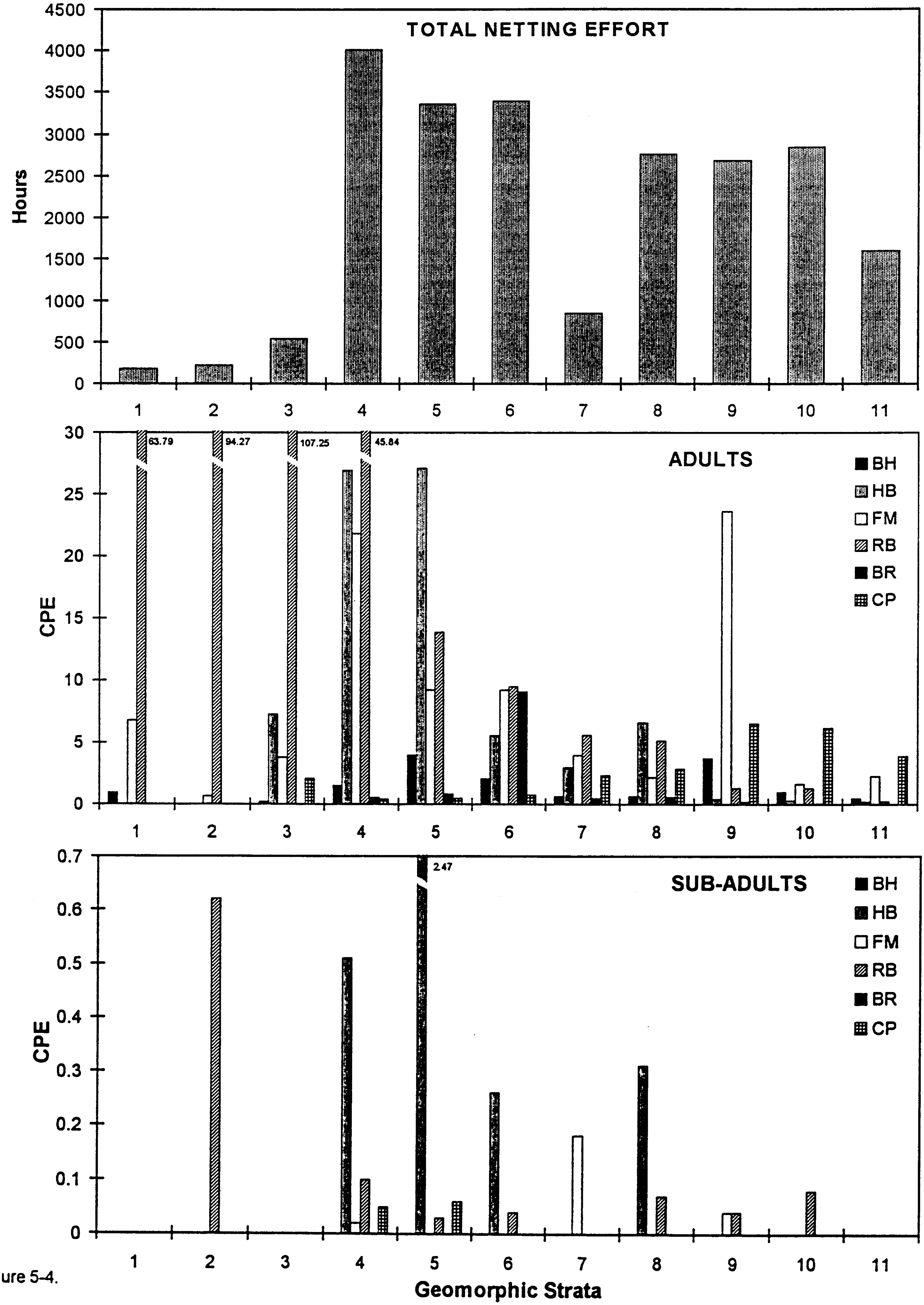

Reach 0
□# adult fish
▨# sub-adult fish
Percentage
BH FM FR FV HB SD
Native (3%)
BR CC CP FH PK RB SB Other
Non-Native (97%)
Reach 1
□# adult fish
▨# sub-adult fish
Percentage
BH FM FR FV HB SD SU
Native (62%)
BR CC CP FH PK RB SB Other
Non-Native (38%)
Reach 2
□# adult fish
▨# sub-adult fish
Percentage
BH FM FR FV HB SD SU
Native (29%)
BR CC CP FH PK RB SB Other
Non-Native (71%)
Reach 3
□# adult fish
▨Series2
Percentage
BH FM FR FV HB SD
Native (61%)
BR CC CP FH PK RB SB Other
Non-Native (39%)

Figure 5-2.



Number of Species
Native
Non-Native
Species Diversity Index
Number of Species
Species Diversity Index
Geomorphic Strata
Biomass
Kg/Ha
7627.77 kg/reach 217.44 kg/ha
8080.31 kg/reach 230.34 kg/ha
17549.88 kg/reach 500.28 kg/ha
19731.71 kg/reach 562.48 kg/ha
13582.00 kg/reach 387.17 kg/ha
13446.52 kg/reach 383.31 kg/ha
2739.90 kg/reach 7810 kg/ha
3977.26 kg/reach 113.38 kg/ha
5725.18 kg/reach 163.20 kg/ha
6628.67 kg/reach 188.96 kg/ha
2103.35 kg/reach 59.96 kg/ha
Native
Non-Native
Geomorphic Strata

FiG. 5-3



TOTAL NETTING EFFORT
Hours
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
ADULTS
CPE
63.79
94.27
107.25
45.84
BH
HB
FM
RB
BR
CP
SUB-ADULTS
2.47
Geomorphic Strata

Figure 5-4.

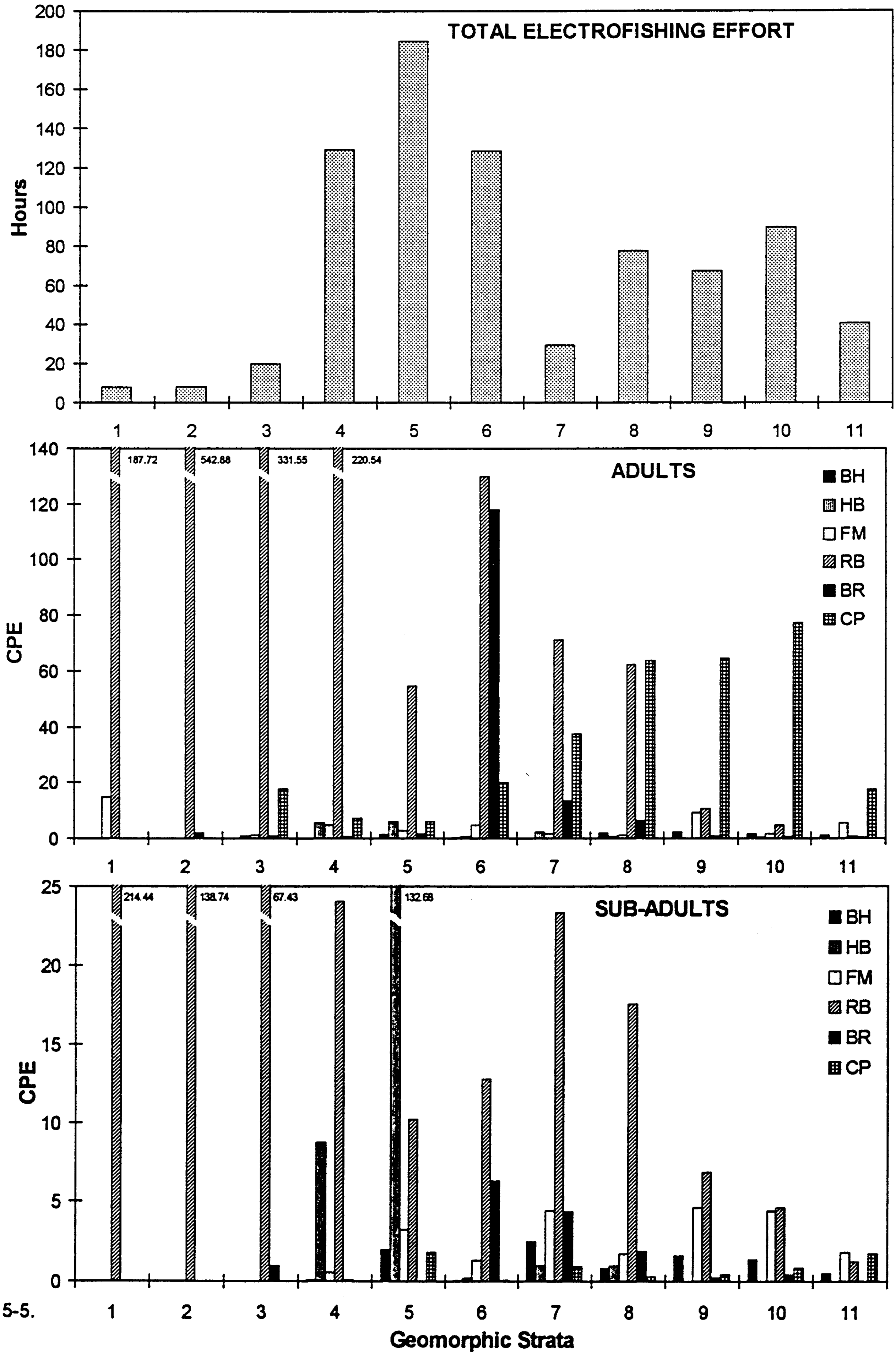
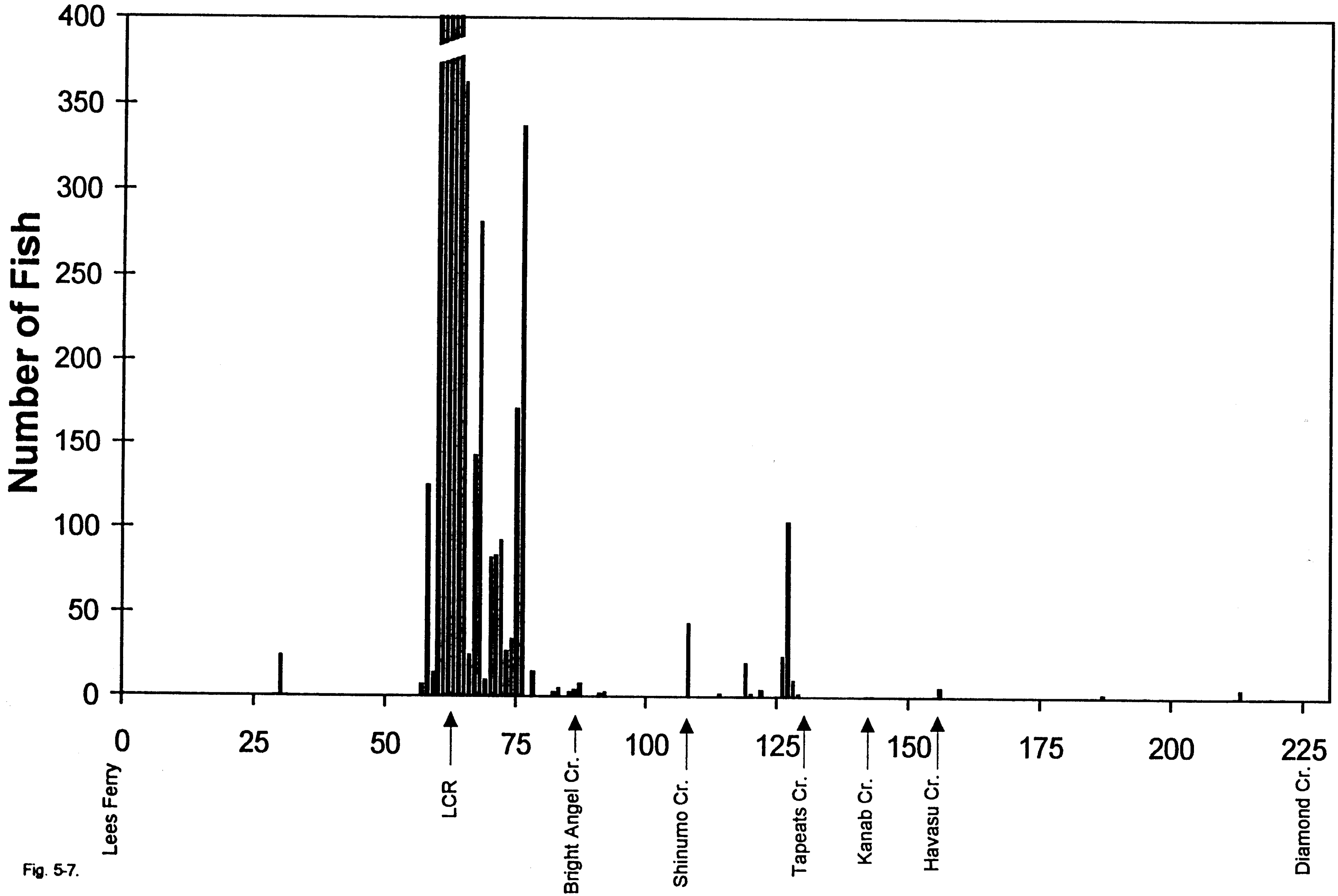
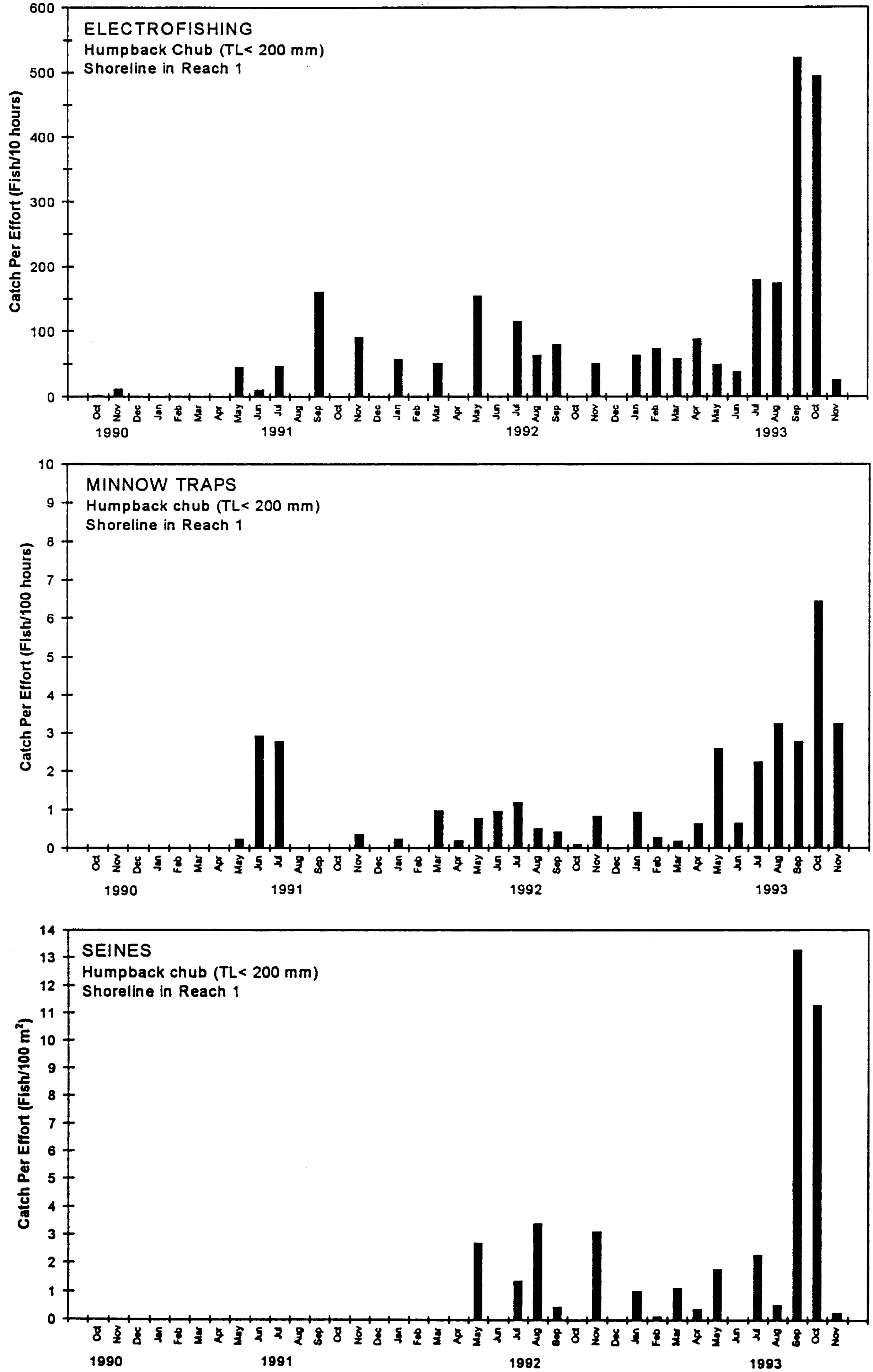

TOTAL ELECTROFISHING EFFORT
Hours
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
ADULTS
CPE
140
120
100
80
60
40
20
0
187.72
542.88
331.55
220.54
BH
HB
FM
RB
BR
CP
SUB-ADULTS
25
20
15
10
5
0
214.44
138.74
67.43
132.68
Geomorphic Strata

Fig. 5-5.



Number of Fish
400
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200
225
Lees Ferry
LCR
Bright Angel Cr.
Shinumo Cr.
Tapeats Cr.
Kanab Cr.
Havasu Cr.
Diamond Cr.

Fig. 5-7.



ELECTROFISHING
Humpback Chub (TL< 200 mm)
Shoreline in Reach 1
Catch Per Effort (Fish/10 hours)
0
100
200
300
400
500
600
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
1990
1991
1992
1993
MINNOW TRAPS
Humpback chub (TL< 200 mm)
Shoreline in Reach 1
Catch Per Effort (Fish/100 hours)
0
1
2
3
4
5
6
7
8
9
10
SEINES
Humpback chub (TL< 200 mm)
Shoreline in Reach 1
Catch Per Effort (Fish/100 m²)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 5-8.

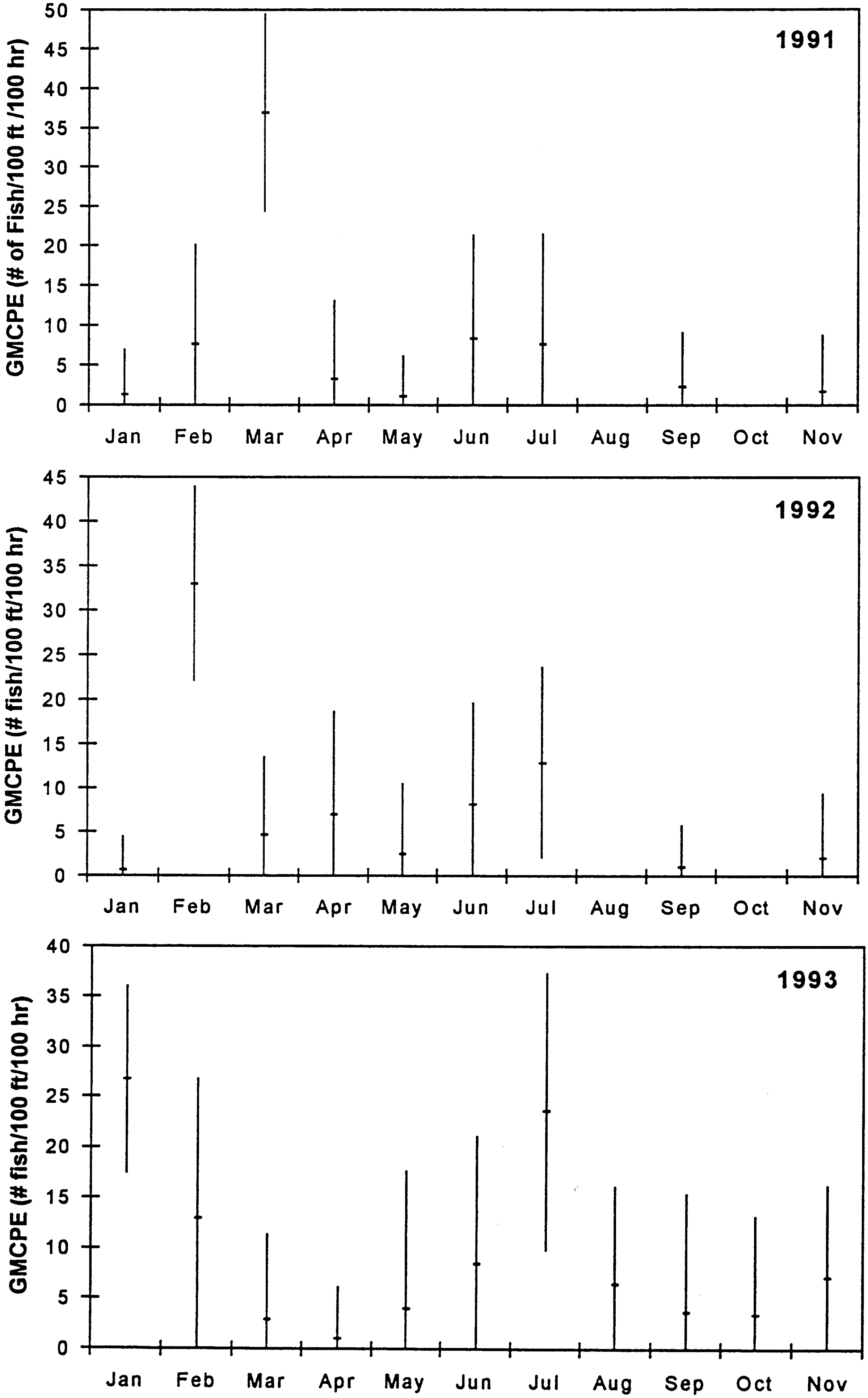
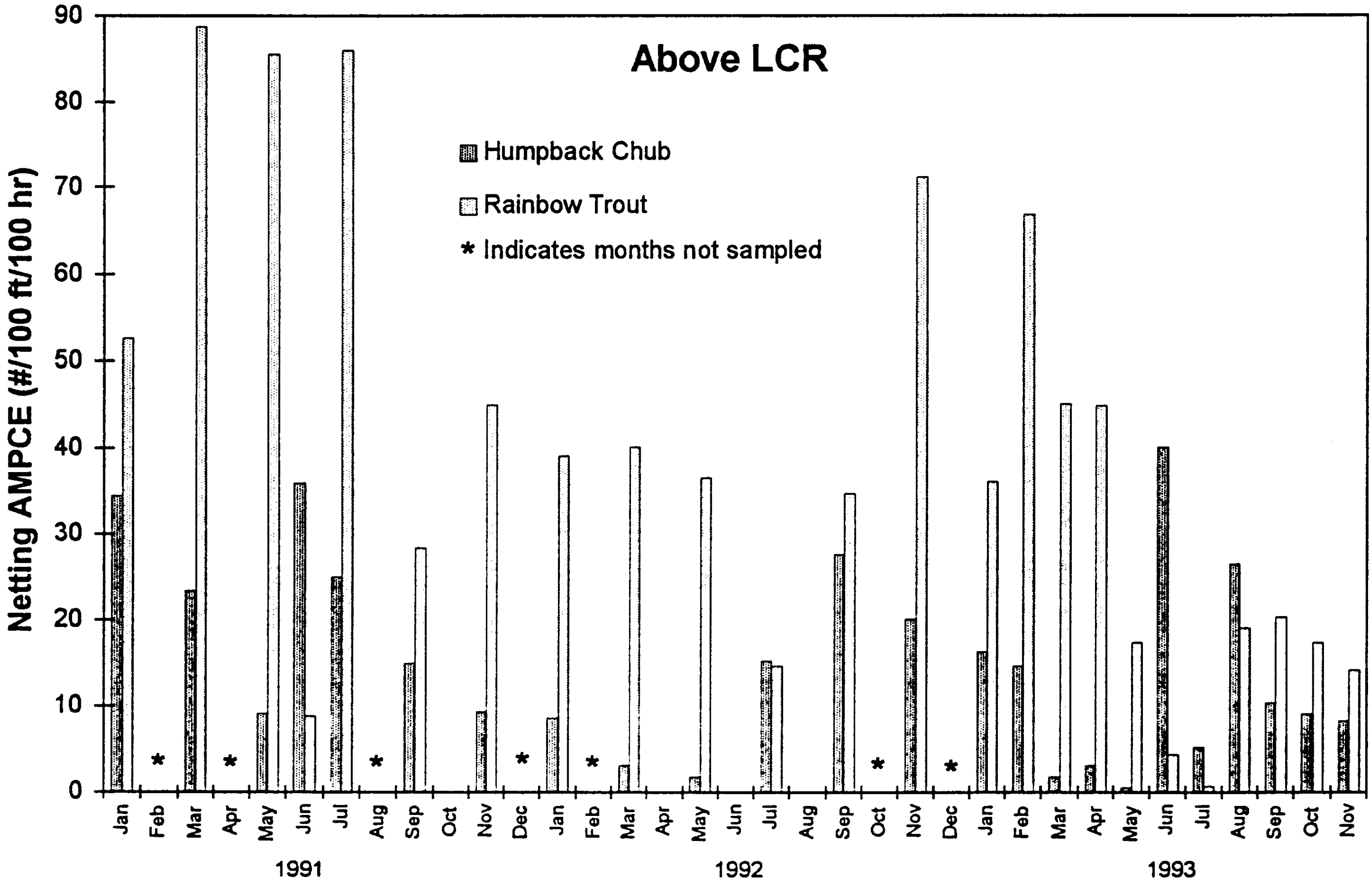
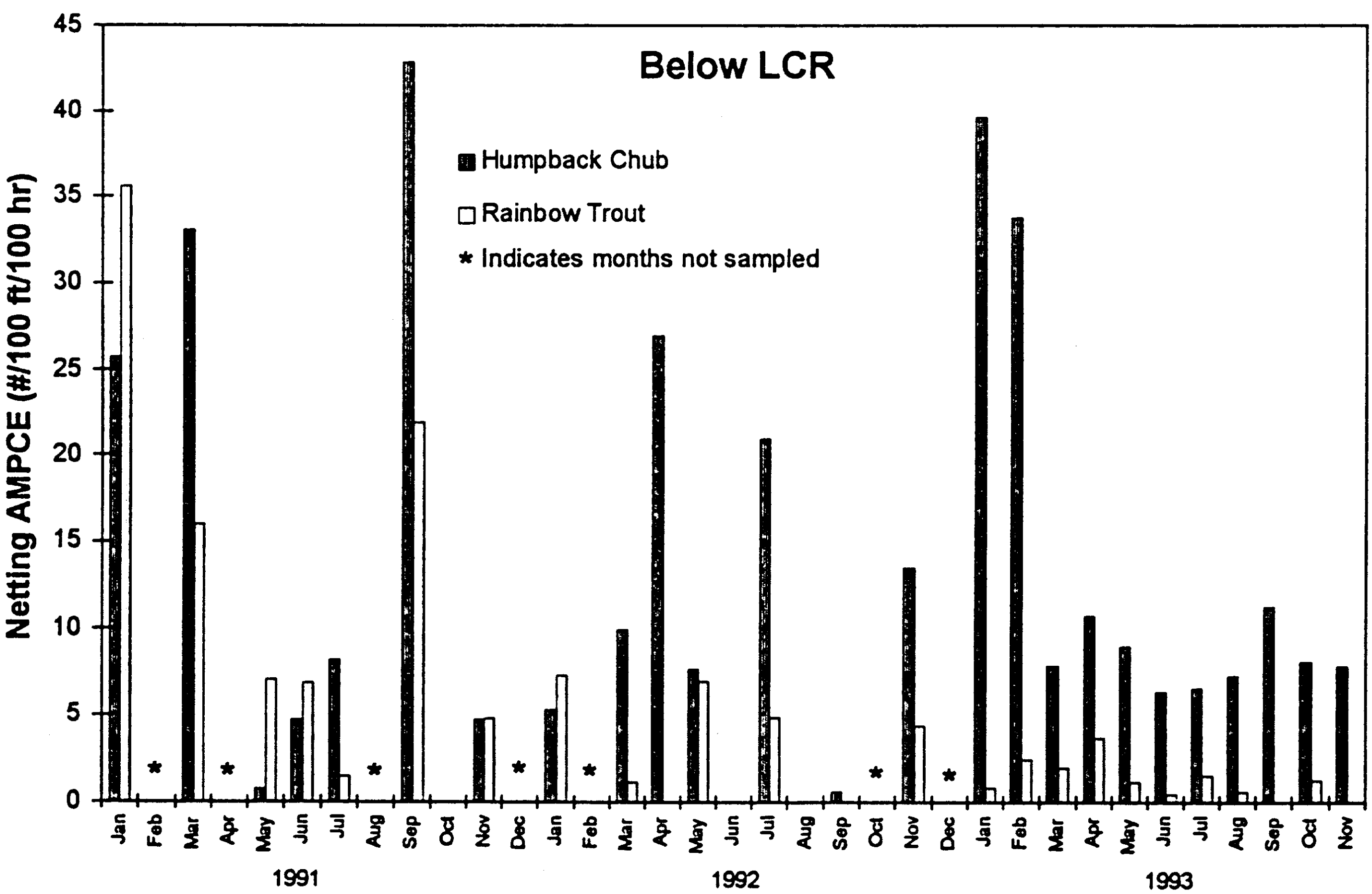

1991
GMCPE (# of Fish/100 ft /100 hr)
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
1992
GMCPE (# fish/100 ft/100 hr)
0
5
10
15
20
25
30
35
40
45
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
1993
GMCPE (# fish/100 ft/100 hr)
0
5
10
15
20
25
30
35
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Fig. 5-10



Above LCR
Humpback Chub
Rainbow Trout
* Indicates months not sampled
Netting AMPCE (#/100 ft/100 hr)
0
10
20
30
40
50
60
70
80
90
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1991
1992
1993



Below LCR
Humpback Chub
Rainbow Trout
* Indicates months not sampled
Netting AMPCE (#/100 ft/100 hr)
0
5
10
15
20
25
30
35
40
45
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1991
1992
1993

FIG. 5-11

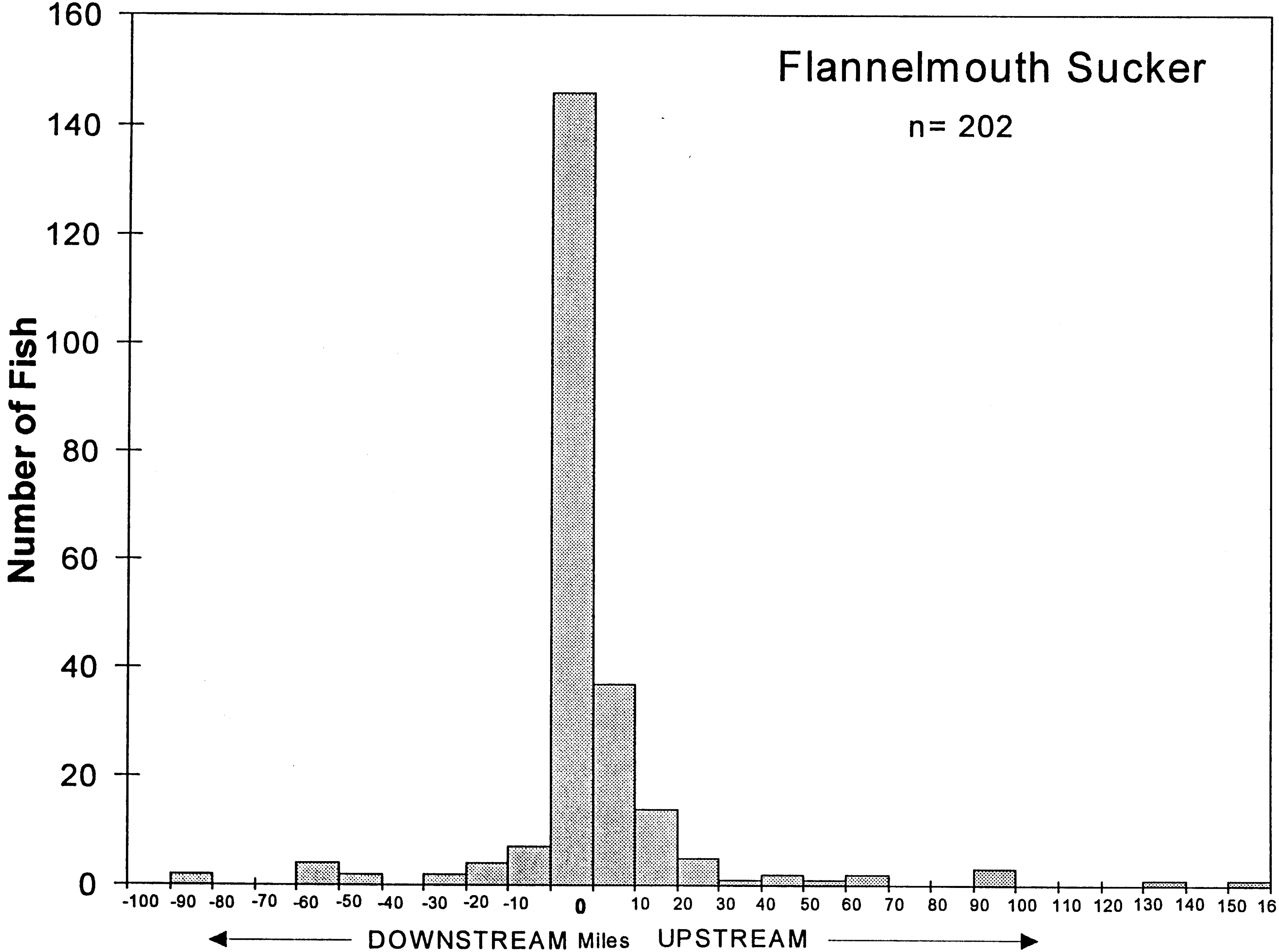
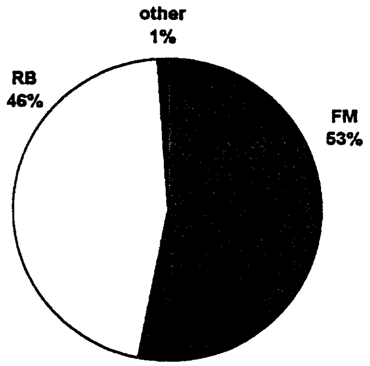
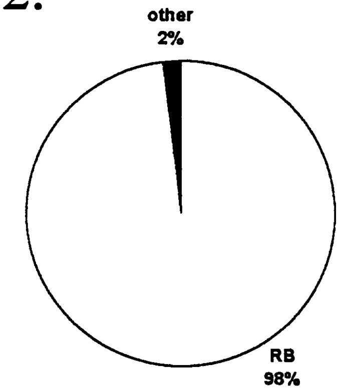

Flannelmouth Sucker
n= 202
160
140
120
100
80
60
40
20
0
Number of Fish
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 16
DOWNSTREAM Miles UPSTREAM

FIG. 5-12

1.



2.



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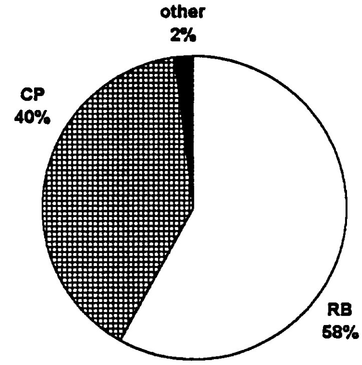

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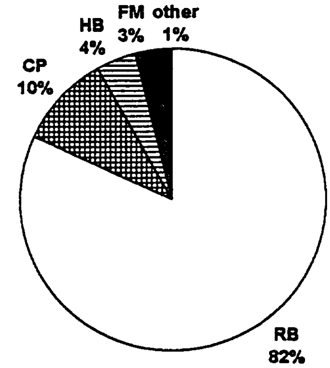

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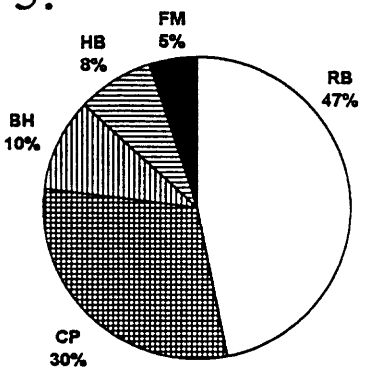

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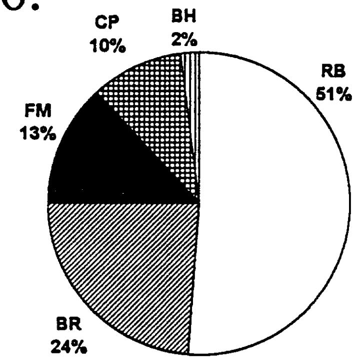

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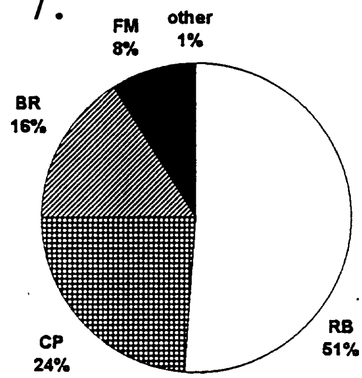

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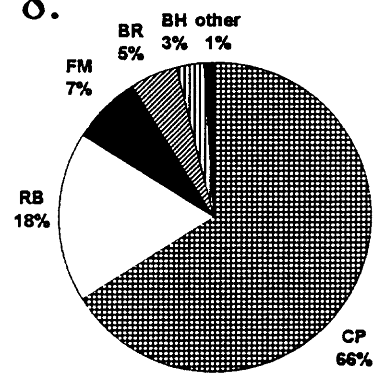

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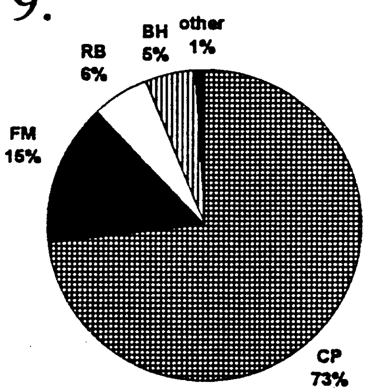

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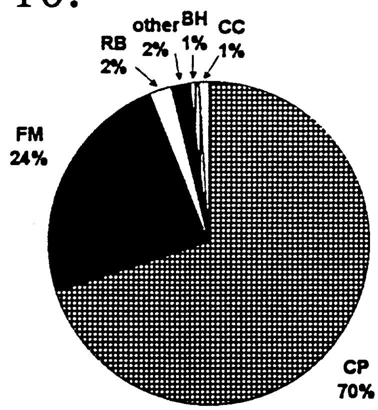

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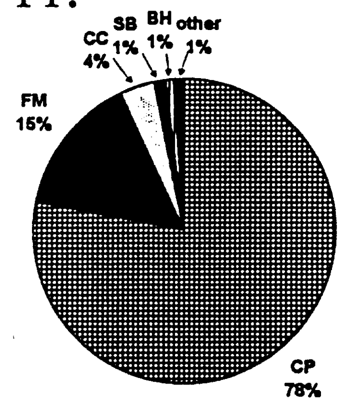

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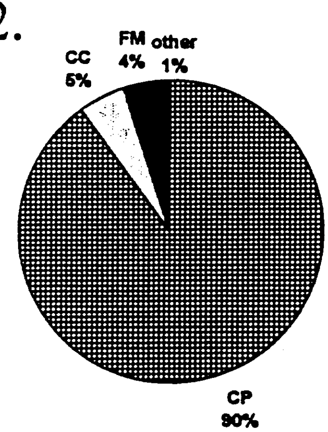
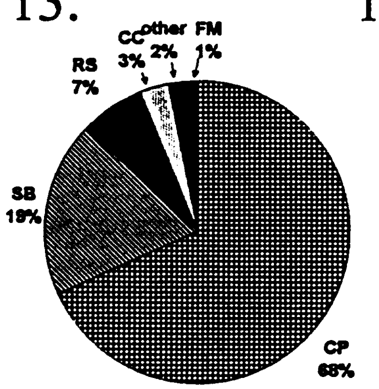


13.



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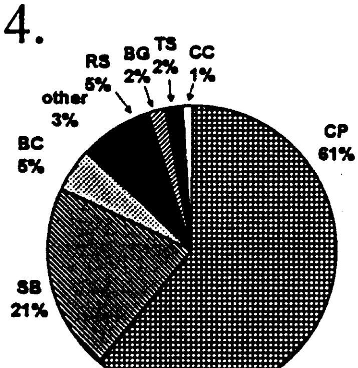


CHAPTER 6 - DEMOGRAPHICS OF HUMPBACK CHUB

INTRODUCTION

Demographics provide information on population attributes important in understanding the life history, ecology, and requirements of a species. Population size, length-weight and age growth relationships, condition factor, sex ratios, predation, parasites and diseases, survival rates, and reproductive potential and success are described in this chapter for humpback chub from the Colorado River in Grand Canyon. These attributes are basic to understanding the effects of Glen Canyon Dam operations and to recommending management practices to minimize detrimental affects. This chapter provides a basic understanding of population characteristics for humpback chub, and identifies and describes factors that limit the population in Grand Canyon, particularly as affected by Glen Canyon Dam operations. This chapter also evaluates population attributes of other native and sympatric non-native species, in order to compare biological responses by different species to similar and simultaneous environmental factors.

Surveys and various investigations have been conducted on the six known populations of humpback chub, including Black Rocks (Valdez et al. 1982, Valdez and Clemmer 1982, Kaeding et al. 1990), Westwater Canyon (Valdez et al. 1982, UDWR 1992, 1993, 1994), Cataract Canyon (Valdez et al. 1982, Valdez 1990, Valdez and Williams 1994), Desolation Canyon (Tyus et al. 1982, Moretti et al. 1989, UDWR 1992, 1993, 1994), Yampa Canyon (Tyus et al. 1982, Karp and Tyus 1990), and Grand Canyon (Kaeding and Zimmerman 1983, Miller and Smith 1972, Suttkus et al. 1976, Carothers and Minckley 1978, Maddux et al. 1987, Kubley 1994). These investigations have reported distribution, relative abundance (i.e., catch rates), habitat use, and sympatric species, but relatively little is known of population demographics. Many attributes reported in this chapter have not been previously reported for the species. Understanding the characteristics of one population will help scientists understand other populations, and the requirements of this endangered species throughout the Colorado River Basin.

METHODS

Population Estimates

Numbers of adult humpback chub (TL$\geq$200 mm) in nine distinct aggregations in the mainstem Colorado River were estimated using Schnabel's maximum likelihood (ML) estimator (Schnabel 1938, Seber 1973, White et al. 1982) from multiple censuses, as modified by Chapman (Ricker 1975), and presented in Equation 6-1:

(Equation 6-1)

$$N=\frac{\sum(C_t M_t)}{\sum R_t+1}=\frac{\sum(C_t M_t)}{R+1}$$

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

The distribution of this estimator is Poisson, and limits of confidence were computed using Equation 6-2 for large numbers of recaptures (i.e., ≥50). For sample events with fewer than 50 recaptures, a range of R was obtained from Poisson variable tables.

(Equation 6-2)

$$V\left(\frac{1}{N}\right)=\frac{R}{\left(\sum C_t M_t\right)^2}$$

The following assumptions were inherent to the Schnabel estimator, relative to dynamics and catchability of the population:

1. no recruitment occurred to the sample population,
2. mortality of marked and unmarked fish was equal,
3. marked fish became randomly distributed throughout the population, or sampling was conducted randomly so likelihood of capture was equal for marked and unmarked fish, and
4. migration to and from the population was minimal or equal (Ricker 1958).

Fish were first marked (PIT-tagged) and released in October 1990, and sampled monthly for recaptures, and to add additional marks to the population. Sampling was conducted for 32 months through November 1993, and was not conducted in December 1990; August, October, and December 1991; and October and December 1992. Individuals that were known to have died were removed from consideration for the estimator. Fish tagged by other researchers were not used in the estimator, except when these fish were captured, released, and recaptured by B/W.

Length-Frequency

Length-frequency analysis was used to characterize length composition of aggregations, help discern cohorts, and evaluate growth of humpback chub. Frequency of lengths of fish from common cohorts typically form a normal distribution from which age can be determined by comparing consecutive modes, and growth estimated from average length or weight of individuals within the normal distribution over time (Pauly 1984).

Length-frequency analyses were performed separately for recognized mainstem aggregations (See Chapter 5 - DISTRIBUTION AND ABUNDANCE) to avoid mixing groups of fish with possibly different spawning times, growth characteristics, and age compositions. Pooled length-frequency histograms were developed for each of three major aggregations to characterize size and possibly age composition of each, including the 30-Mile aggregation (RM 29.8-30.9), LCR aggregation (RM 52.85-60.85), and Middle Granite Gorge aggregation (RM 126.1-129.0). Monthly length-frequency histograms were developed for the LCR aggregation for each year sampled, from October 1990 through November 1993.

Numbers and sizes of fish captured were influenced by season and sampling methods that possibly biased length-frequency analyses. Samples in the LCR inflow from February through May, and intensive efforts to capture large adults, produced disproportionate numbers of large fish, while shoreline samples from August through October usually included large numbers of small juveniles.

Length-Weight Relationship and Condition Factor

Length-weight relationships were determined for humpback chub captured in 1990-91, 1992, and 1993, using the power function presented in Equation 6-3 (Anderson and Gutreuter 1983):

$$W = aTL^b \qquad \text{(Equation 6-3)}$$

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

The coefficients 'a' and 'b' were estimated by taking the logarithms of both sides of the equation such that:

$$\log_{10}W = \log_{10} a + b \log_{10}TL \qquad \text{(Equation 6-4)}$$

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

Generally, slope 'b' of less than 3.0 describes fish that become less rotund as length increases, and 'b' greater than 3.0 describes fish that become more rotund as length increases. A slope 'b' of 3.0 describes fish that do not change shape as length increases (isometric growth), such that the weight of the fish is the cube (10^3) of the length (Lagler 1959).

An index of well-being, or condition factor, was used to evaluate the relationship of length to weight by fish aggregation, gender, and season, and to help identify environmental factors (e.g., flow, food supplies, etc.) affecting condition and therefore, health of fish (Murphy and Willis 1992). Relative condition factor (Kn) was used to compensate for allometric growth (LeCren 1951), since humpback chub change shape appreciably with maturity (i.e., development and enlargement of a nuchal hump). Relative condition was calculated according to

Equation 6-5:

$$Kn = \frac{W}{(aL^{b})} \qquad \text{(Equation 6-5)}$$

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

Relative condition factor was used to evaluate the relationship between length and weight of individual fish or groups of fish, based on a determination of average condition for a sample of fish. Fish with Kn greater than 1.0 are more robust than average condition for fish of the same length, while fish with Kn less than 1.0 are less robust.

Relative condition factors were computed for humpback chub equal to or greater than 150 mm TL, using a constant 'a' and exponent 'b' derived from a least squares regression from the pool of humpback chub handled in 1990-1991 equal to or greater than 150 mm TL (n=550). Recaptured fish bearing Carlin fingerling tags or Floy tags, previously tagged by other investigators, were not included in the analysis because of possible effects of these tags on growth and condition (Scheirer and Coble 1991).

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

Age and Growth

Three methods were used to estimate growth of humpback chub: back-calculation of fish lengths from annular rings on scales, length-frequency analysis through time, and recapture of marked individuals of known size at previous capture (Busacker et al. 1990).

Scales were collected from subadult humpback chub (TL<200 mm) in 1992-1993 to assess age and growth of young fish, and to determine size and age of descent from the LCR to the mainstem. Scales of adults (TL≥200 mm) were not examined because of indistinct annular rings following maturation, and possible resorption of scales margins from energy demands during spawning (Lagler 1956). Kaeding and Zimmerman (1983) used scales of humpback chub from the LCR as indicators of age, and found that annuli correlated directly with modes of length-frequency distributions for fish up to about 3 years old and 250-300 mm TL. Otolith bones, the lapilli, have been used to age humpback chub from the LCR (Hendrickson 1993), but this technique has not been validated, and requires sacrificing the fish.

Scales were taken from 89 humpback chub captured in the mainstem by B/W, and from 44 captured in the upper LCR by AGF. These were examined to determine the presence of a "transition check", or a disruption in scale growth rings, or circuli, cause by a change in ambient temperature from the LCR (~22° C) to the mainstem (~10° C). We hypothesized that young fish captured in the upper LCR had probably not been in the mainstem, and lacked a disruption of early circular rings. Conversely, fish captured in the mainstem had presumably hatched and descended from the LCR, and should exhibit circuli disruption corresponding to the time of transition. This check should be present and distinct on most young fish, and can be used to backcalculate length at the time a fish descended from the LCR.

Scales were taken from an area above the lateral line, and below the insertion (posterior end) of the dorsal fin, approximately where scale development begins (Muth 1990). Scales from this region were less variable, reducing inclusion of false annuli or exclusion of true ones (Hirschhorn and Small 1987). A sample of 2-6 scales were plucked with forceps or scraped with a scalpel, placed on waxed paper, and stored in labeled envelopes. In the laboratory, scales of each sample were moistened and placed on a microscope slide beneath a coverslip, then dried into place with low heat. Each microscope slide was labeled with sample and fish number for future reference.

Scales were measured with an ocular micrometer on an Olympus microscope under 20X magnification. Two scales were selected from each fish and examined with reflected light. Scales were examined by first locating the focus, or growth center of the scale, and overlaying it with the micrometer origin, so the micrometer lines were 45 degrees from the median posterior margin of the scale. Scale radius and distance to each annulus were measured from the focus along either posterior-lateral margins (A-B or A-B' in Fig. 6-1) as described by Hawkins (1991) for Colorado squawfish. Only the lateral margin with greatest clarity and annulus definition was used.

Annular rings were identified by (1) crowding of circuli, indicating slowed winter growth, (2) discontinuous circuli, indicating disrupted growth, or (3) "cutting over" of circuli, indicating resumption of growth following a period of slowed growth (Jearld 1983). The distance from the focus of the scale to the outermost disrupted circulus of the annulus was measured for use in backcalculation of fish length as described by Hawkins (1991) for Colorado squawfish.

The Lee method was used to describe the relationship of fish length to scale radius described in Equation 6-6 (Lagler 1956, Chugunova 1963):

$$TL = a + b \times SR \qquad \text{(Equation 6-6)}$$

where:

TL = total length (mm)
SR = scale radius (micrometers)
a = y-intercept
b = slope

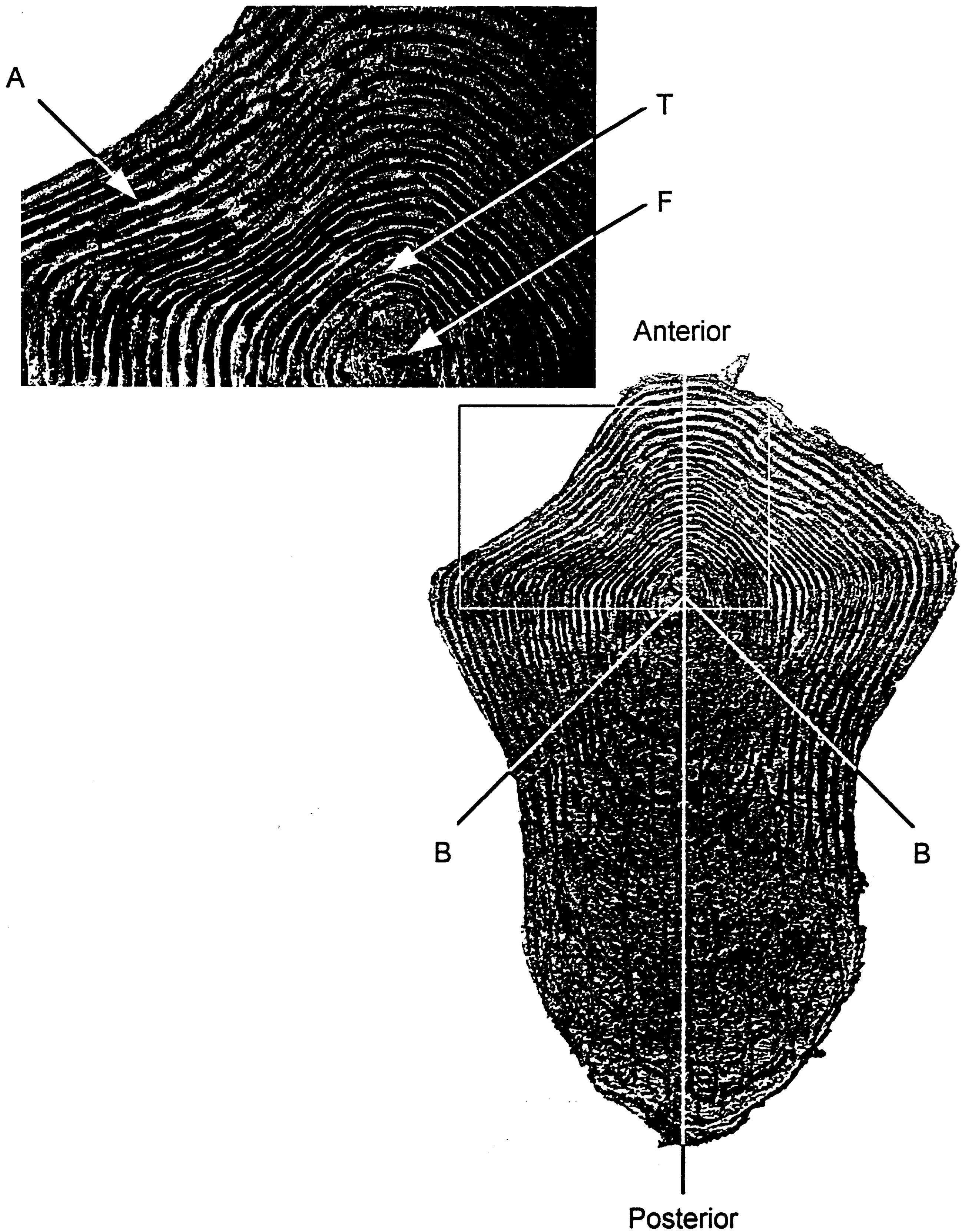


Fig. 6-1. Scale of age I+ humpback chub (TL=146 mm) from Grand Canyon, 1994. Measurements were made from the focus (F) along the posterio-lateral lines B or B'. Inset shows transition check (T) and first annulus (A).

This mathematical relationship assumes that the coefficient 'a', or y-intercept represents the size of fish at initial scale development. The relationship in Equation 6-6 yielded a coefficient of determination (r^2) of 0.77 for fish lengths of up to 200 mm TL and corresponding scale radius of up to 14 microns. This linear relationship was used to backcalculate lengths of fish at annulus formation, since attempts to fit the data to Carlander's third degree polynomial (Lagler 1956, Bagenal and Tesch 1978) yielded lower r^2 values. Although the relationship of fish length to scale radius for all sizes of humpback chub is probably a third degree polynomial, the relationship for fish less than 200 mm TL was best described by the linear model.

The above relationship was developed for two partitions of data, including the mainstem fish and fish from the upper LCR. Each relationship was used to develop a table of backcalculated lengths for the respective data set to determine age, size at annulus formation, growth, and length of fish at time of descent from the LCR to the mainstem. Backcalculated lengths at the time of transition were compared, using length-frequency analyses, with lengths of humpback chub captured in the mainstem.

Relationships were developed from all humpback chub captured by B/W to provide conversions of total length (TL) to standard length (SL)(Equation 6-7) or standard length to total length (Equation 6-8).

$$SL = 0.822 \times TL \qquad \text{(Equation 6-7)}$$

$$TL = 1.217 \times SL \qquad \text{(Equation 6-8)}$$

Sex Ratios

Humpback chub, flannelmouth sucker, and bluehead sucker over 175 mm TL were examined externally for determination of gender. Slight pressure was applied to the abdomen of each fish for expression of milt from males or eggs from females. Where sex products could not be expressed, humpback chub males were distinguished from females on the basis of size and shape of the urogenital papillae (Suttkus and Clemmer 1976). Males exhibited a more pronounced, erect, and anteriorly-oriented papillae, when palpated with slight pressure to the anterior region of the vent. Female papillae was less pronounced and broader than that of males. This technique of external examination is used by personnel at the Willow Beach National Fish Hatchery to sort males from females of Colorado squawfish, bonytail, and humpback chub, when eggs and milt are not being expressed by the fish (B. Jensen, USFWS, pers. comm.). Douglas (1993) failed to find reliable external morphological characters by which to distinguish male from female humpback chub, but did not consider the urogential papillae.

Gender of flannelmouth sucker and bluehead sucker was determined from expression of sex products or examination of the urogenital papillae, as described above for humpback chub, and from the size and shape of the anal fin. Male suckers had a narrower and longer anal fin than the shorter and broader fin of females.

Reproductive Potential and Success

Reproductive potential of humpback chub in the mainstem was determined from information found in literature, primarily from laboratory or hatchery studies. Fish were not sacrificed during this investigation to supplement these data, because of the endangered status of the species. A relationship between fish length and fecundity (number of eggs per female) was developed for the size range reported in literature.

Reproductive success of humpback chub in the mainstem was assessed from reproductive condition of adults (i.e., expression of milt or eggs, tuberculation, coloration), presence of larvae, and aggregations of adults that indicated possible spawning activity in the area. Widespread sampling and radiotelemetry were used to aid these searches for fish in reproductive condition.

Predation

Diet analyses were conducted for the four most common large predatory fish species in Grand Canyon, including brown trout, rainbow trout, channel catfish, and striped bass (See Chapter 9 - DRIFT AND DIET). Total numbers of humpback chub potentially consumed by these predators were estimated with the aid of predator to prey size relationships, and predation rates determined from these diet analyses.

Prey potential of humpback chub was evaluated by relating predator mouth gape (maximum diameter) to maximum body depth of humpback chub. The relationship of total length to maximum body depth was developed for humpback chub from morphometric measurements taken in the field during this investigation (See Chapter 2 - STUDY DESIGN). The relationship between predator length and maximum mouth gape was developed using measurements reported for brown trout (Bannon and Ringler 1986), channel catfish (Crowl ***), and striped bass (Chervinski et. al., 1989). The length to mouth gape relationship for rainbow trout was taken from a relationship developed for the closely related cutthroat trout ((Reimchen 1991).

These relationships were used to determine maximum size of humpback chub suseptible to predation by each predator species. It was assumed that mouth gape for each predator was equivalent to maximum body depth of humpback chub that could potentially be consumed. This relationship was confirmed by examining size of fish actually consumed by specific predators. It was also assumed, and confirmed from literature, that digestive rates of all four predators at 10-12°C were 24 hours, and potential numbers of humpback chub consumed daily were based on average numbers per stomach by predator species examined in the field.

Parasites and Diseases

Incidence of apparent diseases, and numbers and kinds of large parasites were recorded for each native fish captured, incidental to field measurements and observations. No attempt was made to conduct a complete or thorough survey of diseases and parasites during this investigation. Locations and effects (e.g., lesions, open sores, etc.) of external parasites were noted, and internal parasites were recorded, when possible. Internal parasites were revealed during handling, or with the aid of a pump used to evacuate stomach contents for diet analysis (See Chapter 9 - DRIFT AND DIET).

Survival

Indices to survival of subadult and adult humpback chub were derived by different methods. Densities of subadults (TL<200 mm), from the LCR inflow (RM 61.3) to Lava Canyon (RM 64.5), were determined monthly from catch rates of shoreline electrofishing, seining, and minnow traps. Decreased densities in this area were attributed to mortality (i.e., predation, starvation, thermal shock, parasites and diseases) and emigration, and offset by immigration from the LCR. These decreases in catch rates were used as indices of survival for periods of time when emigration and immigration were low, based on presence or absence of high LCR flows. Peak mainstem densities in September 1991, May 1992, and September 1993 reflected downstream dispersal of subadults from the LCR, concurrent with high LCR flows. Decreases in monthly densities were evaluated for 6-month periods starting with peak mainstem densities. These decreases were best described by a negative exponential (Equation 6-9), with a slope that served as an index to monthly decline of subadults during that sample period (Ricker 1975, Everhart and Young 1981).

$$N_{(t)}=N_{(o)}e^{-zt} \quad \text{(Equation 6-9)}$$

where: $N_{(t)}$=number of fish at time, t
$N_{(o)}$=number of fish at start of sample period
-z=instantaneous mortality rate

Survival of adults (TL≥200 mm) was estimated from recaptures of PIT-tagged humpback chub, using estimators developed for band-recovery data (Brownie et al. 1985). This class of estimators uses numbers of individuals marked and recovered at regular intervals, with survival and recovery rates estimated. In this study, each sampling trip represented a mark recovery period. However, because of insufficient numbers captured during each sampling trip, captures were combined into seasonal periods, and survival was calculated between seasons.

Three models were used to estimate survival rates for adult humpback chubs: 1) time-specific survival and recovery rates, 2) constant survival rate and time-specific recovery rates, and 3) constant survival and recovery rates. Goodness of fitness tests, and tests between models, were made to determine which models and assumptions fit the data. The simplest model which fit the data was used for estimating survival.

RESULTS AND DISCUSSION

Population Estimates

The estimated number of adult humpback chub (TL≥200 mm) in the mainstem LCR inflow aggregation was 3447 (95% C.I. = 3072-3926) (Table 6-1, Table 6-2, Fig. 6-2, Appendix F-5a - F-5i), based on Schnabel's ML estimator. Confidence intervals (C.I.) around the estimate (N) assumed a Poisson distribution, with greater

Table 6-1. Estimated numbers (N) and 95% confidence limits (Low, High) of adult humpback chub (TL≥200 mm) by mainstem aggregation based on Schnabel's maximum likelihood estimator.

Aggregation	No. Adults Captured	No. Adults Recaptured	N	95% Confidence Intervals Low	High
A-1 (30 Mile)	26	6	40	20	106
A-2 (LCR Inflow)	1524	280	3447	3072	3926
A-3 (Lava to Hance)	15	3	23	12	110
A-4 (Bright Angel Inflow)	9	1	31	8	300
A-5 (Shinumo Inflow)	27	6	45	21	119
A-6 (Stephen Aisle)	17	2	36	15	355
A-7 (Middle Granite Gorge)	124	48	104	76	152
A-8 (Havasu Inflow)	7	1	17	6	160
A-9 (Pumpkin Spring)	6	2	5	4	40

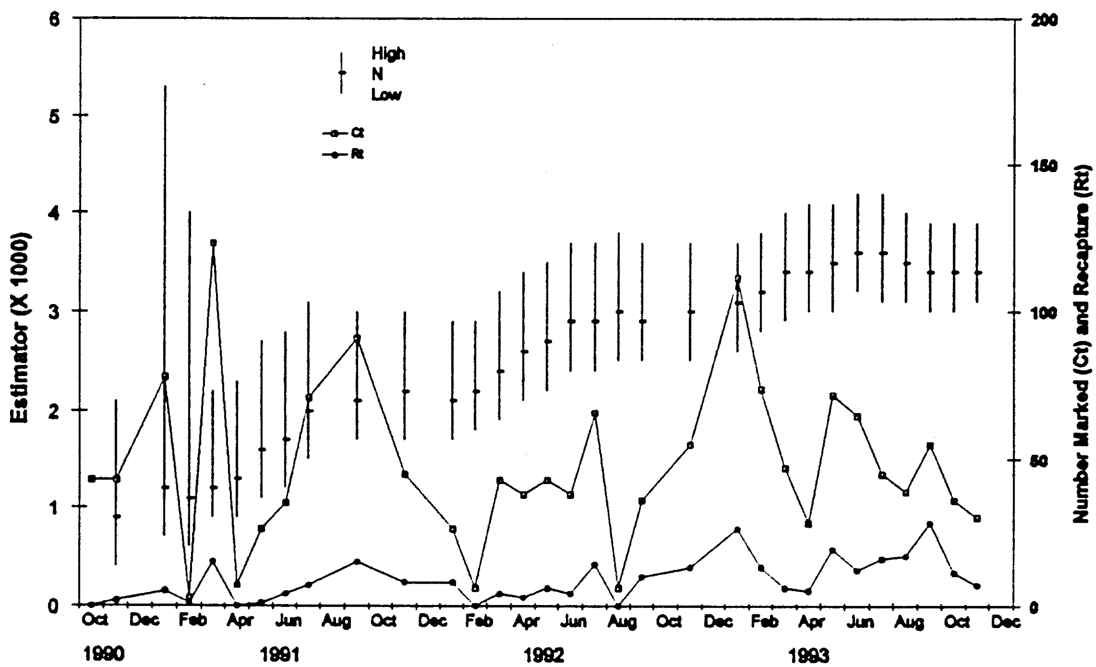


Fig. 6-2. Monthly estimates (N) and 95% confidence limits (Low, High) of adult humpback chub (TL≥200 mm) in the LCR inflow aggregation, based on Schnabel's maximum likelihood estimator. Ct = number of fish captured, Rt = number of fish recaptured.

upper than lower bounds. The next largest mainstem aggregation, located in Middle Granite Gorge, had an estimated 104 adults (95% C.I. = 76-152), followed by aggregations at the Shinumo inflow (N=45, 95% C.I. = 21-119), 30-Mile (N=40, 95% C.I. = 20-106), Stephen Aisle (N=36, 95% C.I. = 15-355), Bright Angel inflow (N=31, 95% C.I. = 8-300), Lava to Hance (N=23, 95% C.I. = 12-110), Havasu inflow (N=17, 95% C.I. = 6-160), and Pumpkin Spring (N=5, 95% C.I. = 4-40). The sum of these estimates (3748) indicates that about 3750 adult humpback chub were in the mainstem during this investigation. The sum of the estimates ranged from about 3230 to 5270 adults. These estimates were based on recapture rates within aggregations ranging from 11 to 39%, and an overall recapture rate of about 20%, i.e., 349 of 1755 adults were marked and recaptured by B/W. Fish tagged by other researchers were not considered recaptures except when fish were captured, released, and recaptured by B/W.

Although the estimated number of adults from the LCR inflow aggregation had a lower bound of only 11% and an upper bound of 14% of the point estimate, the accuracy of the estimate could not be evaluated. Comparable estimates of adults in the LCR by other investigators before, during, and after the spring spawning event, will help to confirm accuracy of this estimate.

The validity of these estimates is based on adherence to the four assumptions of Schnabel's ML estimator, i.e., (1) no recruitment, (2) equal mortality of marked and unmarked fish, (3) equal likelihood of capture for marked and unmarked fish, and (4) minimal migration. Although the Colorado River through Grand Canyon is a large open system the fidelity of adult humpback chub for specific areas (See Chapter 8 - MOVEMENT) minimized the likelihood that violations of these assumptions would result in significant errors in estimates. There was little evidence of mainstem reproduction, and no movement of adults between aggregations. Survival of adults marked with PIT tags was high, and similar to that of unmarked fish, and marked fish were released close to their capture location to minimize unnecessary movement and stress in relocating favorite areas (See Chapter 8 - MOVEMENT). Marked fish were assumed to redistributed randomly within groups of unmarked fish, although fidelity for specific areas increased the likelihood of recapturing the same groups of fish, leading to an underestimate in numbers.

Length-Frequency

Pooled length-frequency histograms (Fig. 6-3) were generated to characterize size distributions of humpback chub in four groups, including the 30-mile aggregation (RM 29.8-31.3), Middle Granite Gorge aggregation (RM 126.1-129.0), and LCR inflow aggregation subdivided into a group above the LCR (RM 56.0-61.3) and below the LCR (RM 61.3-65.4). Size range of fish in the 30-mile aggregation was 330-460 mm TL, and all fish were considered adults. Absence of fish smaller than 330 mm TL indicated little, if any successful reproduction and recruitment , and significantly larger adults (Fisher's LSD;T<= 0.05) (Fig. 6-4) indicated old

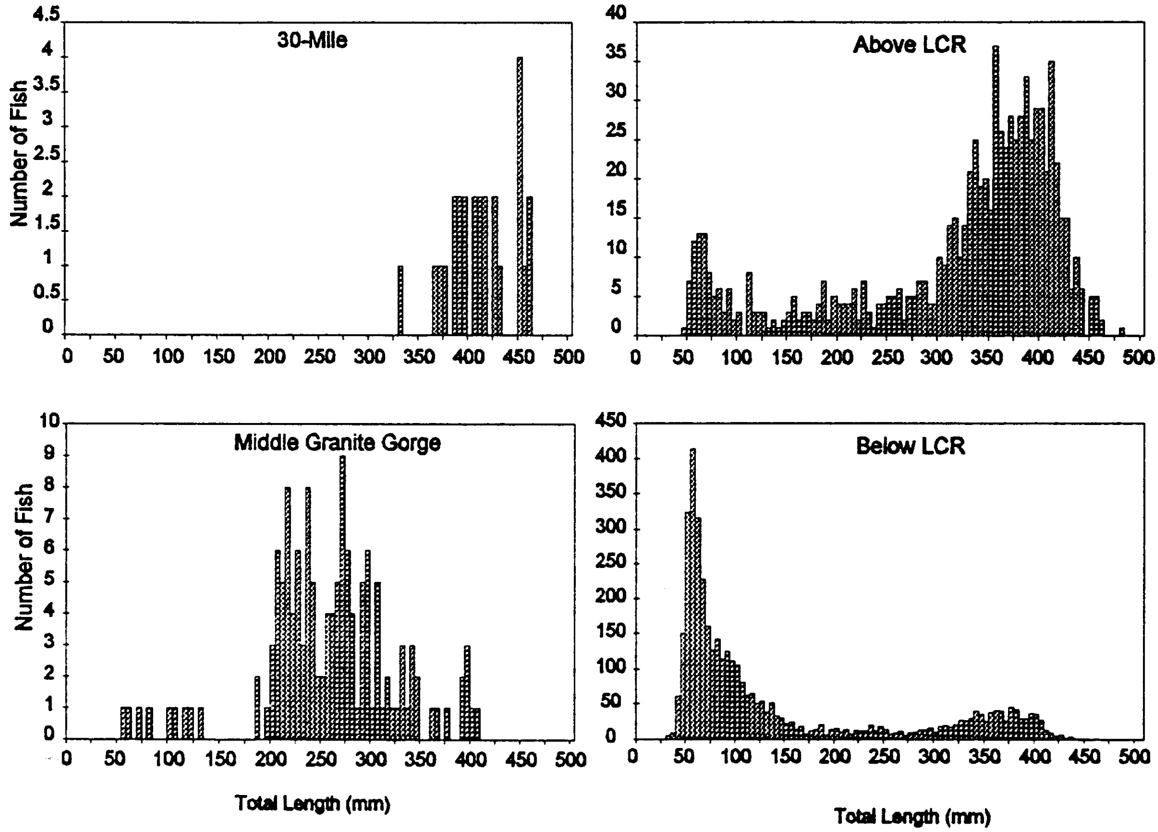


Fig. 6-3. Length-frequency histograms for four major aggregations of humpback chub in the Colorado River, October 1990-November 1993. Note scale change.

and senescent individuals.

Length-frequency histograms for humpback chub near the LCR revealed a greater proportion of small fish downstream of the LCR inflow than below. Most individuals <150 mm TL above the inflow were within 0.5 mi upstream, indicating these fish originated in the LCR and swam short distances upstream. Four fish (TL=74-88 mm) captured in January through November 1992, were within 0.25 mi upstream of the LCR inflow. Kaeding and Zimmerman (1983) failed to collect humpback chub smaller than 145 mm TL in the mainstem upstream of the LCR in October and November 1980-81, and April and May 1981. Significantly smaller adults (Fisher's LSD;T<= 0.05) downstream of the LCR inflow suggests a metapopulation phenomenon with dispersal from the LCR population to downstream areas.

Length distribution of humpback chub in Middle Granite Gorge was composed of few small fish, and numerous large subadults and adults, indicating little if any local reproduction, but substantial immigration of subadults. With a size range of 53-405 mm TL, this aggregation appeared to be maintained by immigration of young fish and longevity of adults.

Monthly length-frequency histograms were generated for the LCR inflow aggregation for 1991 (Fig. 6-5), 1992 (Fig. 6-6), and 1993 (Fig. 6-7). Slow growth in the mainstem, and differential dispersal of young from the LCR (i.e., faster growing young moved from the LCR to the mainstem at different ages) precluded definitive segregation of age 0, I, and II cohorts (TL<200 mm). Adults (TL≥200 mm) were impossible to segregate to cohort by length-frequency analysis, because of disrupted growth from spawning, slowed growth at maturity, and longevity of adults.

The appearance of large numbers of humpback chubs <75 mm TL at the LCR inflow in September 1991, May 1992, and September 1993, was the result of dispersal of young from the LCR, concurrent with summer, rain-induced floods. This mode persisted and was dominant for about 6 months, during which time either mortality or emigration dramatically reduced monthly mainstem densities (See Survival). Scale backcalculations indicate that the majority of these young fish were age 0, but also included age I fish. The age 0 fish were variable sizes because of prolonged spawning time (i.e., late March to early June), and variable time of transition from the warm faster-growing environment of the LCR to the cold slower-growing environment of the mainstem. Age 0 fish, remaining in the LCR most of the first summer of life, were hypothetically as long or longer than age I fish, hatched late in the previous spawning period and moving to the mainstem at a small size (Fig. 6-8).

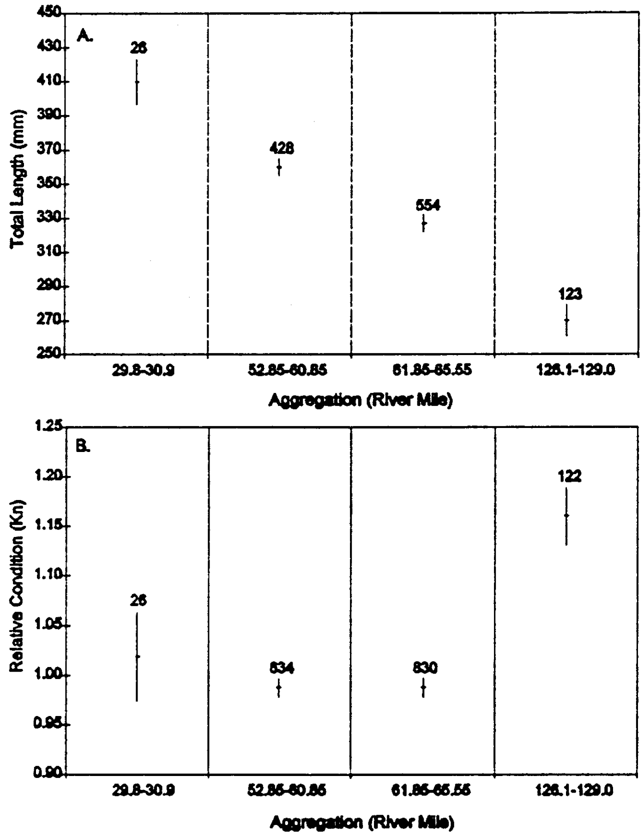


Fig. 6-4. Mean total length (A) and mean condition factor (Kn) (B) for adult humpback chub (TL≥200 mm) in four mainstem aggregations in Grand Canyon, 1990-93. Sample size is listed above each bar and error bars represent mean and 95% confidence intervals.

Length-Weight Relationship and Condition Factor

Humpback Chub. Length-weight relationships for humpback chub (Fig. 6-9) were described for 1990-91 (Equation 6-9), 1992 (Equation 6-10), and 1993 (Equation 6-11):

$$\log_{10}W = -5.324 + 3.117 \log_{10}TL \quad (r^2 = 0.99) \qquad \text{(Equation 6-9)}$$

$$\log_{10}W = -5.176 + 3.056 \log_{10}TL \quad (r^2 = 0.99) \qquad \text{(Equation 6-10)}$$

$$\log_{10}W = -5.034 + 2.986 \log_{10}TL \quad (r^2 = 0.98) \qquad \text{(Equation 6-11)}$$

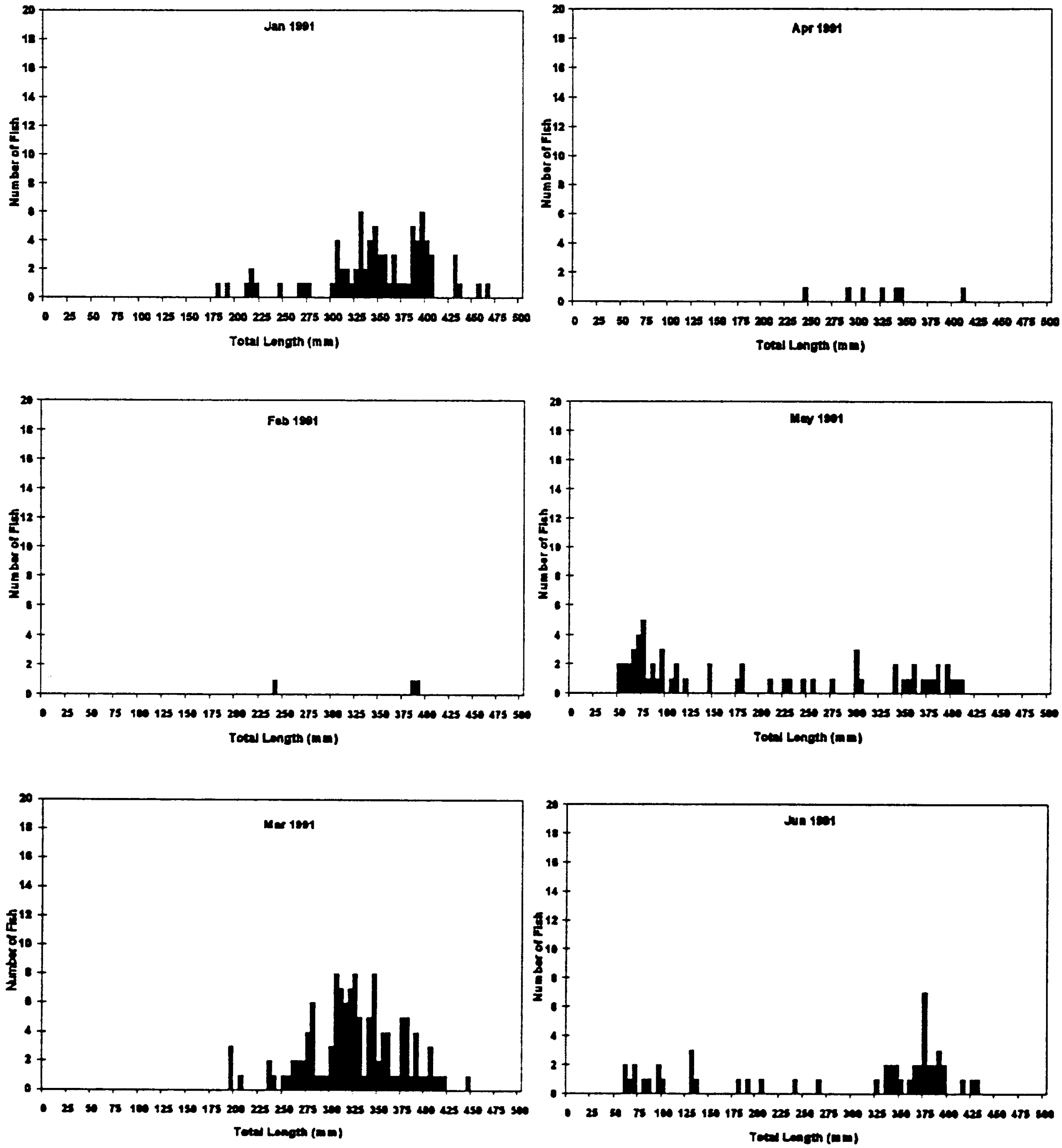


Fig. 6-5. Monthly length-frequency histograms for humpback chub from the LCR inflow aggregation for 1991.

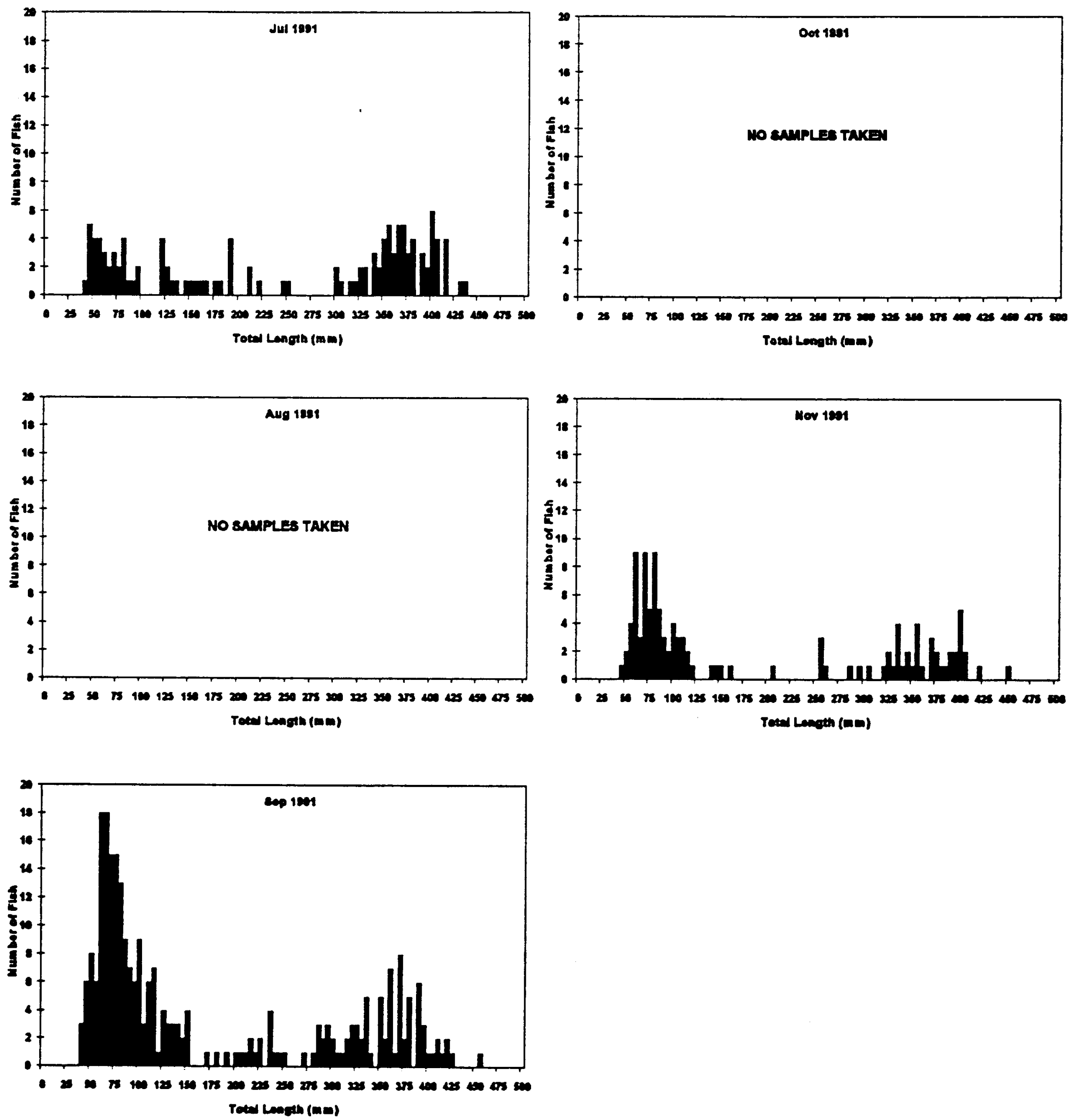

Jul 1991
Oct 1991
NO SAMPLES TAKEN
Aug 1991
NO SAMPLES TAKEN
Nov 1991
Sep 1991
Number of Fish
Total Length (mm)

Fig. 6-5 cont.

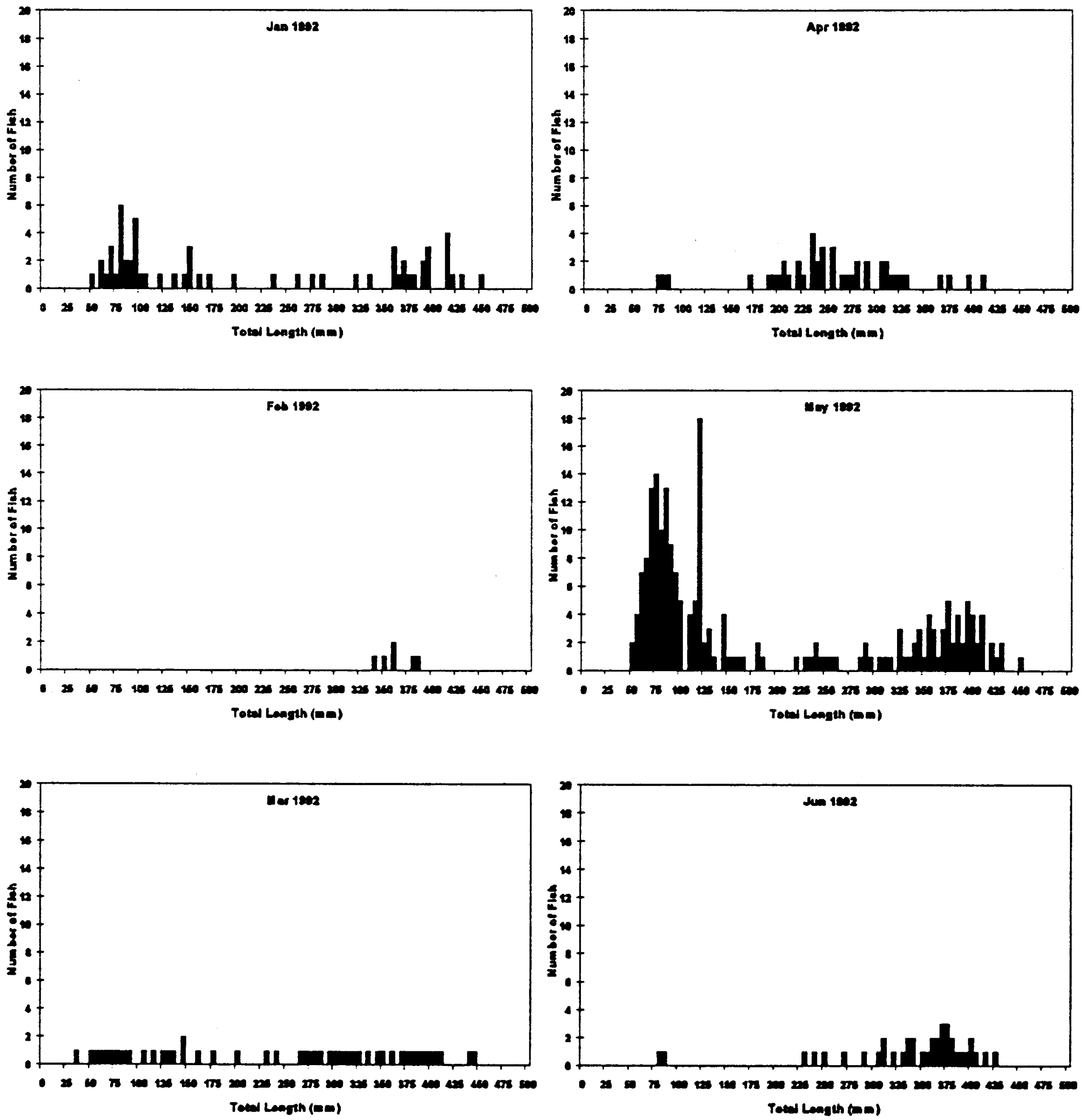


Fig. 6-6. Monthly length-frequency histograms for humpback chub from the LCR inflow aggregation for 1992.

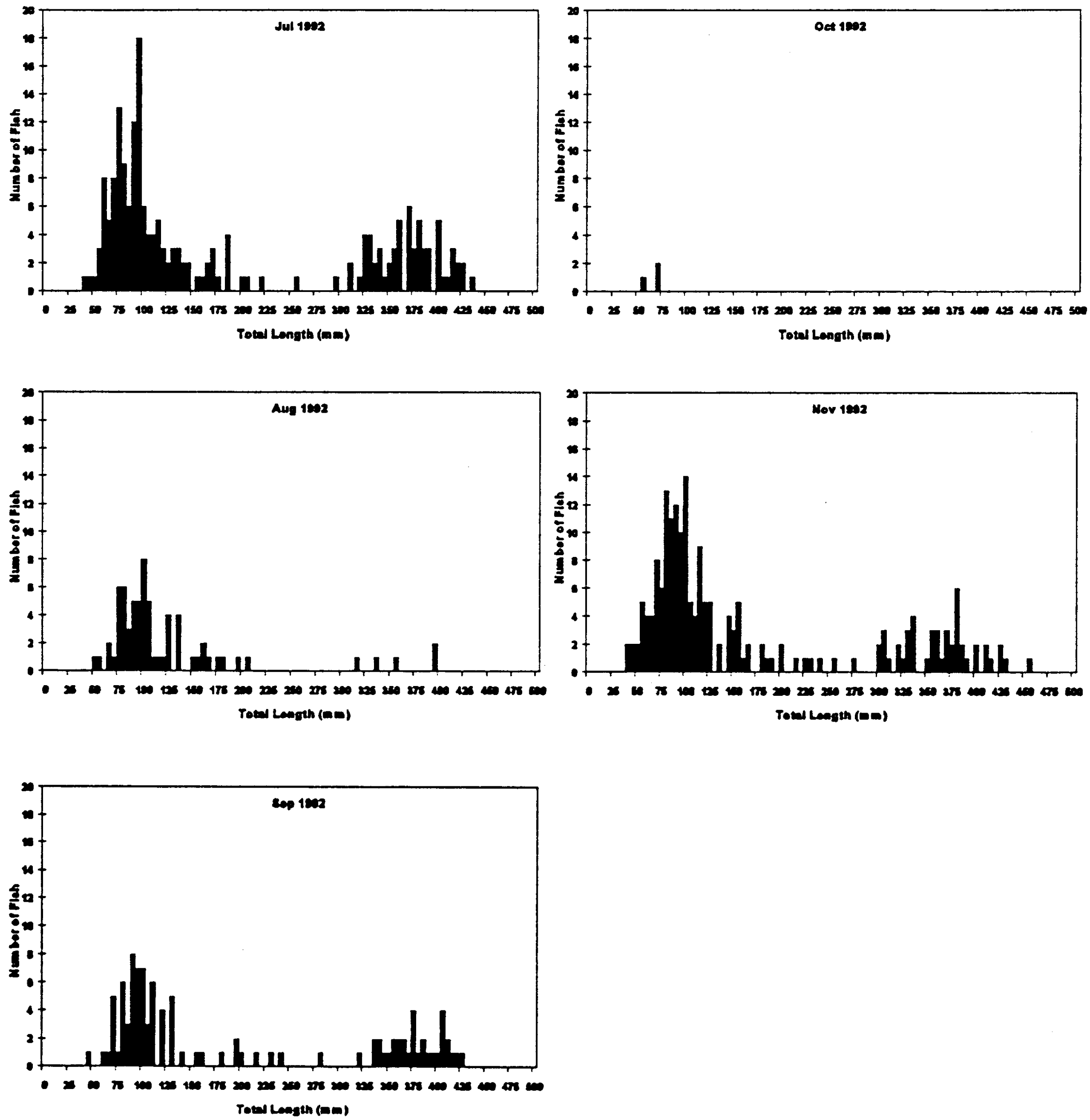

Jul 1992
Oct 1992
Aug 1992
Nov 1992
Sep 1992
Number of Fish
Total Length (mm)

Fig. 6-6 cont.

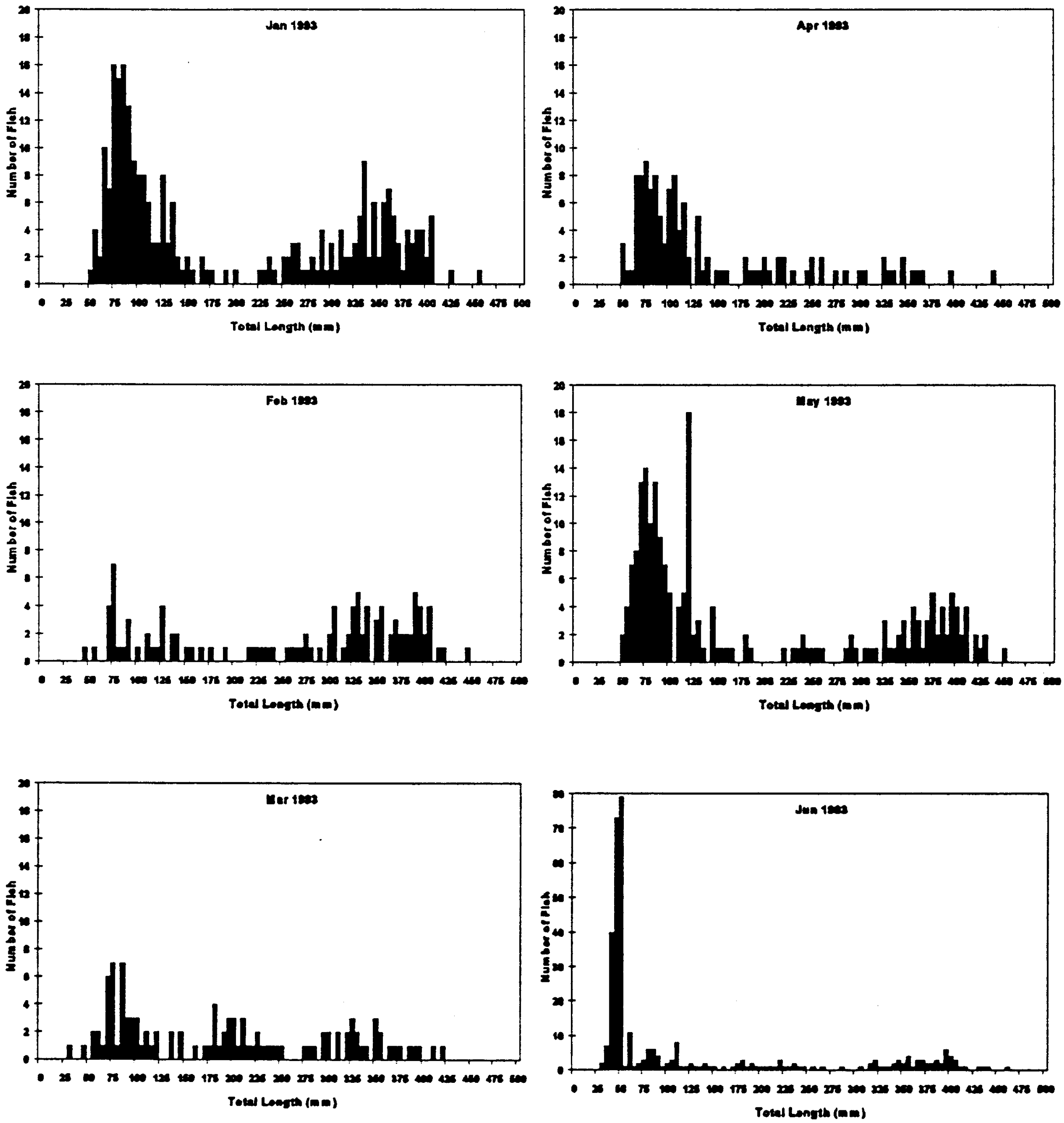
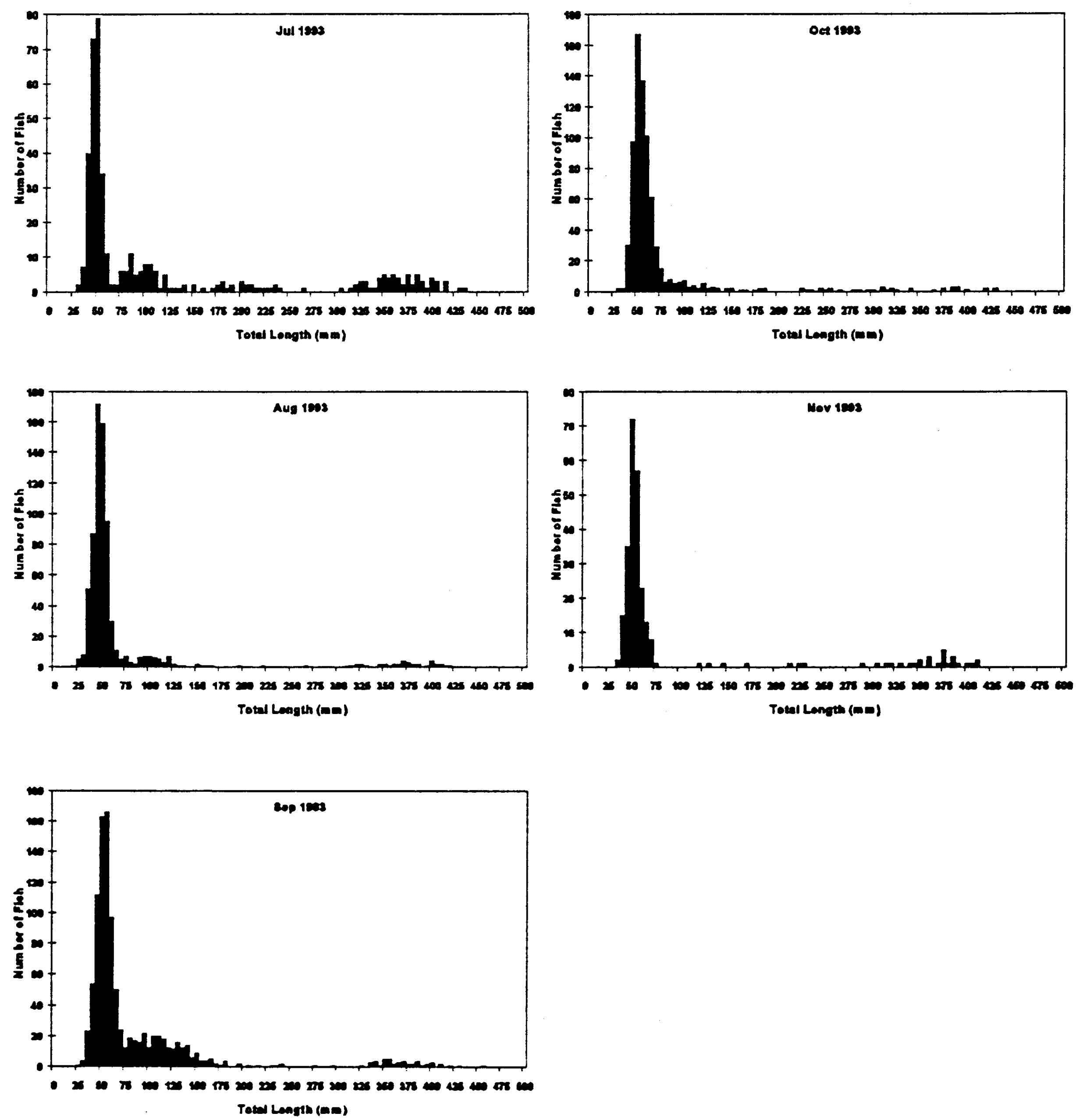


Fig. 6-7. Monthly length-frequency histograms for humpback chub from the LCR inflow aggregation for 1993.



Jul 1993
Oct 1993
Aug 1993
Nov 1993
Sep 1993
Number of Fish
Total Length (mm)

Fig. 6-7 cont.

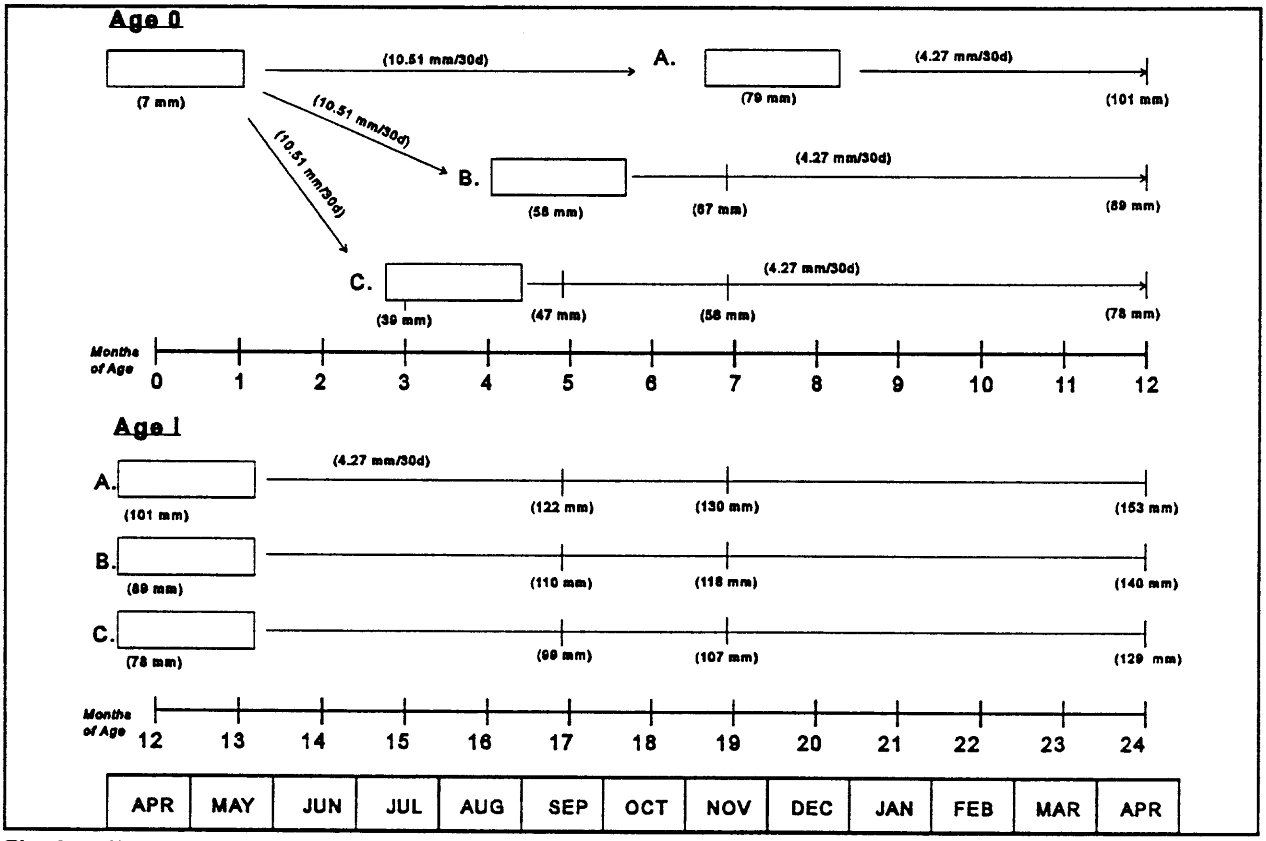


Fig. 6-8. Theoretical total length (range) of YOY humpback chub in the mainstem Colorado River following descent from the LCR at mean scale backcalculated length of 79 mm TL (A), at minimum scale backcalculated length of 58 mm TL (B), and at early July transition at 39 mm TL (C). Figures of 10.51 mm/30 d and 4.27 mm/30 d are used for LCR and mainstem growth rates, respectively.

Exponents of 3.117, 3.056, and 2.986 indicate that growth pattern approximated the cube law (LeCren 1951, Lagler 1956), and was approximately isometric, i.e., an exponent of 3.0 indicates a constant relationship between length and weight. Although humpback chub change shape dramatically with age (i.e., enlargement of a nuchal hump), the length to weight relationship was constant, as was reported in other species (Anderson and Gutreuter 1983). The small decrease in the exponent 'b' for the 3 years examined was attributed to increasingly greater numbers of young fish in 1992 and 1993 samples, that typically exhibit isometric growth.

Monthly trends in relative condition (Kn) of adult humpback chub (TL≥200 mm) from October 1990 through November 1993 (Table 6-3, Fig. 6-10) reflected robustness prior to spawning, by the LCR aggregation, loss of weight during spawning, and regained weight following spawning. Except for October 1990, monthly mean Kn was highest in January, February, March or April of 1991, 1992, and 1993, just prior to spawning by the LCR inflow aggregation. Kn was lowest in June of 1991 and 1992, and August 1993, , during descent of adults from the LCR following spawning. Relative condition increased most drastically from June to September, when fish were recovering from spawning, and from November to March, in advance of spawning. Increased Kn from June to September may also be associated with increased robustness by adults in other mainstem aggregations involved in later spawning (See Reproductive Potential and Success).

Kn for October and November were higher in 1990 than in 1991, 1992, and 1993, although significantly different only between October 1990 and 1993 (p=0.041). Higher Kn for October 1990 was possibly related to greater availability of food under research flows, which were replaced by interim flows on August 1, 1991 (See Chapter 3 - HYDROLOGY). Lower Kn in October 1991, 1992, and 1993 suggest reduced availability of food from lower fluctuations associated with interim flows (See Chapter 9 - DRIFT AND DIET).

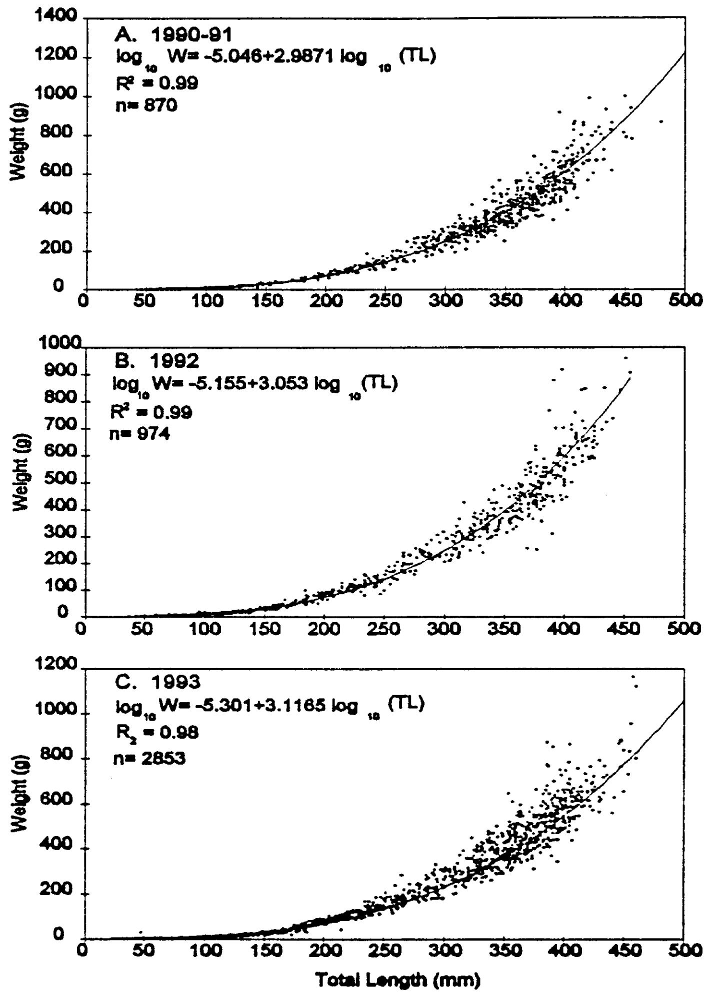


Fig. 6-9. Length-weight relationship for humpback chub from the Colorado River in Grand Canyon for 1990-91 (A), 1992 (B), and 1993 (C).

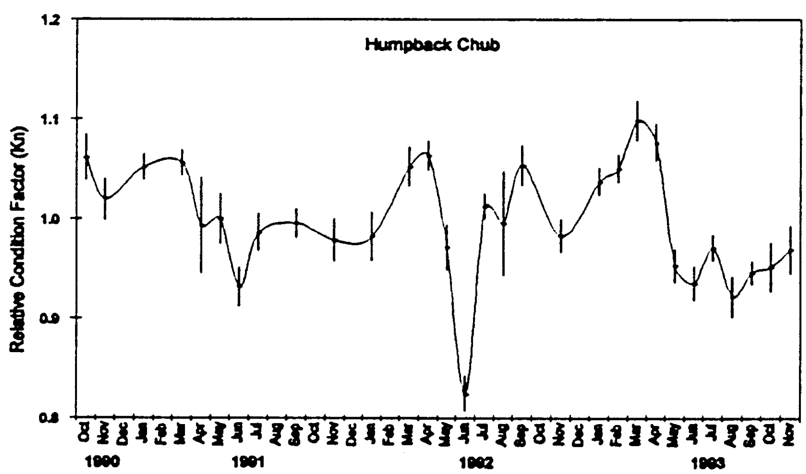


Fig. 6-10. Mean monthly relative condition (Kn) of adult humpback chub (TL≥200mm) from the Colorado River in Grand Canyon, October 1990 - November 1993. Values represent means ± one standard error. Means are connected with a smooth line to enhance visual r epresentation of trends.

Table 6-3. Mean monthly relative condition (Kn) for 1693 humpback chub (TL ≥200 mm) from the Colorado River in Grand Canyon, October 1990 - November 1993.

Month	No. Fish	Mean Relative Condition	Standard Error
		1990	
October	38	1.061	0.023
November	43	1.020	0.022
		1991	
January	76	1.052	0.013
March	109	1.054	0.014
April	7	0.993	0.048
May	33	0.997	0.025
June	30	0.930	0.020
July	72	0.986	0.020
September	96	0.997	0.015
November	40	0.989	0.021
		1992	
January	25	1.020	0.024
March	42	1.057	0.021
April	37	1.058	0.016
May	52	0.949	0.022
June	34	0.824	0.018
July	98	1.009	0.014
August	6	1.047	0.039
September	46	1.047	0.022
November	56	0.997	0.018
		1993	
January	108	1.044	0.013
February	78	1.058	0.014
March	58	1.102	0.023
April	45	1.076	0.021
May	92	0.949	0.018
June	71	0.925	0.016
July	93	0.977	0.013
August	39	0.935	0.022
September	86	0.977	0.015
October	44	0.996	0.021
November	39	0.983	0.019

Pooled relative condition of adult female humpback chub (1.022) was significantly greater (p=0.009) than that of males (0.980), indicating gender differences in robustness, most likely from the weight of egg masses. Monthly Kn were significantly higher (p=0.008) for females in June, July, and November of 1992 (Table 6-4, Fig. 6-11).

Relative condition of adults above and below the LCR inflow was compared to assess the importance of the LCR inflow to fish condition. Fish caught in the LCR inflow staging area (RM 60.9-61.9) were excluded from the analysis to reduce bias from exceptionally robust fish during spawning. The analysis showed that fish caught below the confluence (RM>61.9) had significantly higher Kn (p=0.003) than those caught above (RM <60.9), indicating a greater availability of food downstream of the LCR confluence (See Chapter 9 - DRIFT AND DIET).

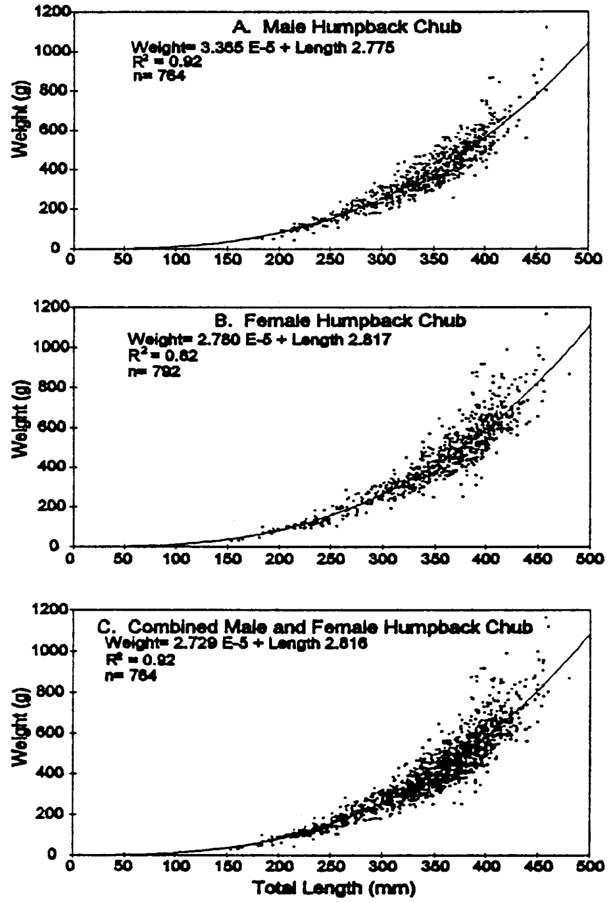


Fig. 6-11. Length-weight relationship for males (A), females (B), and combined (C) from the Colorado River in Grand Canyon, October 1990-November 1993.

Table 6-4. A comparison ('t' test) of mean monthly relative condition (Kn) for male and female humpback chub (TL ≥200 mm) from the Colorado River in Grand Canyon, 1992.

Month	Males		Females		P values
	No	Kn	No.	Kn	
January	9	0.996	14	1.050	0.280
March	17	1.080	19	1.069	0.813
April	17	1.070	14	1.063	0.853
May	14	1.023	32	0.939	0.108
June	18	0.783	15	0.883	0.003*
July	38	0.969	55	1.031	0.024*
September	22	1.017	22	1.092	0.096
November	25	0.960	25	1.050	0.014*

*significant at α = 0.05

Flannelmouth Sucker. A length-weight relationship was developed for 1903 flannelmouth sucker captured in the mainstem from October 1990 through November 1993 (Fig. 6-12), and described by Equation 6-12:

$\log_{10}W = -5.222 + 3.076 \log_{10}TL$ ($r^2 = 0.98$) (Equation 6-12)

The exponent of 3.076 indicates that growth of flannelmouth suckers was approximately isometric. Average monthly relative condition of adult flannelmouths suckers followed a seasonal pattern with highest values prior to spawning, in March-April, and lowest values after spawning, in June-September (Fig. 6-11).

Bluehead Sucker. A length-weight relationship (r^2=0.97) was also developed for 693 bluehead suckers captured in the mainstem from October 1990 through November 1993 (Fig. 10A), and represented by Equation 6-13:

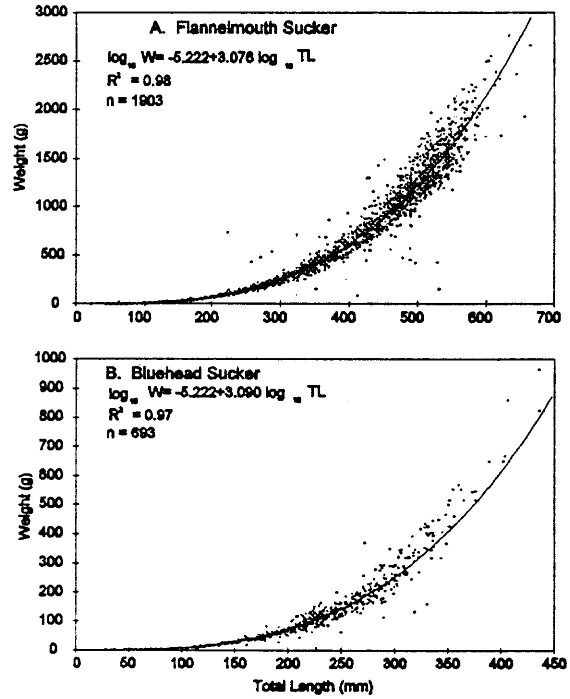


Fig. 6-12. Length-weight relationships for flannelmouth sucker (A) and bluehead sucker (B) from the Colorado River in Grand Canyon, October 1990 - November 1993.

$\log_{10}W = -5.222 + 3.090 \log_{10}TL$ ($r_2 = 0.97$) (Equation 6-13)

An exponent of 3.090 indicates that growth of bluehead suckers was approximately isometric. Annual patterns in average monthly relative condition were irregular, probably because of small sample size (Fig. 6-13).

Rainbow Trout. A length-weight relationship was developed for 3568 rainbow trout captured in the mainstem in 1990-91 (TL≥200 mm), and represented by Equation 6-14:

$\log_{10}W = -4.013 + 2.582 \log_{10}TL$ (r^2=0.99) (Equation 6-14)

An exponent of 2.582 indicates that rainbow trout did not exhibit isometric growth, but became less robust with length. Average monthly Kn of adult rainbow trout failed to follow the same pattern in the 3 years observed, 1991, 1992, and 1993 (Fig. 6-14, Table 6-5). Assuming that robustness is affected primarily by spawning activity and food availability (Anderson and Gutreuter 1983), rainbow trout in Grand Canyon were expected to exhibit high Kn in late fall and early winter in preparation for spawning in January through March

(Maddux et al. 1987), followed by low Kn through spring and early summer, and increasing in late summer and fall.

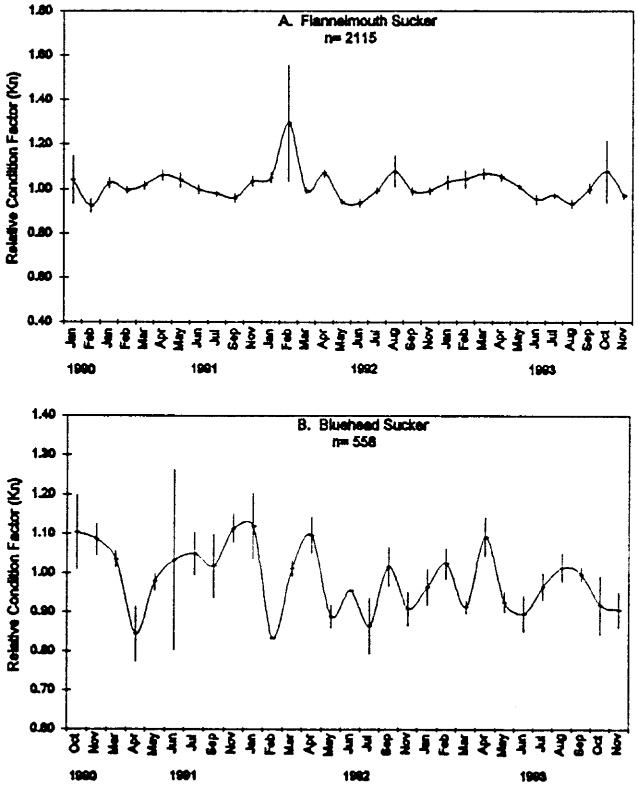


Fig. 6-13. Mean monthly relative condition (Kn) for flannelmouth sucker (A) and bluehead sucker (B) (TL≥150 mm) from the Colorado River in Grand Canyon, October 1990-November 1993. Values represent means ± one standard error. Means are connected with a smooth line to enhance visual representation of trends.

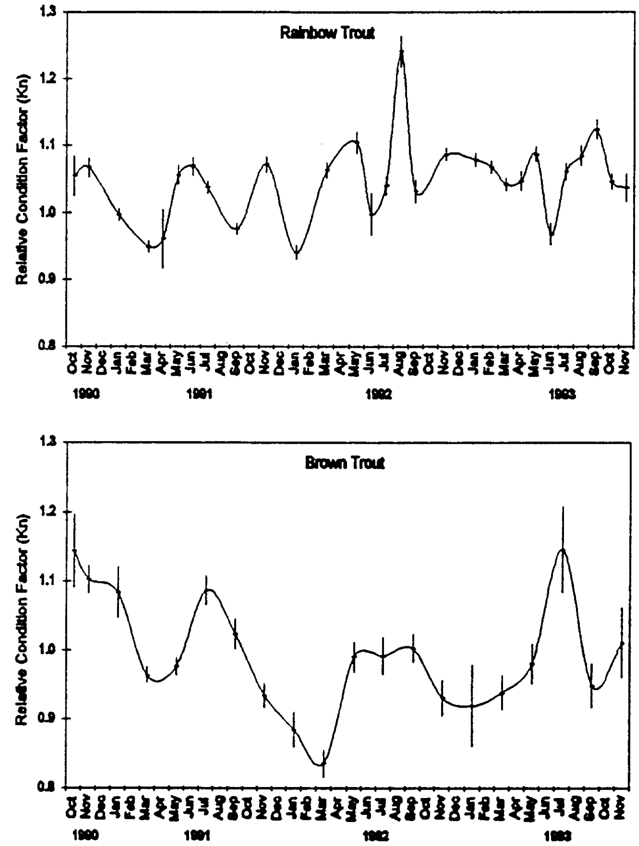


Fig. 6-14. Mean monthly relative condition (Kn) for rainbow trout (A) and brown trout (B) (TL≥200 mm) from the Colorado River in Grand Canyon, October 1990-November 1993. Values represent means ± one standard error. Means are connected with a smooth line to enhance visual representation of trends

The pattern in condition from fall to spring of each year was as expected with respect to spawning activity, but variable high and low Kn through 1991, 1992, and 1993 suggests that the fish were also responding to environmental variable, such as flow and turbidity. Relative condition of rainbow trout tended to be low in later winter (January-March) and in late summer (August-October), when tributaries flood most frequently with increased turbidity that is known to reduce feeding activity of this species (citation).

Table 6-5. Mean monthly relative condition (Kn) of 9126 rainbow trout (TL ≥200 mm) from the Colorado River in Grand Canyon, October 1990 - November 1993.

Month	No.	Kn	Standard Error
		1990	
October	84	1.054	0.028
November	336	1.067	0.014
		1991	
January	522	0.997	0.009
March	518	0.949	0.008
April	10	0.962	0.044
May	643	1.056	0.011
June	161	1.069	0.013
July	667	1.038	0.009
September	672	0.976	0.008
November	433	1.072	0.012
		1992	
January	478	0.941	0.011
March	406	1.066	0.011
May	256	1.104	0.016
June	14	0.998	0.031
July	280	1.044	0.015
August	120	1.241	0.023
September	190	1.032	0.017
November	401	1.091	0.010
		1993	
January	411	1.076	0.010
February	301	1.068	0.009
March	500	1.042	0.010
April	182	1.047	0.014
May	340	1.087	0.011
June	112	0.968	0.016
July	290	1.061	0.012
August	190	1.085	0.015
September	181	1.124	0.014
October	348	1.046	0.011
November	80	1.037	0.021

Brown Trout. A length-weight relationship was also developed for 603 brown trout captured in 1990-91, and described by Equation 6-15:

$$\log_{10}W = -4.967 + 2.958 \log_{10}TL \qquad \text{(Equation 6-15)}$$

An exponent of 2.958 indicates that the growth pattern for brown trout was approximately isometric. Annual patterns in average monthly Kn were irregular and variable, like those of rainbow trout (Fig. 6-13, Table 6-6). Average Kn for brown trout in Grand Canyon was expected to be high in late summer and early fall in preparation for spawning in October through November, followed by low Kn through winter and early spring, and increasing in summer and fall. The decrease in Kn from fall to winter occurred in all years sampled, but other seasonal patterns were irregular, and probably caused by environmental factors, such as flow patterns or food availability.

Age and Growth

Total length to scale radius relationships were developed for humpback chub less than 200 mm TL from the mainstem Colorado River and from the upper LCR (Fig. 6-15). The coefficient 'a' (y-intercept or fish length at scale formation) for the mainstem relationship was 42.6 mm TL, about 9 mm larger than known length at scale formation (TL<34 mm, SL<26 mm) for laboratory-reared humpback chub (Muth 1990). This descrepancy demonstrates Lee's phenomenon where, at a given annulus, backcalculated lengths are relatively larger in younger fish (Miranda, 1987). Relatively faster growth produced a steeper slope in the linear relationship for the LCR fish, and a smaller y-intercept (TL=8.42 mm). The typical body length to scale radius relationship is a third degree polynomial with a specified y-intercept, but his model was not used because the data for these subadult fish more closely fit a linear model.

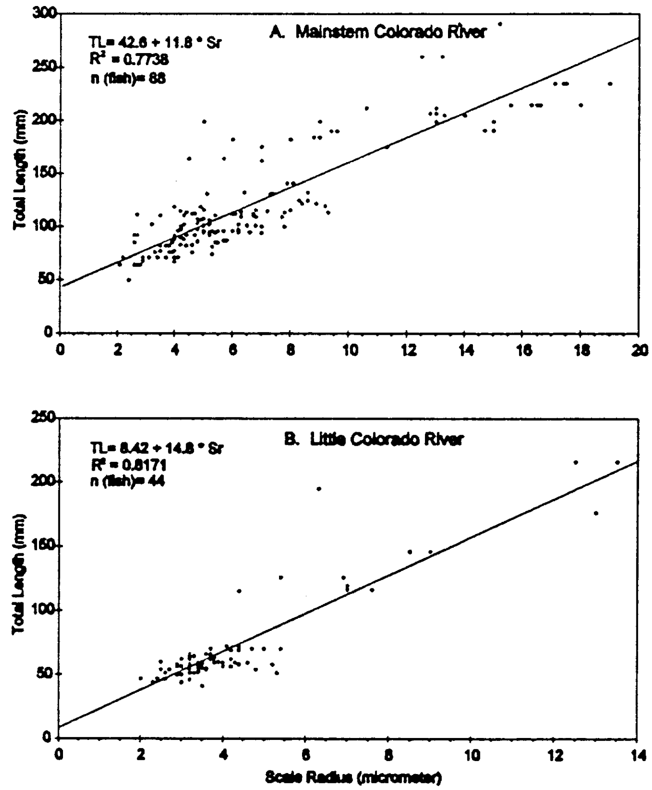


Fig. 6-15 Total length to scale radius relationship for humpback chub from the Colorado River (A) and Little Colorado River (B) in Grand Canyon.

Table 6-6. Mean monthly relative condition (Kn) of 1421 brown trout (TL ≥200 mm) from the Colorado River in Grand Canyon, October 1990 - November 1993.

Month	No.	Kn	Standard Error
		1990	
October	5	1.144	0.053
November	29	1.103	0.020
		1991	
January	24	1.084	0.037
March	131	0.963	0.013
May	137	0.977	0.013
July	66	1.087	0.021
September	114	1.024	0.022
November	109	0.935	0.018
		1992	
January	71	0.885	0.025
March	70	0.836	0.020
May	154	0.991	0.022
July	73	0.992	0.027
September	98	1.003	0.021
November	73	0.931	0.026
		1993	
January	24	0.920	0.059
March	61	0.939	0.025
May	84	0.981	0.029
July	31	1.146	0.062
September	48	0.949	0.032
November	19	1.011	0.051

Annular rings were distinguished by crowding, cross-over, and disruption of several adjacent circuli. The first annulus usually began to form with disruption of the 10th to 13th circulus from the focus. Scales of fish captured in November showed crowded or discontinuous circuli, indicating the start of the winter annular ring. Scales collected between January and March usually displayed crowding and discontinuity of several circuli at or near the outer margin of the scale. Those collected in April and May showed complete circuli at the margin, indicating that annulus formation occurred during the winter period of about November through March. Kaeding and Zimmerman (1983) observed crowded circuli at scale margins in October-November, few scales with new annuli (resumed growth) in February, and new annuli on many scales in April-May.

Average backcalculated lengths of mainstem subadults at 1, 2, and 3 annuli were 101, 153, and 193 mm TL, with 79 mm TL as average length at time of transition from the LCR to the mainstem (Table 6-7). The majority of the growth in the first year occurred in the LCR, since scale transition checks indicated that fish averaged 79 mm TL at the time of descent. Minimum size of fish at transition was 58 mm TL, indicating little or no surivival of smaller fish descending from the LCR; the most likely cause of mortality was thermal shock or predation illicited by abberant thermal-shock behavior, i.e., erratic swimming, flashing. With annulus formation complete by the end of March, and most spawning and hatching in April, scale interpretation for this population closely approximated calendar years of age, i.e., backcalculated length at 1st annulus formation approximated length at 1 calendar year of age.

Table 6-7. Summary of back calculated total length (mm) at each annulus (A_i) and transition check (T_x), based on the linear regression formula: TL = 42.6 + 11.8 (Sr), for 88 humpback chub collected by BIO/WEST from the mainstem Colorado River in Grand Canyon, 1992-93. N = number of scales.

Age	No. Fish		T_x	A_1	A_2	A_3	A_4
0	33	Mean	76				
		Range	58-102				
		N	33				
I	41	Mean	80	100			
		Range	63-134	64-129			
		N	40	41			
II	6	Mean	84	116	166		
		Range	64-106	80-146	90-229		
		N	6	6	6		
III	6	Mean	71	105	154	207	
		Range	63-76	80-124	128-184	149-249	
		N	2	6	6	6	
IV	2	Mean	-	77	111	153	174
		Range	-	65-87	90-142	130-168	151-203
		N	-	2	2	2	2
Summary	88	Mean	79	101	153	193	174
		Range	58-134	64-146	90-229	130-249	151-203
		N	81	55	14	8	2

Average backcalculated lengths of humpback chub from the LCR at 1st and 2nd annulus formations were 96 and 144 mm TL (Table 6-8). Kaeding and Zimmerman (1982) reported 1st annulus formation at 100 mm TL for LCR fish. They also reported that humpback chub 250 to 300 mm TL were approximately 3 years of age.

Table 6-8. Summary of back calculated total length (mm) at each annulus (A_i), based on the linear regression formula: TL = 8.42 + 14.8 (Sr), for 44 humpback chub collected from the Little Colorado River in Grand Canyon. Scales were provided by Arizona Game and Fish Department, 1992-93. N = number of scales.

Age	No. Fish		A_1	A_2
0	36	Mean	-	
		Range	-	
		N	-	
I	5	Mean	91	-
		Range	50-127	-
		N	5	-
II	3	Mean	105	144
		Range	41-179	72-193
		N	3	3
Summary	44	Mean	96	144
		Range	41-179	72-193
		N	8	3

Backcalculated lengths at annulus formation were used to estimate growth of humpback chub in the mainstem for the first 3 years of life (Fig. 6-16). Assuming a length of 7 mm at hatching (Muth 1990), annual growth increments were 94 (7 to 101 mm TL), 52, and 40 mm for years 1, 2, and 3, respectively. Respective average 30-day growth rates were 10.51 mm (for fish ≤79 mm TL), 4.27 mm (for fish ≤153 mm TL), and 3.29 mm (for fish ≤193 mm TL). Lupher and Clarkson (1994) reported growth of 39-41 day old humpback chub transferred from 20° C to 10° C of 6.9 mm (mean TL of 20.9 to 26.0) after 93 days. Average 30-day growth of these laboratory fish was about 2.30 mm at 10° C and about 10.63 mm at 20° C. The 30-day growth rate of 10.63 mm is comparable to 10.51 mm determined for the LCR fish from this study, but the higher rate of 4.27 mm for mainstem fish (compared to 2.30 mm) may be attributed to the fish spending time in warmer shallow shorelines or backwaters.

Average 30-day growth rates by 50-mm length increments, based on recaptured PIT-tagged fish from the mainstem (Table 6-9), were slightly lower at 2.25 mm for the 150-200 mm TL increment. Mean growth rate dropped dramatically from 2.50 mm to 1.16 mm/30 days for fish over 300 mm TL. Average 30-day growth rate ranged from 2.79 mm (33.95 mm/year) for fish 200-250 mm TL to 0.79 mm (9.61 mm/year) for fish 350-400 mm TL. A logarithmic relationship similar to that proposed by von Bertalanfly (1938, see also Ricker 1975, Everhart and Youngs 1981) is presented to approximate growth of humpback chub in the mainstem (Fig. 6-16) based on scale backcalculations for ages 0-3, and recaptured PIT-tagged fish for ages 4+.

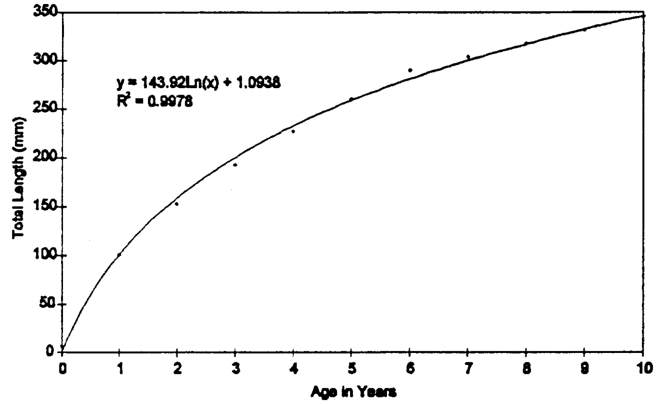


Fig. 6-16. Logarithmic growth curve for humpback chub in the mainstem Colorado River in Grand Canyon. Hatching length of 7 mm from Muth (1990); length at 1-3 years from scale back-calculations; lengths at 50 mm increments for 4+ years from PIT tag recaptures.

Table 6-9. Growth rates of humpback chub (TL ≥ 150 mm) by 50-mm length intervals, based on recapture of PIT tagged fish, October 1990 - November 1993.

TL Increment (mm)	No.	Mean Growth Rate (mm/30 days)	S.D.	Annual growth (mm/year)
150-200	19	2.25	2.05	27.38
200-250	106	2.79	2.44	33.95
250-300	157	2.50	2.62	30.42
300-350	324	1.16	1.17	14.11
350-400	383	0.79	1.17	9.61
400-450	131	0.91	1.47	11.07
450-500	5	0.96	1.03	11.68
Summary	1,125	1.36	1.80	16.55

As a comparison with mainstem growth rates, C.O. Minckley (1992) reported average annual growth rates of humpback chub from the LCR by size group, i.e., 17 mm (23 mm for 497 d) for fish less than 200 mm TL, 16 mm (22 mm for 497 d) for 200-250 mm TL, 13 mm (18 mm for 497 d) for 250-300 mm TL, 5 mm (7 mm for 497 d) for 300-350 mm, 6 mm (8 mm for 497 d) for 350-400 mm, and only 1 mm (2 mm for 497 d) for over 400 mm TL. Average growth for all sizes and ages of fish handled by Minckley was 0.037 mm per day, 1.1 mm per month, and 13.5 mm per year.

Scales of humpback chub from the two systems were examined to determine fish length at transition from the LCR into the Colorado River. Transition checks were usually identified as a cross-over or discontinuity in one to three circuli, starting with the fourth or fifth circulus from the scale focus. This disruption in growth was attributed to the transition from the LCR (~20° C) to the mainstem (~10° C). Transition checks usually preceded annular rings, indicating that most humpback chub descended from the LCR at less than 1 year of age. Backcalculated lengths of humpback chub at these transition checks averaged 79 mm TL (range, 58-134 mm) (Table 6-7), indicating that the majority of the fish sampled descended from the LCR before 1 year of age, and none descended or survived less than 58 mm TL.

Histograms of backcalculated lengths at transition checks, and actual captures of humpback chub less than 200 mm TL (Fig. 6-17), showed substantial numbers of fish sampled less than the minimum backcalculated size. The discrepancy is explained by errors in the backcalculation relationship, Lee's phenomenon, or lack of long-term survival by humpback chub descending from the LCR less than about 58 mm TL. Survival of juvenile humpback chub exposed to thermal gradients is not well known. Hamman (1982) reported only 15% survival for "swim-up fry" (6.9 mm long), and Bulkley et al. (1982) reported a temperature preference by juveniles of 24° C. Lupher and Clarkson (1994) reported "cold shock" in 5-7 d old (TL~9 mm) and 11-13 d old (TL~11 mm) humpback chub, transferred from 20° C to 10° C. These findings suggest low survival by humpback chub smaller than 58 mm TL following descent from the LCR to the mainstem.

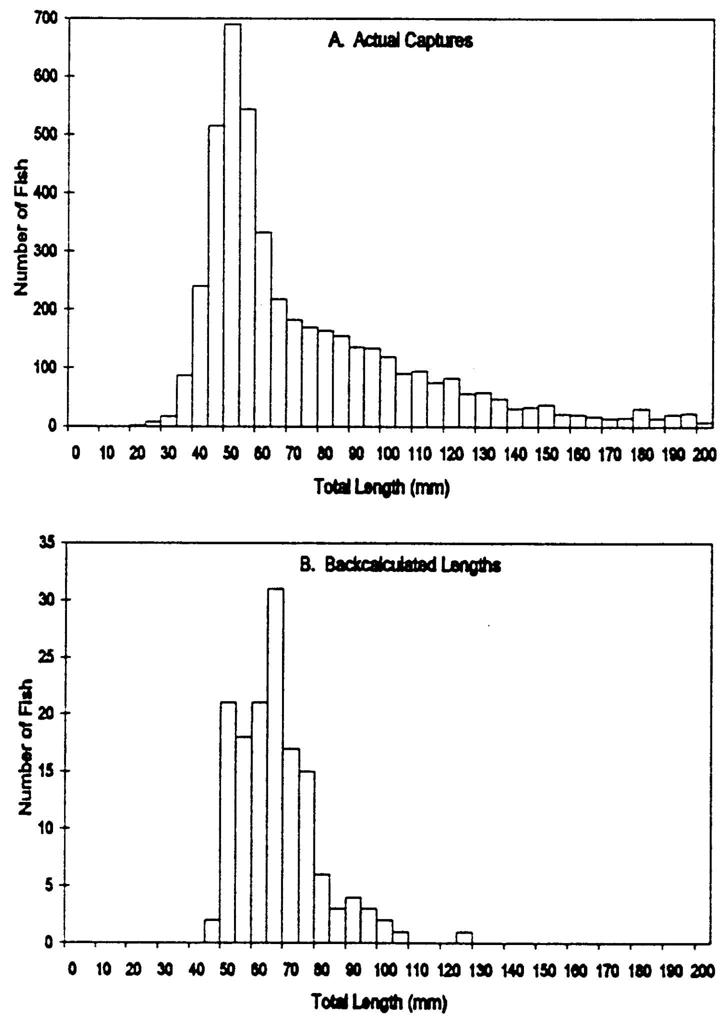


Fig. 6-17. Lenght-frequency histograms for humpback chub <200 mm TL captured in the Colorado River, 1990-93 (A), and for backcalculated lengths from scales of humpback chub taken in the Colorado River (B).

Subtle disruptions in scale growth patterns have been used to differentiate between hatchery stocked salmon and naturally-spawned fish (Schwartzberg and Fryer 1993). Circuler disruptions on scales of humpback chub have not been used to determine lengths of fish in transition between thermal regimes, although Hendrickson (1993) recognized the possible use of otolith daily growth increments as indices of warm backwater or cold mainstem occupation. Although Kaeding and Zimmerman (1983) failed to discern "false checks" in scales of LCR fish less than 3 years of age, Hendrickson (1993) observed abrupt transitions in early growth rates from otoliths (lapilli) of humpback chub from the LCR, similar to those seen in hatcheries following temperature manipulation.

Scales from 7 of 88 (8%) fish examined from the mainstem did not exhibit transition checks, indicating that either these fish failed to show scale disruption at transition, or they were spawned and hatched in the mainstem. Conversely, scales of 7 of 44 (16%) humpback chub sampled from the LCR exhibited a disruption in circuli, indicating that other environmental conditions altered early scale growth, including floods, food shortages, and fluxes in calcium carbonates and salinity (Morales-Nin 1987). None of the 36 LCR fish classified as age 0 (lacking annuli) exhibited disruptions of circuli, indicating that age I or II fish from the upper LCR sample could have moved to the mainstem and back.

Sex Ratios

Sex ratios and average total length and weight were summarized for adult humpback chub for 1990-93 from three mainstem aggregations, including 30-Mile (RM 29.8-30.9), LCR inflow (RM 56.0-65.5), and Middle Granite Gorge (RM 126.1-129.0). Male:female sex ratios for the three aggregations were 50:50, 48:52, and 52:48, with an overall ratio of 49:51 (Table 6-10). Overall, average total length of females was 355 mm TL, or 17 mm greater than males at 338 mm TL. Average weight of females was 454 g or 79 g more than males at 375 g (Table 6-11). These field determinations of gener indicate that both male and female humpback chub mature as small as 200 mm TL or 3 years of age.

Discrepancies in sex determination afield were estimated from 62 of 265 (23%) recaptured humpback chub that were classified as a different gender from original capture. This level of error assumes that none of the fish were independently misclassified at capture, at recapture, or at both events, so a descrepancy was not apparent in the database.

Reproductive Potential and Success

Fecundity

Fewer attempts have been made to propagate and culture humpback chub than any of the Colorado River endangered species. This investigation did not attempt to determine fecundity of fishes handled, but instead relied on existing literature. Hamman (1982) reported stripping an average of 2523 eggs per female from 8 females

Table 6-10. Sex ratios for adult humpback chub (≥ 200 mm) from three major aggregations in the Colorado River in Grand Canyon, October 1990 - November 1993.

Aggregation	Location (RM)	Year	No. Fish	Ratio (Male:Female)
A-1	29.8 - 30.9	1990	-	-
		1991	-	-
		1992	-	-
		1993	20	50:50
		A-1 Summary	20	50:50
A-2	56.0 - 65.5	1990	73	41:59
		1991	372	47:53
		1992	264	45:55
		1993	399	53:47
		A-2 Summary	1108	48:52
A-7	126.1 - 129.0	1990	-	-
		1991	8	25:75
		1992	21	38:62
		1993	34	68:62
		A-3 Summary	63	52:48
	Overall Summary	1990-1993	1246	49:51

Table 6-11. Average total length (TL in mm) and weight (WT in g) for adult male (M) and female (F) humpback chub (TL ≥ 200 mm) from the Colorado River in Grand Canyon, October 1990 - November 1993.

Year	No.	Sex	TL (range)	WT (range)
1990	31	M	351 (225-451)	432 (125-790)
	45	F	373 (294-439)	529 (250-865)
1991	185	M	345 (220-423)	385 (106-870)
	207	F	359 (221-480)	470 (104-999)
1992	131	M	331 (202-455)	358 (64-908)
	162	F	339 (200-451)	396 (85-959)
1993	252	M	336 (204-460)	371 (43-1122)
	209	F	360 (210-458)	467 (98-1165)
Summary	599	M	338 (202-460)	375 (43-1122)
	623	F	355 (200-480)	454 (85-1165)

(TL=355-406 mm, WT=350-690 g) 20 h after injection with carp pituitary (Table 6-12, Fig. 6-18). These fish yielded 5262 eggs/kg of body weight. Egg diameter ranged from 2.6 to 2.8 mm (mean, 2.7 mm). Number of eggs per female was determined volumetrically by measuring displacement in water, and using a conversion of 55

Table 6-12. Number of eggs per female and corresponding lengths and weights for humpback chub by different researchers.

Investigation	No. Fish	Origin	Mean TL (mm)	Mean WT (g)	Mean No. eggs/female	Range eggs/female	Mean No. eggs/g body weight	Range eggs/g	Mean Egg diameter (mm)
Hamman 1992	8	Black Rocks	382	507	2523	330-5,445	4.9	0.65-10.7	2.7
Hamman 1992	9	LCR	395	588	3,333[a]	–	5.7		2.8
Clarkson 1992	11	LCR	362	401	4831	320-11,717	12	0.8-29.2	–

[a]Based on estimate number of eggs voluntarily deposited by 9 females = 30,000.

eggs/ml (range, 51-58). The relationship of body weight (W) to number of eggs per female (EPF) for this sample of fish is expressed by Equation 6-16.

$$EPF = -4443 + 14.53W \quad (r^2=0.96) \qquad \text{(Equation 6-16)}$$

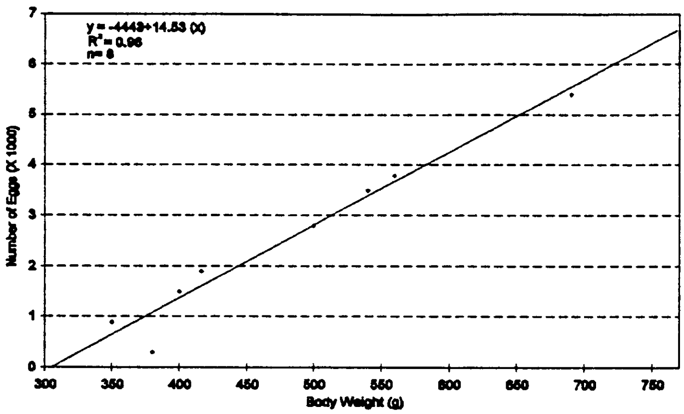


Fig. 6-17. Fecundity of humpback chub, as a relationship between body weight of fish and number of eggs. Data from Hamman (1982).

Hamman (1982) also estimated 30,000 eggs were deposited by 9 females injected with carp pituitary at 24-h intervals and allowed to spawn unassisted over cobble substrates in raceways. Egg diameters varied from 2.6 to 2.9 mm (mean 2.8 mm), and the eggs were adhesive. Assuming the estimated number of eggs was accurate, these fish yielded approximately 3333 eggs per female.

Clarkson (1993) reported higher fecundity using egg weight as a conversion for field-stripped humpback chub from the LCR in 1992. An average fecundity of 4831 eggs per female (range, 320-11,717) was reported for 11 females that were manually striped. Some fish were injected with carp pituitary up to three times and others were spawned without injection.

Of 3503 subadult humpback chub captured by BIO/WEST in shoreline habitats outside of backwaters (AGF sampled backwaters) in 1990-93, the smallest was 23 mm TL, but only nine (0.3%) were smaller than 30 mm TL. Most of these young fish were captured near the LCR inflow, but subadult humpback chub were captured as far downstream as the Shinumo Creek area (RM 119-129), and at Whitmore Wash (RM 187.6).

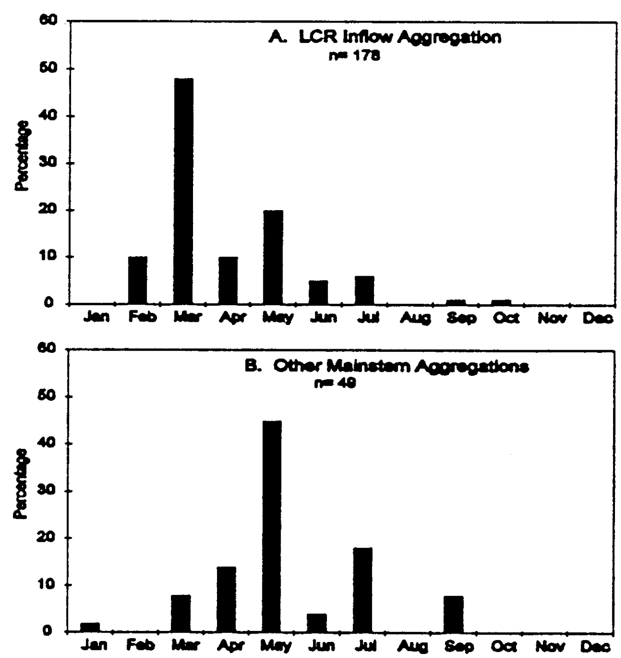


Fig. 6-19. Percentage of adult humpback chub in spawning condition from monthly samples in the LCR inflow aggregation (A) and eight disjunct mainstem aggregations (B).

A total of 178 adult humpback chub captured in the mainstem in 1990-93 exhibited a peak of spawning characteristics (i.e., expression of milt or eggs, tuberculation, coloration) in March, associated with spawning in the LCR (Table 6-13, Fig. 6-19). A

Table 6-13. Spawning condition of adult humpback chub in nine aggregations in the Colorado River.

Aggregation	Males				Females				
	Milt	Tubercled	Spent	Colored	Eggs	Tubercled	Spent	Colored	Total
A-1 (30-Mile)	2	2	0	0	0	2	1	0	7
A-2 (LCR Inflow)	10	91	3	13	3	25	11	22	178
A-3 (Lava to Hance)	0	0	0	1	0	0	0	0	1
A-4 (Bright Angel Inflow)	1	4	0	0	0	0	0	0	5
A-5 (Shinumo Inflow)	1	2	0	0	0	1	0	1	5
A-6 (Stephen Aisle)	1	0	0	1	0	0	0	0	2
A-7 (Middle Granite Gorge)	6	8	0	0	0	7	0	2	23
A-8 (Havasu Inflow)	0	3	0	0	0	2	0	0	5
A-9 (Pumpkin Spring)	0	1	0	0	0	0	0	0	1
Totals	**21**	**111**	**3**	**15**	**3**	**37**	**12**	**25**	**227**

total of 48 adults from seven aggregations, other than the LCR, also displayed spawning characteristics, but these were most common in May. Greatest numbers of adults with spawning characters were in the Middle Granite Gorege aggregation (n=23) and the 30-Mile aggregation (n=7). Also, 15 (31%) of these fish were captured near tributaries, including 4 within 0.3 mi of Clear Creek, 1 within 0.3 mi of Bright Angel Creek, 5 within 0.6 mi of Shinumo Creek, and 5 within 0.9 mi of Havasu Creek.

Ripe fish found in the mainstem, away from the LCR inflow aggregation, were captured from March through July at maximum water temperatures of 10-14° C, a range that is marginal for survival of eggs and larvae of humpback chub. Ripe humpback chub were reported at 16° C from Cataract Canyon, Utah, in June 1988 (Valdez and Williams 1993), and at 11.5° C from Black Rocks, Colorado, in June 1980 (Valdez and Clemmer 1982), where Kaeding et al. (1986) also reported spawning at 13-17° C in June 1983 and at 15-23° C in July 1984. Reports of spawning by humpback chub in the LCR were in water temperatures of 16-20° C (Suttkus and Clemmer 1977, Carothers and Minckley 1981, Kaeding and Zimmerman 1983). Hatching success under laboratory conditions was 12%, 62%, 84%, and 79% at 12-13° C, 16-17° C, 19-20° C, and 21-22° C, respectively, while survival of larvae was 15%, 91%, 95%, and 99%, respectively (Hamman 1982). Thus, although hatching success was highest at 19-20° C, larval survival was highest at warmer temperatures of 21-22° C.

The best evidence of mainstem reproduction discovered by this investigation were ripe fish and post-larve from spring 'J', a small warm spring inhabitated by the 30-Mile aggregation near Fence Fault (See Chapter 4 - WATER QUALITY). Seven adults (TL=330-451 mm) were found in spawning condition in this area, including

1 in May 1993 (milting male), 3 in September 1993 (2 tubercled males, 1 tubercled female), and 3 in July 1994 (1 tubercled male, 1 milting male, 1 spent female). Also, on July 12-14, 1994 about 100 YOY humpback chub were sighted among boulders in the warm plume, and 14 specimens (TL=18-31 mm) were captured to verify identification. Water temperature at the source of Spring J was constant at 21.5° C, compared to 11° C in the adjacent mainchannel. These young fish were considered to belong to the 1994 year class, and probably hatched from eggs deposited in the warm spring plume, since mainstem water temperature was too cold for survival of eggs or larvae (Hammon 1982, Marsh 1985). Based on average TL of 24 mm (SL = 20 mm) these young were approximatly 36 d old (hatched about June 8, 1994), based on the relationship in Equation 6-17 (Muth 1990).

$$D = \frac{\ln SL - \ln 7.2843}{0.0280} \qquad \text{(Equation 6-17)}$$

where: D = days from hatching
SL = standard length of fish

It is unlikely that these young originated from upstream locations, because of the thermal restriction and large numbers of predators (i.e., rainbow trout) in the area. Spawning by humpback chub in this area is further discussed in Chapter 5.

Previous evidence of spawning in this area was found by other investigators. In 1993, AGF (Persons et al. 1994) captured 20 YOY (TL=20-50 mm) humpback chub (3 in July, 3 in September, and 14 in October) in a backwater at RM 44.3 (just below President Harding Rapid). These fish probably emerged from eggs deposited in one of three areas--springs in the vicinity of Fence Fault (30-Mile area), the Paria River, or an undiscovered spring below the river surface and near the subject backwater. Although it is unlikely that larval humpback chub could survive the thermal shock of a transition from a spring plume of 20° C to a mainstem temperature of 10° C, sufficient size and temperature of some plumes may persist under variable mainstem flows to allow fish to age and acclimate for greater thermal tolerance. If young fish reached sufficient size to survive the thermal transition, chances of survival would be further reduced by transport through 14 miles (RM 30 to RM 44) of clear water and high densities of predators (i.e., rainbow trout). It is also unlikely that these young fish originated from the Paria River, since adult humpback chub have not been reported in that tributary, and a large number of young would be necessary to supply a distant backwater with 20 individuals, under normal dispersal. The potential for humpback chub spawning in the Eminence Fault area was difficult to assess, because little was known of the area, and it was sampled only twice during this investigation. A geologic fault (Eminence Break Fault) indicates the presence of warm springs, but none were visible along the shoreline. Historically, at least one juvenile humpback chub was captured at RM 44 between 1970 and 1976, but no length was reported (Carothers and Minckley 1981, Suttkus et al. 1976).

Aside from the 15 ripe fish captured near four tributaries, so substantial evidence of mainstem reproduction was found in any inflow sampled. Five eggs (1.9-2.5 mm diameter) recovered from the LCR inflow in May 1991 were believed to be eggs of humpback chub that were dislodged from upstream spawning redds.

Predation

Humpback chub were recovered from stomachs of brown trout and channel catfish during this investigation. Total numbers of humpback chub subject to predation by brown trout, rainbow trout, channel catfish, and striped bass in the mainstem were estimated by determining percentage of chubs in the diet, and expanding for told numbers of predators. Suseptible prey size was determined by comparing predator size and mouth gape with prey size and body depth.

Brown Trout

Ten humpback chub were found in 5 of 48 (10.4%) brown trout stomachs examined for an average of 2.0 chubs per stomach. One brown trout stomach contained 4 humpback chub. These trout eating chubs were 393-500 mm TL, and the ingested chub were about 78-130 mm SL (mean, 95 mm SL). Tail fins of ingested fish were too frayed for total length measurements, so a conversion of 1.217 was used to yield total lengths of 95-158 mm TL (mean, 116 mm TL). All predation of humpback chub by brown trout occurred in Region 1, between RM 57.0 and RM 65.4, above and below the LCR inflow (RM 61.3).

Observed lengths of predaceous brown trout of 393-500 mm TL were related to maximum mouth diameters of 38.9-50.1 mm (Fig. 6-20), or maximum body depth of potential prey. Using a relationship of total length to maximum body depth for humpback chub (Fig. 6-21), maximum size range of chubs potentially consumed by predaceous brown trout was 167-222 mm TL. The size of ingested humpback chub was 78-130 mm SL (95-158 mm TL), which was within the maximum range of expected prey size.

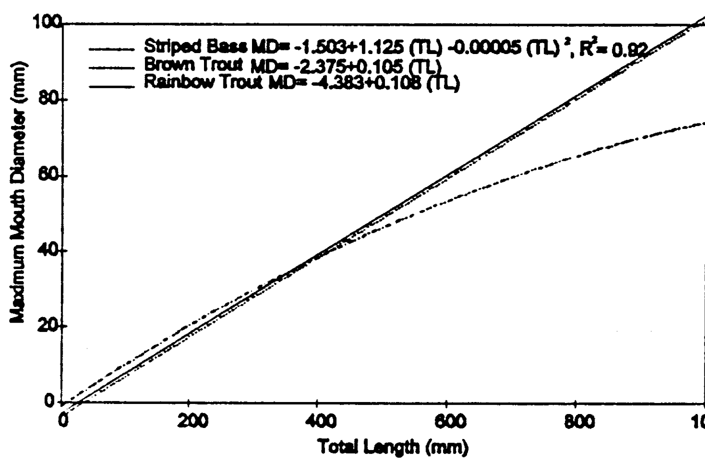


Fig. 6-20. Total length to maximum mouth diameter relationships for four predaceous fish species in Grand Canyon. Brown trout relationship from data presented in Bannon and Ringler (1986); rainbow trout relationship from cutthroat trout equation by Reinacher (1991); channel catfish relationship from data obtained from T. Crowl (pers. comm.); striped bass relationship from Chervinski et al. (1989).

Size range of 1466 adult brown trout captured and measured was 200-730 mm TL, and average was 332 mm TL. Average adult brown trout were able to ingest humpback chub with a maximum body depth of 32.5 mm and a length of 136 mm TL. The largest brown trout captured during this investigation, 730 mm TL, was capable of ingesting a fish with a body depth of 74.3 mm, or a humpback chub 340 mm TL.

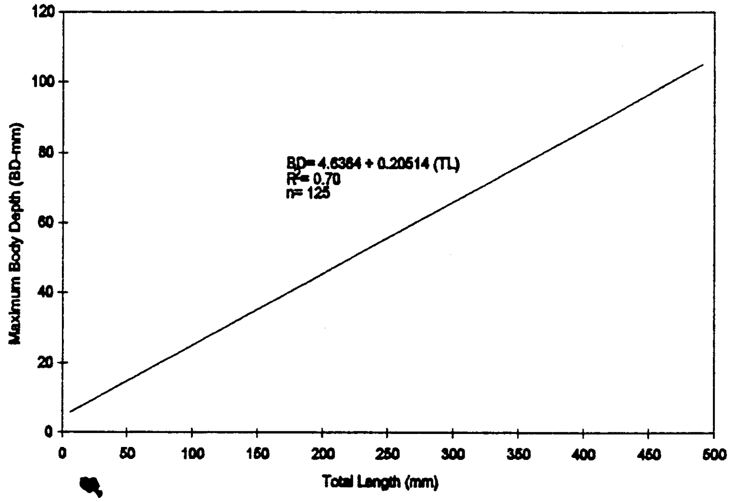


Fig. 6-21. Total length to maximum body depth relationship for humpback chub in the Colorado River in Grand Canyon.

Brown trout are reported to have a primarily piscivorous diet as adults, starting at about 200 mm TL (Carlander 1969), and Elliott (1991) determined that large adult brown trout evacuated 93% of stomach contents after 24 h at 10° C, the approximate temperature of the Colorado River in middle Grand Canyon. Assuming only brown trout over 200 mm TL were preying on humpback chub, and that 10.4% of these each consumed 2 humpback chub per day, the estimated annual consumption of chubs depends on total numbers of brown trout in the river sympatric with humpback chub. Highest consistent densities of subadult humpback chub were reported from the LCR inflow (RM 61.3) to Red Canyon (RM 76.6) (See Chapter 5 - DISTRIBUTION AND ABUNDANCE). A relationship was developed for different numbers of trout, using the previous assumptions (Fig. 6-22). This relationship indicates that 500 adult brown trout could consume 104 humpback chub daily, or 37,960 chub annually. A population of 10,000 adult brown trout could consume 2080 chubs daily or 759,200 chubs annually. Electrofishing catch rates of brown trout converted to numbers per reach (See Chapter 5 - DISTRIBUTION AND ABUNDANCE) indicate that the area from the LCR inflow to Red Canyon had an estimated 3000 adult brown trout. If 10.4% of 3000 adult brown trout consumed 2 humpback chub daily, total annual consumption would be 227,760 chubs (Table 6-14). The size of adult brown trout indicates that all were capable of consuming subadult chubs (TL <200 mm) and

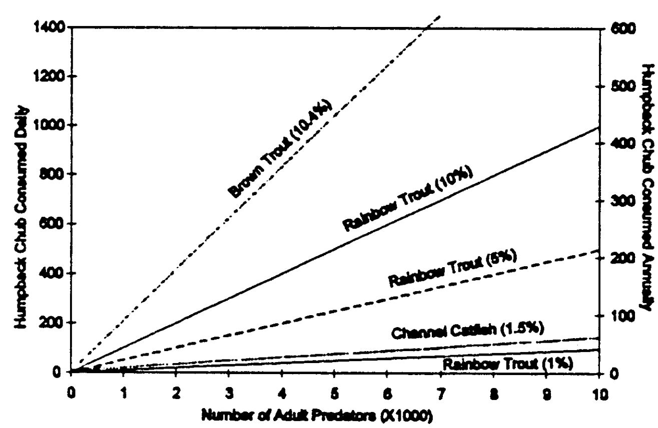


Fig. 6-22. Potential daily and annual consumption of humpback chub by adults of three predator fish species in the Colorado River in Grand Canyon. Relationships assume 2 chubs consumed daily by 10.4% of adult brown trout; 1 chub consumed daily by 1, 5, or 10% of adult rainbow trout; 1 chub consumed daily by 1.5% of adult channel catfish.

Table 6-14. Sizes of four predaceous fish species and susceptible sizes of humpback chub (HB).

Species	N	Size of Adults (TL - mm) Range	Mean	Susceptible size of HB (TL - mm) Range	Mean	Annual Consumption[a]
brown trout	1466	200 - 730	332	68 - 340	136	227,760
rainbow trout	9358	200-708	339	61 - 329	135	328,500
channel catfish	103	200-712	368			
striped bass	39	315-857	453	138-313	196	

[a]Assumes a 10% predation level (i.e., 10% of adults were preying on humpback chub).

some were capable of sonsuming adults, although Bannon and Ringler (1986) found that optimal prey size for brown trout is form minimal sizes. A length-frequency distribution of brown trout from the LCR inflow to Red Canyon shows that about 31% of brown trout in this area were capable of consuming adult humpback chub (TL>=200 mm), and 69% could only consume subadults.

Rainbow Trout

Although humpback chub were not confirmed in stomachs of rainbow trout during this investigation, (Marsh 1994) reported that 1.5% of adult rainbow trout captured at the LCR inflow contained humpback chub in their stomachs. For the purposes of this treatise, and to provide a perspective of possible predation by rainbow trout on humpback chub, an analysis was performed similar to that previously presented for brown trout.

A relationship of standard length to mouth diameter for cutthroat trout (Reimchen 1991) was used in the absence of literature for rainbow trout. The relationship was regenerated for total length, using a conversion factor of TL = 1.15 x SL for cutthrout trout (Carlander 1969) to facilitate comparison with other predator species and with data collected during this investigation (Fig. 6-20).

Size range of 9358 adult rainbow trout measured, 200-579 mm TL, was related to maximum mouth diameter of 17.2-58.1 mm. Humpback chub of corresponding body depth were 61-261 mm TL, or the size range suseptible to predation by rainbow trout. Rainbow trout with average length of 339 mm TL were capable of consuming a fish with a body depth of 32.2 mm or a humpback chub 135 mm TL. Windell et al. (1976) determined that rainbow trout evacuated 80% of stomach contents after 24 h at 10° C. Assuming a 24-h digestive rate, and a consumption rate of 1 humpback chub per day, daily and annual consumption rates were estimated from relationships for 1%, 5%, and 10% predation levels, i.e., percentage of adults consuming humpback chub (Fig. 6-22).

Assuming only rainbow trout over 200 mm TL were predaceous (Carlander 1969), estimated annual consumption of humpback chub depends on total numbers of rainbow trout sympatric with humpback chub. A relationship was developed for different numbers of trout, using the previous assumptions (Fig. 6-22). This relationship indicates that 1% of 500 adult rainbow trout could consume 5 humpback chub daily (500 x 0.01 = 5), or 1825 chub annually. A population of 10,000 adult rainbow trout could consume 100 chubs daily or 36,500 chubs annually. Electrofishing catch rates of rainbow trout converted to numbers per reach (See Chapter 5) indicate that the area of highest juvenile humpback chub concentrations, LCR inflow (RM 61.3) to Red Canyon (RM 76.6), had an estimated 9000 adult rainbow trout. One percent of 9000 adult rainbow trout consuming 1 humpback chub daily, could consume 32,850 chubs annually, while 5% of 9000 adult rainbow trout consuming 1 subadult humpback chub daily, could consume 164,250 chubs annually, and 10% of adult rainbow trout could consume 328,500 humpback chub annually.

A length-frequency distribution of rainbow trout from the LCR inflow to Red Canyon indicates that the majority of rainbow trout in this area were capable of consuming primarily subadult humpback chub (TL<200 mm). Previously described relationships indicate that only rainbow trout ≥464 mm TL were capable of consuming adult humpback chub (TL≥200 mm).

Channel Catfish

The predation analysis for channel catfish is based on an observed predation rate of 1.5%, i.e., one humpback chub (SL~95 mm) was found in 1 of 68 (1.5%) channel catfish stomachs examined from the mainstem. The catfish was 475 mm TL, and was captured at RM 61.7, immediately below the LCR inflow. Predation of humpback chub by channel catfish was also reported in the LCR by AGF (C.O. Minckley, AGF, pers. comm.) and ASU (M. Douglas, ASU, pers. comm.).

Total length to maximum mouth gape relationship for channel catfish (Fig. 6-20) indicates that a fish 475 mm TL was capable of ingesting a fish with a body depth of *** mm and a length of *** mm TL. Assuming a digestive rate of 24 h, it was determined that 1.5% of predaceous channel catfish consumed an average of 1 humpback chub per day. Shrable et al. (1969) determined that adult channel catfish evacuated 80% of stomach contents after 24 h at 10° C, the approximate temperature of the Colorado River in middle Grand Canyon.

Size range of 103 adult channel catfish measured was 200-712 mm TL, and average was 368 mm TL. Relationship of total length to mouth diameter for channel catfish indicates that this size range of catfish was capable of ingesting humpback chub with body depths of ***-*** mm, or ***-*** mm TL. Average adult channel catfish were able to ingest humpback chub with a maximum body depth of *** mm and a length of *** mm TL.

Channel catfish are reported to have a primarily piscivorous diet as adults, starting at about 200 mm TL (Carlander 1969). Assuming only channel catfish over 200 mm TL were preying on humpback chub, and that 1.5% of these each consumed 1 humpback chub per day, the estimated annual consumption of chubs depends on total numbers of channel catfish in the river sympatric with humpback chub. A relationship was developed for different numbers of catfish, using the previous assumptions (Fig. 6-22). This relationship indicates that 100 adult channel catfish could consume 548 humpback chub annually, and a population of 200 adult channel catfish could consume 1095 humpback chub annually. Electrofishing catch rates of channel catfish converted to numbers per reach indicate that the area of highest juvenile humpback chub concentrations, LCR inflow (RM 61.3) to Red Canyon (RM 76.6), had an estimated 200 adult channel catfish. Like brown trout and rainbow trout, the majority of humpback chub consumed by channel catfish were probably subadults, because of the predominate size of catfish and selection for minimal size prey.

Striped Bass

A relationship of total length to mouth gape is presented for striped bass (Fig. 6-20) to identify size range of humpback chub suseptible to predation by this migratory predator in Grand Canyon. Humpback chub were not found in 39 adult striped bass examined. The striped bass ranged in size from 315 to 857 mm TL (mean, 453 mm TL), and corresponding mouth gape ranged from 32.9 to 68.9 mm (mean, 44.9 mm). Using this relationship, striped bass captured in the mainstem could potentially consume humpback chub ranging from 138 to 313 mm TL.

Although adult striped bass typically fast during spawning migrations (Thomas 1967, Stevens et al. 1987), individuals will strike aggressively at lures or occasionally ingest other fishes. Four of 40 adults captured in the mainstem contained fish remains, including 3 trout and 4 unidentified fish (See Chapter 9 - DRIFT AND DIET). The likelihood of predation on humpback chub is unknown, considering the relatively small numbers of striped bass captured annually in the mainstem, and their fasting behavior.

Parasites and Diseases

Lernaea cyprinacea

The only external parasite noted on humpback chub from the mainstem was Lernaea cyprinacea. This parasitic copepod was found on 8 of 6294 humpback chub examined, for an infestation rate of 0.13%. An average of 1.25 copepods (range, 1-2) were found for the 8 infected fish. Lernaea cyprinacea was reported on most species of fish examined from the upper basin, including Micropterus salmoides, Lepomis cyanellus, Ictalurus punctatus, I. melas, G. robusta, Notropis lutrensis, Catostomus latipinnis, and C. discobolus (Flagg 1982). Valdez et al. (1982) reported this parasitic copepod in 26% of 234 humpback chub examined from the upper Colorado River. The parasite was not found in YOY, but 17% of juveniles, and 31% of adults were infected with 1-13 copepods. None of the infected fish showed signs of stress or illness, although some had open lesions where the parasites had attached.

Approximately 40 species of the genus Lernaea (Copeopoda, Cyclopoida) have been reported (Hoffman

1967). Most are found in marine species (Amlacher 1970), and many are specific to families or genera, e.g., L. esocina (pikes) and L. phoxinacea (daces). Species reported from the Colorado River Basin include L. cyprinacea and L. elegans (from Harvey Gap Reservoir) (Williams 1993). Only the former is reported from the Colorado River proper.

Lernaea cyprinacea is cosmopolitan, and is the best known of the copepod parasites. Adult females range from 9 to 22 mm in length, and live in the muscles of fish. The majority of the body is outside the host, and is attached by a cephalic region, characterized by four horns, known as cephalic horns, of which the anterior two are digitiform and the posterior two are "T" shape. These cephaic horns are situated around the mouth and enable the parasite to fix itself into the host musculature. Only females penetrate the host to form the typical "anchor worms", while the smaller males enter into permanent copulation with the females. Host fish show irritation and local hemorrhaging from initial penetration by the females. These anchor points may be secondarily infected with bacteria.

Females develop large egg sacs that retain up to 700 eggs until hatching. The life cycle is temperature dependent, and maturation can take as little as 15 d at 30° C (Stoskopf 1993). Females release eggs into the water, which hatch into microscopic, elliptically-shaped free-swimming nauplii, about 140 micrometers long and 80 micrometers wide. Within 80 h, the nauplii molt and become metanauplii, which molt again in 20-40 hours, into the first of six copepodid stages (Hoffman 1976). The first copepodid stage, at about 230 micrometers long and 110 micrometers wide, must find a host within 3 d or it will die (Khalifa 1973). All copepodid stages feed on fish mucous, but only the female is parasitic and attaches. Lernaea cyprinacea is unable to complete its life cycle at pH levels below 7.0, temperature below 15° C, and salinity level at or above 1.8% (Hoffman 1976).

The favorable temperature range of L. cyprinacea is 14-32° C, and a constant relationship between temperature and development from hatching to transformation of female larvae is reported (Nakai and Kokai 1931, Shields and Tidd 1968). From transformation of female larvae to the end of the life cycle, temperature effects were slight. Copepods have been observed parasitizing fish only during summer, when water temperatures exceeded 25° C (Marcogliese 1991).

Asian Tapeworm

The only internal parasite recorded from humpback chub was the Asian tapeworm (Bothriocephalus acheilognathi). This parasite was found in the gut of 6 of 168 (3.6%) adult humpback chub flushed with a stomach pump (See Chapter 9 - DRIFT AND DIET). An average of 6.7 tapeworms (range, 1-28) were found for the 6 infected fish. The Asian tapeworm was first reported from North America in 1975 in golden shiners and fathead minnows, and in the United States in grass carp (Ctenopharyngodon idella) (Hoffman 1976). It is believed to develop in any member of the minnow family, but has been found in non-cyprinids in Asia and Europe

(Babaev 1965, Bauer et al. 1969), where it is considered a dangerous parasite to fish (Bauer et al. 1981). It is well established in the southeastern U.S., where it often has an adverse impact on the baitfish industry (Granath and Esch 1983a, Riggs and Esch 1987). It was first reported in humpback chub from Grand Canyon in 1990 (D. Hendrickson, pers. comm.). Angradi et al. (1992) reported tapeworms in 80% of juvenile humpback chub (TL=13-35 mm) examined in 1990, and none from humpback chub examined in 1989. Asian tapeworms were also reported from the Virgin River in endangered woundfin (Plagopterus argentissimus), speckled dace (Rhinichthys osculus), Virgin River chub (G. robusta seminuda), Virgin spinedace (Lepidomeda mollispinis), and red shiner (Cyprinella lutrensis) (Heckman et al. 1986). Asian tapeworms were not reported in a survey of Colorado squawfish, humpback chub, bonytail, and razorback suckers from the upper Colorado River basin (Flagg 1982).

The Asian tapeworm has a complex life cycle with operculate eggs shed into the water via feces from an infected fish. After a period of development (e.g., 96 h at 20° C), a motile coracidium emerges (Granath and Esch 1983a,b), and is ingested by a primary host, one of several species of cyclopoid copepods, some of which occur in the Colorado River and its tributaries in Grand Canyon (Haury 1986). A procercoid stage develops in the copepod, and matures to an adult tapeworm, when ingested by the final fish host. Development of the adult occurs in the intestine of the fish, and adult tapeworms can be rather large, up to 100 mm long and 2 mm wide (Hoffman 1980). The scolex or head, is large and triangular, and diagnostic for the species.

Temperature has a significant effect on maturation and growth of B. acheilognathi (Granath and Esch 1983b). Maximum egg hatching and development of all life stages occurred at 30° C, although highest densities of tapeworms were found at 20° C (temperatures below 20° C were not tested). Stimulation for growth, development, and maturation of eggs in adults occurred above 25° C. Coracidia failed to develop into procercoids, and procercoids failed to develop into adults at 20° C.

Saprolegnia

Other external maladies noted on 17 of 6294 (2.7%) humpback chub included "fungus" or "bacterial infections", and "growths" or "tumors". The "fungus" was characteristic of the fungus Saprolegnia spp., which is a facultative pathogen that attacks necrotic tissue, but can also breach the integrity of the host skin, or invade external abrasions or cuts (Davis 1967). Flagg (1982) identified Saprolegnia spp. from Gila sp. in the upper basin, and cautioned that "Abrasions from net capture and tagging were also prime targets for Saprolegnia but no mortalities could be attributed to this alone". Suspected Saprolegnia was observed during this investigation primarily on the tail region of adult humpback chub, and could have been caused primarily by abrasions inflicted on the fish during spawning.

Survival

Subadults

Decreases in mainstem catch rates for subadult humpback chub for 6-month periods following maximum densities in the subreach from the LCR inflow to Lava Canyon, were similar for 1991-92 and 1992-93 (Fig. 6-23, Table 6-15). Negative exponentials showed survival rates of 0.824, and 0.099 from 1, 6, and 12-month periods using electrofishing catch rate data from September 1991 through March 1992. Similar survival rates of 0.831, 0.330, and 0.109 respectively, were found with electrofishing catch rate data for May through November 1992.

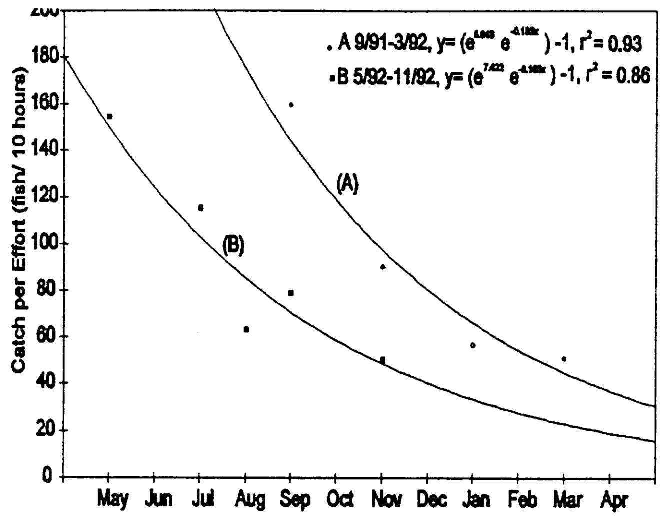


Fig. 6-23. Exponential decreases in densities of subadult humpback chub in the mainstem Colorado River from the LCR (RM 61.3) to Lava Canyon (RM 65.4) for September 1991 through March 1992 (A) and May through November 1992 (B).

Table 6-15. Exponential decreases in density of subadult humpback chub (TL <200 mm) for electrofishing, seines, and minnow traps in the mainstem Colorado River from the LCR (RM 61.3) to Lava Canyon (RM 65.4).

Gear	Period	Exponential Function	Survival Rate 1 mo	6 mo	12 mo	Coefficient of Determination r^2
Electrofishing	9/91-3/92	$N_{(t)}=(144.18e^{-0.193t})-1$	0.824	0.314	0.099	0.93
	5/92-11/92	$N_{(t)}=(149.96e^{-0.185t})-1$	0.831	0.330	0.109	0.86
	5/92-4/93	$N_{(t)}=(106.55e^{-0.053t})-1$	0.948	0.728	0.529	0.36
	9/93-7/94	$N_{(t)}=(224.88e^{-0.090t})-1$	0.914	0.583	0.340	0.09
	9/93-11/93	$N_{(t)}=(849.80e^{-1.515t})-1$	0.220	<0.001	<0.001	0.77
Seines	5/92-4/93	$N_{(t)}=(2.14e^{-0.073t})-1$	0.930	0.645	0.416	0.24
	5/92-9/92	$N_{(t)}=(2.93e^{-0.162t})-1$	0.850	0.378	0.143	0.3
	9/93-7/94	$N_{(t)}=(7.22e^{-0.232t})-1$	0.793	0.249	0.062	0.55
	9/93-11/93	$N_{(t)}=(20.43e^{-1.220t})-1$	0.295	0.001	<0.001	0.8
Minnow Traps	5/92-10/92	$N_{(t)}=(1.11e^{-0.107t})-1$	0.899	0.526	0.277	0.66
	5/92-4/93	$N_{(t)}=(0.81e^{-0.025t})-1$	0.975	0.861	0.741	0.18
	9/93-7/94	$N_{(t)}=(4.50e^{-0.107t})-1$	0.899	0.526	0.277	0.7

Survival rates for 1993, using electrofishing catch rate data for September through November 1993 were 0.220, 0.0001, and <0.001 for 1, 6, and 12-month periods respectively. Similar rates of 0.295, 0.001, and <0.001, respectively, were found using seine catch rate data for September through November 1993. These rates represent survival for subadults in themainstem following descent from the LCR, and when the youngest fish were about 2 months of age.

Factors that probably contributed to decreased densities of subadult humpback chub in this area, included downstream dispersal and mortality (i.e., predation, thermal shock, diseases and parasites, starvation). Decreases in numbers of subadults were also offset by dispersal from the LCR. This effect was minimized by performing analyses during periods with few LCR floods. The effects of each of these factors was not determined and remain the subject of needed research to fully understand causitive factors for mortality of young humpback chub.

Adults

Three models were used to estimate adult survival over 13 seasons (fall 1990 - fall 1993). Only models 1 and 2 were found to fit the data using goodness of fitness tests. The test between Model 1 and Model 2 (testing time-dependent vs. constant survival rates) was not significantly different, and Model 2 was chosen as the simplest model that fit the data. These results indicate that survival between seasons was relatively constant. Tests comparing Model 3 with Models 1 and 2 were significant and indicated that recovery rates were not constant between season. Adult survival from one season to the next, estimated with Model 2, was 0.954 (95% confidence interval = 0.908 - 0.999). This translated to an annual survival rate of 0.827 (95% c. i. = 0.788 - 0.866).

DISCUSSION

Humpback chub in the mainstem Colorado River in Grand Canyon occurred in nine aggregations, from RM 30 (South Canyon) to RM 213 (Pumpkin Spring), that consisted of 5 to 3447 adults. Length-frequency distributions indicated that only the LCR inflow aggregation contained a cross-section of lengths and ages of fish, primarily as a result of dispersal of young from the LCR, which was the major spawning and nursery area for the species in Grand Canyon. The LCR inflow aggregation was the largest enountered in the mainstem, and was considered a component of the LCR population, since most mainstem adults within a 15-km area of the inflow ascended the LCR to spawn, and large numbers of progeny of undetermined origin (mainstem adults or LCR adults) descended annually to supplement the mainstem component and downstream aggregations. Mark-recapture ML estimators indicated that about 3750 (3230-5270) adult humpback chub were in the nine mainstem aggregations during this investigation. Male:female sex ratios for the three largest aggregations (30-Mile, LCR, MGG) were 50:50, 48:52, and 52:48, for an overall ratio of 49:51, revealing a reproductive potential in at least these aggregations of fish.

The only aggregation upstream of the LCR inflow, the 30-Mile aggregation (RM 29.8-31.3), was composed entirely of adults, significantly larger (TL>=330 mm) than adults of other aggregations. Although a concentration of about 100 post-larval humpback chub (TL=18-31 mm, n=14), observed in a warm shoreline spring near RM 30, was evidence of successful reproduction in this spring, the absence of juveniles and subadults from this aggregation indicated little or no survival of young and recruitment to adults from past spawnings. Estimated hatching time of early June for these post-larvae, and peak in spawning condition of adults in May indicate that mainstem fish away from the LCR aggregation reached spawning readiness 2 months later than the LCR fish, or approximately the same time as fish in the five other populations in the basin. While maturation and spawning cues were not apparent, temperature-degree days, light intensity, and water temperature (although mainstem temperature was only 1.5-2.0° C higher in summer than spring) were probably major factors, and the constant spring temperature of 21.5° C provided suitable spawning and incubation conditions.

While age determination of adults in the 30-Mile aggregation was not possible, large sizes and distinct morphological characters (i.e., enlargened nuchal humps, high incidence of body scars) inferred fish of a remnant population surviving since construction of Glen Canyon Dam in 1963. Assuming little or no recruitment to this aggregation, some of these fish may be 30 years old or more, and may represent a unique genetic stock of mainstem fish, unaffected by the LCR inflow population, i.e., no extensive upstream movement was recorded during this investigation for radiotagged adults, or PIT-tagged adults and subadults from the LCR inflow aggregation. Also, humpback chub were not captured in a 24-mile reach, between RM 32 and RM 56, during this investigation.

The seven other aggregations of humpback chub, all downstream of the LCR inflow, were composed primarily of large subadults and adults, and were associated with tributary inflows (3), springs (1), or areas of unique habitat (3). Small humpback chub found in these aggregations indicated local reproduction, but the majority were attributed to downstream dispersal from the LCR population. Size composition indicated that none of these downstream aggregations was self-sustaining, i.e., reproduction and recruitment was insufficient to maintain a full-complement of ages.

Monthly length-frequency analyses of the LCR inflow aggregations indicated substantial overlap in lengths of fish from different cohorts. A large and distinct mode of fish less than 100 mm TL reached peak densities in September 1991, May 1992, and September 1993, and was attributed to dispersal of young (ages 0, I, and possibly II), concurrent with summer freshets from the LCR. Considerable overlap in length of fish of different age was suspected and attributed to timing of descent from the warmer LCR to the colder mainstem, i.e., slow-growing fish from the cold mainstem were older, but of similar size to faster-growing, younger fish from the LCR. Separation of cohorts was also difficult because of the expanded spawning time, perhaps as much as

3 months (March-May).

Length-weight relationships and relative condition factors (Kn) for adult humpback chub were typically highest prior to spawning, in March and April, and lowest in June, after spawning. Greatest increases in Kn were from June to September, when fish were recovering from spawning, and from November to March, in advance of spawning. Significantly higher Kn for October 1990 was possibly related to research flows, which ended July 29, 1991. Lower Kn in October 1991, 1992, and 1993 suggested differential effects of interim flows, i.e., possibly less food from lower magnitude fluctuations. Relative Kn of humpback chub may be an excellent indicator to local environmental conditions, because the absence of a pyloric caecum (i.e., fat absorption and storage organ at the posterior end of the stomach of most fishes, Lagler et al. 1962) restricts fat storage to mesenteries and muscle. Fat from these sites is more quickly utlized, reflecting rapid weight changes of individual fish. Kn of males and females was not signficantly different prior to spawning, indicating that both sexes directed substantial energy into gonadal and ovarian development.

Kn for adults of other species, including flannelmouth sucker, bluehead sucker, rainbow trout, and brown trout, were similarly reflective of physiological events. Kn of flannelmouth sucker and bluehead sucker, like that of humpback chub, was highest in March-April, prior to spawning, and lowest in late summer, following spawning. Highest Kn for rainbow trout was in fall, and lowest was in early spring, while Kn for brown trout was highest in October-November, and lowest in winter and early spring.

Scales of subadult humpback chub were cycloid, with a center focus, concentric growth circuli, and annular rings that formed from November through March. Winter annular ring establishment was consistent with most temperate species (Lagler et al. 1962), although maximum mainstem temperature variation near the LCR inflow was from a monthly mean of 11° C in July to 6° C in January. The adult component of the population may have different winter physiological characteristics than subadults, as indicated by high Kn and spawning activity. Circuli in scales of adults were too distorted and disrupted to distinguish annular rings. Average backcalculated lengths of mainstem subadults at 1, 2, and 3 years were 101, 153, and 193 mm TL, with 79 mm TL as average length at time of transition from the LCR to the mainstem. Average 30-d growth rate for age 0 chubs in the LCR was 10.51 mm, and 4.27 mm in the mainstem for ages 0 and I. Growth rate of age II fish was 3.29 mm/30 d. Average 30-d growth rates by 50-mm increments from recapture of PIT-tagged fish, was 2.25 mm (TL=150-200 mm), 2.79 mm (TL=200-250), 2.50 mm (TL=250-300 mm), 1.16 mm (TL=300-350 mm), 0.79 mm (TL=350-400 mm), 0.91 (TL=400-450 mm), and 0.96 mm (TL=450-500 mm). The majority of the growth in the first year occurred in the LCR, since scale transition checks indicated that fish averaged 79 mm TL at the time of descent. Minimum size of fish at transition was 58 mm TL, indicating little or no surivival of smaller fish descending from the LCR; the most likely cause of mortality was thermal shock or predation illicited by abberant thermal-shock behavior, i.e., erratic swimming, flashing.

An estimated 10.4% of adult brown trout and 1.5% of adult channel catfish had subadult humpback chub (TL=95-158 mm) in their stomachs, as well as 1.5% of rainbow trout (Marsh 1994). Adult brown trout (TL=200-730 mm) and adult channel catfish (TL= 200-712 mm) could consume humpback chub of up to 340 mm TL, although 90% of these predators were of a size that could consume only subadults (TL<200 mm), and neither brown trout nor channel catfish feed on prey as large as their mouth gapes will allow. Assuming 10.4% of 3000 adult brown trout consumed 2 humpback chub daily in the area of highest subadult densities, annual consumption was an estimated 227,760 chubs. Predation by 1.5% of an estimated 5000 adult rainbow trout, and 500 adult channel catfish (1 chub/day) in the area of highest subadult densities could result in estimated annual consumption rates of 27,375 and 2738 humpback chub, respectively. Given the above assumptions, brown trout, rainbow trout, and channel catfish could consume over 250,000 subadult humpback chub annually.

Other causes of mortality for mainstem humpback chub were identified in addition to predation, including thermal shock, parasites and diseases, and starvation, although no attempt was made to quantify these causes. Incidence of two parasite species was recorded for humpback chub. The parasitic copepod, Lernaea cyprinacea, was found on 0.13% (8 of 6294) of fish examined, and the Asian tapeworm, Bothriocephalus acheilognathi) was found in the intestine of 3.6% (6 of 168) of adults flushed for gut content with a stomach pump. Some subadult humpback chub with tapeworms were emaciated, but the incidence of tapeworms in subadults could not be accurately recorded.

Densities of subadult humpback chub from the LCR inflow (RM 61.3) to Lava Canyon (RM 65.4), followed a typical negative exponential relationship that was attributed to mortality (i.e., predation, thermal shock, diseases and parasites, starvation) and emigration (i.e., downstream dispersal), offset by immigration (i.e., dispersal from the LCR). Decreases in peak densities for 1991 and 1992 were similar, and believed to be indicative of survival since fish densities below this subreach decreased dramatically. Negative exponents using electrofishing catch rate data from September 1991 through March 1992 showed survival rates of 0.824, 0.314, and 0.099 for 1, 6, and 12 months, respectively, while data from May 1992 through November 1992 showed similar rates of 0.831, 0.330, and 0.109, respectively. Decreases in peak densities for 1993 were much greater for electrofishing catch rate data from September through November 1993, with survival rates of 0.220, <0.001, and <0.001 for 1, 6, and 12 months, respectively. Decline in densities of subadult humpback chub during their first 6 months in the mainstem was 69% in 1991, 67% in 1992, and over 99% in 1993.

While annual survival rates of subadult humpback chub were 0.099, 0.109, and <0.001 for 1991, 1992, and 1993, respectively, survival of adult humpback chub from one season to the next (e.g., summer to fall) was 0.954, and annual survival rate was 0.827.

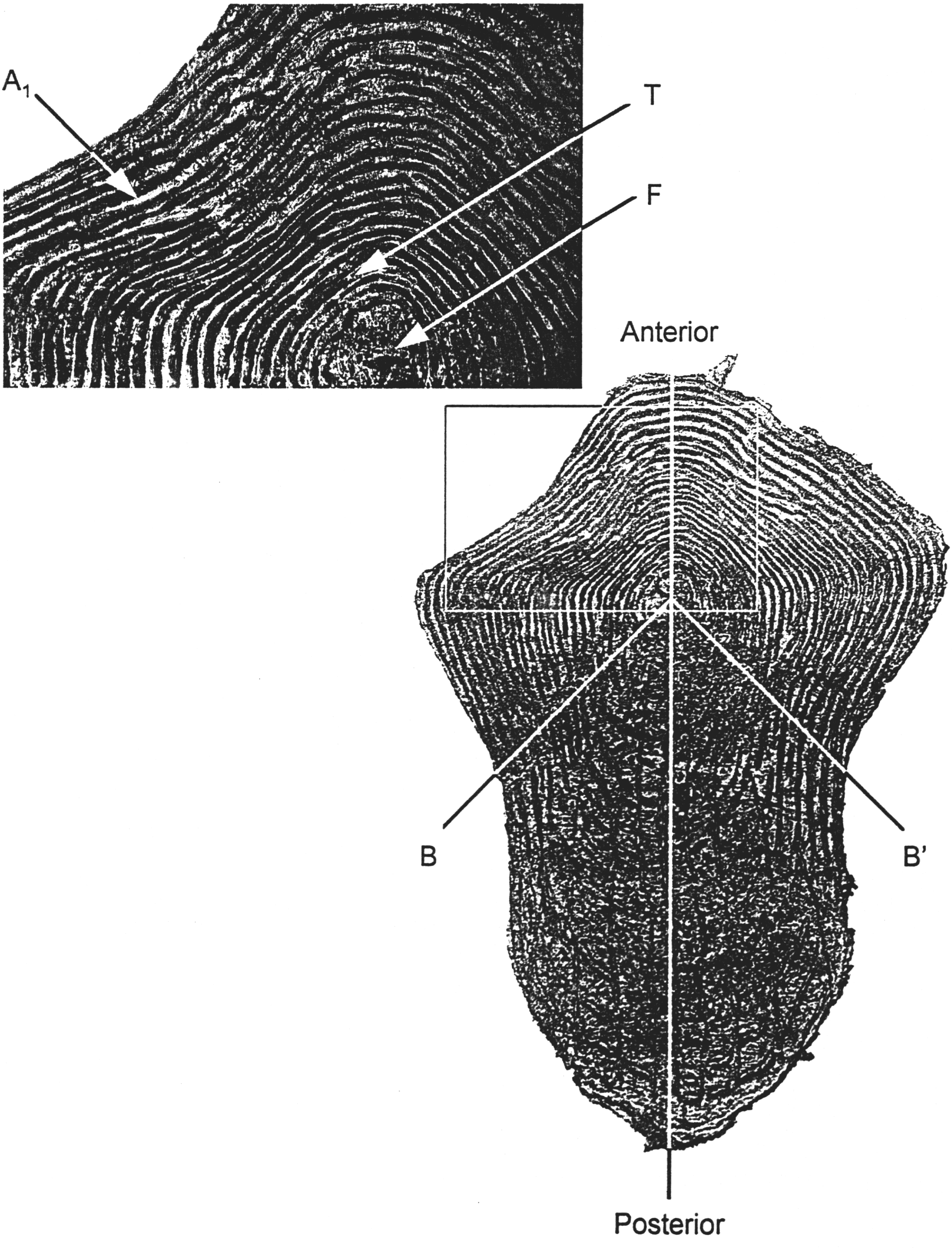
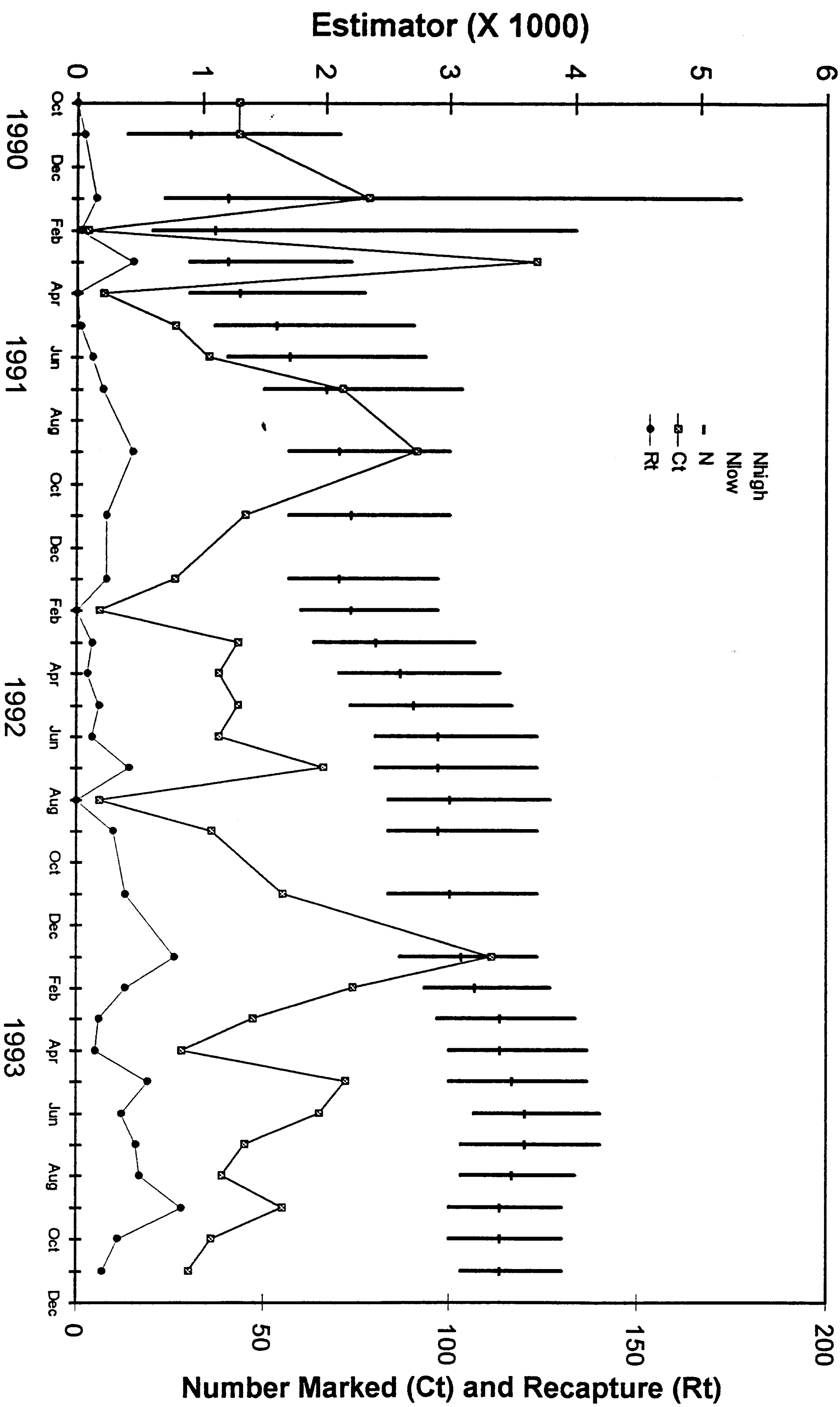
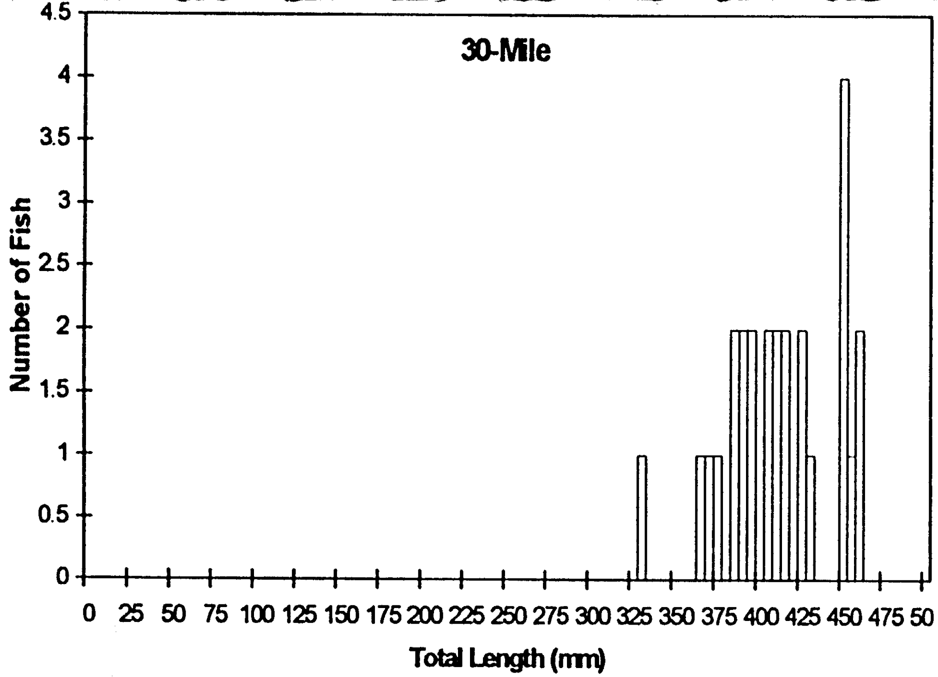
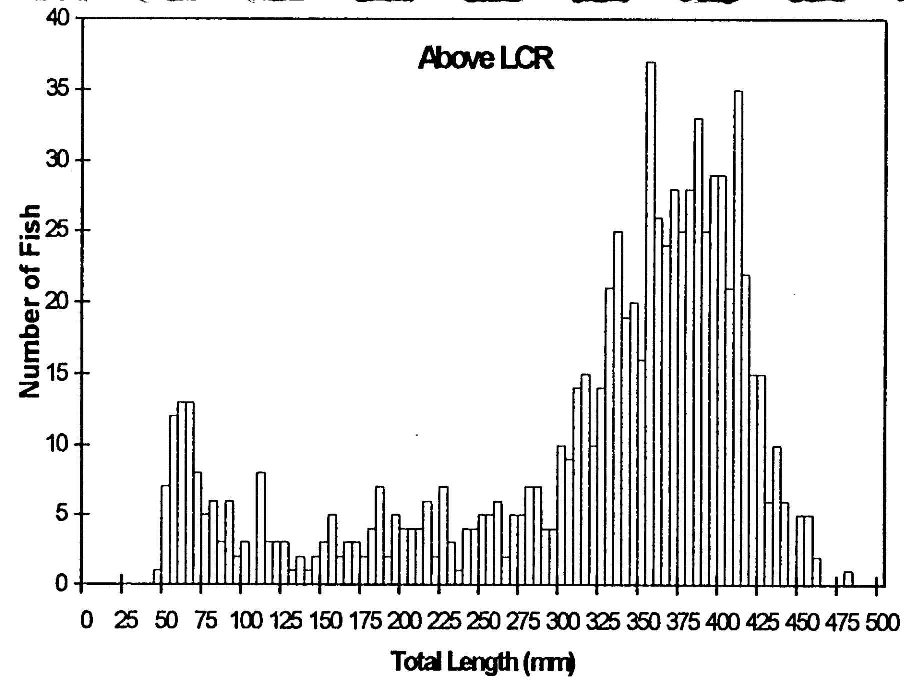


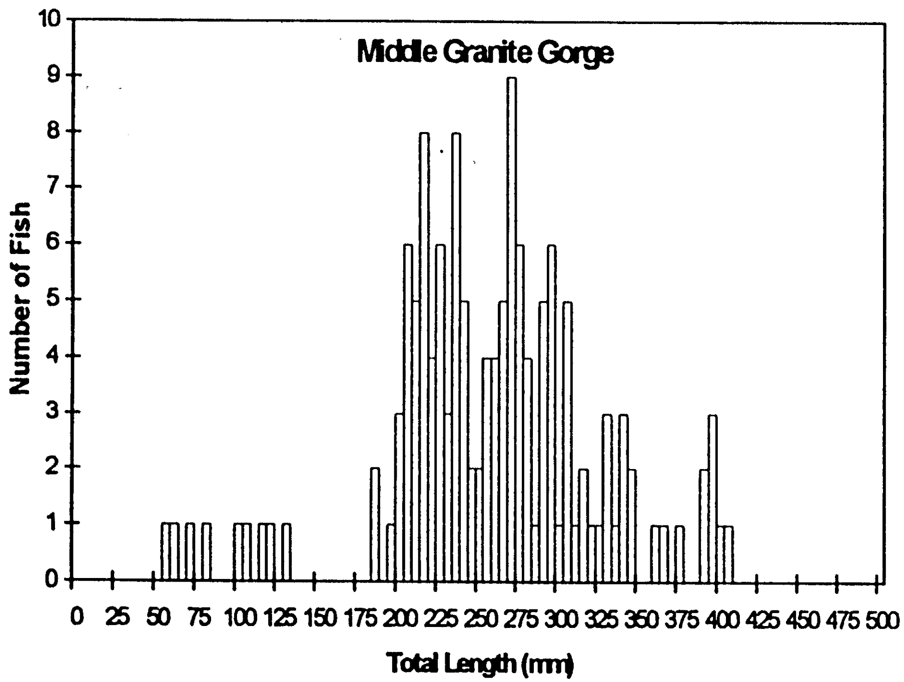
Fig. 6-1. Scale of age I+ humpback chub (TL=146 mm) from Grand Canyon. Measurements were made from the focus (F) along the posterio-lateral lines B or B'. Inset shows transition check (T) and first annulus (A_1).

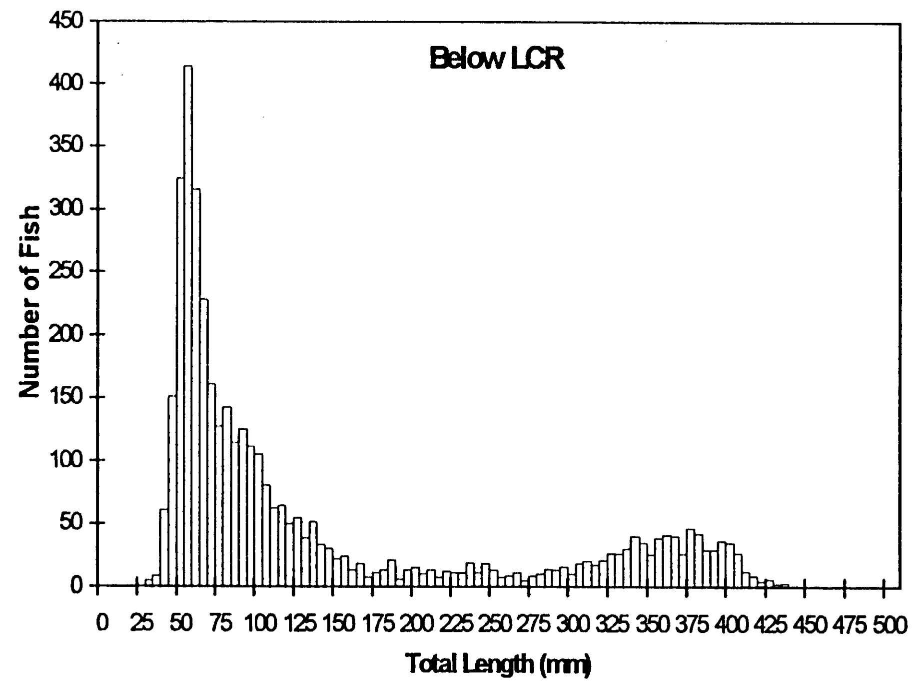
Fig. 6-2


Estimator (X 1000)
0
1
2
3
4
5
6
Nhigh
Nlow
N
Ct
Rt
1990
1991
1992
1993
Oct
Dec
Feb
Apr
Jun
Aug
0
50
100
150
200
Number Marked (Ct) and Recapture (Rt)

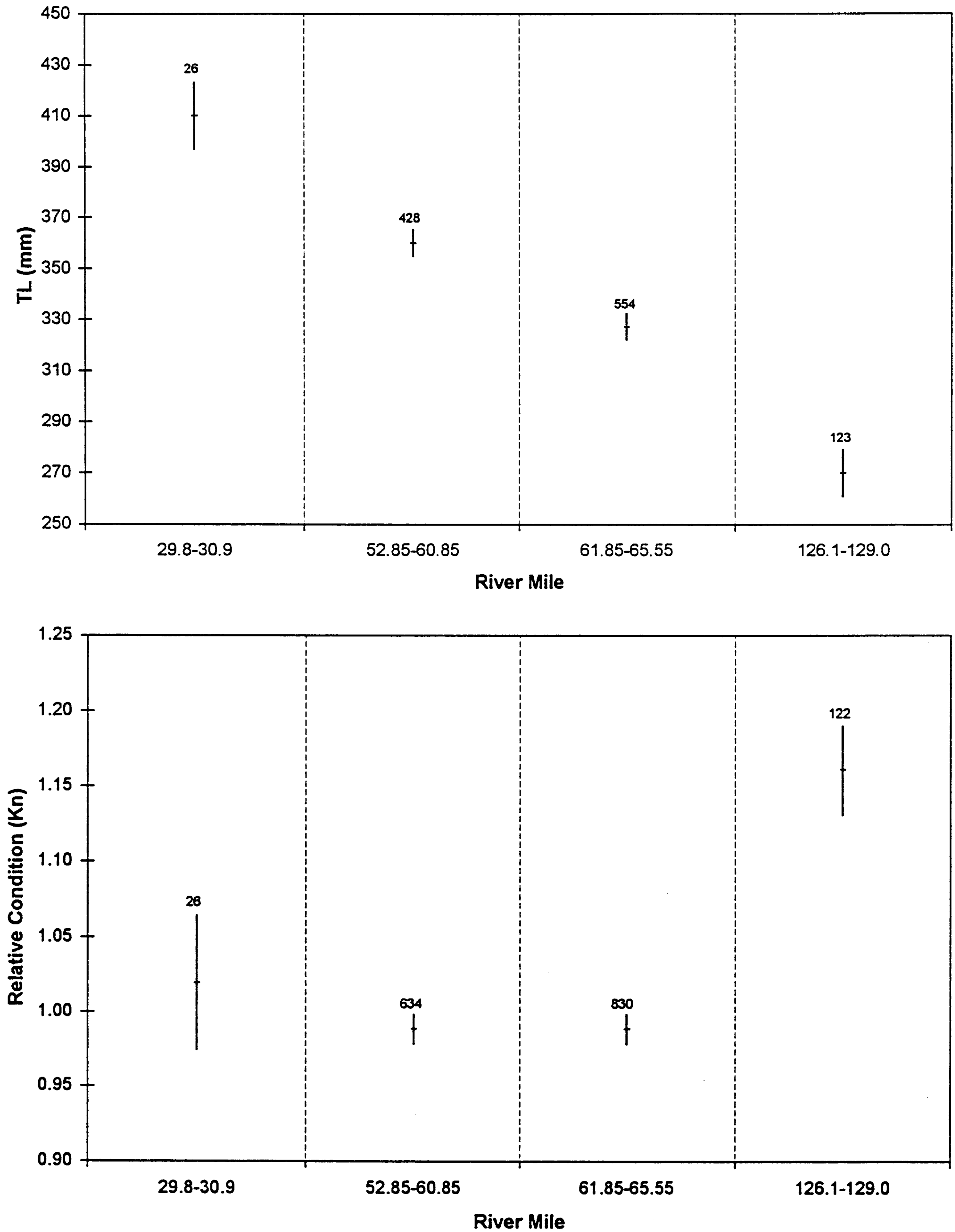

30-Mile
Number of Fish
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 50
Total Length (mm)


Above LCR
Number of Fish
0
5
10
15
20
25
30
35
40
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (mm)


Middle Granite Gorge
Number of Fish
0
1
2
3
4
5
6
7
8
9
10
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (mm)


Below LCR
Number of Fish
0
50
100
150
200
250
300
350
400
450
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (mm)

6-3



450
430
410
390
370
350
330
310
290
270
250
TL (mm)
26
428
554
123
29.8-30.9
52.85-60.85
61.85-65.55
126.1-129.0
River Mile
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
Relative Condition (Kn)
122
26
634
830
29.8-30.9
52.85-60.85
61.85-65.55
126.1-129.0
River Mile

FIG. 6-4

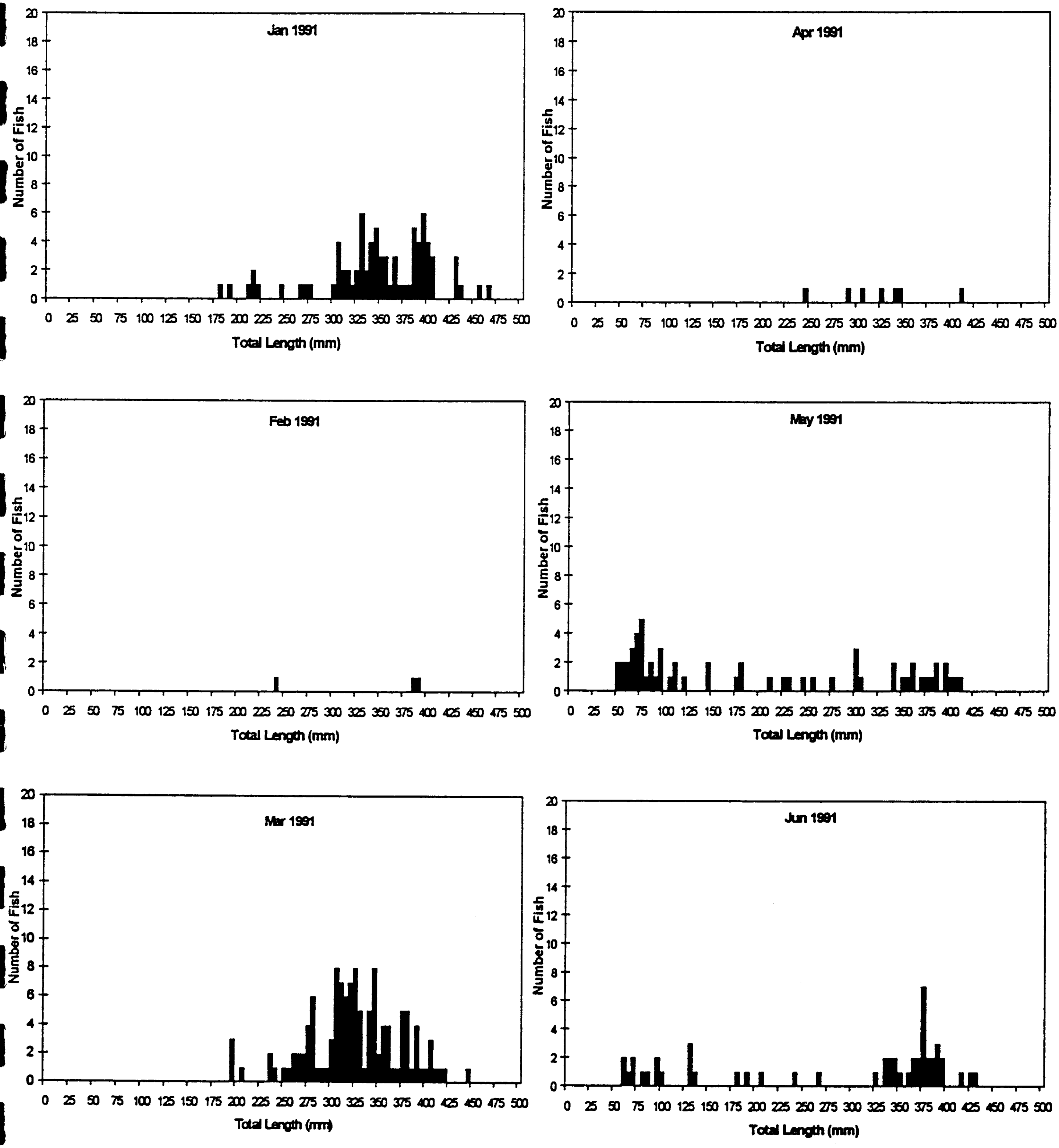
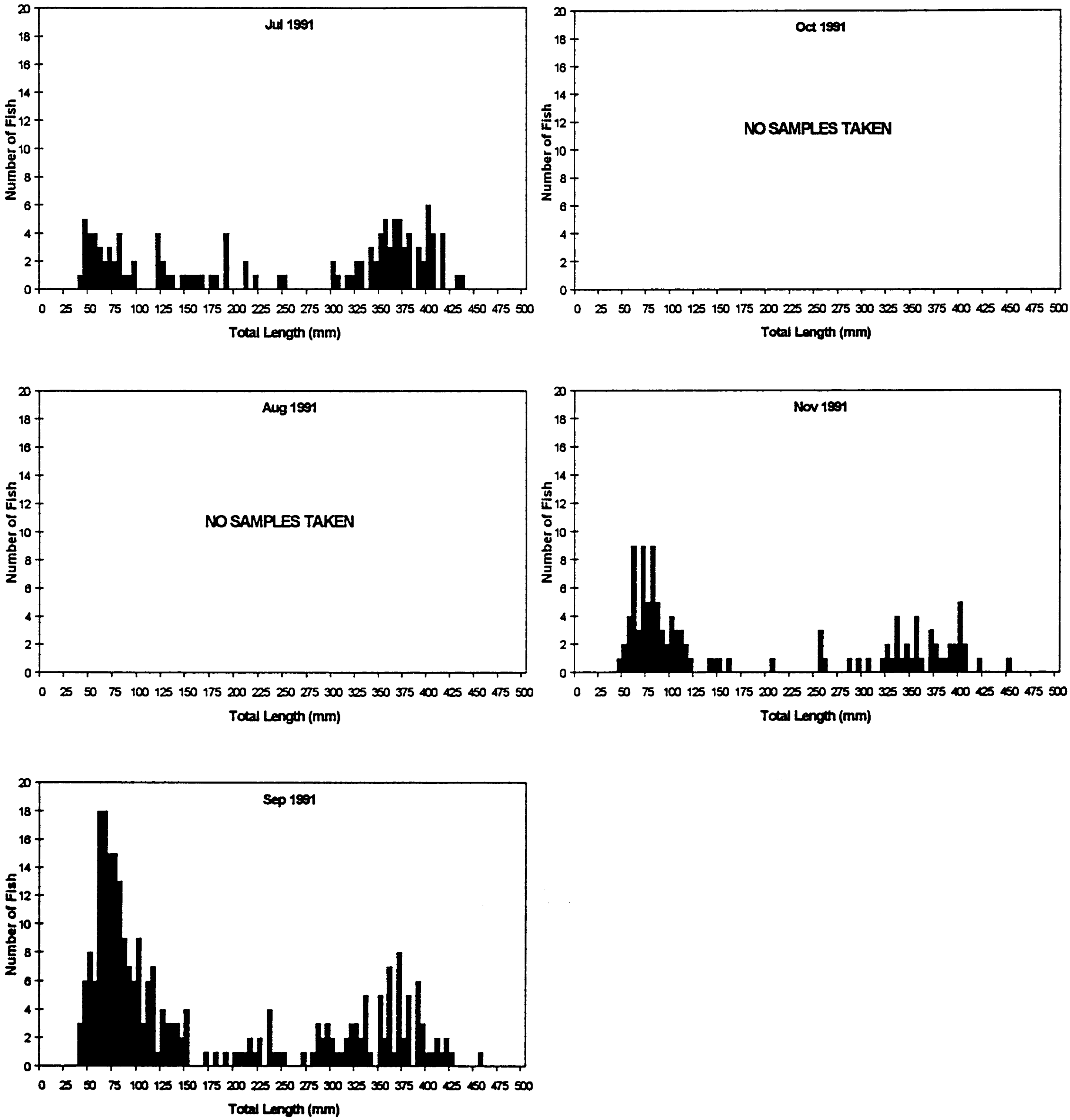

Jan 1991
Apr 1991
Feb 1991
May 1991
Mar 1991
Jun 1991
Number of Fish
0 2 4 6 8 10 12 14 16 18 20
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (mm)

FIG. 6-5



Jul 1991
Oct 1991
NO SAMPLES TAKEN
Aug 1991
NO SAMPLES TAKEN
Nov 1991
Sep 1991
Number of Fish
Total Length (mm)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
0 2 4 6 8 10 12 14 16 18 20

FIG. 6-5A

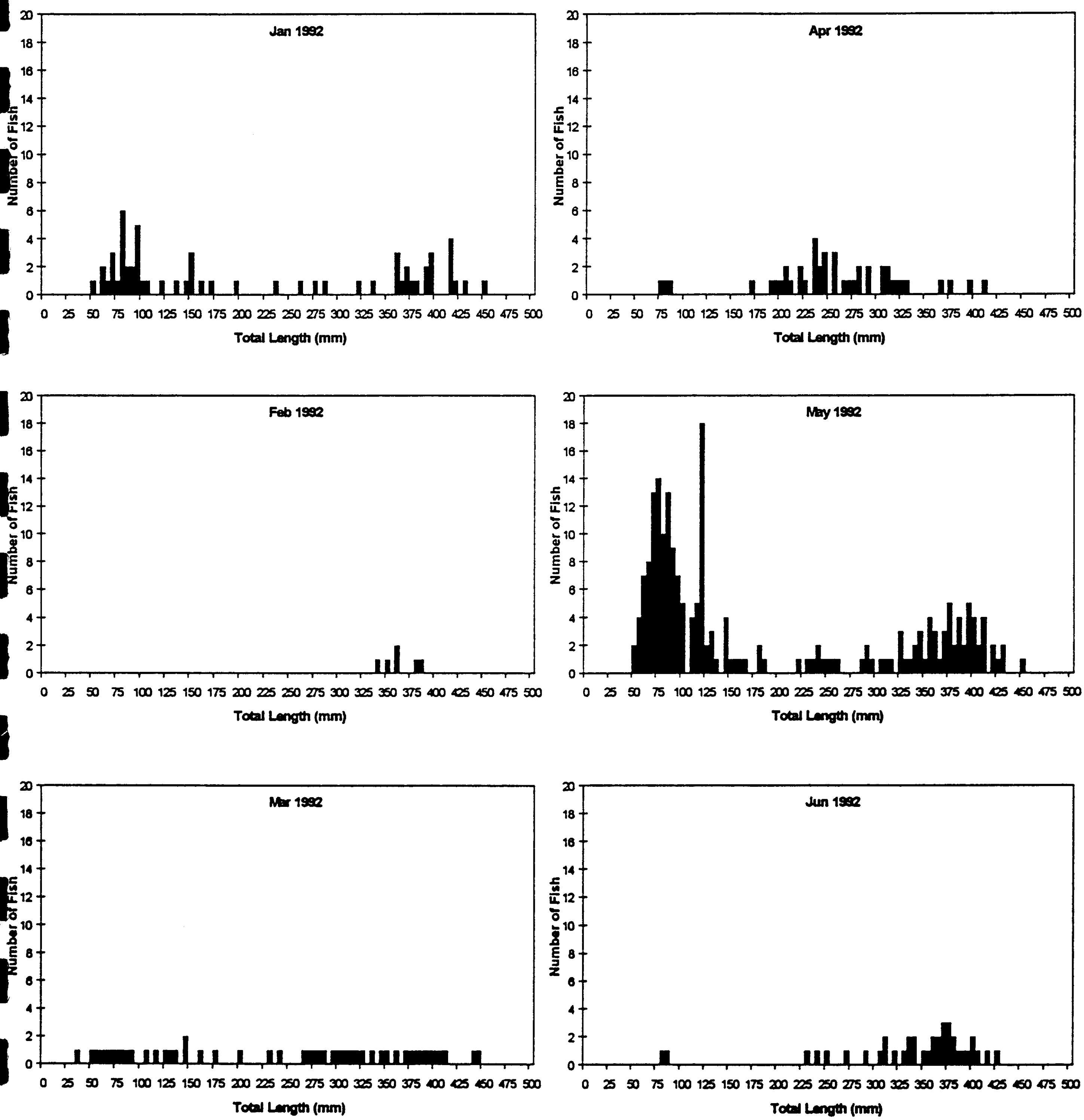

Jan 1992
Apr 1992
Feb 1992
May 1992
Mar 1992
Jun 1992
Number of Fish
Total Length (mm)
0 2 4 6 8 10 12 14 16 18 20
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500

FIG. 6-6

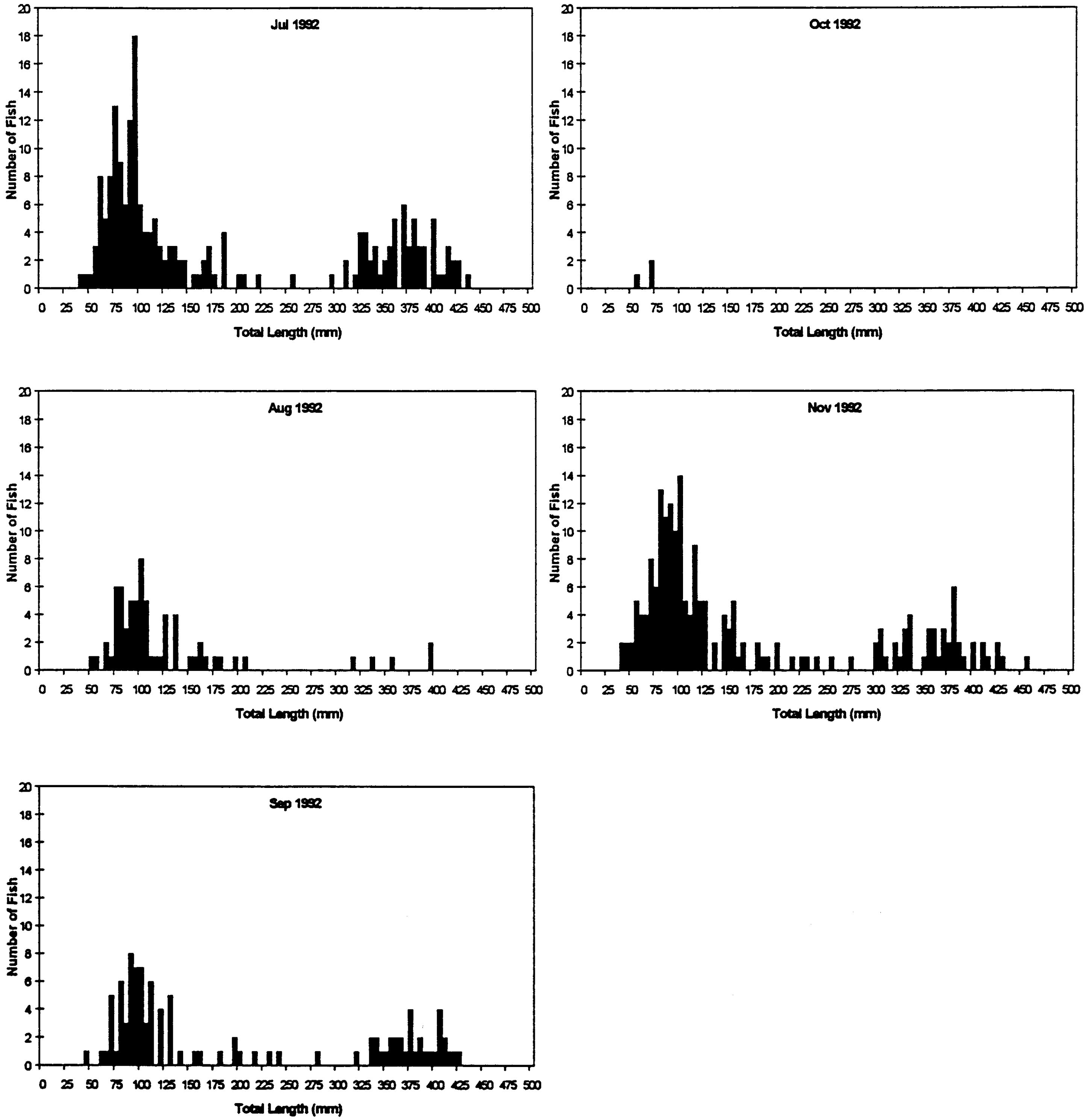
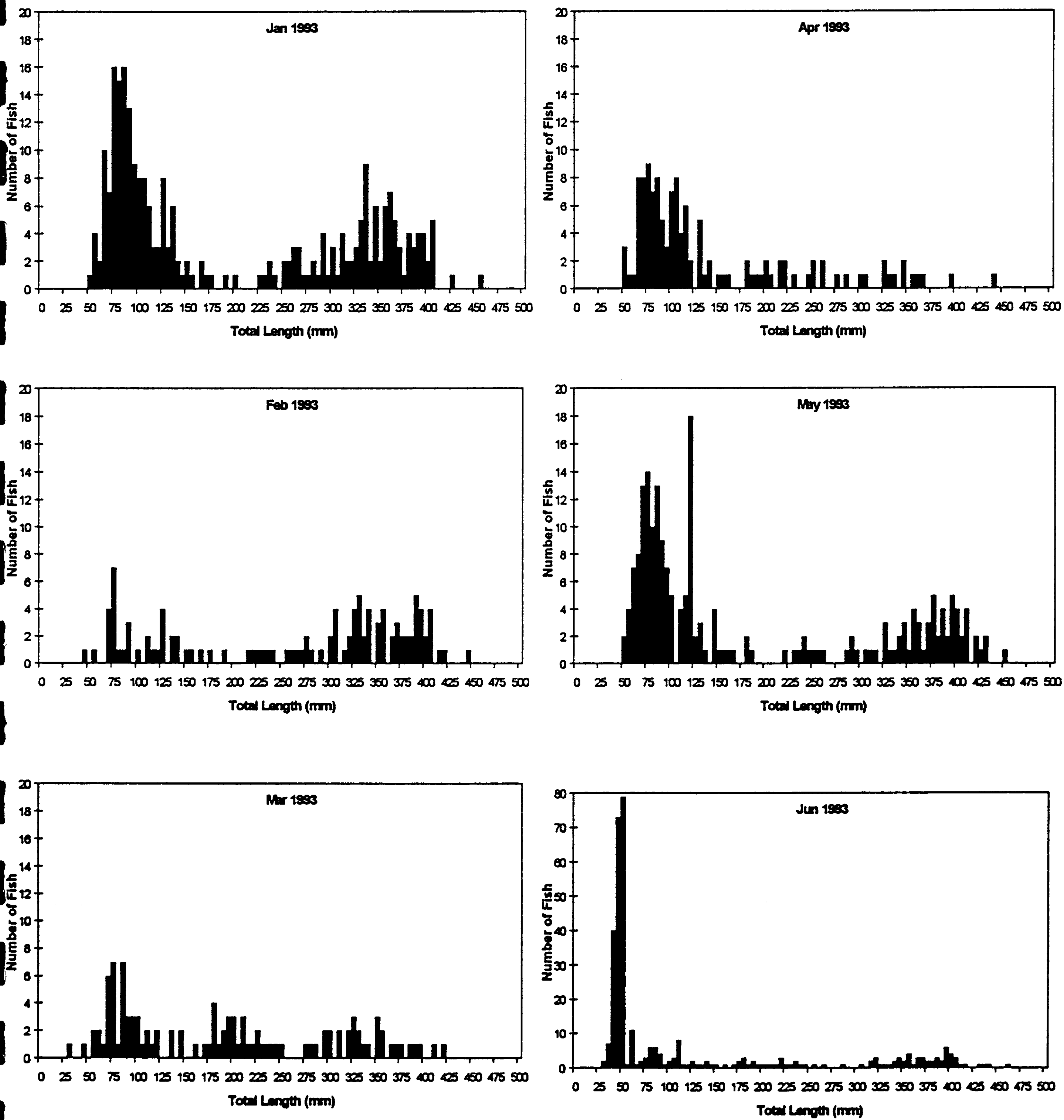

Jul 1992
Oct 1992
Aug 1992
Nov 1992
Sep 1992
Number of Fish
0 2 4 6 8 10 12 14 16 18 20
Total Length (mm)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500

FIG. 6-6a



Jan 1993
Apr 1993
Feb 1993
May 1993
Mar 1993
Jun 1993
Number of Fish
Total Length (mm)

FIG. 6-1

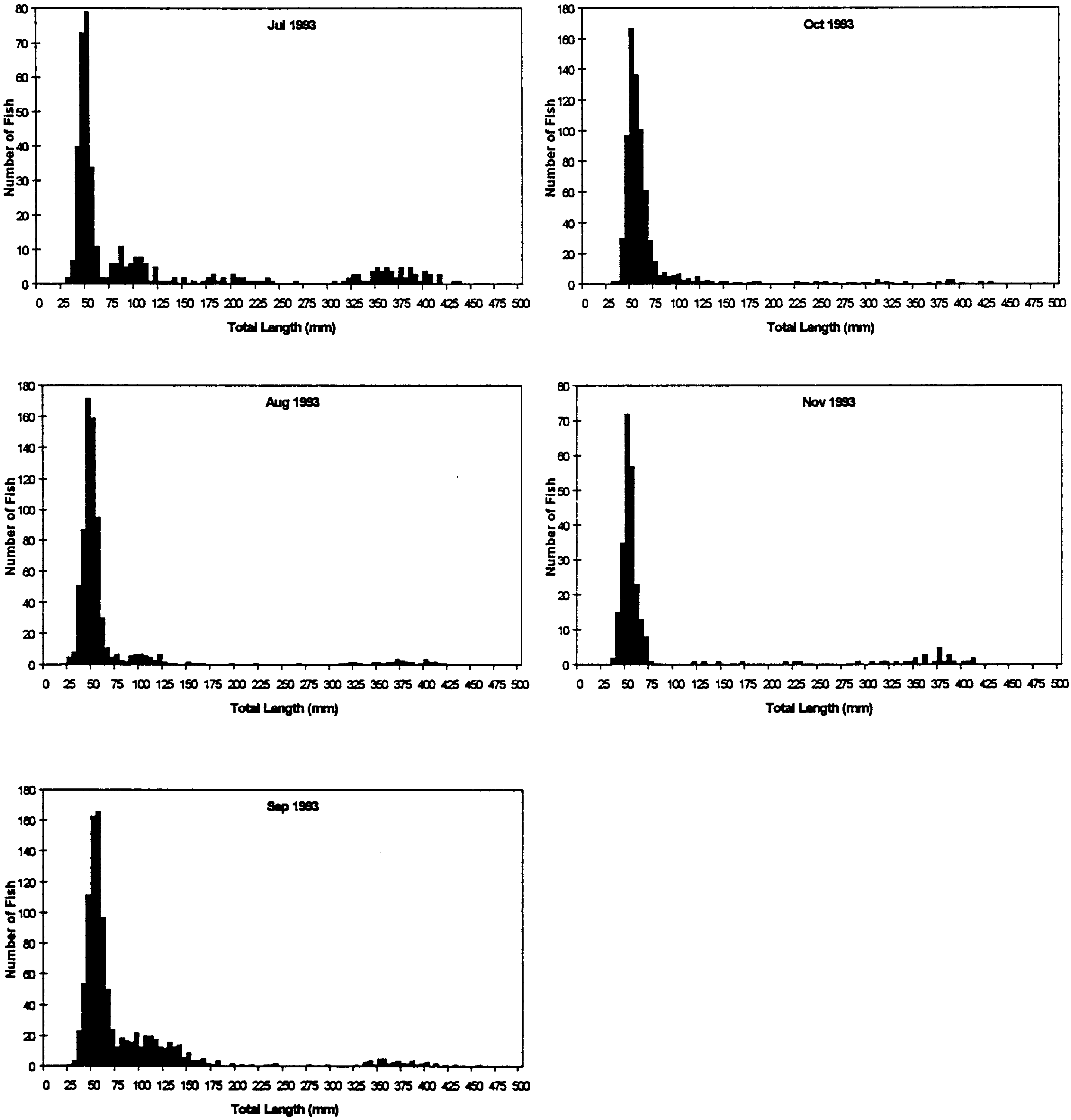

Jul 1993
Oct 1993
Aug 1993
Nov 1993
Sep 1993
Number of Fish
Total Length (mm)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500

FIG. 6-7a

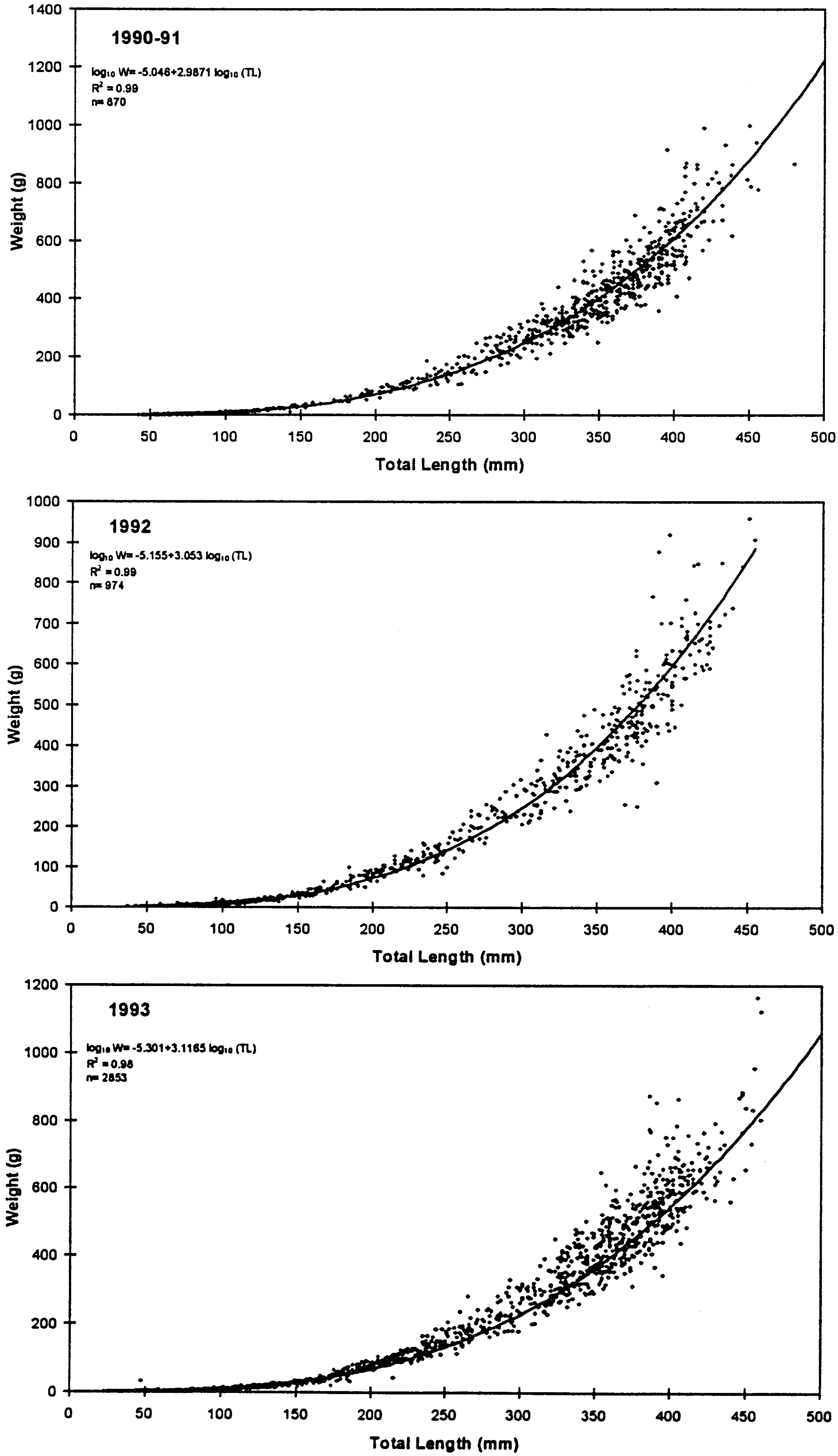
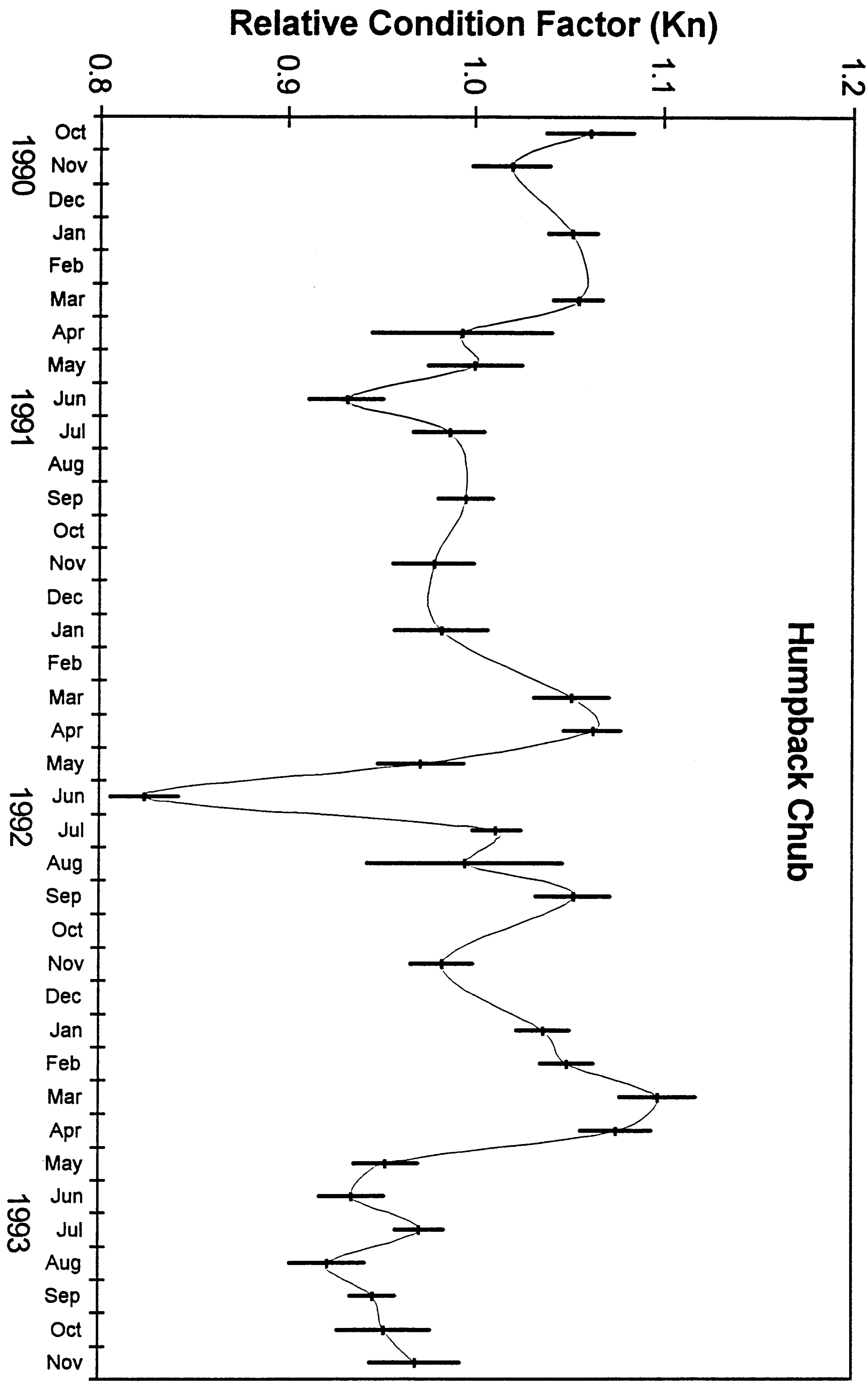

1990-91
log10 W= -5.046+2.9871 log10 (TL)
R² = 0.99
n= 870
Weight (g)
Total Length (mm)
1992
log10 W= -5.155+3.053 log10 (TL)
R² = 0.99
n= 974
Weight (g)
Total Length (mm)
1993
log10 W= -5.301+3.1165 log10 (TL)
R² = 0.98
n= 2853
Weight (g)
Total Length (mm)

FIG. 6-9

FIG. 6-10


Relative Condition Factor (Kn)
0.8
0.9
1.0
1.1
1.2
Humpback Chub
1990
1991
1992
1993
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

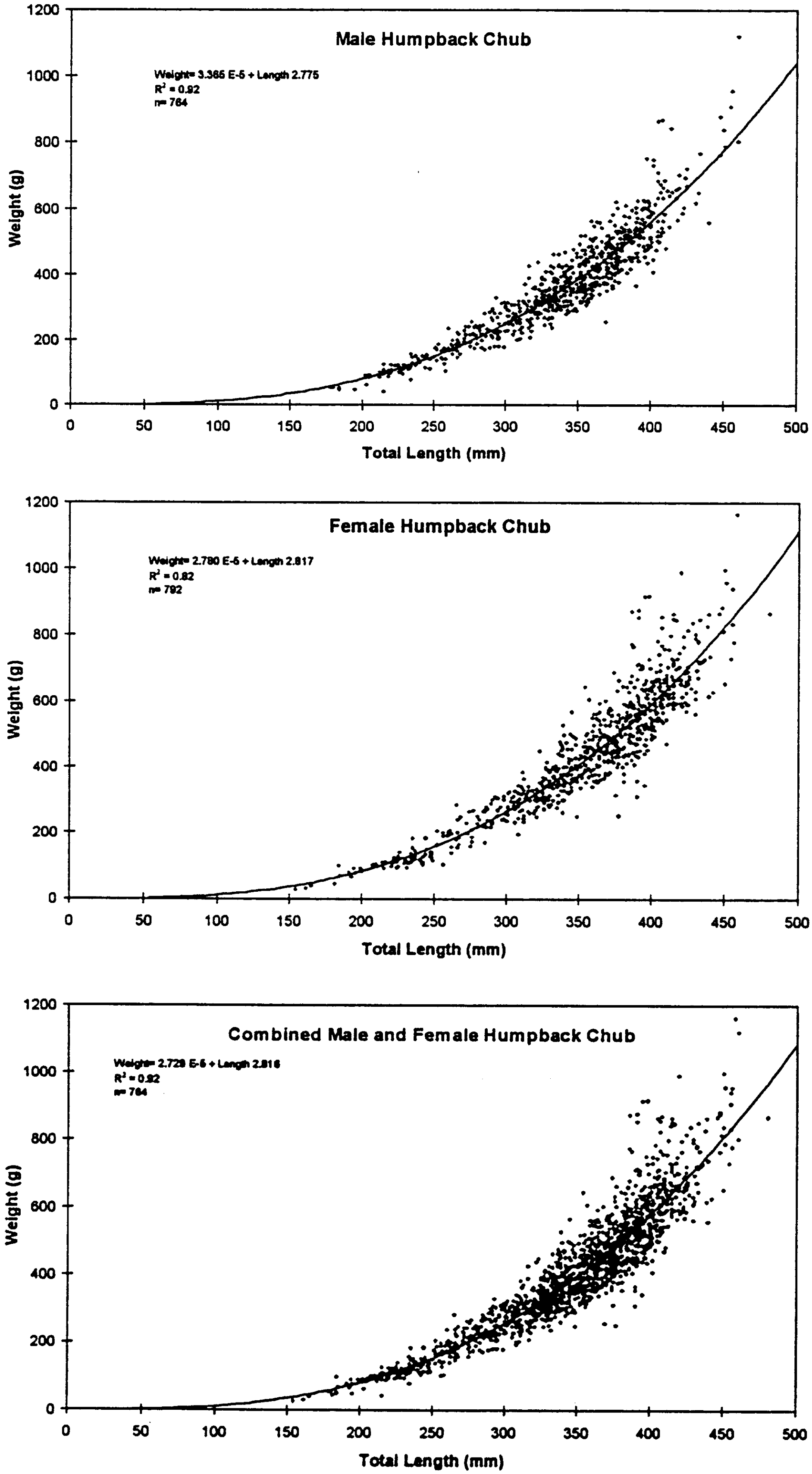

Male Humpback Chub
Weight= 3.365 E-6 + Length 2.775
R^2 = 0.92
n= 764
Weight (g)
Total Length (mm)
Female Humpback Chub
Weight= 2.780 E-6 + Length 2.817
R^2 = 0.82
n= 792
Weight (g)
Total Length (mm)
Combined Male and Female Humpback Chub
Weight= 2.729 E-6 + Length 2.816
R^2 = 0.92
n= 764
Weight (g)
Total Length (mm)

FIG. 6-11

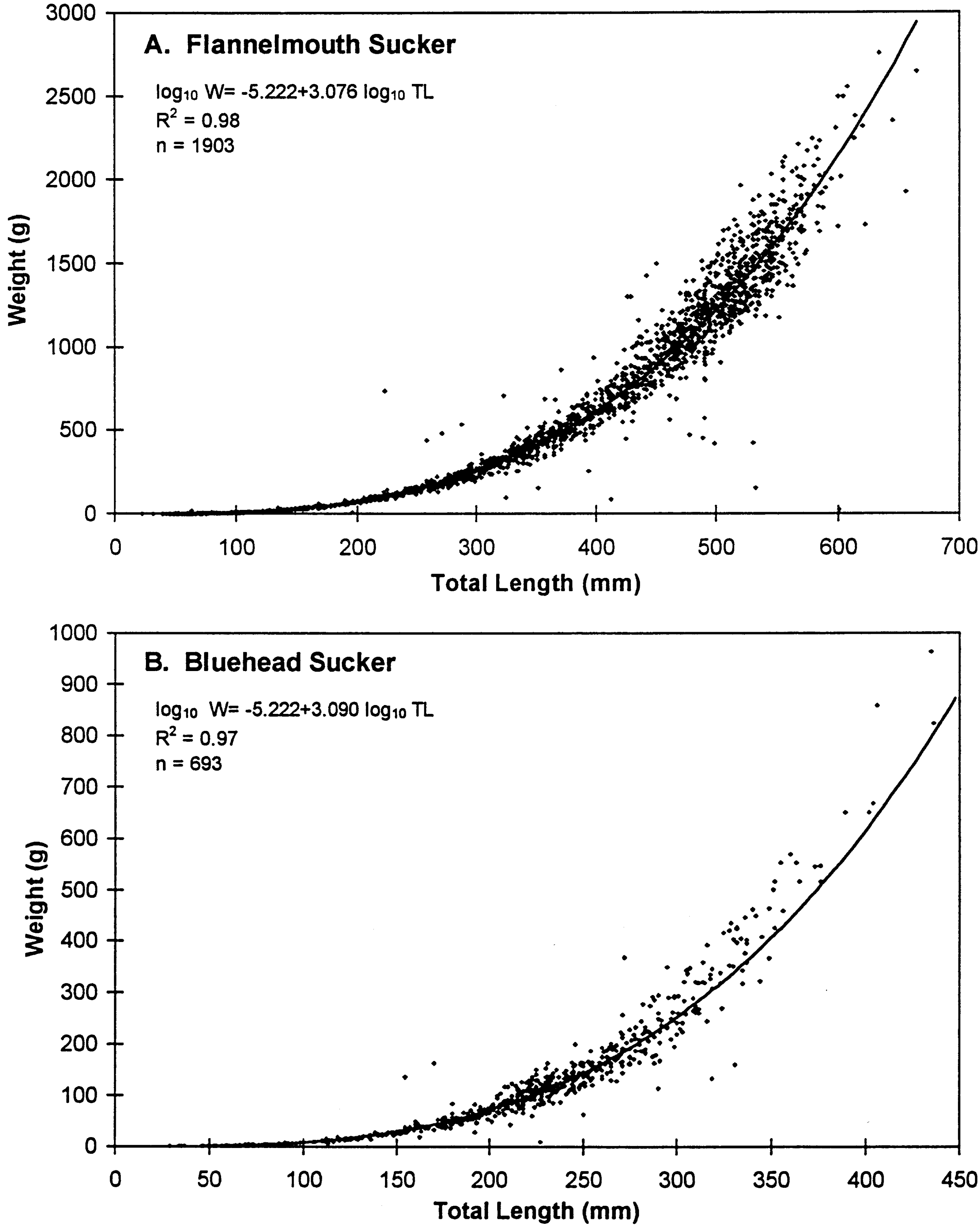
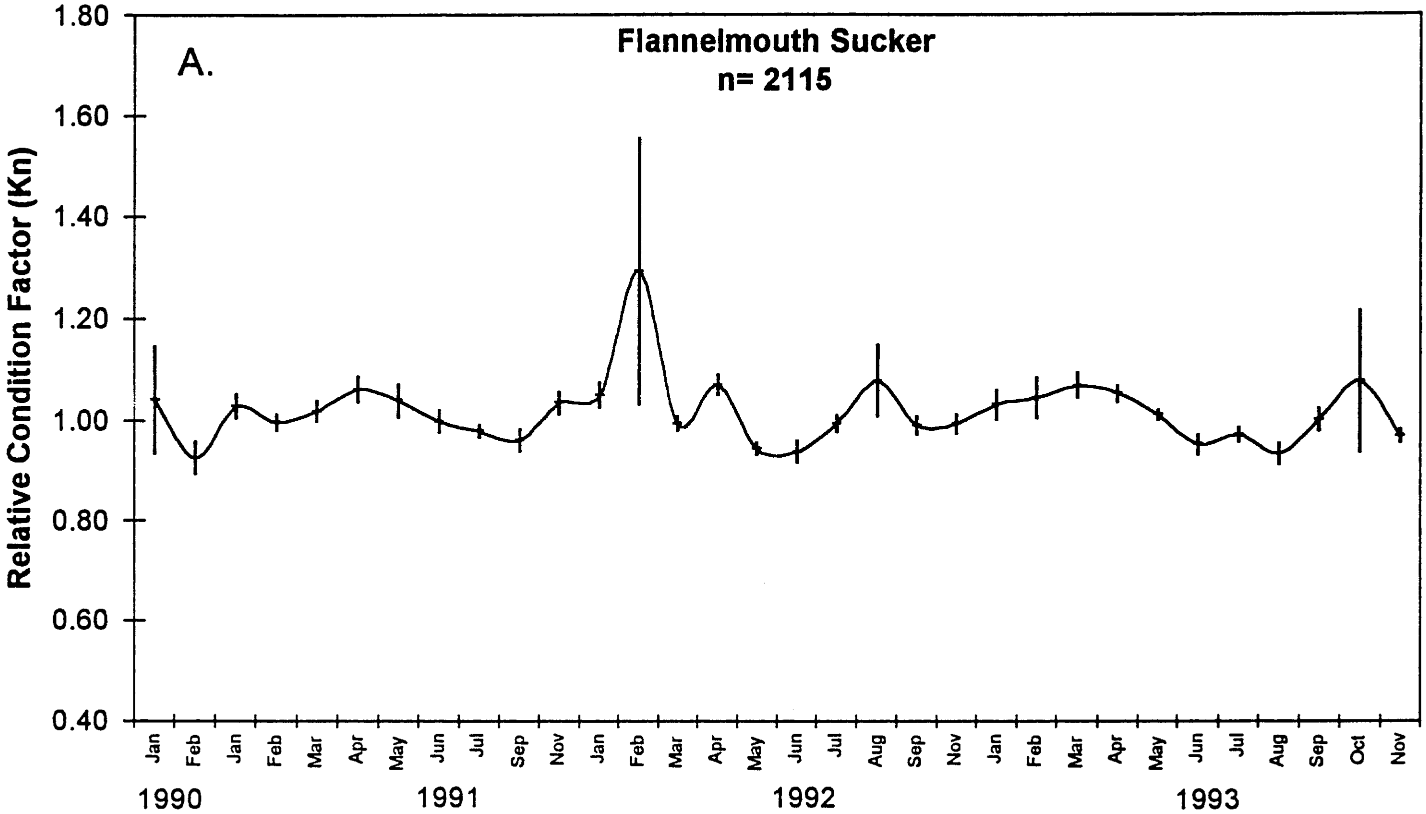

3000
2500
2000
1500
1000
500
0
Weight (g)
A. Flannelmouth Sucker
log10 W= -5.222+3.076 log10 TL
R2 = 0.98
n = 1903
0
100
200
300
400
500
600
700
Total Length (mm)
1000
900
800
700
600
500
400
300
200
100
0
Weight (g)
B. Bluehead Sucker
log10 W= -5.222+3.090 log10 TL
R2 = 0.97
n = 693
0
50
100
150
200
250
300
350
400
450
Total Length (mm)

FIG. 6-12


A.
Flannelmouth Sucker
n= 2115
Relative Condition Factor (Kn)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
Jan Feb Jan Feb Mar Apr May Jun Jul Sep Nov Jan Feb Mar Apr May Jun Jul Aug Sep Nov Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
1990
1991
1992
1993

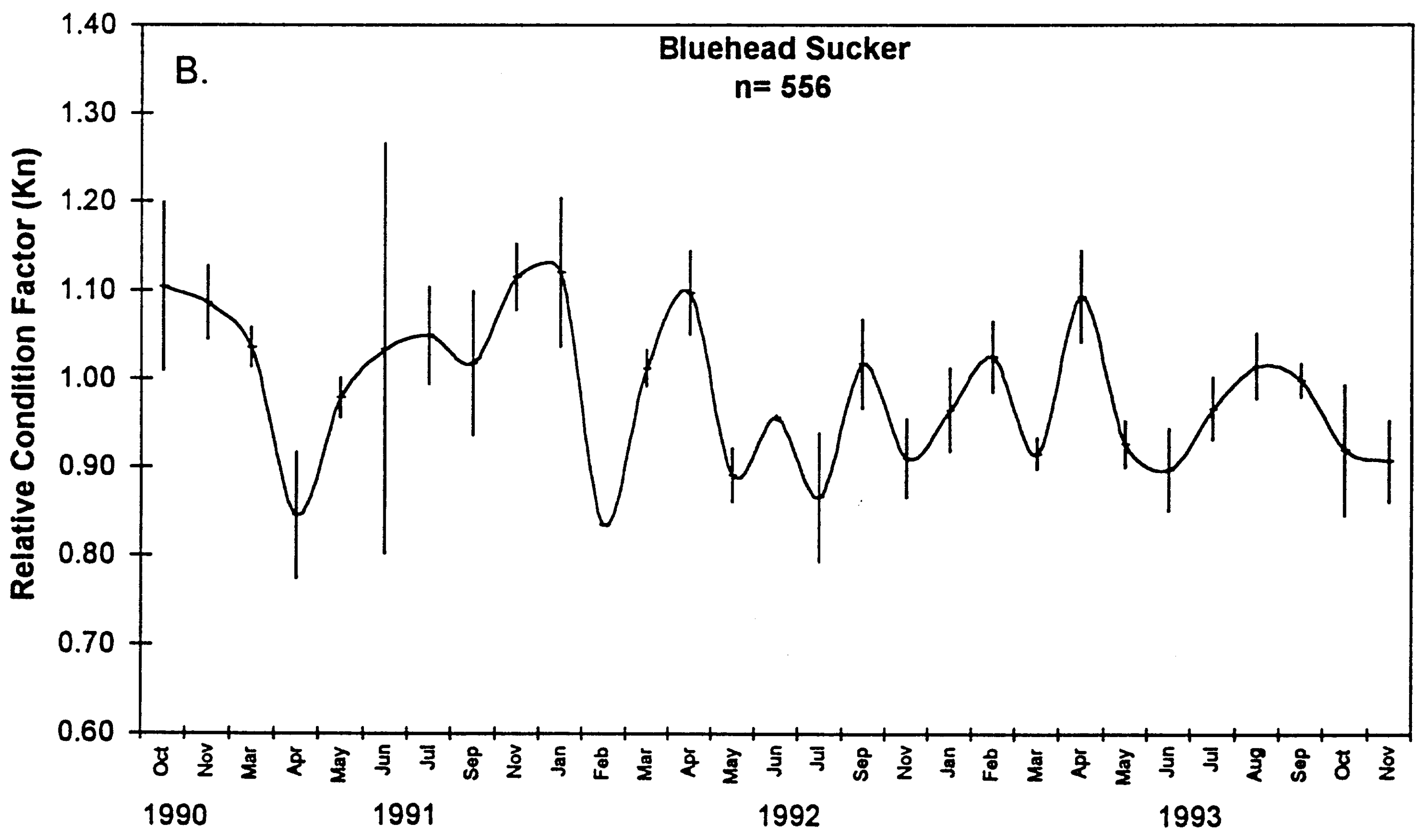
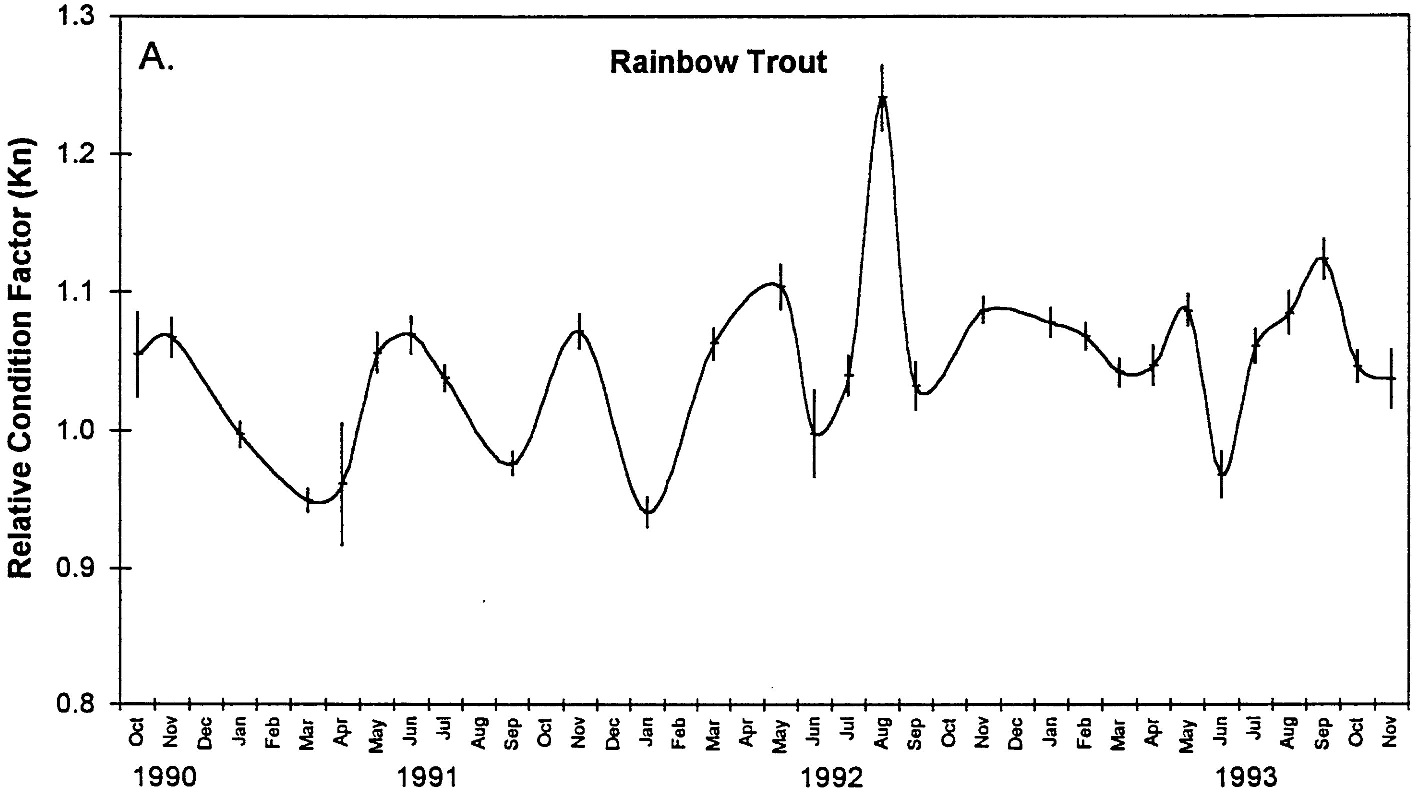

B.
Bluehead Sucker
n= 556
Relative Condition Factor (Kn)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
Oct Nov Mar Apr May Jun Jul Sep Nov Jan Feb Mar Apr May Jun Jul Sep Nov Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
1990
1991
1992
1993

FIG. 6-13


1.3
A.
Rainbow Trout
1.2
Relative Condition Factor (Kn)
1.1
1.0
0.9
0.8
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
1990
1991
1992
1993

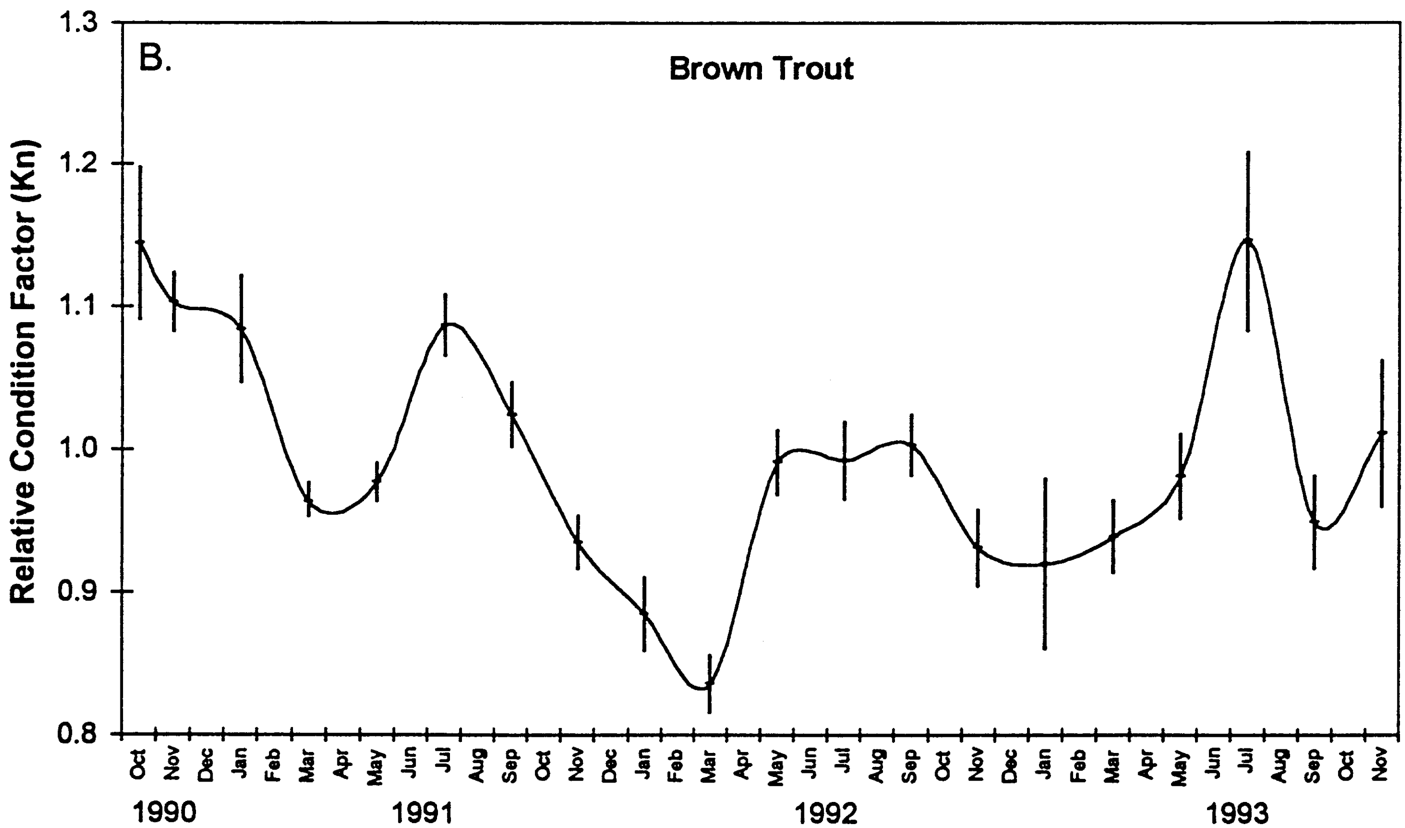
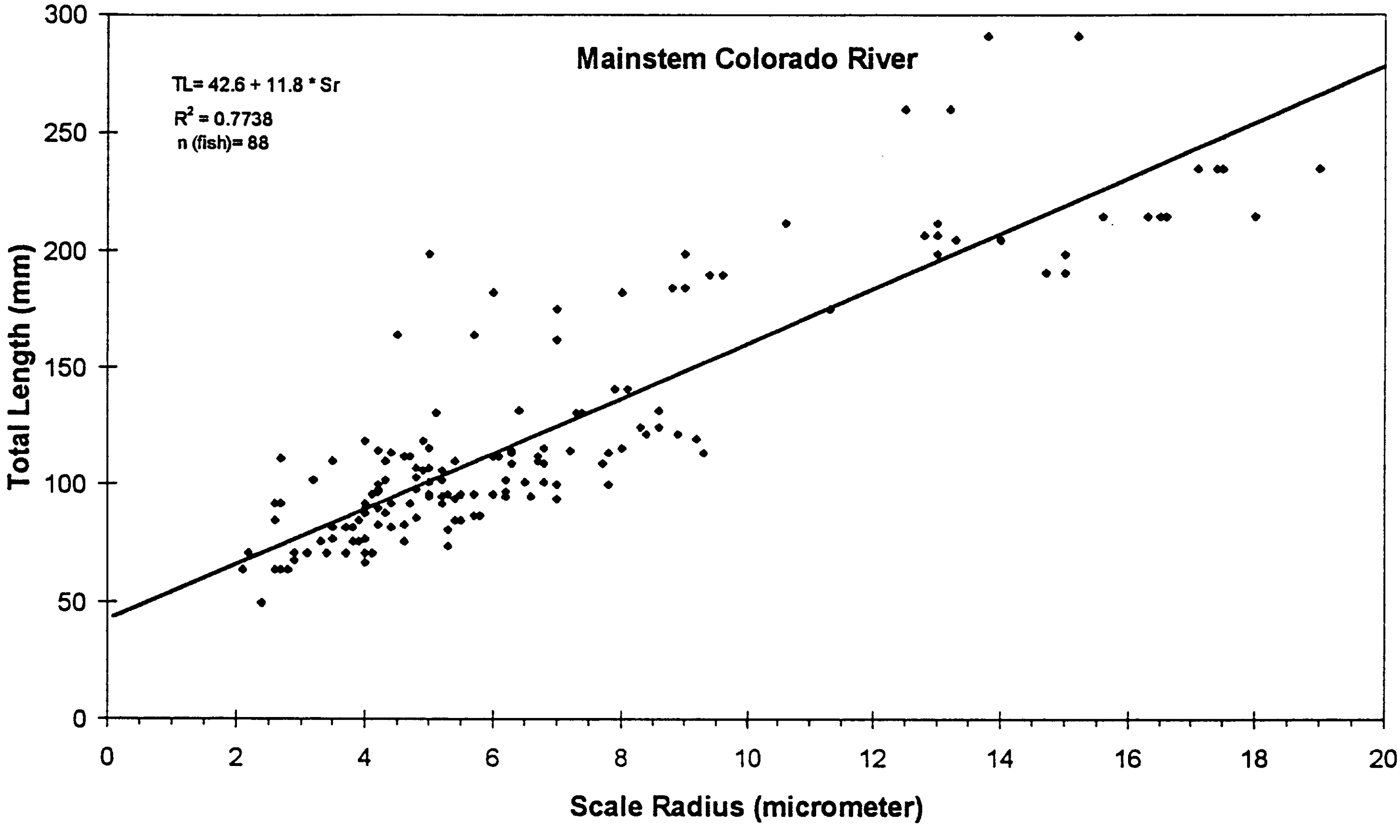

1.3
B.
Brown Trout
1.2
Relative Condition Factor (Kn)
1.1
1.0
0.9
0.8
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov
1990
1991
1992
1993

FIG 6-13


Mainstem Colorado River
TL= 42.6 + 11.8 * Sr
R² = 0.7738
n (fish)= 88
Total Length (mm)
Scale Radius (micrometer)
0
50
100
150
200
250
300
0
2
4
6
8
10
12
14
16
18
20

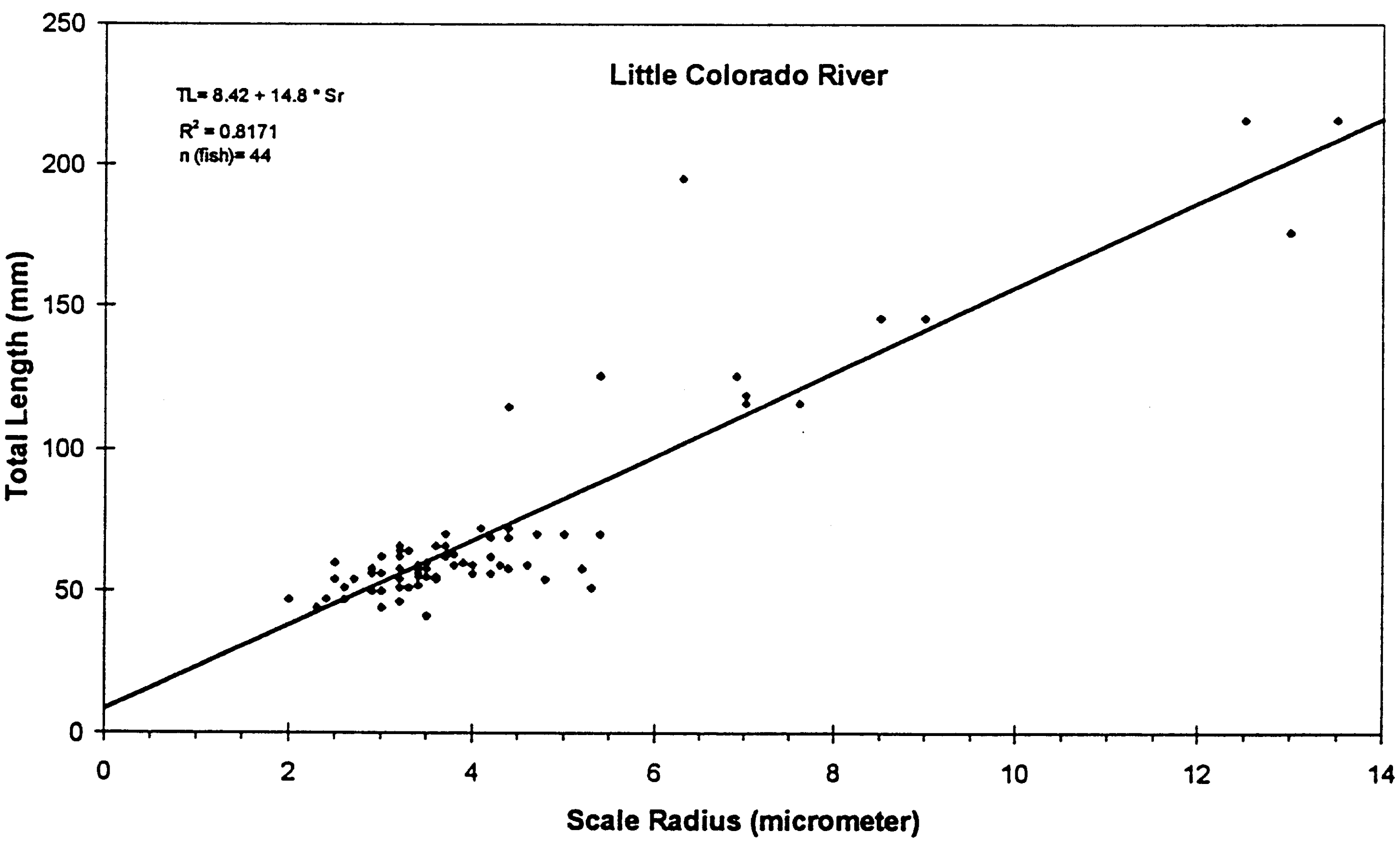
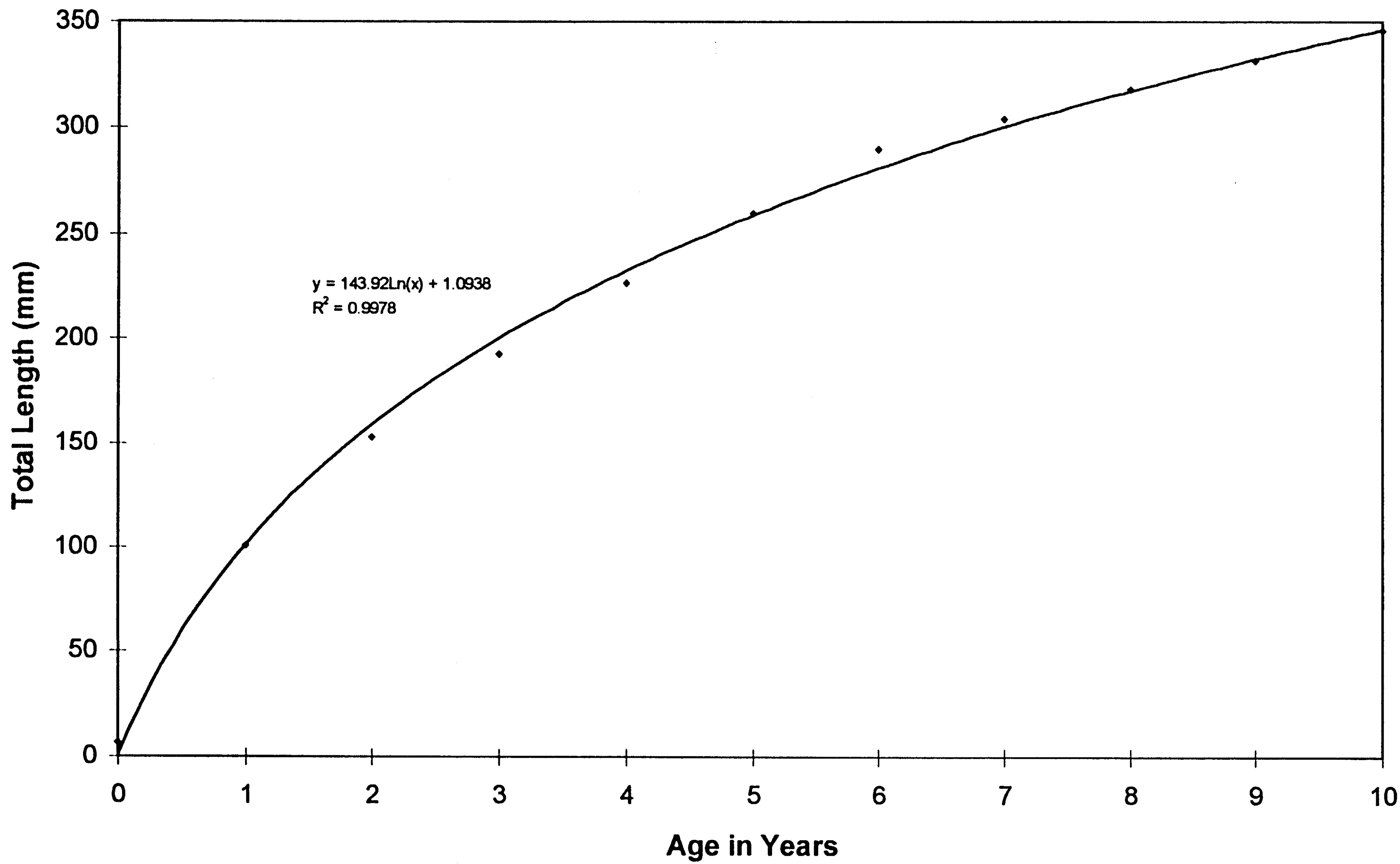
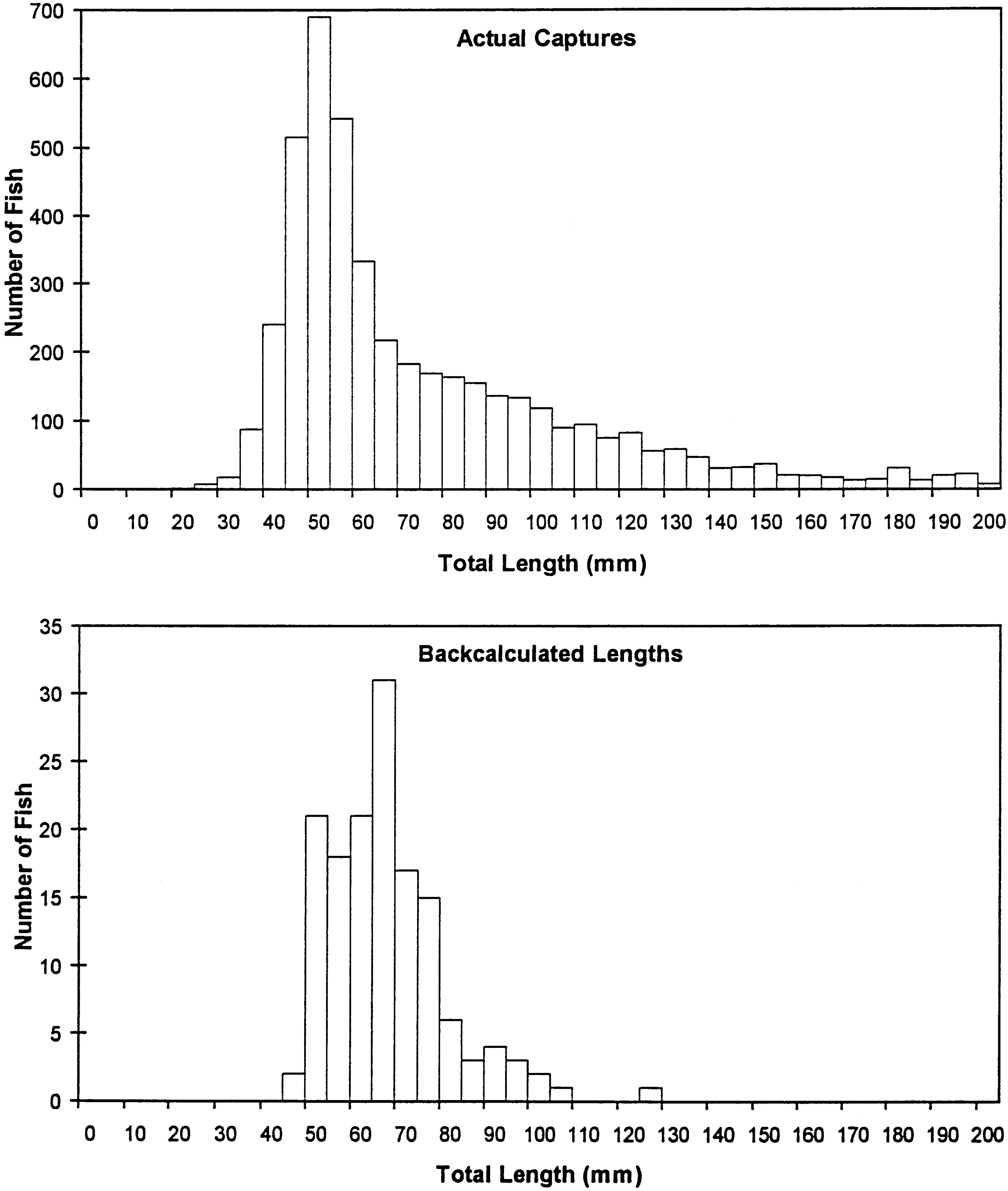

Little Colorado River
TL= 8.42 + 14.8 * Sr
R² = 0.8171
n (fish)= 44
Total Length (mm)
Scale Radius (micrometer)
0
50
100
150
200
250
0
2
4
6
8
10
12
14

FIG. 6-15



Total Length (mm)
350
300
250
200
150
100
50
0
y = 143.92Ln(x) + 1.0938
R2 = 0.9978
0
1
2
3
4
5
6
7
8
9
10
Age in Years

FIG. 6-16



Actual Captures
Number of Fish
0
100
200
300
400
500
600
700
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Total Length (mm)
Backcalculated Lengths
Number of Fish
0
5
10
15
20
25
30
35
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Total Length (mm)

FIG. 6-17

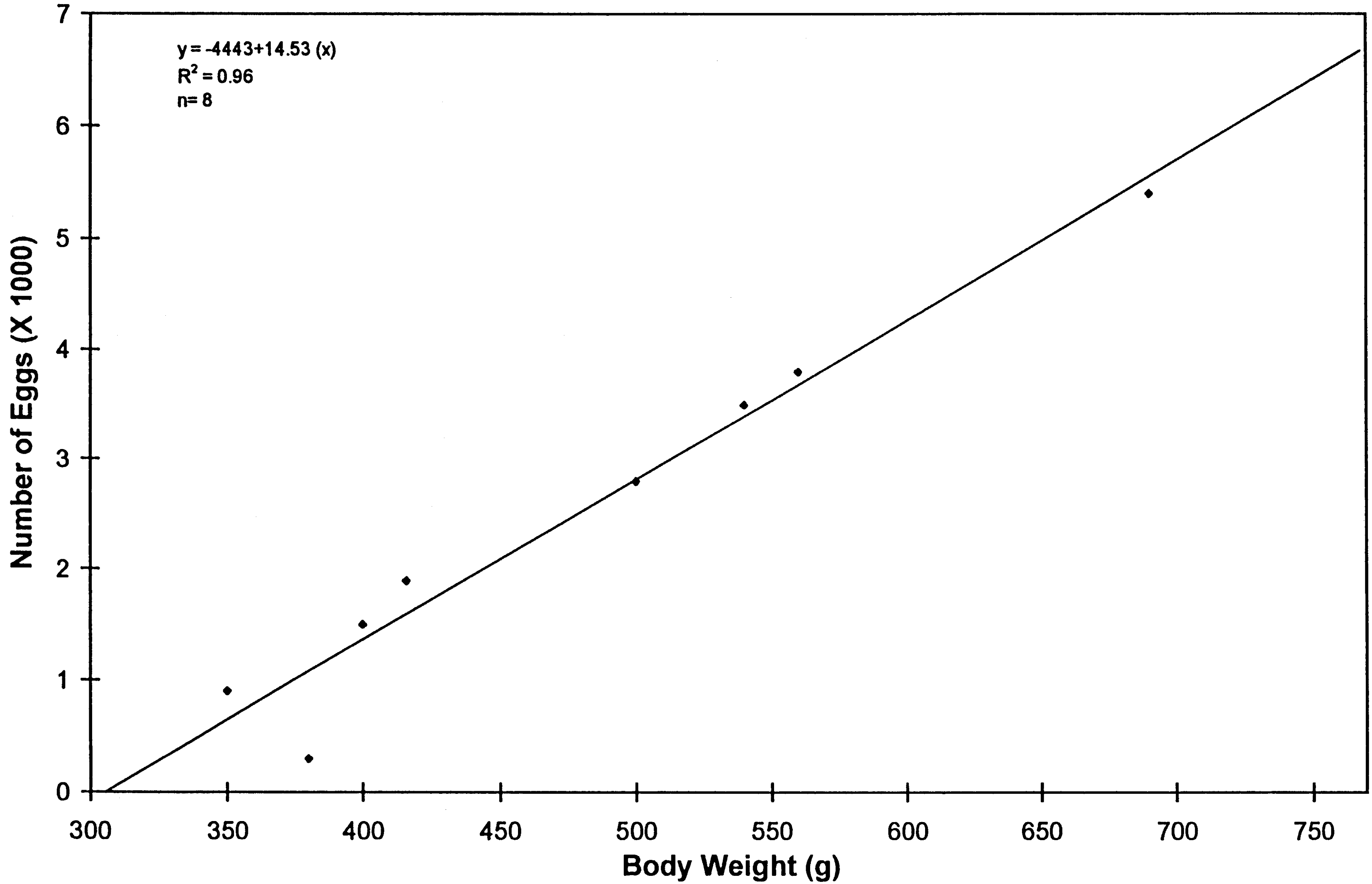
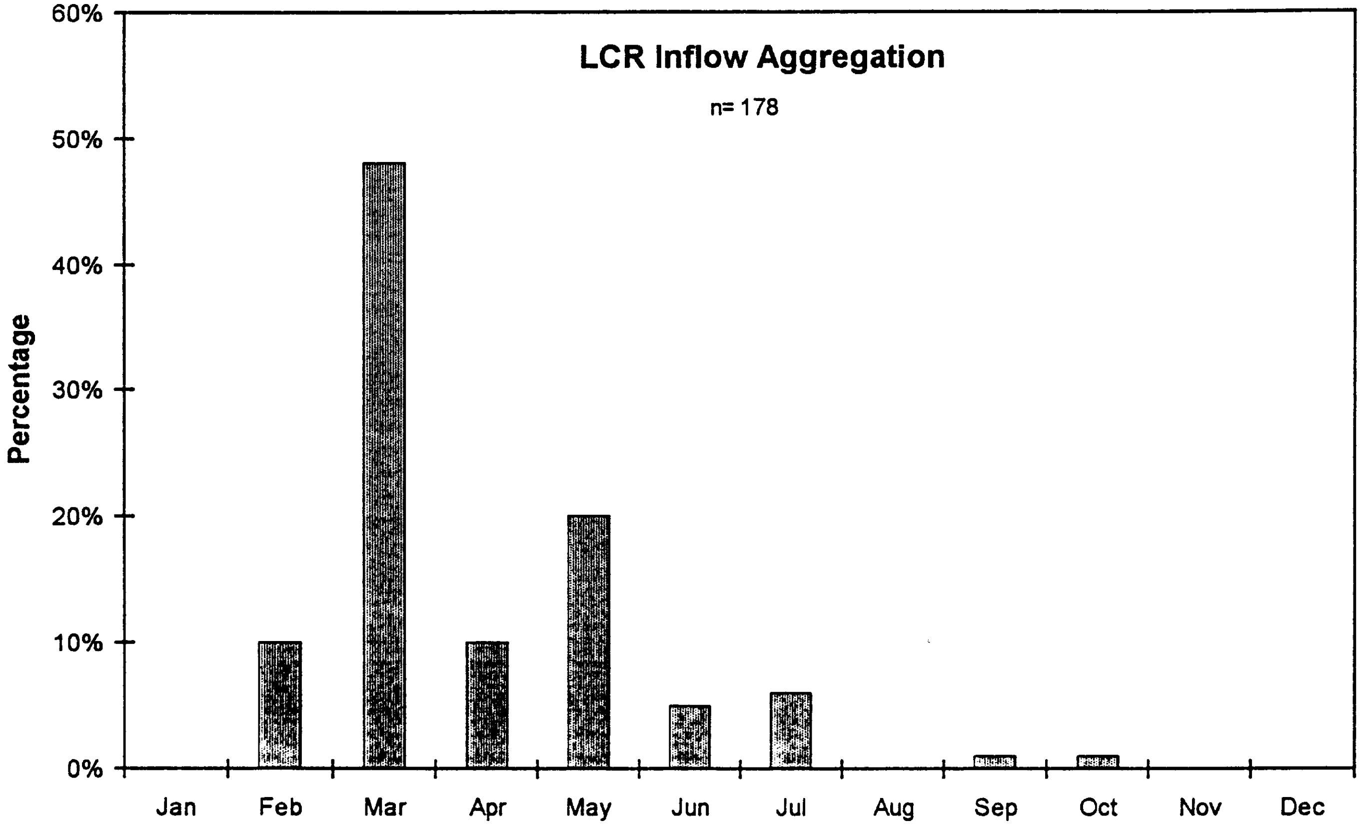

y = -4443+14.53 (x)
R2 = 0.96
n= 8
Number of Eggs (X 1000)
0
1
2
3
4
5
6
7
300
350
400
450
500
550
600
650
700
750
Body Weight (g)

FIG. 6-18


LCR Inflow Aggregation
n= 178
Percentage
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

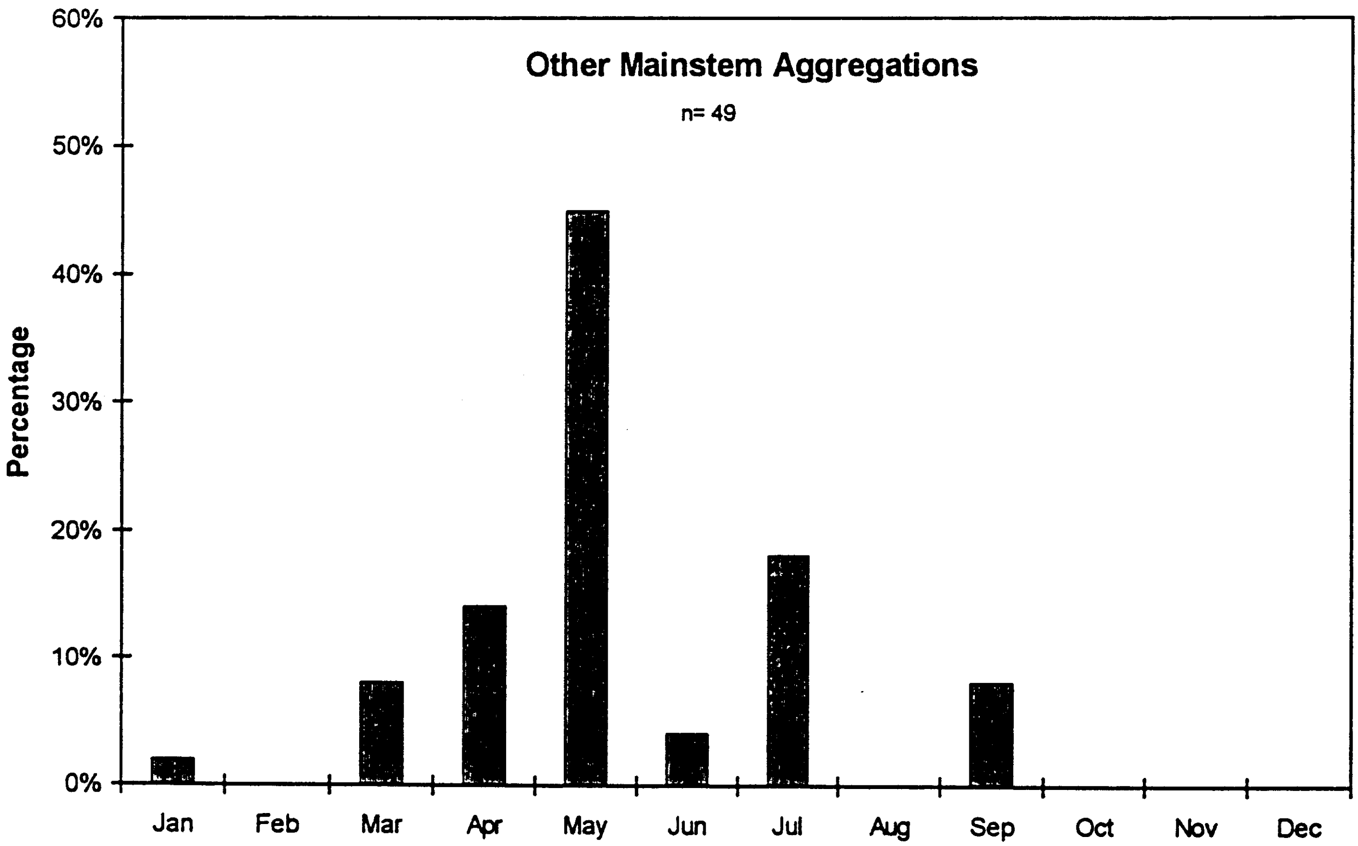

Other Mainstem Aggregations
n= 49
Percentage
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

FIG. 6-19

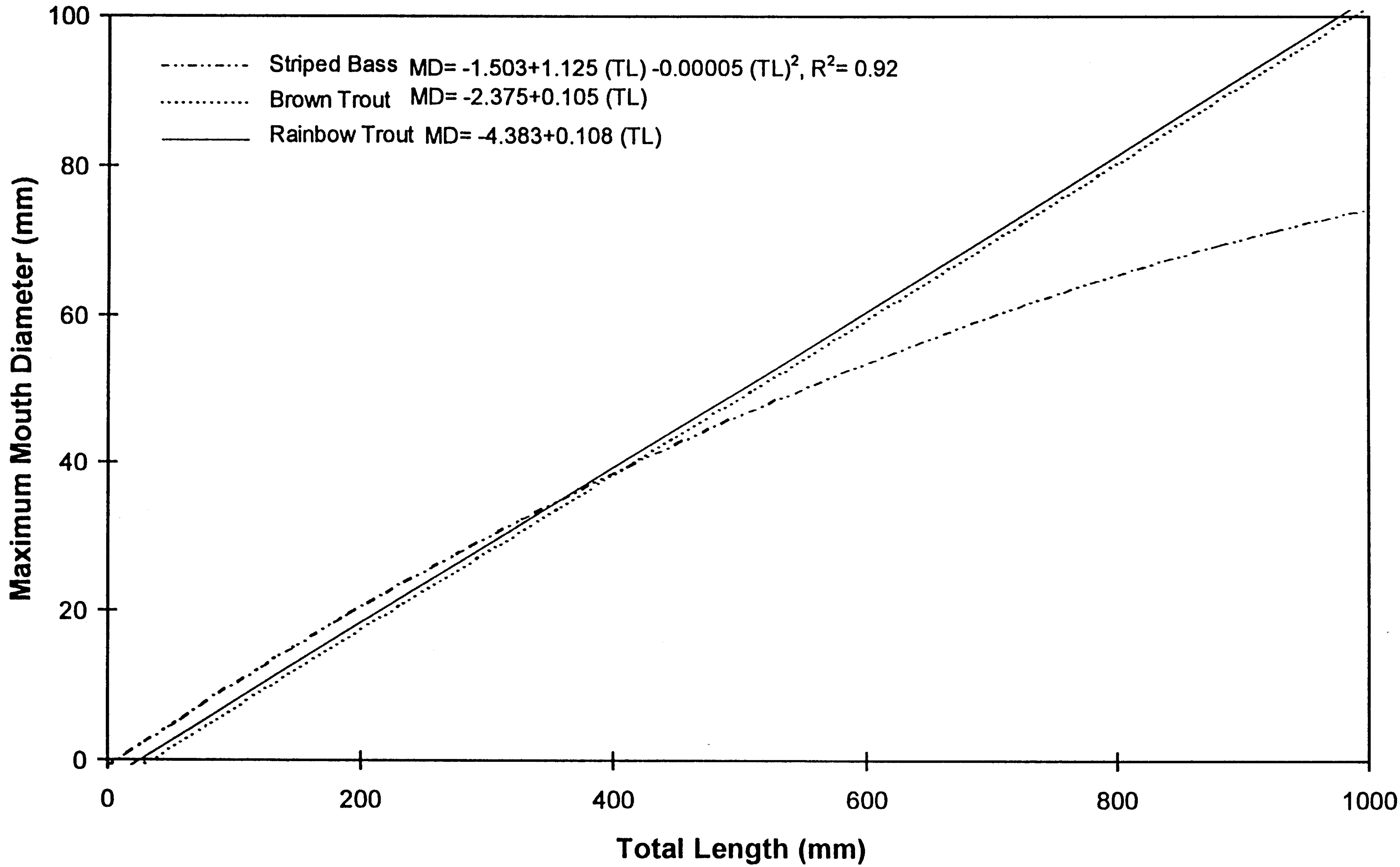
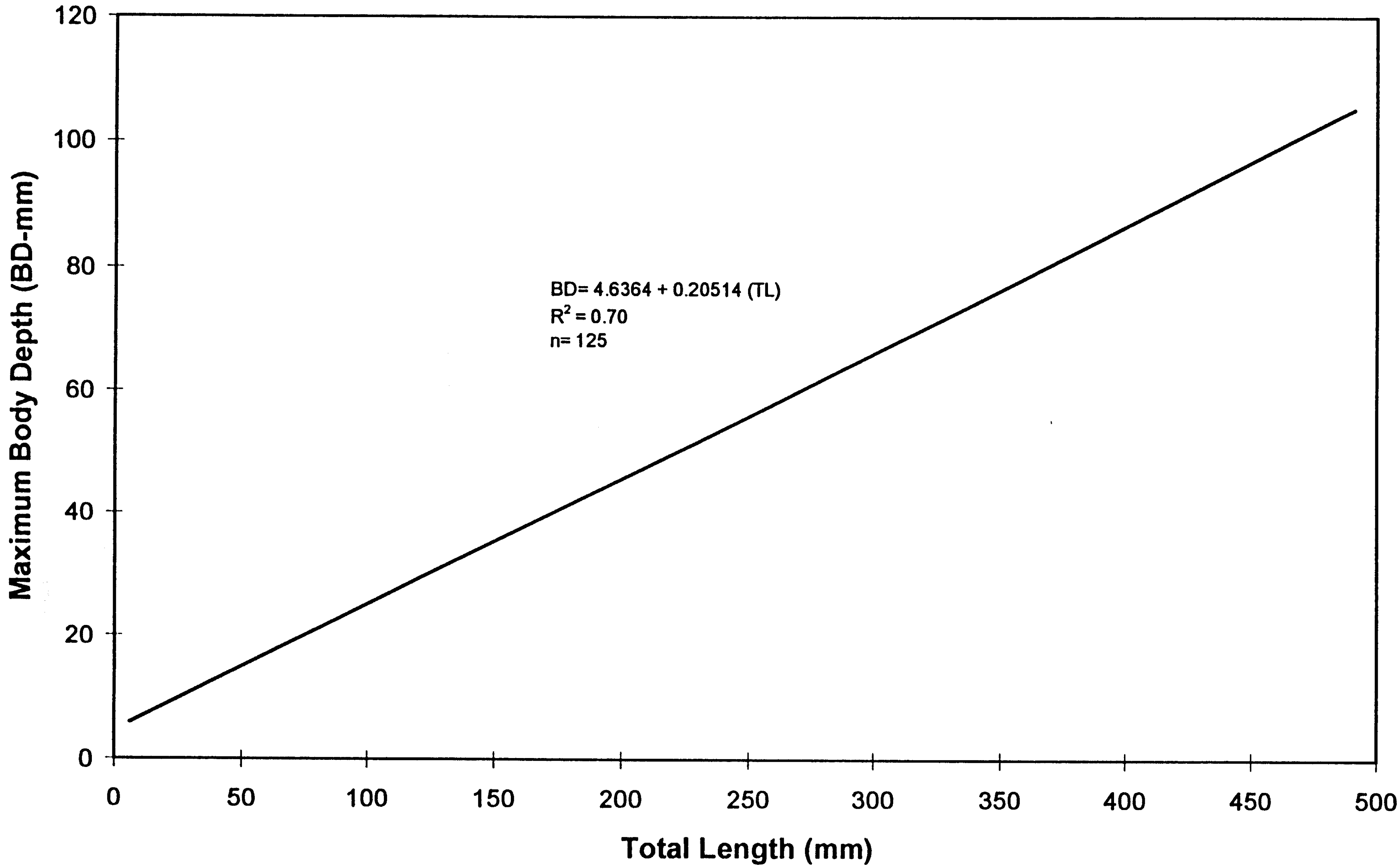
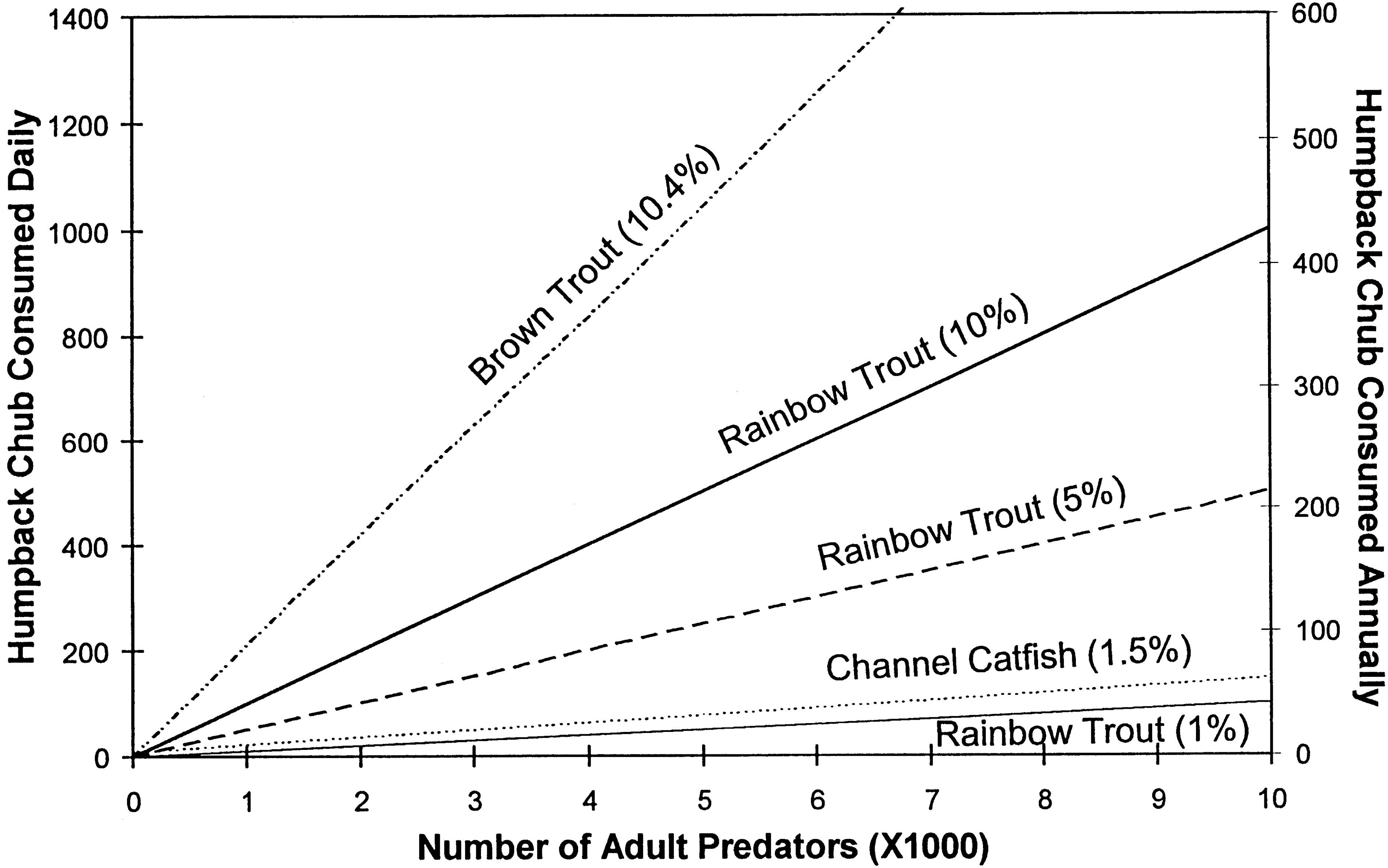

Maximum Mouth Diameter (mm)
Total Length (mm)
Striped Bass MD= -1.503+1.125 (TL) -0.00005 (TL)², R²= 0.92
Brown Trout MD= -2.375+0.105 (TL)
Rainbow Trout MD= -4.383+0.108 (TL)
0
20
40
60
80
100
0
200
400
600
800
1000

FIG. 6-20



Maximum Body Depth (BD-mm)
120
100
80
60
40
20
0
BD= 4.6364 + 0.20514 (TL)
R2 = 0.70
n= 125
0
50
100
150
200
250
300
350
400
450
500
Total Length (mm)

FIG. 6-21



Humpback Chub Consumed Daily
Humpback Chub Consumed Annually
Number of Adult Predators (X1000)
Brown Trout (10.4%)
Rainbow Trout (10%)
Rainbow Trout (5%)
Channel Catfish (1.5%)
Rainbow Trout (1%)
0
200
400
600
800
1000
1200
1400
100
300
500
1
2
3
4
5
6
7
8
9
10

FIG 6-2-2

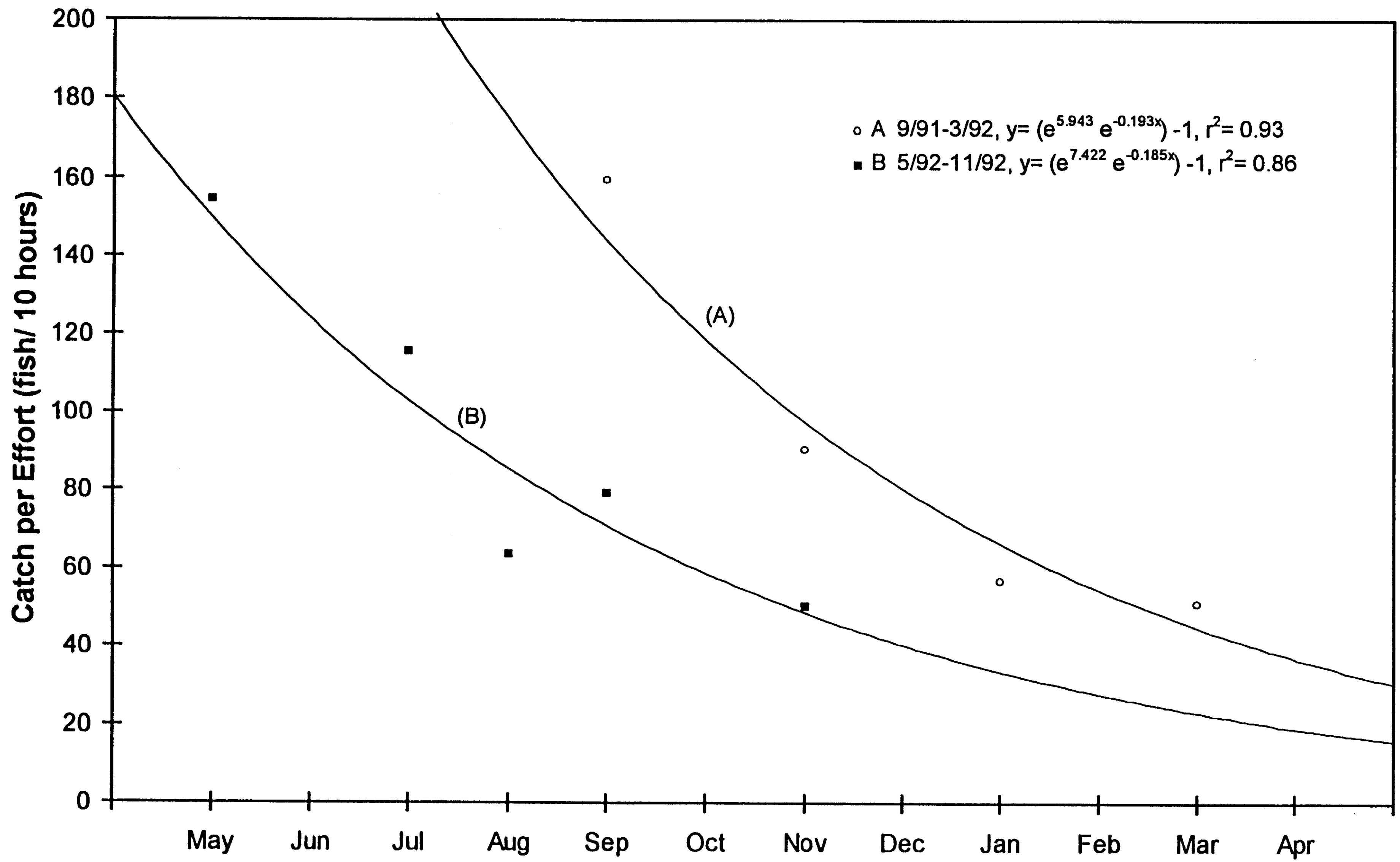

Catch per Effort (fish/ 10 hours)
200
180
160
140
120
100
80
60
40
20
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
(A)
(B)
A 9/91-3/92, y= (e^5.943 e^-0.193x) -1, r^2= 0.93
B 5/92-11/92, y= (e^7.422 e^-0.185x) -1, r^2= 0.86

FIG. 6-23

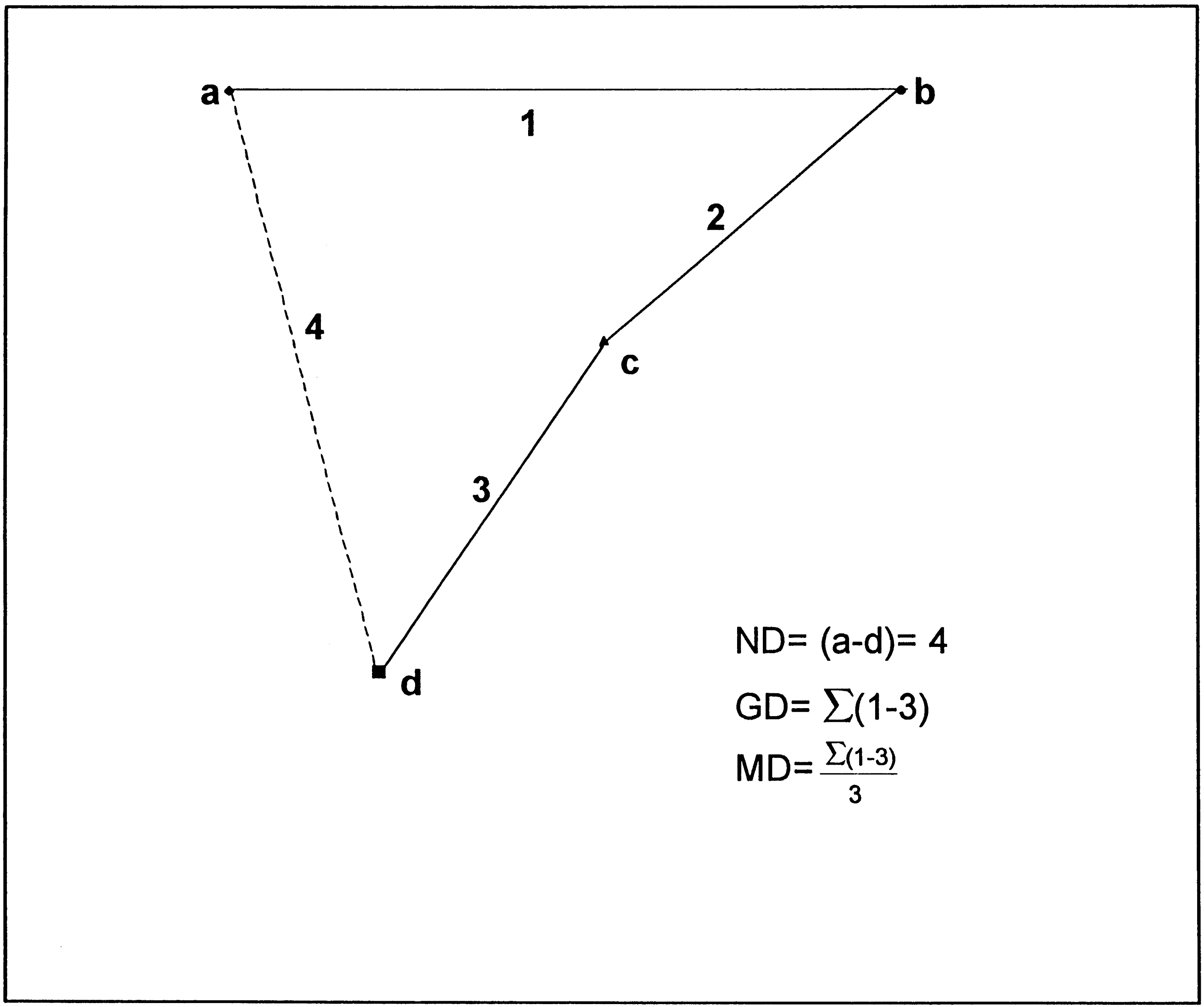


FIG. 8-3

CHAPTER 7 - HABITAT

INTRODUCTION

Habitat of humpback chub has been variously described for each of the six known populations, including Black Rocks and Westwater Canyon (Valdez et al. 1982, Valdez and Clemmer 1982), Cataract Canyon (Valdez et al. 1982, Valdez 1990, Valdez and Williams 1993), Yampa Canyon (Tyus et al. 1982, Karp and Tyus 1990), Desolation/Gray Canyon (Holden 1978, Tyus et al. 1982, Karp and Tyus 1990, Tyus and Karp 1991), and Grand Canyon (Kaeding and Zimmerman 1983, Gorman 1994). Data from the five upper basin populations were assimilated into habitat suitability index (HSI) curves for four age categories, including larvae, young-of-year (YOY), juvenile, and adult (Valdez et al. 1990). These HSI curves were developed by consensus of species experts, using professional opinion where little or no quantitative data existed. A paucity of quantitative habitat information and lack of flow to habitat relationships severely limit evaluating effects of altered flow regimes on the species. Because deep, swift, and turbid canyon regions used by the species preclude direct observations of individuals, accurate evaluation of habitat parameters is not effectively done with radiotelemetry (Valdez and Nilson 1981, Valdez and Clemmer 1982, Valdez et al. 1993), as in this investigation.

Fish habitat is the sum of physical, chemical, and biological elements that surround a fish throughout its life (Hynes 1970, Olsen et al. 1981, Lotspeich and Platts 1982, Orth 1983, and references cited therein). Fish habitat is determined by water quality and quantity, channel geomorphology (i.e., size, shape, substrate type), and associated life forms (i.e., plants, macroinvertebrates, other fish). Given a variety of choices, fish of a given species and age frequently select similar sites that best meet immediate needs for resting, feeding, spawning, and escape cover.

Changes in stream flow have short and long-term effects on fish habitat. Increased or reduced flow volume often results in immediate changes in water depth or velocity, or both, that may violate habitat needs, forcing fish to seek other sites or occupy less desirable ones. Flow patterns also have long-term effects on fish habitat by reshaping channel features and contours, thus affecting relational current patterns and juxtaposition of habitat parameters.

Flow patterns in most streams, particularly western rivers, are naturally dynamic and seasonal habitat changes are common. However, effects of characteristic daily fluctuations from mainstem hydropower production facilities, such as Glen Canyon Dam, on aquatic ecosystems are not well understood (Stanford 1994). Daily changes in habitat components, that occur more frequently than natural flows may result in greater energy expenditure by fish or greater exposure to predation.

The relationship of flow to habitat is determined by channel size and shape, and appears to be unique for a given reach of river. In the upper Colorado River, surficial area of fish habitat remained relatively constant at base and midrange flows, but dramatically changed in a threshold response to small increases at higher flows (Carter et al. 1985). Small changes in river volume may have a greater affect on fish habitat than large changes, and these relationships must be understood for particular rivers and regions affected by mainstem facilities such as Glen Canyon Dam.

METHODS

A standard system of habitat nomenclature is not available for large western streams, such as the mainstem Colorado River, although several habitat classification systems have been developed for salmonids in small streams (Bisson et al. 1982, 1988, Sullivan 1986, Hawkins et al. 1993). While a common assemblage of terms continues to be used by various investigators in the Colorado River (Valdez and Wick 1983, Tyus 1984, Kaeding and Osmundson 1989, Harvey et al. 1993, Stanford 1994), a general habitat classification system is needed to establish a standard frame of reference to facilitate communications among researchers and managers (Hawkins et al. 1993), and to provide integrative and comparative data analyses.

This chapter describes a classification system proposed for fish habitat in the Colorado River in Grand Canyon. The system is based on geologic formative processes, and was designed to integrate with existing descriptors of channel geomorphology in order to better describe the greater Grand Canyon ecosystem. This habitat classification system is based on the hypothesis that predominant shoreline geology and channel geomorphology change longitudinally, and determine hydraulic characteristics and thus, interrelationships of cover, substrate, depth, and velocity of fish habitat. These characteristics were identified at four levels of resolution, including geomorphic reaches, shoreline types, hydraulic units, and microhabitat parameters (Fig. 7-1). The first level consists of geomorphic reaches consistent with the designations of Schmidt and Graf (1988), and subsequent levels are embedded, i.e., 4 microhabitat parameters within each hydraulic unit, 8 hydraulic units within each shoreline type, and 8 shoreline types within each geomorphic reach. Only selected portions of this classification system were evaluated, primarily because of lack of suitable data to evaluate all possible combinations. This system was used to describe habitat availability and use of humpback chub in the Colorado River in Grand Canyon, primarily subadults along shorelines, and adults in offshore and nearshore habitats. Similar habitat classifications were used by Anderson et al. (1986), with video imagery, to analyze aquatic habitat for low and high flows of the Colorado River in Grand Canyon.

Habitat Availability

Habitat availability in select areas of the Colorado River in Grand Canyon was determined from (1) surficial habitat and shoreline maps, (2) two- and three-dimensional bathymetry, (3) velocity isopleths, (4) temperature isopleths, (5) substrate maps, and (6) shoreline microhabitat measurements. Map products (1) through (5) were incorporated into the GCES Geographic Information System (GIS) developed for resource monitoring on the Colorado River in Grand Canyon (Werth et al. 1993). Shoreline microhabitat measurements were integrated into a fisheries database and stored in dBASE IV. Each map product was referenced to an established control network for use as informational layers on the GIS. A multi-temporal, multi-accuracy GIS database was developed to accommodate the different data types and accuracies associated with these maps (Hougaard and Valdez 1994).

Level 1: Geomorphic Reach

Reach Morphology

The 11 geomorphic reaches described by Schmidt and Graf (1988, 1990) were the basis for longitudinal comparisons of fish populations and habitat. Reach characteristics, including major geologic units at river level, width to depth ratio, channel width, channel slope, and bed composition (Table 1-2) were evaluated to identify major geomorphic attributes that may determine longitudinal fish distribution. Recognized distribution and aggregations of humpback chub were used to identify specific river subreaches for determining reach selection. Number of debris fans, slope, and average width to depth ratio were compared for the two largest aggregations (LCR Inflow and Middle Granite Gorge), and for a third subreach with few fish. Detailed characteristics of selected areas of river channel in the Furnace Flats Reach (near the LCR inflow) were also described with depth bathymetry, velocity and temperature isopleths, and substrate polygons to more comprehensively describe portions of the river channel selected by radiotagged adult humpback chub.

Two- And Three-Dimensional Bathymetry

The Super-Hydro bathymetric mapping system was used to map underwater topography of the mainstem Colorado River in Grand Canyon (F. Protiva, M. Gonzales, GCES, pers. comm.), and presented as two-dimensional isopleths or three-dimensional bathymetry. Bathymetry maps were developed for five sites with high use by humpback chub (Fig. 7-2), including (A) Awatubi Canyon, RM 58.5, (B) 60-Mile Canyon, RM 60.1, (C) ESPN Rock, RM 60.8, (D) LCR Inflow, RM 61.3, and (E) Carbon Creek, RM 64.7.

The Super-Hydro system consisted of a shore station, located by coordinates with the aid of an Ashtech Global Positioning System (GPS), to track and send position information to a main computer located on a boat. The boat computer used a graphics screen to guide the helmsman along a pre-determined sampling pattern of transects set 10 m apart. Survey readings, including distance and angle, were taken with the aid of a prism on the traversing boat, and simultaneous to measurements of depth (using a Lowrance depth sonar) and velocity (using a Marsh-McBirney current meter). Data point collection interval for depth was adjustable, from once every 2 sec to 4 points/sec. Over 10,000 points were collected to develop a bathymetric map for the LCR site (1.6 km distance of river). Elevational starting points for each map were based on a local coordinate system above the high water line in order to reliably reestablish control points and allow for future resurveys.

Field information was stored on the main computer, and transferred to GCES for processing, and plotting. Data processing included editing erroneous points, generating a database from surveyed points, visual reality check of data points, depth reductions to relative elevation, generation of a surface model, and orientation to established network coordinate points (Werth, et al. 1993). Bathymetric plots were generated with contour intervals of 0.5 m (consistent with GCES/GIS).

Velocity Isopleths

Velocity isopleths were developed with the aid of the Super-Hydro for two sites (Fig. 7-2), including ESPN Rock (RM 60.8) and Carbon Creek (RM 64.7). Velocity was measured 1 m below the water surface with a Marsh-McBirney current meter, and recorded simultaneous to depth readings. Temperature in degrees Celsius was plotted with contour intervals of 0.1 m/sec.

The velocity plots were considered inaccurate, because (1) river flow changed by nearly 8,000 cfs during the 5 h required to collect the field data, and (2) multi-directional velocity shears often occurred in a single vertical transect, even at constant flow. Nevertheless, the velocity plots were included in this report to provide a perspective of velocity magnitude, and distribution and location of high and low velocity zones, relative to channel morphology.

Temperature Isopleths

Thermal isopleths of the LCR inflow were developed from water temperature data collected with hand-held thermometers over a series of points located by a latice grid system. Data were collected May 16, 20, and 21, and July 21, 22, 23, 24, and 25, 1992, and assimilated by four mainstem flow ranges, including (1) 9200-9600 cfs, (2) 12,130-12,809 cfs, (3) 13,947-14,504 cfs, and (4) 17,470-17,798 cfs. Flow of the LCR was approximately 230 cfs during each measurement. Thermal isopleths were plotted at 0.5°C intervals over a corresponding bathymetry map with 2.0-m contour intervals.

Substrate Maps

Substrate of the LCR inflow was delineated with the aid of the Super-Hydro, simultaneous to development of bathymetry maps. Observers from the tracking boat or wading in shallow areas, classified substrate according to a modification of the Wentworth system (Table 7-1). Substrate was segregated as a separate layer of the GIS, and surficial area of each type determined in square meters.

Level 2: Shoreline Type

Shoreline types were classified to reflect predominant formative shoreline geology, and included bedrock, cobble bar, debris fan, sand bar, talus slope, and vegetation (Table 7-2, Fig. 7-3). This classification was similar to that used by Werth et al. (1993), except that rock ledge and rock face were combined as bedrock, and alluvial fan was termed debris fan. This shoreline classification was part of the overall spatial sampling design for this investigation (See Chapter 2 - SAMPLING DESIGN), and was based on geomorphic processes, which have the greatest influence on size, shape, and transposition of shoreline material, and thus fish habitat. For example, cobble is material worked by river processes that is typically rounded and embedded, while talus is typically angular and formed from shoreline rockfalls and slides, providing more irregular surfaces and sheltered, low-velocity interstitial spaces.

Shoreline types were delineated at various flows simultaneous to macrohabitat types at seven map sites, as described in the following section entitled Level 3: Hydraulic Unit. Shoreline typing and macrohabitat quantification were extended from the LCR inflow (RM 61.3) to Hance Rapid (RM 76.4) to relate longitudinal shoreline geomorphology with occurrence and densities of juvenile humpback chub, and with shoreline microhabitat measurements. These relationships were the subject of a Master's Thesis (Converse 1995), and are described in the section under Habitat Use, entitled Subadult Humpback Chub.

Level 3: Hydraulic Unit

Fish macrohabitat types were classified on the basis of hydraulic characteristics, and included eddy, pool, rapid, return channel, riffle, and run (Table 7-3, Fig. 7-4). These were termed macrohabitats to reflect general areas occupied by fish, and were consistent with terms and definitions adopted by the American Fisheries Society (Helm 1985). This habitat classification system was also consistent with the elements of the GCES/GIS classification scheme for aquatic biology (Werth et al. 1993), and with common usage of terms throughout the Colorado River basin (Tyus et al. 1982, Valdez et al. 1982, Maddux et al. 1987). These hydraulic units reflect areas of differential fish use that are distinguishable at the water's surface, so that changes in surface area reflect changes in flow, and thus effect of dam operations on large hydraulic habitat units.

Twenty-five habitat maps were developed for seven sites in the vicinity of the LCR (Fig. 7-2, Table 7-4) for determination of flow to habitat relationships. These sites were (1) ESPN, RM 60.8-61.0, (2) CAMP, RM 61.0-61.2, (3) LCRI, RM 61.2-61.5, (4) HOPI, RM 62.2-62.4, (5) SALT, RM 62.4-62.6, (6) WHAL, RM 62.6-62.9, and (7) WEEP, RM 63.9-64.2. Aerial photographs at a 1:1200 scale (1 cm = 12 m) were used as base maps to delineate macrohabitats and shoreline types for an area of river about 400 m long at each site. Two to four maps were developed at each site for different flows during interim flow criteria in 1991 and 1992 (See Chapter 3 - HYDROLOGY).

Fish macrohabitat types and shoreline types were simultaneously delineated from visual interpretation on clear acetate overlays on the 1:1200 aerial photographs. Maps were developed by the same observer for each area at as many flows as possible. Visual interpretations of macrohabitats at each site were made from two or three established high shoreline vantage points. Binoculars were used to better define water levels, habitat interfaces, and shoreline types, and all observations were made early and late in the day to minimize solar reflection and water surface disturbances from wind.

Habitat maps were rectified to orthophoto base maps for GCES/GIS monitoring site #5 (Werth et al. 1993), from the LCR to Cardenas (RM 61.3-72). Surficial area of each macrohabitat type in square meters, and linear distance of each shoreline type in meters were determined from the GIS, and related to river flow at the midpoint of habitat map development (habitat maps were developed in 35-60 min). A flow routing model described in Chapter 3 was used to estimate flow at the site at each time (nearest 0.5 h) of map development.

Level 4: Habitat Parameter

Shoreline areas commonly used by juvenile humpback chub were evaluated by six shoreline types to distinguish habitat selection and determine relationships of flow to microhabitat parameters. For each shoreline type, depth, velocity, substrate, and cover were measured and classified at three 1-m intervals from shore, along each of ten parallel transects. Depth was measured with a graduated staff, velocity with a Marsh-McBirney current meter, substrate was classified according to Table 7-1, and cover was classified as instream, lateral, and overhead (Helm 1985). About 85 sites were measured at different flows to evaluate changes in available habitat components within sites and within shoreline types. These sites were also sampled with electrofishing to relate fish density to shoreline type, and to evaluate effects of dam operations on juvenile humpback chub habitat.

Habitat Use

Habitat used by humpback chub and sympatric species in the mainstem Colorado River in Grand Canyon was determined from radiotelemetry and capture information. Radiotagged adults were located and observed as described in Chapter 8 (MOVEMENT), and habitat use was determined as the percentage of radiocontacts in respective macrohabitats, i.e., contact locations were mapped for each of two to four daily boat surveillances through the area occupied by radiotagged fish. Efforts to measure microhabitat (depth, velocity, substrate, cover) of radiotagged adults were abandoned because water depths, channel widths, and high, multi-directional velocities precluded accurate measurements. Macrohabitat of juvenile and YOY humpback chub, and sympatric species, was determined from catch locations associated with electrofishing, nets, seines, minnow traps, and hoop nets. Capture locations of adults were used to supplement and confirm radiotelemetry data, since the latter are generally considered more reliable descriptors of fish habitat (Tyus 19**, Valdez et al. 1990).

Microhabitat of subadult humpback chub (TL<200 mm) was evaluated by shoreline type (Table 7-2) from type-specific electrofishing efforts. Depth, velocity, substrate, and cover were determined from measurements taken along each of ten parallel transects, as previously described in Level 4: Habitat Parameter. Individual capture locations were not used for microhabitat quantification because electrofishing displaced fish from microhabitat sites, as reported by others (Bovee 1986, Valdez et al. 1990). Sampling within specific shoreline types reduced variation of macrohabitat parameter measurements.

RESULTS

Habitat Availability

Level 1: Geomorphic Reach

Reach Morphology

Channel geomorphology and shoreline geology are major determinants of fish habitat characteristics of the Colorado River in Grand Canyon. As the river flows through the Colorado Plateau it encounters successive rock layers of varying hardness. Softer rock strata are less resistant to erosion, allowing the river to widen, while harder, more resistant strata contain the river to a narrower channel. These erosional attributes produce different channel and shoreline morphologies that determine hydraulic and therefore, fish habitat characteristics.

The 11 geomorphic reaches described by Schmidt and Graf (1988, 1990) and presented in Table 1-2 approximately delineate these geologic differences and possibly fish habitat. The widest geomorphic reaches, Lower Marble Canyon and Furnace Flats, with width to depth ratios of 19.1 and 26.6, and average channel widths of 350 and 390 feet, respectively, contained the largest aggregation of humpback chub. Although this aggregation depended on the LCR for spawning, the relatively large numbers of adults in the mainstem were dependent on mainstem habitat, primarily large recirculating eddy complexes below debris fans (See Habitat Use). The major geologic units at river level for these reaches were Muav limestone, Bright Angel shale, Tapeats sandstone, and members of the Unkar group, geology layers of varying resistance that together formed irregular talus shorelines and high frequency of debris fans. The next largest aggregations were found in the Aisles and Middle Granite Gorge reaches, which had similar major geologic units of Tapeats sandstone, members of the Unkar group, and Vishnu Schist, and similar shoreline characteristics.

Other geomorphic reaches were dominated by more resistant geologic units that precluded high frequency of debris fans and expansion areas. Supai Gorge and Redwall Gorge were dominated by relatively resistant limestones, sandstone, and siltstones; Upper Granite Gorge by precambrian Zoraster granite and Vishnu Schist; Muav Gorge by Muav limestone; and Lower Granite Gorge by Vishnu Schist. These reaches contained the narrowest channel widths in which debris fans tended to form rapids instead of expansion zones and large recirculating eddies. Channel slope tended to be greatest in the wider, more erosive reaches, but this attribute failed to clearly delineate channel differences.

Bathymetry, Temperature, and Substrate

Mainstem Colorado River

Bathymetry of four debris fan/expansion zones (Fig. 7-5, Fig. 7-6) showed characteristic topographic features described by Rubin et al. (1990): (1) a main platform, (2) a linear ridge or reattachment bar, (3) an eddy-return channel, and (4) accretionary banks. These features were formed by hydraulic patterns of the associated eddy complex. The main platform was a gentle sloping depositional zone of 0.5-8 m water depth, that changed abruptly to a steep slip face and sand dune at the accretionary bank. Maximum water depth of the scour channel in these expansion areas ranged from 12 m at Carbon Creek (RM 64.7) to 17.5 m at Awatubi Canyon (RM 58.5) (Table 7-5). The recirculation zone and associated features occupied a range of about 30% (60-Mile Canyon) to 50% (Carbon Creek) of the channel expansion area. Linear ridges or reattachment bars were associated with each of the four eddies mapped. The return channel at ESPN Rock was short and associated with the extreme point of the reattachment bar, while the return channel at Carbon Creek was associated with an expansive reattachment bar, and large boulders that modified return channel scour during high flows. The eddy return channels at 60-Mile and Awatubi Canyon were associated with the separation point, indicating a more advanced progression of dunes migrating bankward from the main channel (Rubin et al. 1990).

Velocity isopleths for ESPN Rock and Carbon Creek are included to provide a perspective of velocity regions in the channel (Fig. 7-7). These isopleths reflect a high-velocity scour channel with lower velocity shorelines and recirculation zones. Velocity in the recirculation zones was less than 1 m/sec, and typically less than 0.5 m/sec, and velocity in the midchannel scour zone was 1-3 m/sec. Characteristics of velocity in these eddy complexes were low velocity vortices over corresponding depositional areas, such as the main platform, on the river side of the reattachment bar, and near the separation point. Abrupt changes in velocity occurred at the accretionary banks, from low velocity over the main platform to high velocity at the slip faces of the sand dunes.

Little Colorado River Inflow

The inflow of the LCR into the mainstem Colorado River is one of the most important areas for humpback chub in Grand Canyon. Depth bathymetry (Fig. 7-8) illustrates the geomorphic complexity of the inflow, created primarily by a large cobble/sand island of alluvial material deposited by the LCR. A primary channel scoured through alluvial material left a smaller upstream cobble bar, and a secondary channel was scoured downstream of the deposit. The LCR flowed through the primary channel at base LCR flow and mainstem flow of less than about 15,000 cfs. At mainstem flows greater than 15,000 cfs, base LCR flow was pushed into the secondary channel. The relationship between LCR and mainstem flows, and LCR channel outflow may determine fish use.

The primary channel at low mainstem flow (5000 cfs) and base LCR flow (230 cfs) had a maximum depth of about 1.5 m, and an average depth of about 1.0 m. At high mainstem flow (30,000 cfs), maximum depth was about 4 m, and average depth was about 3 m. It was estimated that minimum flow required for passage of adult humpback chub was 2000 cfs (***), assuming minimum depth of 1.5 times the body depth of a large adult; 100 mm x 1.5 = 150 mm water depth required (See Chapter 6 - DEMOGRAPHICS).

The secondary channel at low mainstem flow (5000 cfs) and base LCR flow (230 cfs) had little flow, with two or three small shoreline pools of about 1 m depth. At high mainstem flow (30,000 cfs), the secondary channel had both mainstem and LCR flow, and maximum depth was about 1.5 m, and average depth was about 0.5 m.

Thermal gradient in the LCR inflow was dynamic for mainstem flows of 9200-17,798 cfs. Thermal gradient was indicated by the expanse of the 18°C+ plume from the high water line (Table

7-6). The main factors influencing these dynamics were flow magnitude and temperature of the mainstem and LCR. At a base flow of about 230 cfs, the LCR flowed into the mainstem through the primary channel at observed mainstem flows of between 14,504 cfs and 17,470 cfs. Periodic photography of the LCR inflow indicates that the LCR at base flow was forced into the secondary channel at mainstem flow of 14,500-15,000 cfs. At mainstem flow of 12,130-14,504 cfs and LCR flow of 230 cfs, temperature in the primary channel in July 1992 was 18-22°C for about 260 m below the high water line (Fig. 7-9, Fig. 7-10). Temperature in the secondary channel was 18-24°C for about 460 m downstream of the high water line, and cooled abruptly at a mixing zone with the mainstem at its lower terminus. Data in May 1992 were insufficient, but it appears that at a lower flow of 9200-9600 cfs, a temperature of 18°C extended only about 150 m below the high water line (Fig. 7-11). Temperature in the secondary channel was also cooler during this May sample, and the 18°C plume extended only about 240 m below the high water line. The warm plume of the LCR in the primary channel was forced to the downstream bank by the colder and higher mainstem flow. At observed mainstem flows of 17,470-17,798 cfs, the LCR was forced into the secondary channel, and temperature in the primary channel was 12-14°C (Fig. 7-12). The 18°C plume ended dramatically, and extended only about 60 m downstream of the high water line.

Substrate of the primary LCR channel below the high water line consisted primarily of boulders and cobble, with varying amounts of silt mixed with boulders at the interface just below the high water line (Fig. 7-13). A small amount of gravel occurred at the lower end of the primary channel, and small gravel deposits were common behind the larger boulders. The secondary channel consisted primarily of silt and sand, deposited during high flows from the LCR. Some cobble and boulders were present at the upper end of the secondary channel.

Level 2: Shoreline Type

Linear distance of shoreline types (***) for seven mapping sites (Table 7-7) were primarily bedrock (40%), talus slope (22%), and alluvial fan (22%). Cobble bars (12%), sand bars (8%), and vegetation (5%) were less common. Relationships of flow to linear distance of shoreline were weak for the six types evaluated, and no significant differences (p=.05) in shoreline type with flow changes were identified, indicating no differences in shoreline availability with flow.

Level 3: Hydraulic Unit

Fish macrohabitat, or major hydraulic units, of the mainstem Colorado River in the vicinity of the LCR inflow (RM 59.75-63.25), were dominated by runs, eddies, and pools at flows of 5268-17,651 cfs (Table 7-8, Appendix Table G-1). Runs composed an average of 69% (range, 48-86%) of surface area in the seven sites measured, while eddies were 19% (range, 10-34%), and pools were 11% (range, 0-41%). Riffles, rapids, and return channels each composed less than 1% of surface area.

Relationships of flow to surface area of eddies, rapids, riffles, and runs were positive and linear for the range of flows observed (Fig. 7-14**). Relationships of flow to surface area of pools was negative (i.e., decrease in surface area with increased flow), and no relationship was evident for eddy return channels. Weiss (1992) showed a 75% decrease in total numbers (36 to 9) and 82% decrease in total area (32,301 to 5708 m^2) of backwaters (eddy return channels) for RM 50-72 with increase in flow from 5000 cfs to 15,000 cfs in 1991. Anderson et al. (1985) reported a 95% difference in numbers of backwaters (eddy return channels) at 28,000 cfs (3) and 4800 cfs (62) between RM 61.5 and RM 77.0 in 1985.

Level 4: Habitat Parameter

Depth, velocity, and cover within the six shoreline types (Fig. 7-3) illustrated differences in these microhabitat parameters that were hypothesized to drive selection of shoreline type by juvenile humpback chub. Mean depth was significantly greater throughout, and velocity significantly higher at 2.5 m from shore along bedrock shorelines.

Average water velocity of a talus shoreline habitat (SALT site) used by juvenile humpback chub increased from 0.083 mps (n=90, s.d.=0.034) to 0.103 mps (n=87, s.d.=0.037), and average water depth increased from 1.067 (n=90, s.d.=0.322) to 1.845 (n=87, s.d.=0.548) at low (10,000-12,000 cfs) and medium observed flows (12,000-14,000 cfs). This analysis showed that velocity and depth along talus shoreline did not change significantly ('t' test, alpha=.05) in the magnitude of flows observed during measurements in 1993.

Habitat Use

Subadult humpback chub (TL<200 mm) were typically captured in shallow, sheltered nearshore habitats, while adults were generally found in low velocity vortices of offshore habitats, although individuals frequented shorelines at night and also used deep bed surface areas. A transition in habitat use occurred with size and age, as indicated by length-frequency distributions (Fig. 7-15**), partitioned by shoreline gears (i.e., electrofishing, seines, minnow traps), and offshore gears (i.e., gill and trammel nets). The length mode for nearshore fish was 80-100 mm TL, although fish 30-460 mm TL were captured (smaller fish were present in return channels restricted to sampling by B/W, See Chapter 2 - STUDY DESIGN). Fish in offshore habitats were 100-460 mm TL; smaller fish were not captured in offshore habitats inspite of sampling with small mesh experimental gill nets. Numbers of fish captured indicates a transition from shorelines to offshore habitats beginning at about 1 year of age (TL≤100 mm) and ending about 3 years of age (TL≥200 mm), which was the average size of field-observed maturity for male (202 mm TL) and female (200 mm TL) humpback chub (See Chapter 6 - DEMOGRAPHICS). Adult humpback chub were frequently captured along shorelines at night or in the daytime under high turbidity, and were sometimes sighted swimming casually near the shore in proximity to cover, and often in the company of rainbow trout of similar size.

Adult Humpback Chub

Humpback chub of different age categories (presumed YOY, juveniles, adults) used macrohabitat types disproportionate to their availability (Table 7-8), and as previously discussed, subadults selected nearshore habitats and adults selected offshore habitats. Most adults (88%) were captured offshore in eddies and most contacts of radiotagged adults (74%) were in eddies, a habitat type that composed an average of only 19% of surface area. Smaller percentages of adults were captured or radiocontacted in runs (7 and 16%, respectively), that composed an average of 69% of surface habitat. Conversely, return channels, which were less than 1% of surface area, accounted for 4% of captured adults and 7% of radiocontacts. Small numbers of adults were also captured or contacted in pools and riffles.

Percentage surface area of macrohabitats and frequency of radiocontacts were compared only for offshore habitats, since radiotagged adults generally remained in large offshore hydraulic units, and away from immediate effects of shoreline structure. Lateral distributions of adults and subadults indicated a relatively narrow shoreline zone of influence, frequently less than 10 m wide. Although some radiotagged adults were contacted within this shoreline zone, the majority were usually offshore in association with hydraulic features rather than nearshore structure.

Radiotagged adult humpback chub in the area occupied by the LCR Inflow aggregation (RM 58.0-65.4), selected shorelines and macrohabitats associated with eddy complexes (Fig. 7-16, Fig. 7-17). Twenty radiotagged adults tracked and observed continuously for periods of 24-72 h in four eddy complexes showed similar patterns of depth, velocity, and substrate selection. Fish observed near Awatubi Canyon (n=w), 60-Mile Canyon (n=x), ESPN Rock (n=y), and Carbon Creek (n=z) were contacted most often on main sand platforms of eddy complexes, or in eddy return channels. Fish used shallow return channels (<2 m deep) primarily at dawn, dusk, and night, and remained over deeper platforms (2-4 m deep) during the day. Vortices of low-velocity (<0.3 mps) were selected, and continuous local activity by some fish suggested a soaring behavior to remain within these vortices at low energy expenditure. Association with sand substrate for most radiotagged fish was not considered selection, but coincidental with depositional areas created by eddy complexes. Fish selected these areas for low-velocity vortices adjacent to high velocity shears and recirculation zones, that served to trap drifting food organisms and particles (See Chapter 9 - DRIFT AND FOOD HABITS).

Radiocontact locations outside of eddy complexes were frequently associated with long-range movement, often as part of a pre- or postspawning migration (See Chapter 8 - MOVEMENT). Radiotagged adults seemed to follow shorelines and select sheltered areas of low velocity for resting. Radiotagged fish were not contacted in the central part of the channel, more than about 40 m from shore, except in large eddy complexes, near midchannel islands and behind instream structure (e.g., large midstream boulders at ESPN Rock). Radiosignal patterns indicated that radiotagged adults crossed the river channel by remaining in deep water, apparently near the bed surface. One fish was tracked from one riverbank to the other within a period of 0.5 h, with an intervening period of about 0.25 h of lost radiocontact, indicating that the fish swam below the 4-m radio extinction depth and used the near-bed shear zone to move across the channel. Maximum depth of the channel at the location crossed was about 14 m.

Radiotagged adults selected eddy complexes except during staging at the LCR inflow in February-March, prior to spawning ascent (Fig. 7-18). During staging, adults moved between the primary channel of the LCR inflow and a deep (8-10 m) adjacent shoreline immediately upstream (See Chapter 8 - MOVEMENT). Although velocity in the LCR inflow was higher than observed in eddy complexes, radiotagged fish frequently remained behind instream boulders or at the interface between the LCR inflow and the mainstem. Fish ascending the LCR frequently moved between the downstream cover of large boulders, entering swift current (>1 mps) for only short periods.

Longitudinal distribution of adult humpback chub in Grand Canyon, as shown by nine aggregations suggested reach selection influenced primarily by warm springs, warm tributaries, and occurrence of large recirculating eddy complexes (See Chapter 5 - DISTRIBUTION AND ABUNDANCE). The largest number of adults (1,524 or 87% of total) were captured in an 8.4-mi subreach near the LCR inflow, and the second largest number (124 or 7% of total) were captured in a 2.9-mi subreach in Middle Granite Gorge. Numbers of adults in these subreaches were used as indices of longitudinal abundance and reach selection by humpback chub.

Geomorphic features of these subreaches were described and compared with features of a subreach in which only two adult humpback chub were caught (Fig. 7-19). Number of debris fans, slope, and average width to depth ratio were compared for three subreaches, including (1) RM 57-65.4, occupied by the LCR Inflow aggregation, (2) RM 122-130.4, occupied by the Middle Granite

Gorge aggregation, and (3) RM 140-148.4, occupied by two humpback chub. Subreach lengths were standardized to 8.4 mi for comparative purposes.

A relationship of occurrence and density of adult humpback chub to frequency of debris fans and channel width to depth ratio was indicated by a comparison of subreaches with high, medium, and low numbers of adults. The greatest number of debris fans (27) and the highest width to depth ratio (19.6) were associated with subreach 1, where the largest number of adults were found. Fewer debris fans (16) and lower width to depth ratio (8.2) for subreach 2, and low number of debris fans (3) and width to depth ratio (7.9) for subreach 3, indicate that at least these geomorphic attributes contributed to reach selection by adult humpback chub. Selection for subreaches with a moderately-wide channel and high frequency of debris fans was consistent with high use of eddy complexes. Large recirculating eddies and expansion zones were more common in subreach 1 than in subreach 2, where fewer debris fans resulted in fewer eddies. Debris fans in subreach 3 were few and associated with hard, erosive-resistance Muav limestone that precluded formation of expansion zones and large recirculating eddies beneath debris fans. The two adult humpback chub captured in this subreach were near the Kanab Creek inflow.

Longitudinal distribution of debris fans also affected distribution and numbers of adult humpback chub. Numbers of adults above and below the LCR inflow corresponded to numbers of debris fans. Of 1,524 adults captured in subreach 1, 1,066 (70%) were between the LCR inflow (RM 61.3) and Lava Canyon (RM 65.4), where number of debris fans was greater (16) than above (11).

The association of adults with recirculating eddy complexes was most evident for the subreach from the LCR inflow (RM 61.4) to Hance Rapid (RM 76.4). Cumulative surface area of eddies at 0.10-mi intervals, compared to total area, showed a dramatic reduction in area of eddies downstream of Lava Canyon (Fig. 7-20). Cumulative numbers of adult humpback chub corresponded to surface area of eddies, indicating that reach selection was based on occurrence of eddy complexes.

Subadult Humpback Chub

The majority of YOY and juvenile humpback chub (i.e., subadults, TL<200 mm) were caught along shorelines in a pattern of clumped distribution, indicating selection for particular shoreline types and attributes. This association was the basis for a special study to determine effects of fluctuating flows on subadult shoreline habitat. The study was the subject of an M.S. Thesis (Converse 1994), presented in detail in Appendix G, and summarized in this subsection. The study evaluated shoreline habitat use with fluctuating flows from Glen Canyon Dam, and related longitudinal distribution of subadults with channel geomorphology and shoreline types in the area of highest subadult densities, from the LCR inflow (RM 61.4) to Hance Rapid (RM 76.4).

Assuming the primary source of young humpback chub to this area was the LCR, a hypothetical Gaussian distribution of young from the spawning outlet would show progressively fewer fish downstream (Fig. 7-21**). Instead, catch rates in 1-mi strata in the 15-mi area showed three distinct modes, consistent for all sample periods. These modes corresponded to three geologic subreaches, each with formations of different erosional resistance, which were hypothesized to produce distinct shoreline types and account for variation in subadult densities.

The first part of this hypothesis was tested by comparing subadult catch rates for six shoreline types, independent of subreaches (Fig. 7-22**). Subadult catch rates were significantly higher (p=.05) in debris fans, talus slopes, and vegetation than in the other three shoreline types. Catch rates along vegetated shorelines were significantly higher than in all other shoreline types, indicating selection for shallow, sheltered, vegetated habitats.

Having identified a significant relationship between subadult densities and shoreline types, the second part of the hypothesis examined the distribution of the three selected shoreline types (i.e., vegetation, talus slope, debris fan) relative to fish densities. Channel width to depth ratios, shoreline types, and microhabitat parameters were compared with subadult catch rates for three subreaches, i.e., (1) RM 61.4-65.4, (2) RM 654.-73.4, and (3) RM 73.4-76.4. Channel width to depth ratios of subreaches 1 and 3 were not significantly different (p=.05) at about 20 and 17, respectively, while the ratio of subreach 2 was significantly greater at about 34, indicating a wider channel in subreach 2 (mean, ***m) than 1 (mean, ***m) or 3 (mean, ***m). Differences in channel width were attributed to shoreline geology. Shoreline of subreach 1 was dominated by relatively resistant Tapeats sandstone and members of Dox sandstone, while subreach 2 shoreline consisted of more erodible members of Dox sandstone, and subreach 3 shoreline was dominated by more resistant members of Dox sandstone.

Shoreline geology also influenced shoreline types. The more erosional shoreline of subreach 2 had less exposed bedrock and fewer sand beaches, but a substantially greater proportion of cobble bars. Subreaches 1 and 3 contained approximately the same percentage of bedrock shoreline, while shorelines in subreach 3 typically contained a high percentage of vegetation, i.e., root wads, inundated shoreline willows, tamarisk, or rushes. While some subreach differences were evident, patterns in distribution of shoreline types were not evident or consistent, because of the apparent within subreach variation.

This variation was evident from longitudinal distribution of shoreline types, which was not uniform between 1-mi strata (Fig. 7-23**). Bedrock (primarily tapeats sandstone) was dominant in the upper two strata, while talus dominated the shoreline between RM 63.4 and RM 68.4. Alluvial fans and cobble bars were intermittent in dominance, while sand bars composed less than 30% of shoreline throughout, and vegetation increased for most downstream strata. Percentage of shoreline composed of debris fans, bedrock, and talus slopes remained relatively constant between subreaches, while cobble bars and sand bars varied, and vegetation increased downstream. These analyses showed that shoreline types were interspersed with varying amount of linearity, but overall availability of the six shoreline types was approximately equal.

Catch rates of subadults by the same 1-mi strata, revealed an association of catch rates with talus slopes (Z=0.341), vegetated shorelines (Z=0.341), and sand beaches (Z=0.341), although not significant, based on two-sided Kolmogorov-Smirnov tests. Little association was seen between CPE and bedrock (Z=0.611), cobble bar (Z=0.894), and debris fan (Z=0.894). These comparisons indicate that, although catch rates of subadult humpback chub were highest along vegetation, talus slopes, and debris fans, the relationship was not consistent by river mile, and it was determined that shoreline type did not entirely explain longitudinal distribution of subadults. Catch rates for all sample trips combined, as well as for three independent sample periods, were consistently highest in subreach 3 and lowest in subreach 2 (Fig. 7-24**), suggesting a reach affect, inspite of approximately uniform distribution of shoreline types. Two-way ANOVA revealed no significant differences in subadult CPE between reaches (F=1.7, p=0.181), but significance in shoreline types (F=4.2, p=0.001) and interaction of reach and shoreline types (F=2.1, p=0.021). This analysis indicated that shoreline type was a more significant indicator of subadult density than reach, but that other factors also contributed to variability.

The attributes of each subreach were not thoroughly known to satisfactorily account for the longitudinal distribution pattern of subadult humpback chub below the LCR inflow. The wider more open channel of subreach 2 contributed to shallower shorelines with lower velocities than those of subreach 1 (Fig. 7-25**). While these attributes appeared favorable for young humpback chub, daily fluctuations from dam operations created greater instability in these more exposed shorelines than in the deeper and swifter shorelines of subreach 1, forcing the fish from these shorelines and exposing them to greater energy expenditure and predation.

Attributes of selected shoreline types (i.e., vegetation, talus slope, debris fan) also helped to explain selection for certain shoreline types (Fig. 7-25**). All shoreline types, except for bedrock, provided depth characteristics similar to HSI curves (Valdez et al. 1990) for YOY (mean = 2.1 ft, range = -5.1 ft) and juveniles (mean = 2.3 ft, range = -4.4 ft). However, only vegetation, talus slope, and sand bars provided suitable velocity for YOY (mean = 0.06 m/sec, range = 0-0.22 m/sec) and juveniles (mean = 0.18 m/sec, range = 0-*** m/s). Although debris fans had the lowest velocity of any shoreline type 1.5 m from shore, velocity quickly increased at 2.5 m from shore. While depth and velocity only partly explained selection by fish for vegetation, talus slope, and debris fans, an assessment of cover provided added attributes that made these shoreline type favorable for the fish.

DISCUSSION

Humpback chub in the Colorado River in Grand Canyon selected low-velocity shorelines as subadults and large eddy complexes as adults. Subadults selected shorelines of vegetation, talus slopes, and debris fans with depth of 0.17-1.10 m, and velocity of 0.05-0.30 m/sec. These ranges were inclusive of average utilization microhabitat parameters (Valdez et al. 1990) of YOY for depth (mean, 0.64 m, range, 0.03-1.55 m) and velocity (mean, 0.06 m/sec, range, 0-0.30 m/sec), and of juveniles for depth (mean, 0.70 m, range, 0.03-1.37 m) and velocity (mean, 0.18 m/sec, range, 0-0.79 m/sec). Although mean catch rates of subadults were significantly higher in shorelines with vegetation, talus slopes, and debris fans, catch rates by 1-mile strata were inconsistent for wide alluvial river subreaches. Lower subadult densities in alluvial subreaches were attributed to greater shoreline instability from daily dam flow fluctuations, causing displacement of fish and greater exposure to predation and energy expenditure.

Subadult humpback chub made a transition in habitat use, from nearshore to offshore habitats, starting at about 1 year of age (TL≤100 mm), and ending about 3 years of age (TL≥200 mm), or at maturity. Adults appeared to restrict use of shorelines to night or day under high turbidity, although individuals were sighted swimming casually near shore in proximity to cover and often in the company of rainbow trout of similar size. Adult humpback chub selected (88% captures, 77% radiocontacts) large recirculating eddy complexes, frequently occupying internal vortices of low velocity (<0.5 m/sec) over sand platforms or in and near eddy return channels. The recirculating zones entrapped drifting food organisms and particles, and the low-velocity vortices provided energy-efficient feeding and resting sites. Local activity of radiotagged adults suggested a "soaring" behavior to maintain position in vascilating currents. Fish were observed using large falcate fins analogous to raptors soaring on wind currents. Combined with the stabilizing effect of the nuchal hump and hydrodynamic body, this feeding mode was unique to adults as an energy efficient strategy, adaptable to a range of flows suitable for formation of recirculation zones. This midwater soaring strategy was probably also a resting mode, although it was most commonly perceived at night and during crepuscular periods, when stomach analyses indicated greatest feeding activity. Water depth (<5 m) and substrate (sand) at selected feeding stations was coincidental with characteristics of recirculating eddies, and did not appear to determine final site selection, as did velocity and food availability. Loss of radiocontact for fish below 4 m depth precluded accurate determination of deep water habitats. Movement patterns and known selection for low-velocity zones suggest that daytime resting sites were near the bed shear zone or behind large instream structure such as boulders. Stomach analyses and radiotelemetry indicate that fish also fed on organisms trapped in sand riffles on reattachment bars and on bottom substrate and woody debris.

Adult humpback chub selected eddy complexes in all months, except February-April, when large numbers staged at the LCR inflow prior to spawning ascent. Radiotagged adults frequented the inflow, typically remaining behind boulders and in low-velocity interfaces during high turbidity and in reduced light. Movement patterns indicated that adults descended to adjacent deep (6-8 m) areas with irregular bed structure, similar to daytime resting habitats used at other times of the year.

While detailed habitat measurements and ongoing monitoring of radiotagged fish were largely restricted to the area of the LCR inflow, information obtained from fish to habitat relationships may help explain the present distribution of the species in other areas of Grand Canyon, and perhaps other regions of the basin. Since large recirculating eddies are formed by debris fans with a frequency dependent on shoreline type and overlying geology, a relationship emerges between fish habitat and longitudinal lithology as a primary factor determining longitudinal fish distribution. While shoreline types selected by subadult humpback chub may be common throughout the canyon, recruitment of these fish to adults is dependent on presence of large recirculating eddies for food and shelter, and associated proximate spawning sites. Suboptimal water temperatures have precluded use of most available mainstem spawning areas, and confined the fish to spawn in warm tributaries associated with geomorphic reaches conducive to debris fan formation and recirculating eddies. The highest frequency of debris fans between Lees Ferry and Diamond Creek occurred from approximately Buck Farm Canyon (RM 41) to Hance Rapid (RM 76.5), which included the identified range of the LCR inflow aggregation of humpback chub (RM 56.0-65.4). Similar geomorphic reaches in Grand Canyon are more limited in area, and occur further downstream, including the area from Stephen Aisle (RM 117) to Specter Rapid (RM 129), which corresponded to the Stephen Aisle and Middle Granite Gorge aggregations of humpback chub, and the only aggregations not associated with tributary inflows or warm springs.

Table 7-1. Substrate types and definitions associated with fish habitat of the Colorado River in Grand Canyon.

SUBSTRATE TYPE	DEFINITION
Sand/Silt	Particles with a size range of 0.004 to 2 mm in diameter
Gravel	Particles 2-64 mm in diameter
Cobble	Particles 64-256 mm in diameter, which are moved by main channel activity, and show a high degree of roundedness
Boulder	Particles larger than 256 mm in diameter that may be rounded or angular, depending on the transportation process
Bedrock	Exposed underlying parental rock material

Table 7-2. Shoreline types and definitions associated with fish habitat of the Colorado River in Grand Canyon.

SHORELINE TYPE	DEFINITION
Bedrock	Exposed underlying parental rock material.
Cobble Bar	Cobble transported and rounded by main channel activity, characteristically well worked and imbricated. May show embededness.
Debris Fan	Material transported from a tributary during flood events, primarily boulders and cobble rounded by transport processes. Material is often embedded, and the angle of repose is generally flatter than talus.
Sand Bar	Predominantly exposed sand.
Talus Slope	Unconsolidated colluvium, predominantly angular boulders, deposited by rockfalls or rockslides from canyon walls. Talus is characteristically not embedded, and has a steeper angle of repose than alluvial fans.
Vegetation	Inundated plant material, consisting of stems, leaves, and/or root wads.

Table 7-3. Fish macrohabitat types and definitions for the Colorado River in Grand Canyon. Illustrations of each habitat type are provided in Fig. 7-4.

MACROHABITAT TYPE	DEFINITION
Eddy	A circular current of water, sometimes quite strong, diverging from and initially flowing contrary to the main current. It is usually formed at a point at which the flow passes some obstruction or on the inside of river bends (Helm 1985). In the Colorado River, an edddy forms in a channel expansion where flow separates from the bank, creating a zone of relatively weak recirculating current (Rubin et al. 1990). Bars accumulate at the weak points of flow where the current separates from the bank (separation point) and where flow reattaches to the bank (reattachment point). Increasingly restricted countercurrent behind the reattachment bar creates a recirculating eddy return channel.
Pool	A portion of the stream with reduced current velocity, often with water deeper than the surounding areas, and which is frequently usable by fish for resting and cover (Helm 1985). In the Colorado River, a pool usually occurs in a deepened scour basin, and there may be small surface boils and upwellings.
Rapid	A relatively deep stream section with considerable surface agitation and swift current. Some waves may be present. Rocks and boulders may be exposed at all but high flows. Drops up to one meter (Helm 1985). In the Colorado River, rapids are whitewater, high velocity area caused by a constriction and drop in elevation. A rapid is deeper than a riffle, and has large, broken standing waves.
Return Channel	A topographic feature of a recirculating eddy that serves as the main pathway for upstream circulation, and forms a narrow channel (Rubin et al. 1990). When flows are below the crest of the reattachment bar, a sheltered body of water forms, bound on three sides by land with one opening to the river. A return channel is one type of backwater.
Riffle	A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitations, but standing waves are absent (Helm 1985).
Run	An area of swiftly flowing water, without surface agitation or waves, which approximates uniform flow and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach (Helm 1985).

Table 7-4. Habitat map areas completed at various flows of the Colorado River in Grand Canyon, 1990-1993.

Map Site	Flow Range	Midpoint	Date (time)
ESPN (RM 59.75-61.00)	5,318-5,467	5,385	May 19, 1991 (1300-1400)
	11,089-11,089	11,089	August 19, 1991 (1830-1856)
	14,792-15,502	14,920	May 22, 1991 (1130-1230)
	17,249-16,749	17,148	August 18, 1991 (0850-0920)
	12,378-12,016	12,085	June 17, 1992 (1130-1245)
CAMP (RM 61.00-61.25)	5,318-5,268	5,234	May 20, 1991 (0830-0930)
	11,297-11,237	11,250	August 19, 1991 (1730-1750)
	15,017-14,888	14,888	May 21, 1991 (1515-1630)
	17,651-17,249	17,500	August 18, 1991 (0800-0834)
	12,916-12,443	12,696	June 17, 1992 (1015-1100)
LCRI (RM 61.25-61.50)	5,335-5,451	5,400	May 19, 1991 (1000-1130)
	11,446-11,326	11,400	August 18, 1991 (1800-1830)
	14,856-14,984	14,920	May 21, 1991 (1330-1430)
	16,451-16,155	16,300	August 18, 1991 (1000-1032)
	8,000	8,000	May 30, 1993 (0630-0700)
HOPI (RM 62.20-62.40)	10,052-10,043	10,050	September 16, 1991 (1530-1618)
	16,122-15,762	16,000	August 20, 1991 (1030-1050)
	11,979-11,643	11,708	June 18, 1992 (1215-1250)
SALT (RM 62.40-62.60)	9,257-10,266	10,266	May 20, 1991 (1720-1815)
	10,043-10,057	10,054	September 16, 1991 (1415-1508)
	14,824-14,888	14,952	May 22, 1991 (0830-0930)
	14,920-14,600	14,500	August 20, 1991 (1200-1230)
WHAL (RM 62.60-63.00)	14,920-14,920	14,920	May 22, 1991 (1810-1900)
WEEP (RM 63.00-63.25)	10,033-10,023	10,030	September 16, 1991 (1630-1718)
	17,517-17,115	17,300	August 20, 1991 (0830-0850)

Table 7-5. Characteristics and attributes of bathymetry for four eddy complexes in the Colorado River, Grand Canyon.

Bathymetric Map Site	River Mile	Size of Eddy Complex		Platform Depth (m)[a]			Maximum Scour Pool Depth (m)
		Area (m^2)	% of Expansion Zone	Max.	Min.	Ave.	
Awatubi Canyon	58.5	4,000	40	8.0	1.0	1.5	17.5
60-Mile Canyon	60.1	2,500	30	4.0	0.5	2.5	13.5
ESPN Rock	60.8	3,000	34	4.0	2.0	3.0	14.0
Carbon Creek	64.7	4,500	50	4.0	0.5	1.0	12.0

[a] Depth of main platform at 12,000 cfs

Table 7-6. Sample dates, times, flow and temperature of the mainstem and LCR for development of temperature isopleths in the LCR inflow.

Sample Dates - Times (1992)	Mainstem		LCR		Expanse of 18°C+Plume (meters)[a]
	Flow (cfs)	Temp. (°C)	Flow (cfs)	Temp. (°C)	
May 16 - 0015 May 21 - 0015 May 21 - 0045	9200-9600	11.0	230	21.0	150
July 23 - 1755 July 24 - 1730 July 25 - 2012 July 25 - 1900 May 20 - 0615	12,130-12,809	12.0	230	21.5-25.3	260
July 21 - 2200 July 22 - 1430 July 24 - 1430	13,947-14,504	11.5	230	21.9-24.8	260
July 22 - 1015 July 25 - 1000 July 25 - 1016	17,470-17,798	11.0	230	22.3-22.7	60

[a]Measured from high water mark, or "Mort Rock", along primary channel

Table 7-7. Average percentage surface area of macrohabitats and linear distance of shoreline types in seven sites in the Colorado River (RM 59.75-63.25) at a flow range of 5,234-17,651 cfs.

Macrohabitat Type	Percentage Surface Area Ave. (range)	Shoreline Type	Percentage Linear Distance Ave. (range)
Run	69 (48-86)	Alluvial Fan	41 ( )
Eddy	19 (10-34)	Bedrock	25 ( )
Pool	11 (0-41)	Cobble Bar	15 ( )
Return Channel	<1 (<1)	Sand Bar	8 ( )
Riffle	<1 (0-1)	Talus Slope	6 ( )
Rapid	<1 (0-1)	Vegetation	5 ( )

compared to surface area of macrohabitats,

Table 7-9. Number and percentage (%) of humpback chub captured and radiocontacted in offshore and nearshore macrohabitats, 1990-93. YOY=young-of-year, JUV=juvenile, ADU=adult). Radiocontacts represent 73 radiotagged adults.

Macrohabitat Type	Percentage Surface Area mean (range)	Fish Captured			Radio Contacts
		YOY (%)	JUV (%)	ADU (%)	ADU (%)
		Offshore Habitats			
Eddy	19 (10-34)	0 (-)	49 (52)	1391 (88)	617 (74)
Run	69 (48-86)	0 (-)	5 (5)	109 (7)	133 (16)
Pool	11 (0-41)	0 (-)	2 (2)	10 (1)	26 (3)
Riffle	<1 (0-1)	0 (-)	0 (-)	0 (-)	3 (<1)
Rapid	<1 (0-1)	0 (-)	0 (-)	0 (-)	0 (-)
Return Channel	<1 (0-1)	0 (-)	38 (41)	69 (4)	56 (7)
Subtotals:		0	94 (100)	1579 (100)	835 (100)
		Nearshore Habitats			
Eddy	-	1261(43)	782 (53)	90 (60)	-
Run	-	792 (27)	244 (17)	19 (12)	-
Pool	-	25 (1)	22 (1)	1 (1)	-
Riffle	-	0 (-)	0 (-)	0 (-)	-
Rapid	-	0 (-)	0 (-)	0 (-)	-
Return Channel	-	551 (19)	282 (20)	30 (20)	-
Embayment	-	156 (5)	7 (<1)	0 (-)	-
Shoreline	-	141 (5)	137 (9)	11 (7)	-
Subtotals		2926 (100)	1474 (100)	151 (100)	

Need to do this for RM 57-65.4 Only

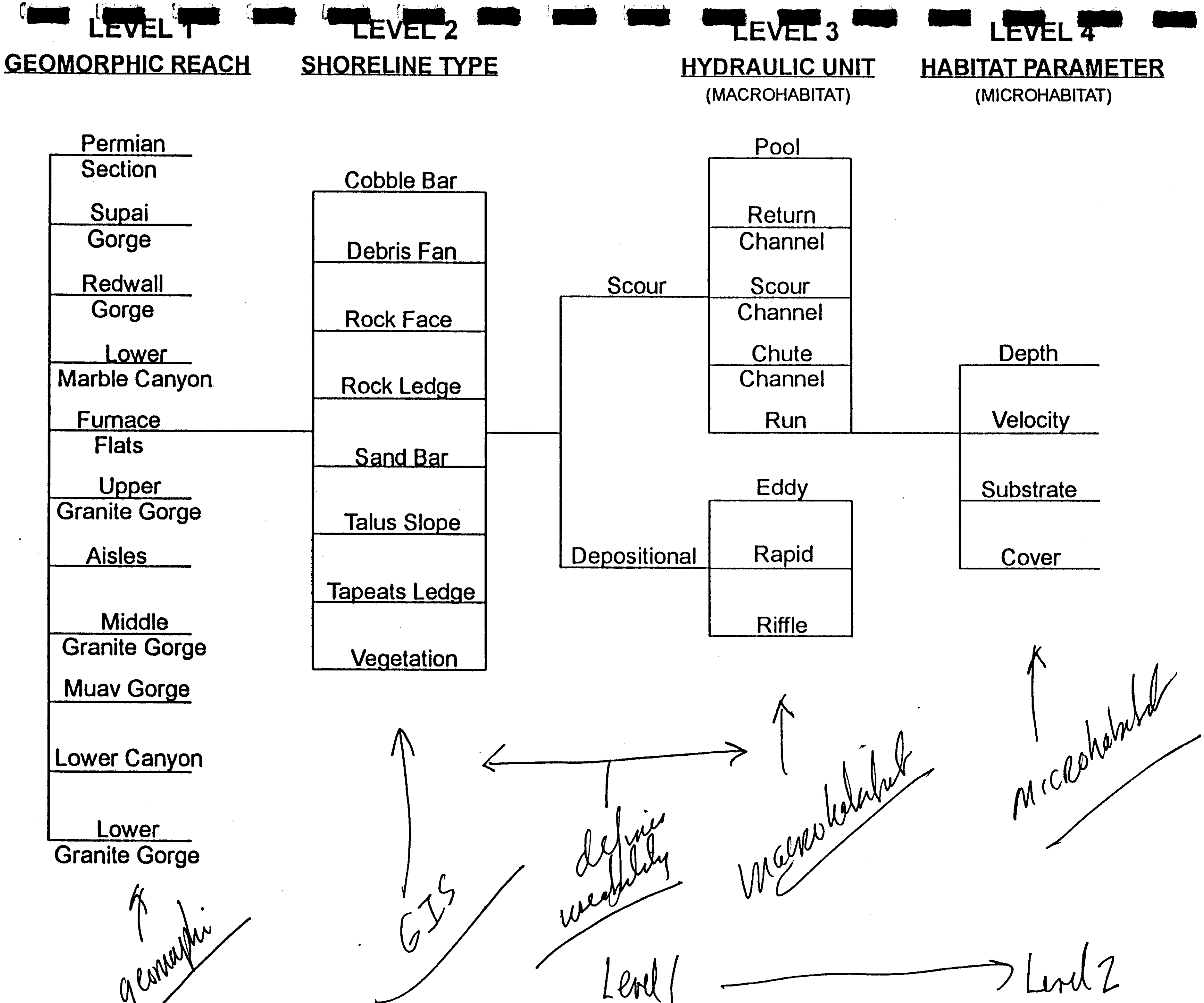


Fig. 7-1. Dendrogram of a classification system for fish habitat in the Colorado River, Grand Canyon.

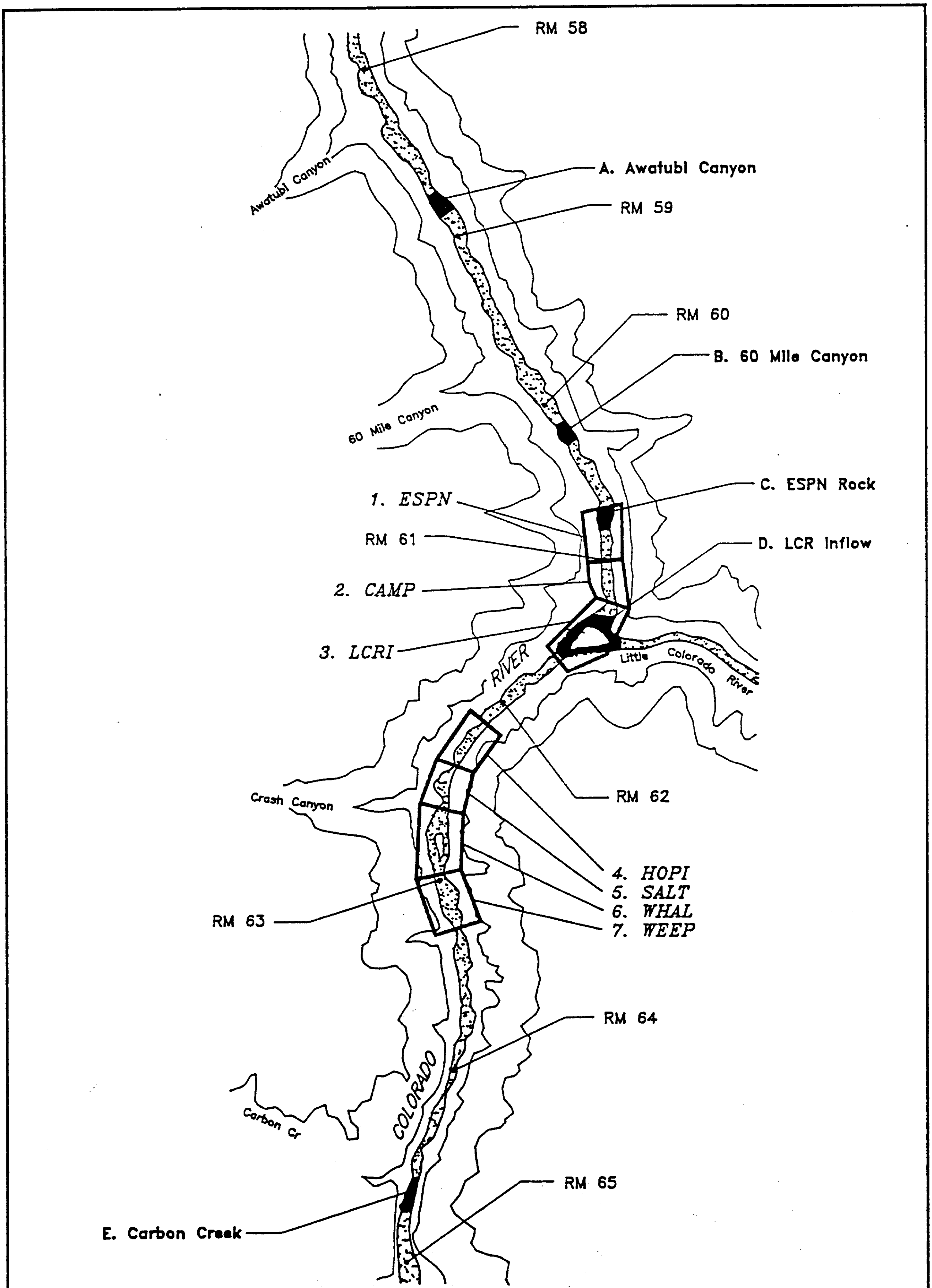


Fig. 7-2. Locations of five bathymetry map sites (A-E) and seven macrohabitat map sites (1-7) on the Colorado River in Grand Canyon.

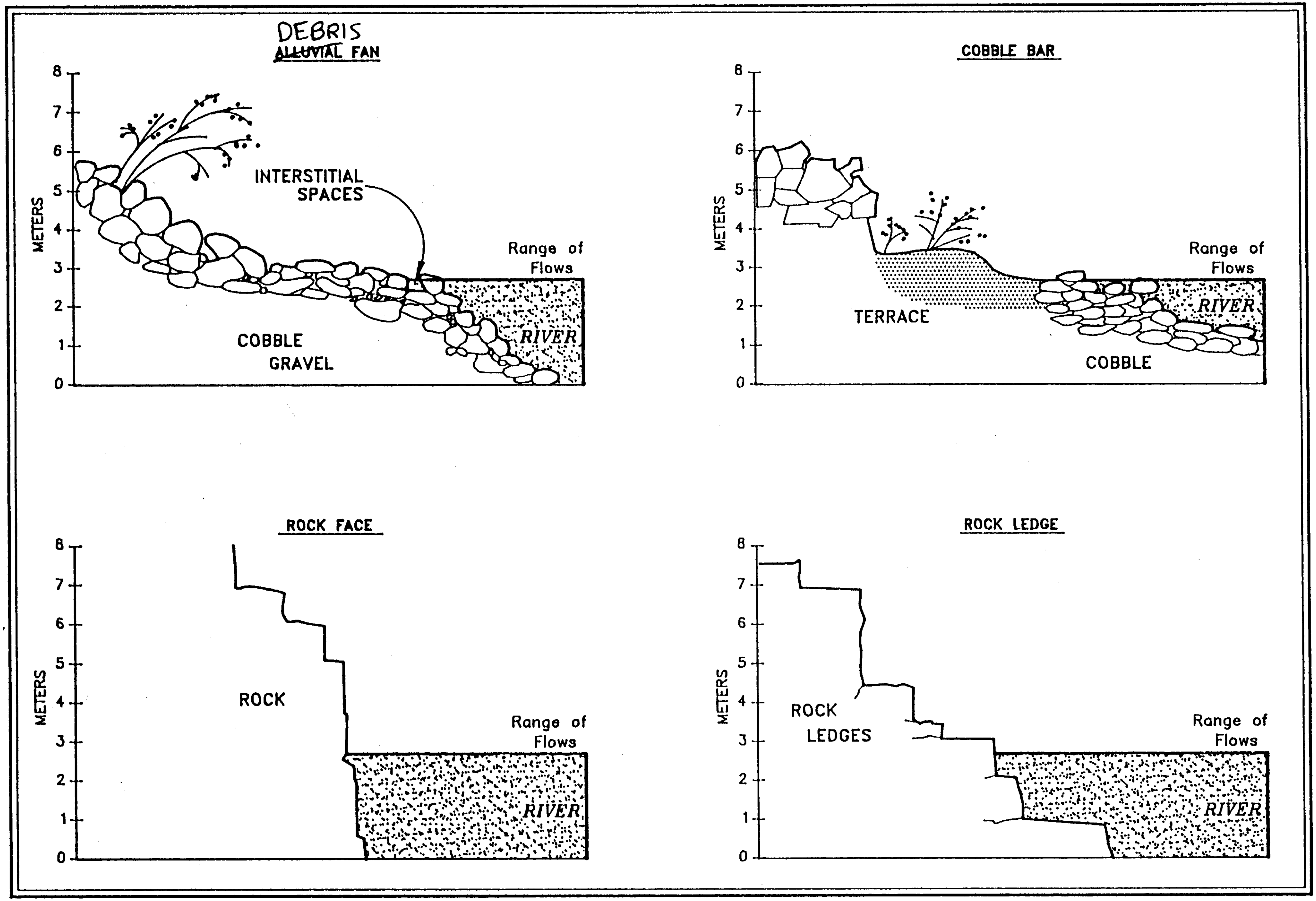


Fig. 7-3. Cross-sections of hypothetical shoreline types.

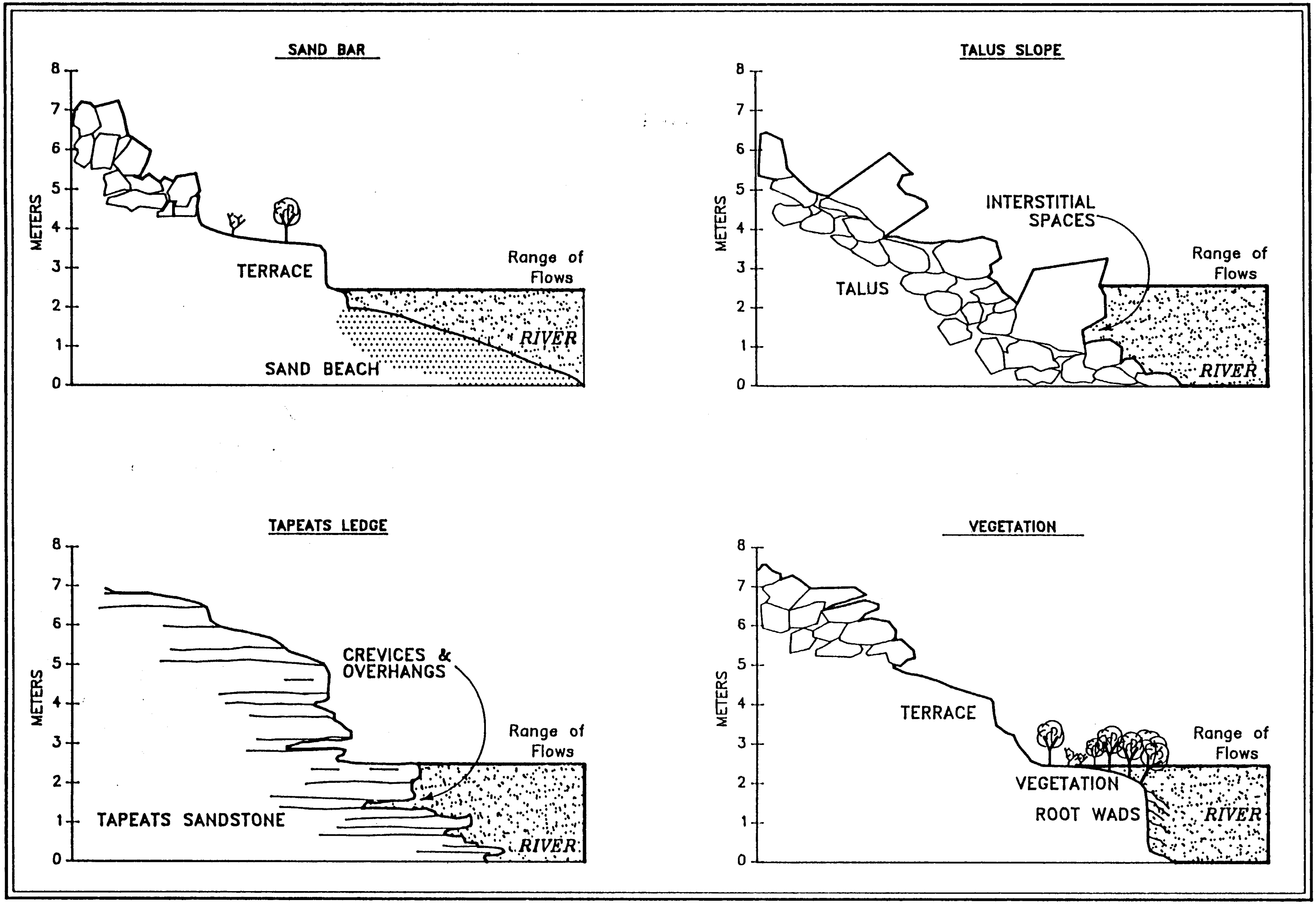


Fig. 7-3. Continued.

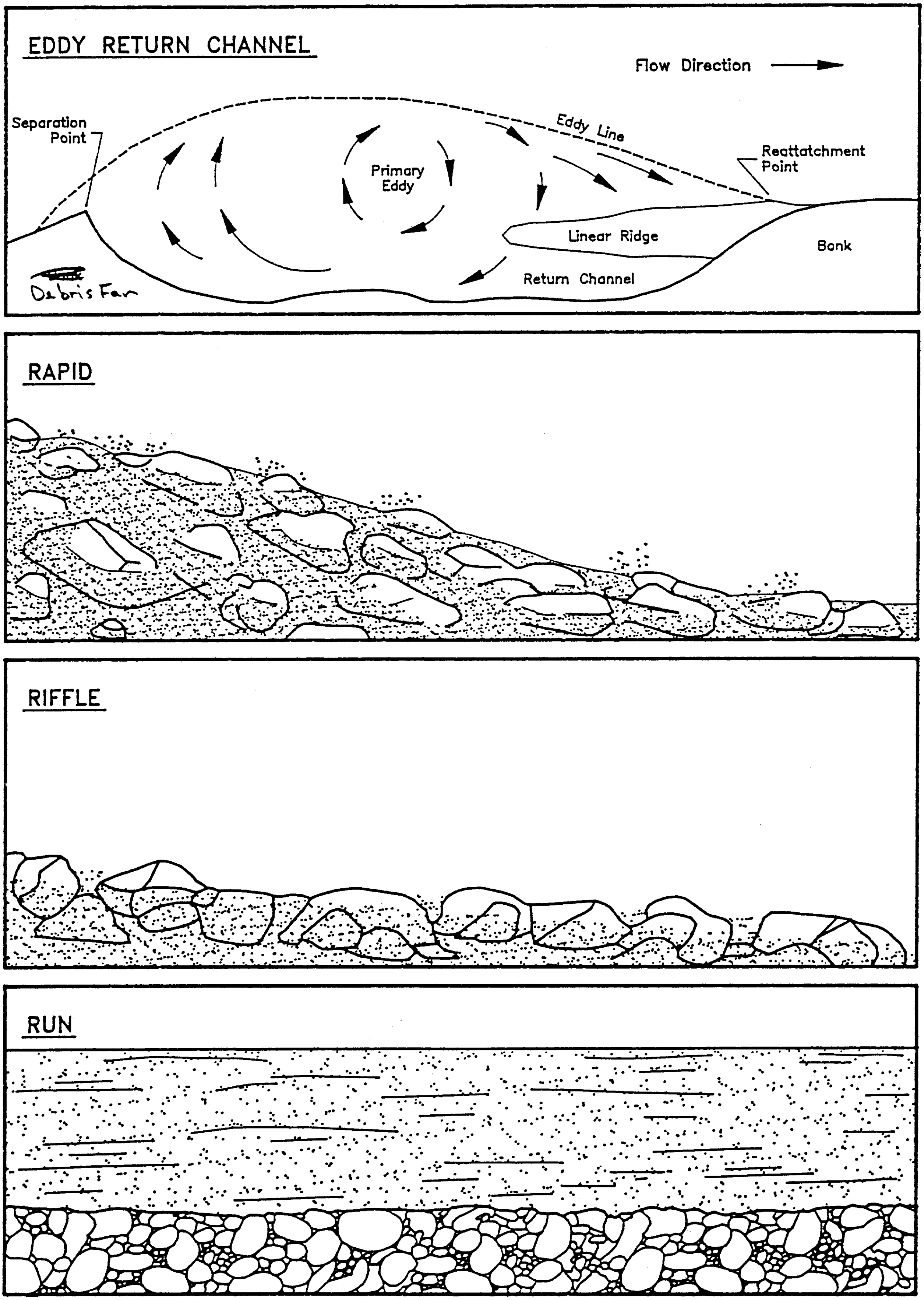
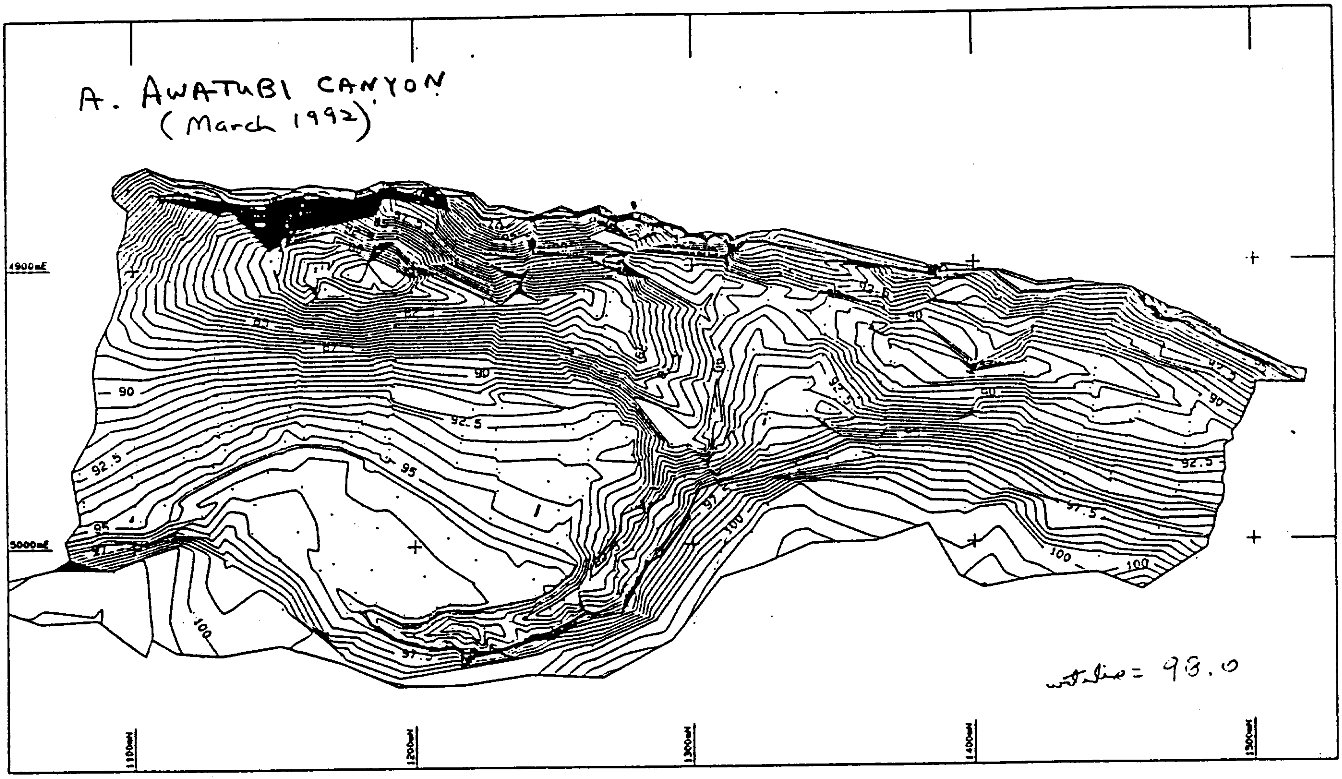


Fig. 7-4. Surface flow pattern of an eddy (A), and cross sections of a rapid (B), riffle (C), and run (D). Sketches of rapid, riffle and run from Helm (1985).



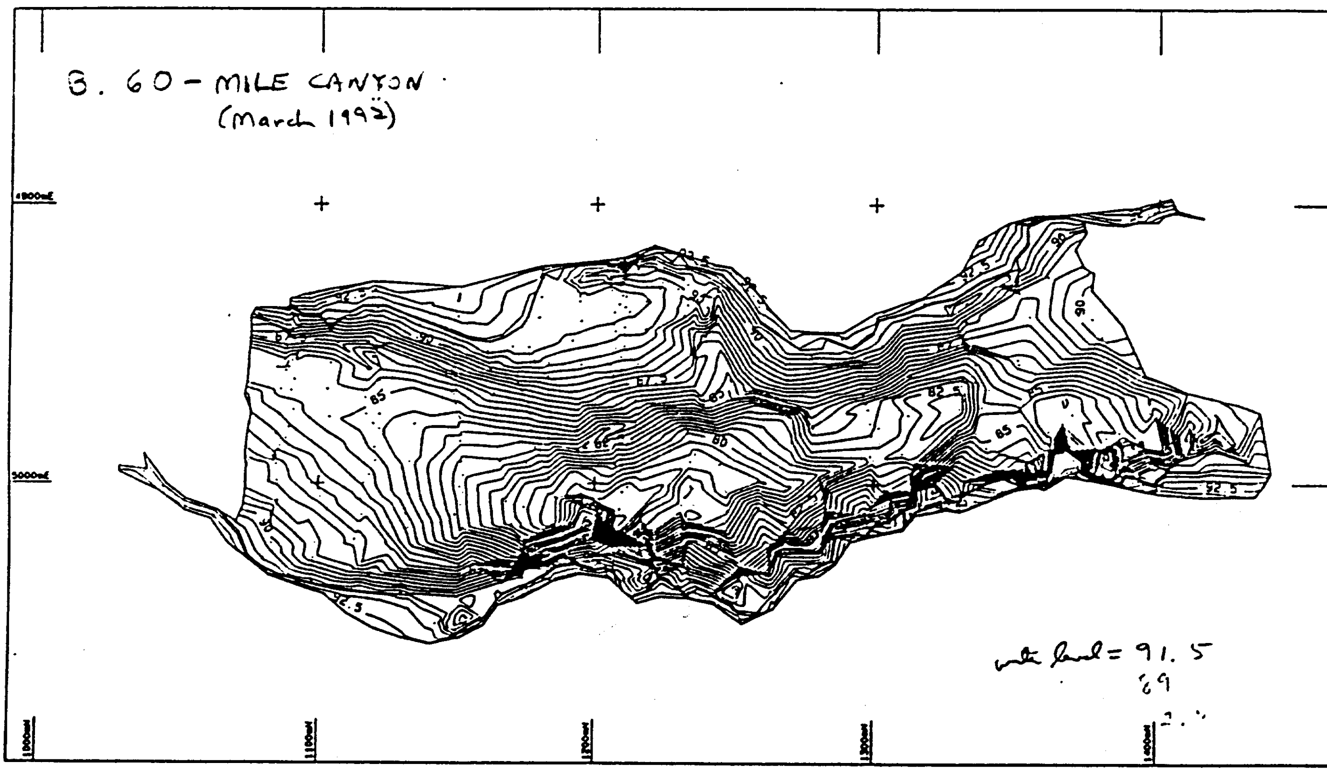


Fig. 7-5. Bathymetric maps of the Colorado River channel at (A) Awatubi Canyon (RM58.5) and (B) 60-Mile Canyon (RM60.1).

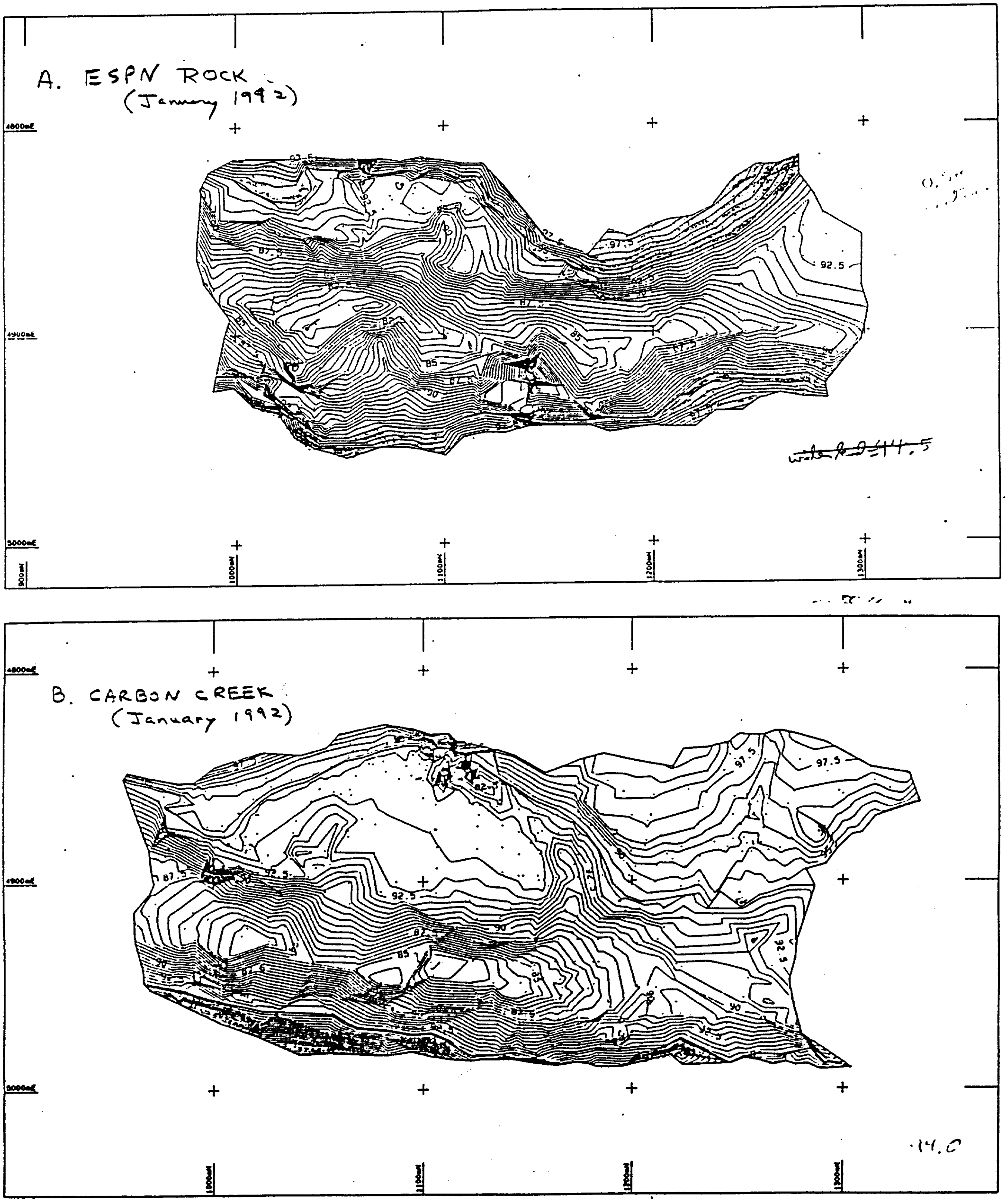


Fig. 7-6. Bathymetric maps of the Colorado River channel at (A) ESPN Rock (RM 60.8) and (B) Carbon Creek (RM 64.7). GIS data.

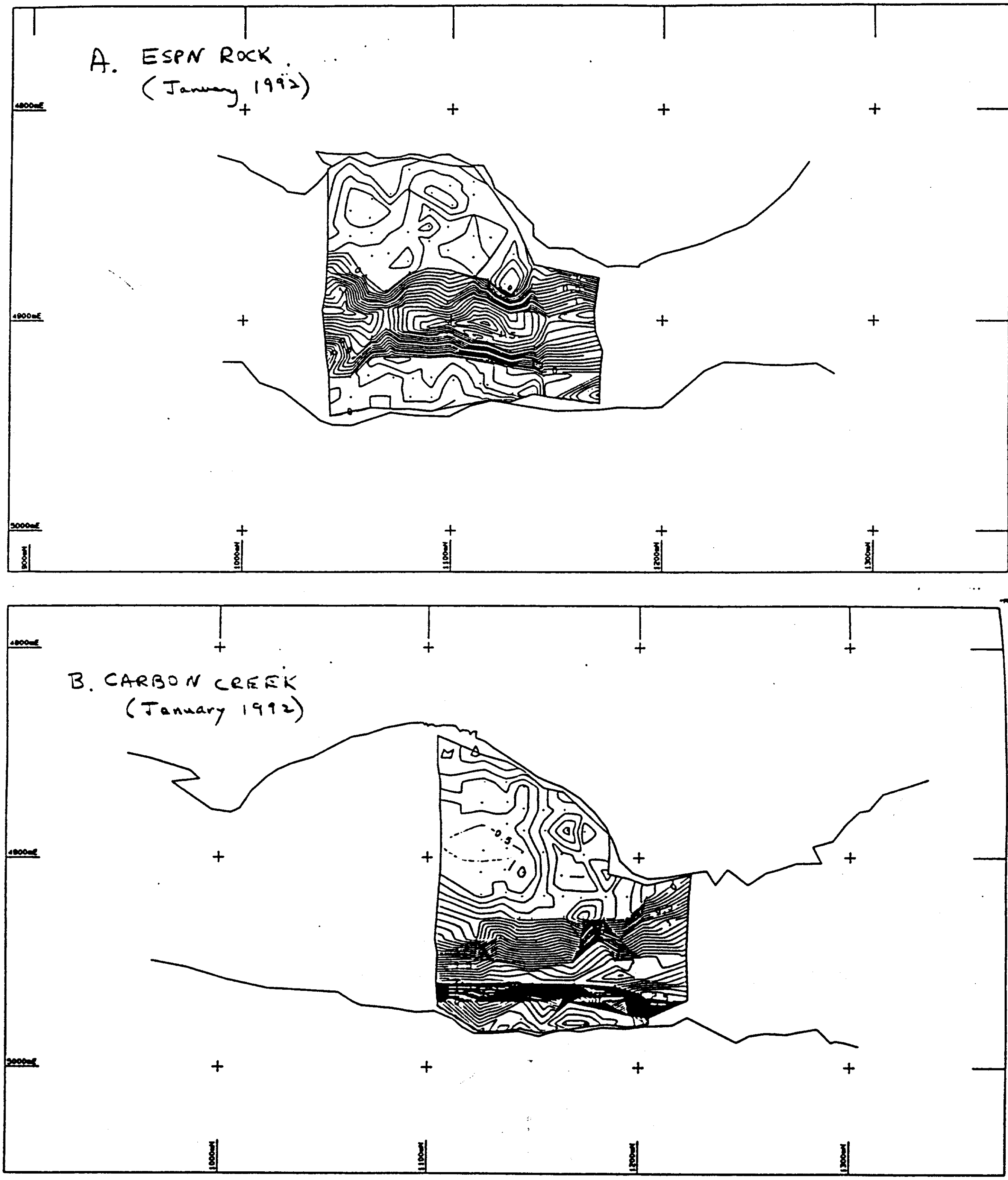


Fig. 7-7. Velocity isopleths for the Colorado River at (A) ESPN Rock (RM 60.8) and (B) Carbon Creek (RM 64.7). GIS data

Fig 7-8. Bathymetric map of the Colorado River channel at the LCR inflow (RM 61.3), January 1992. GIS data.

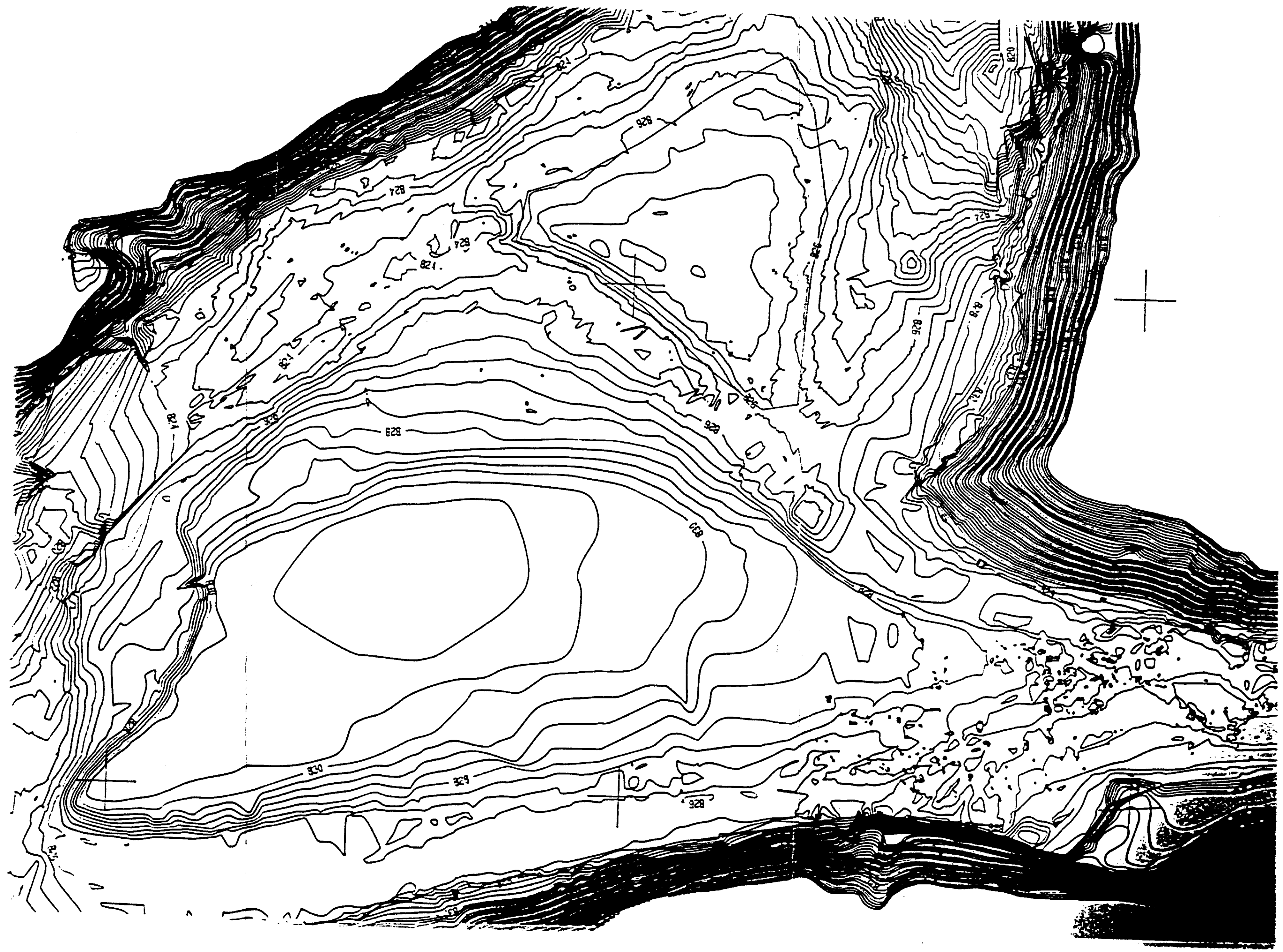


Fig. 7-9. Temperature isopleths at the LCR inflow at base flow of 230 cfs and mainstem flow of 12,130-12,809 cfs. Sample dates were July 23-25, 1992 and May 20, 1992. GIS data.

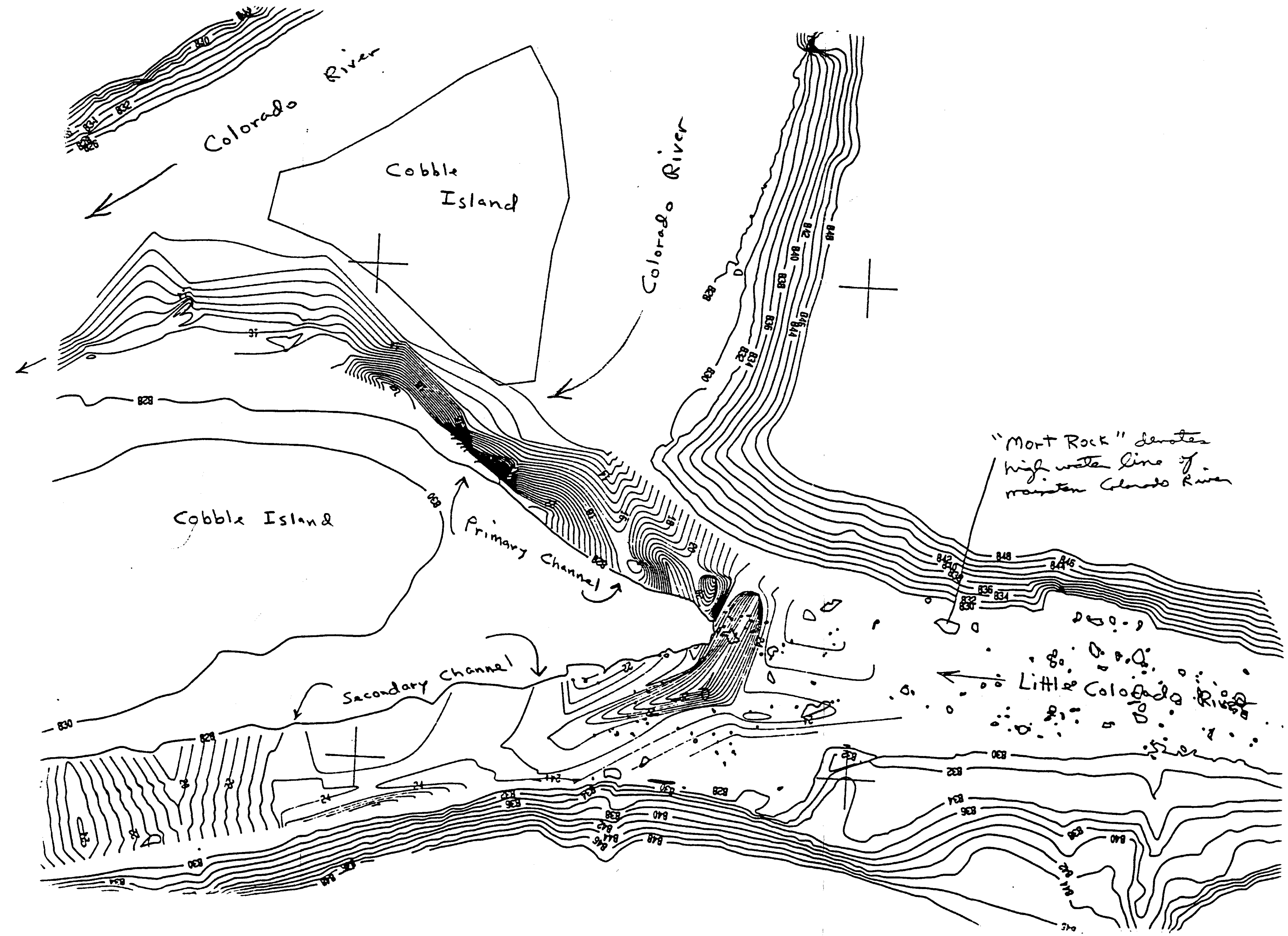


Fig. 7-10. Temperature isopleths at the LCR inflow at base flow of 230 cfs and mainstem flow of 13,947–14,504 cfs. Sample dates were July 21, 22, 24, 1992. GIS data.

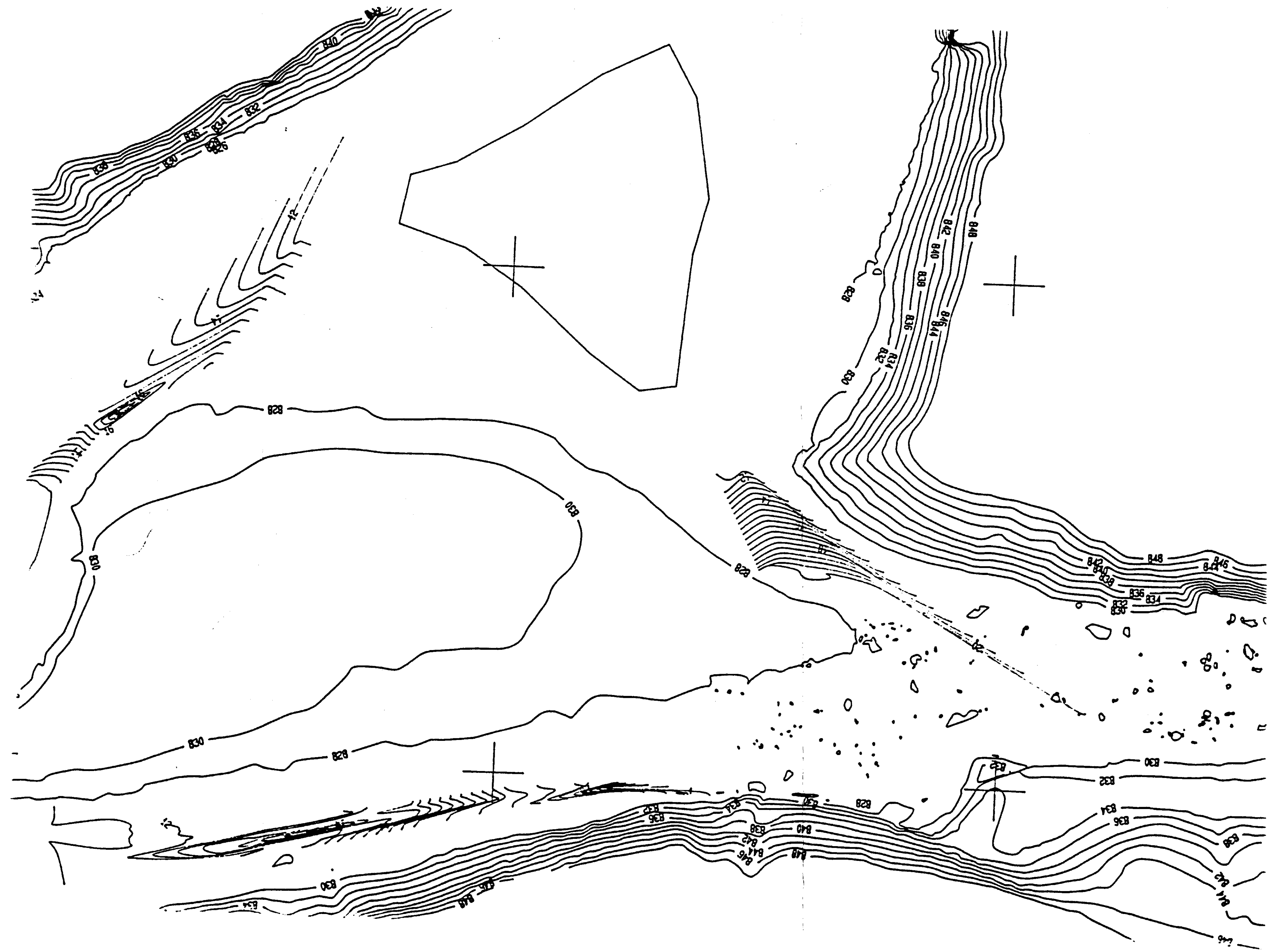


Fig. 7-11. Temperature isopleths at the LCR inflow at base flow of 230 cfs and mainstem flow of 9700-9600 cfs. Sample dates were May 16, 21, 1992. GIS data.

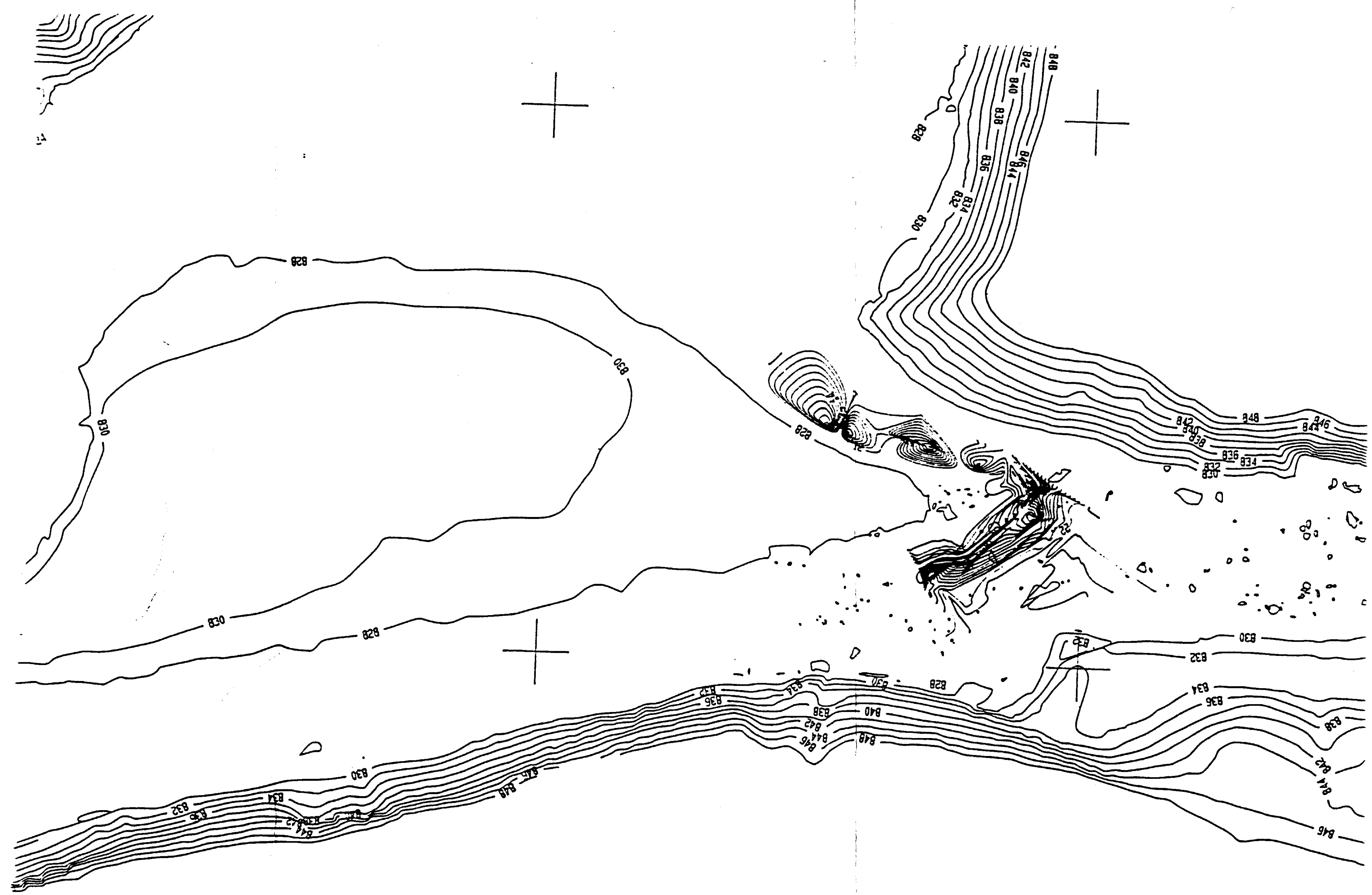


Fig. 7-12. Temperature isopleths at the LCR inflow at base flow of 230 cfs and mainstem flow of 17,470–17,798 cfs. Sample dates were July 22, 25, 1992. GIS data.

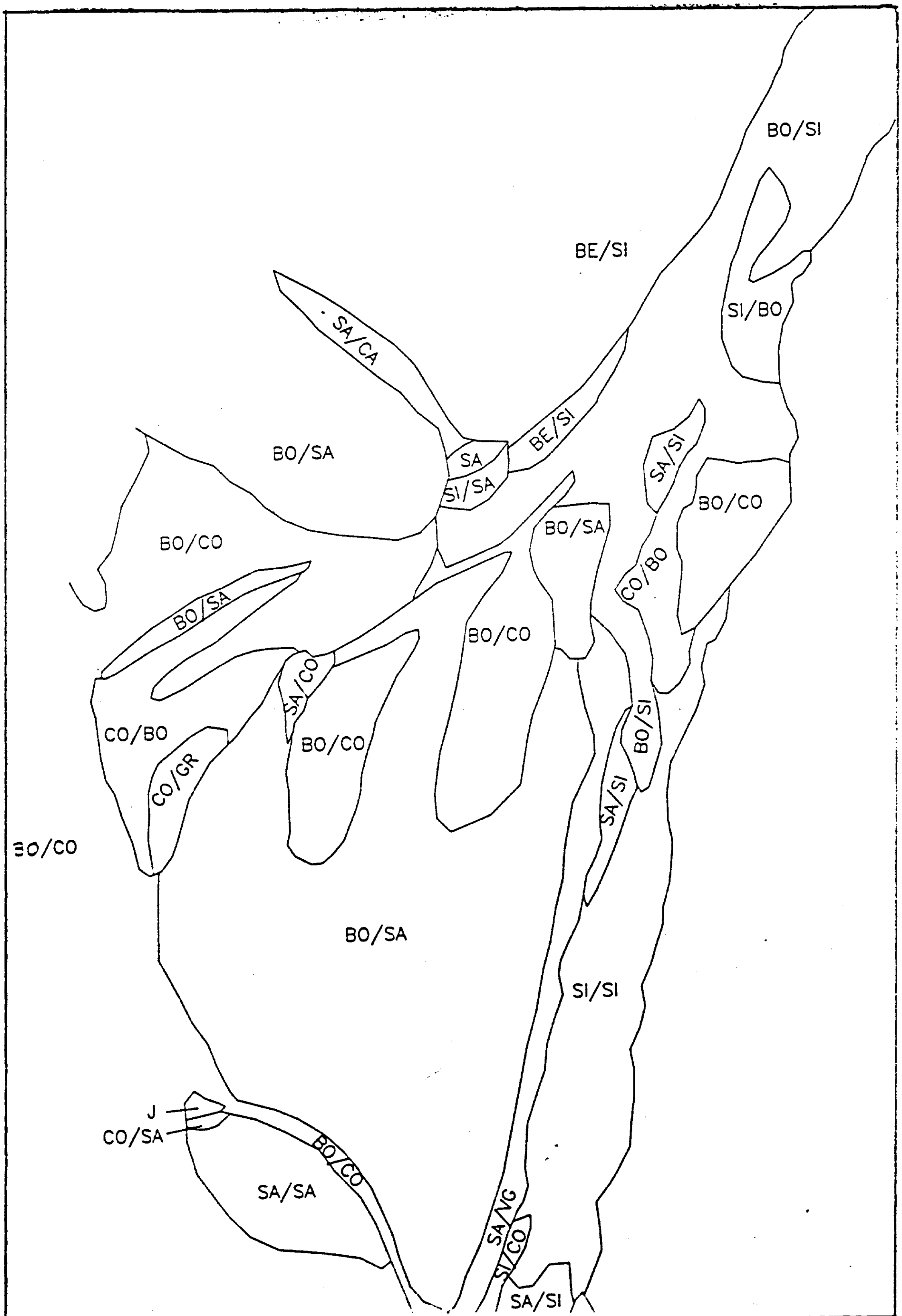


Fig. 7-13. Distribution of substrate types in the LCR inflow. May 15-17, 1993. GIS ~~data~~.

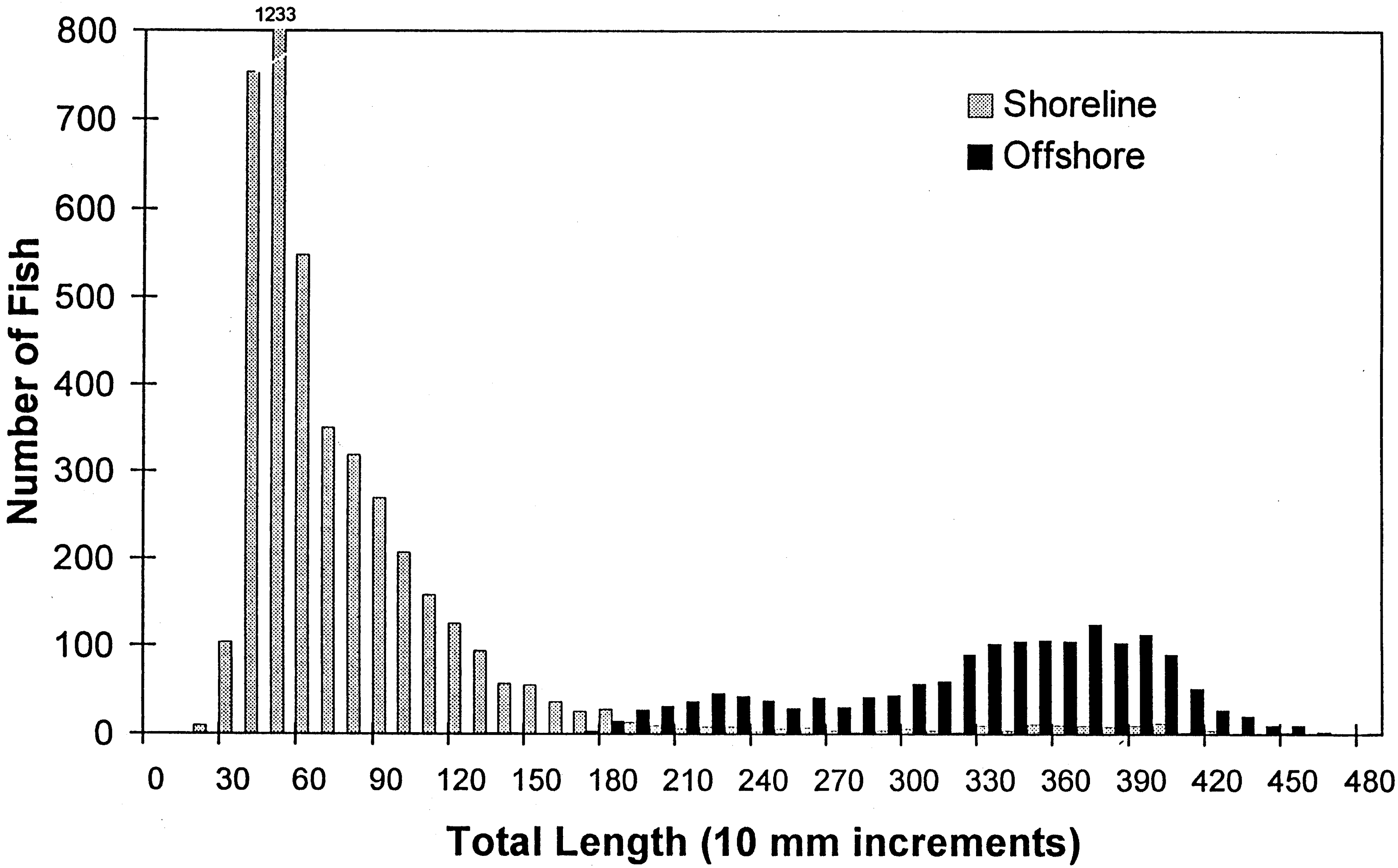

1233
800
700
600
500
400
300
200
100
0
Number of Fish
Shoreline
Offshore
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480
Total Length (10 mm increments)

Fig. 7-15

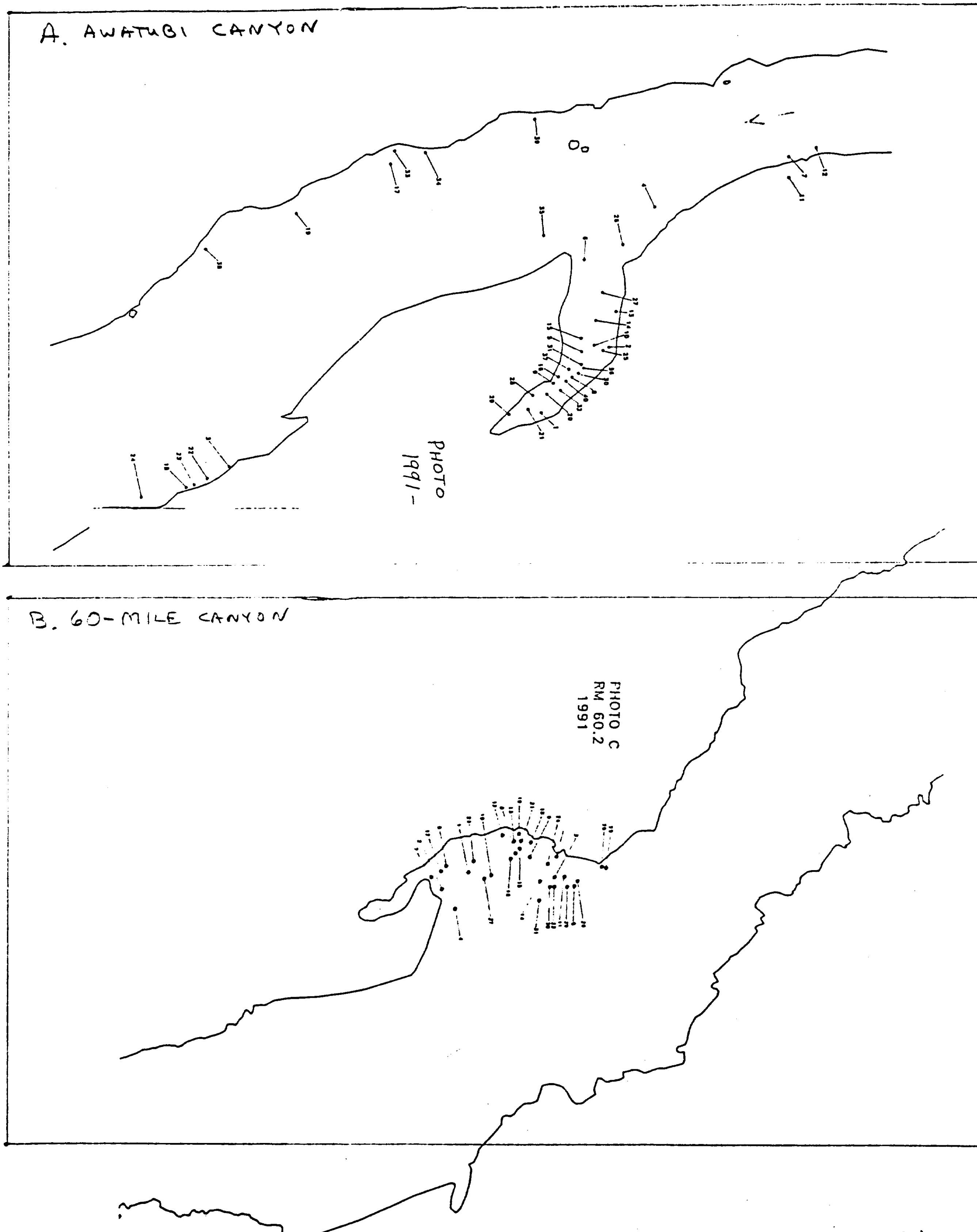


Fig 7-16. Location of radiotagged adult humpback chub (A) near Awatubi Canyon (RM 58.5), and (B) near 60-Mile Canyon (RM 60.1), 1991-92. Points represent radiocontact locations occupied ≥ 15 min, and numbers correspond to data records on an associated dBASE II dataset. GIS data.

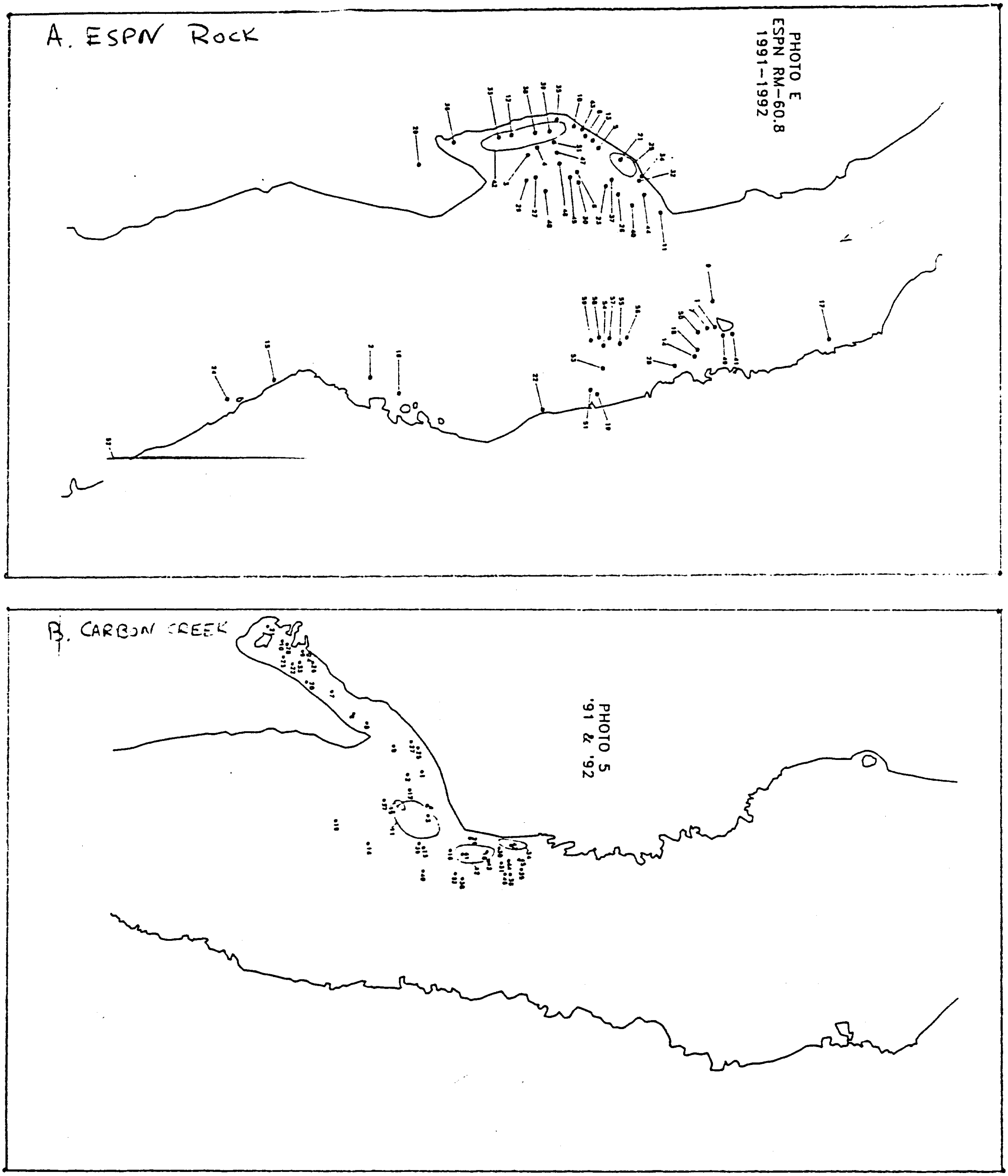
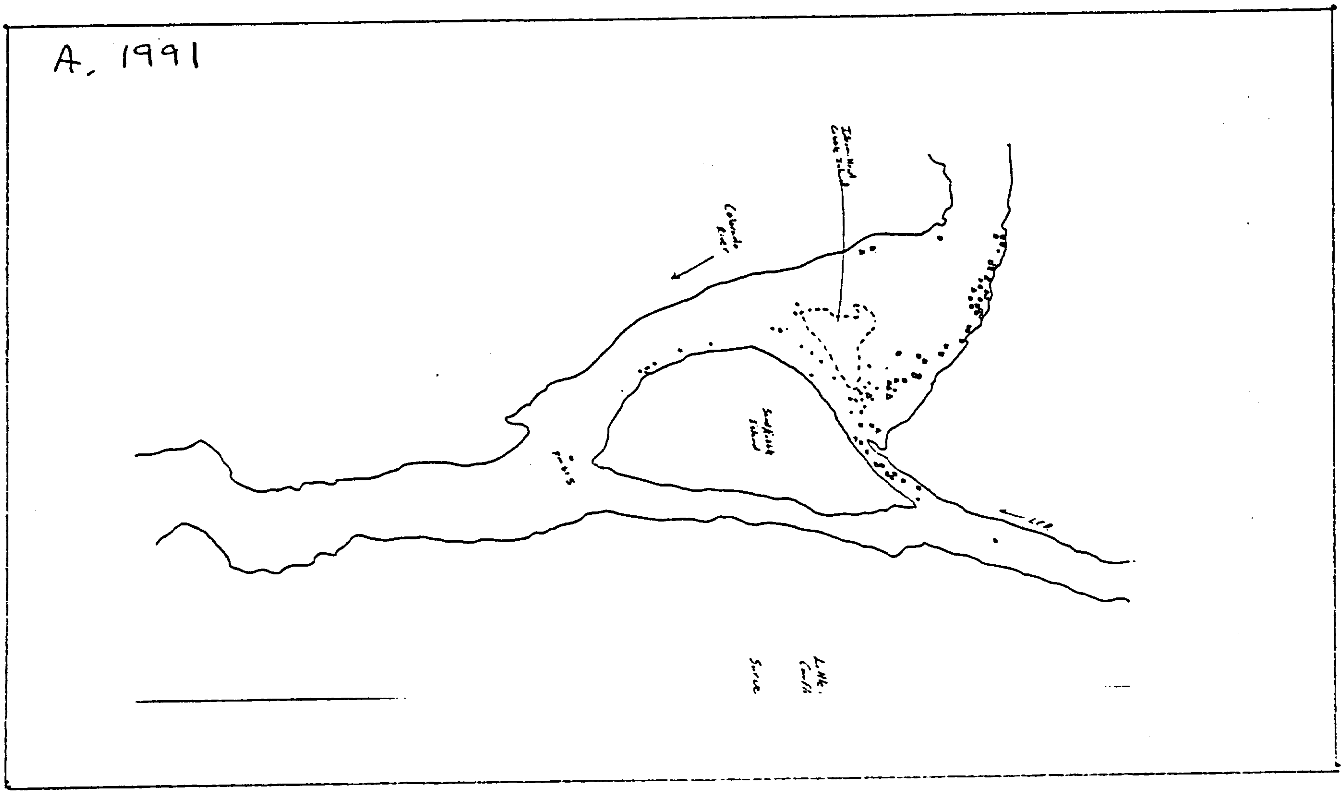


Fig. 7-17. Locations of radiotagged adult humpback chub (A) near ESPN Rock (RM 60.8), and (B) near Carbon Creek (RM 64.7), 1991-92. Points represent radiocontact locations occupied ≥ 15 min, and numbers correspond to data records on an associated dBASE III dataset. GIS data.



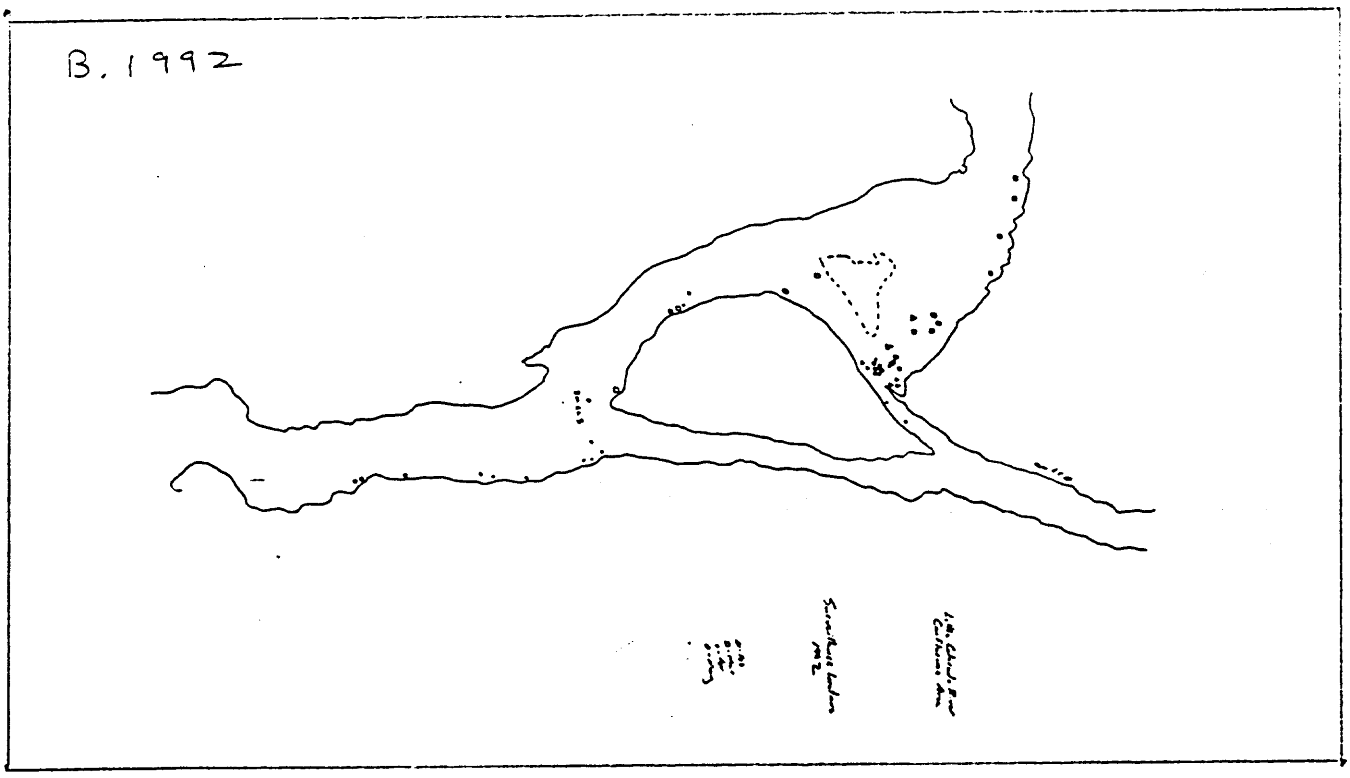


Fig. 7-18. Locations of radiotagged adult humpback chub near the LCR inflow (RM 61.3) in February–May, 1991 (A) and 1992 (B). Points represent radiocontact locations occupied $\geq$15 min, and numbers correspond to data records in an associated dBASE IV dataset. GIS data.

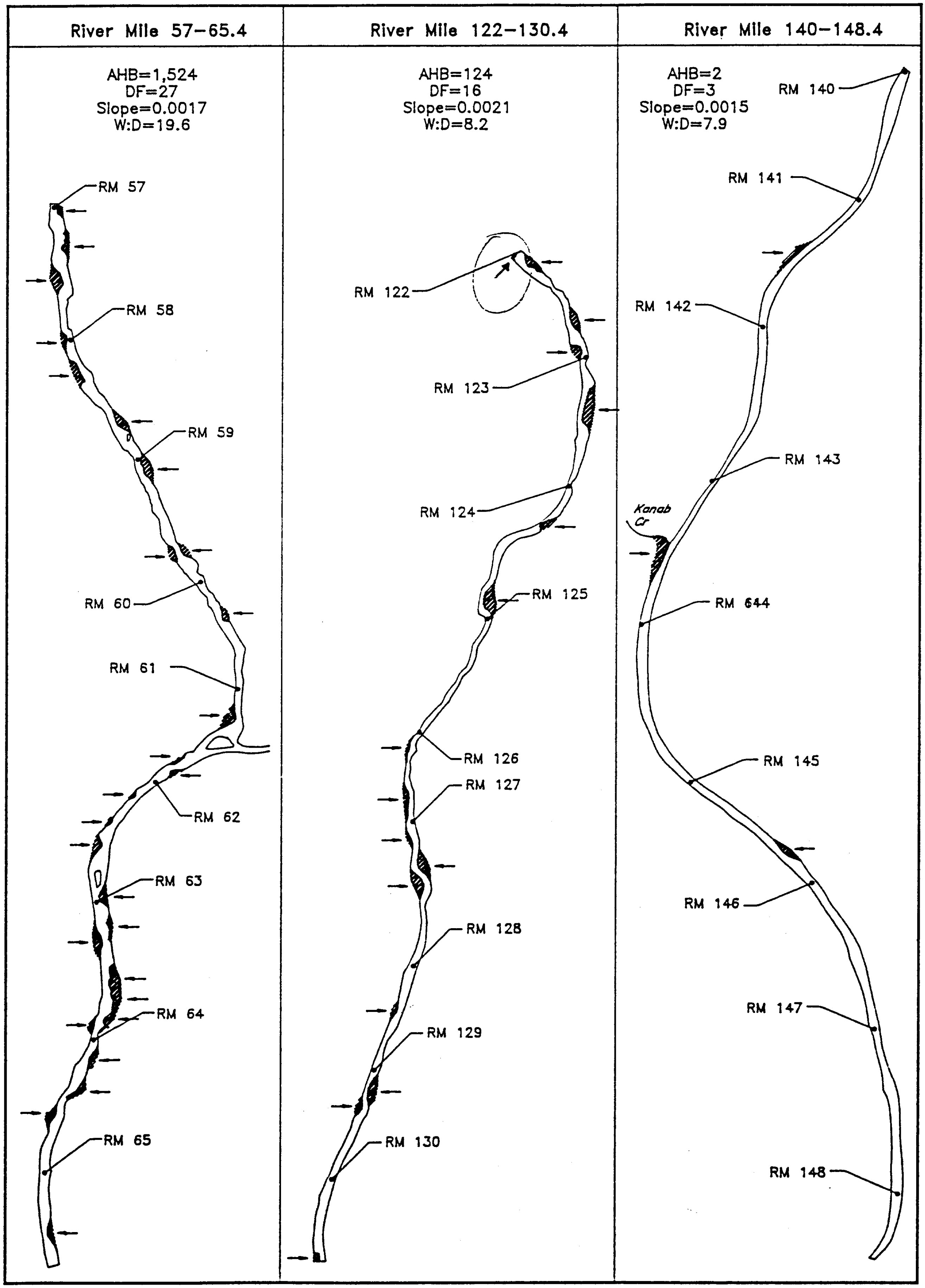


Fig. 7-19. Number of adult humpback chub captured (AHB), debris fans (DF) slope (S), and width to depth ratio (W:D) of three 8.4-mi subreaches of the Colorado River, RM 57-65.4, LCR Inflow Aggregation (A); RM 122-130.4, Middle Granite Gorge Aggregation (B); RM 140-148.4, no aggregations (C).

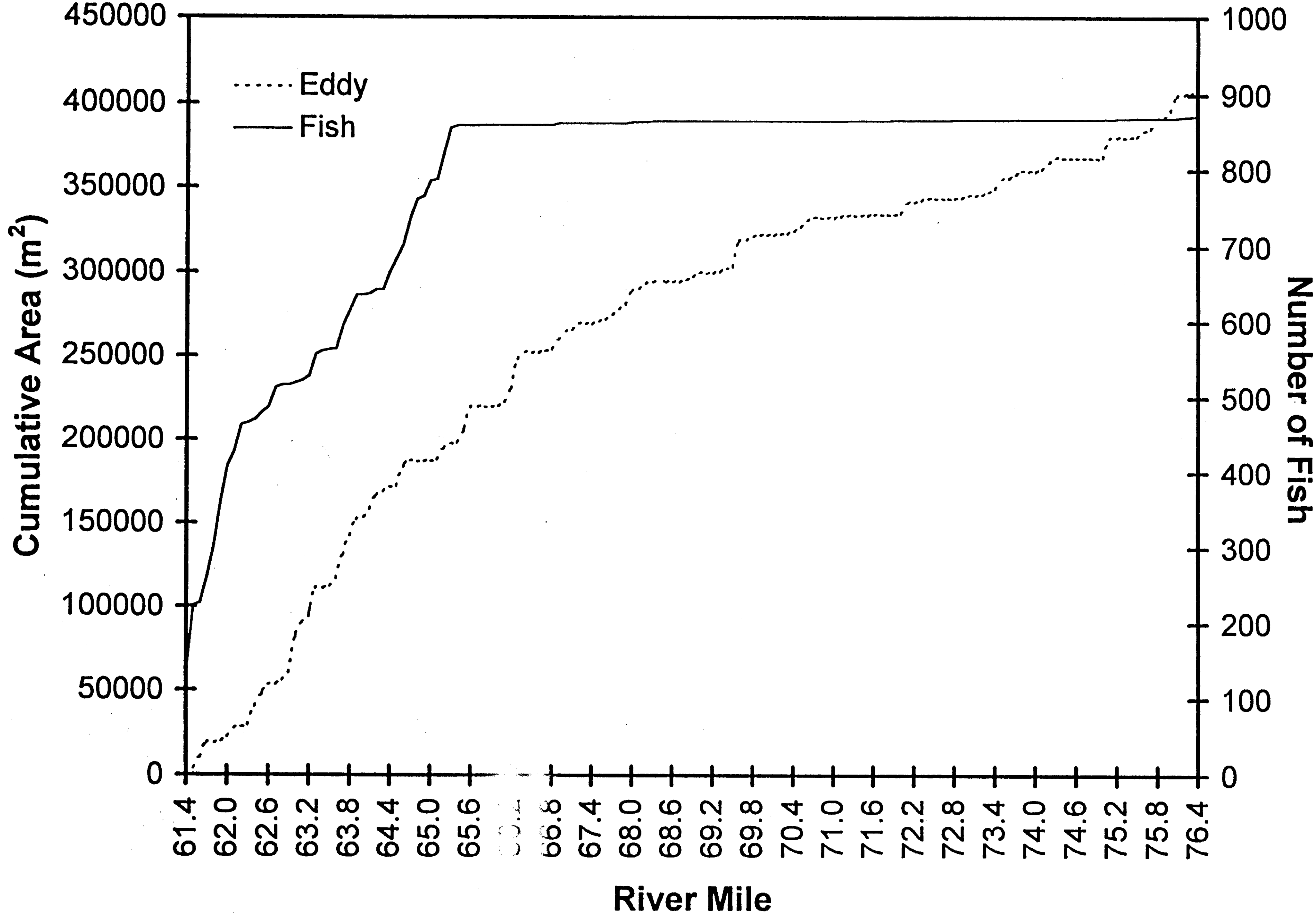
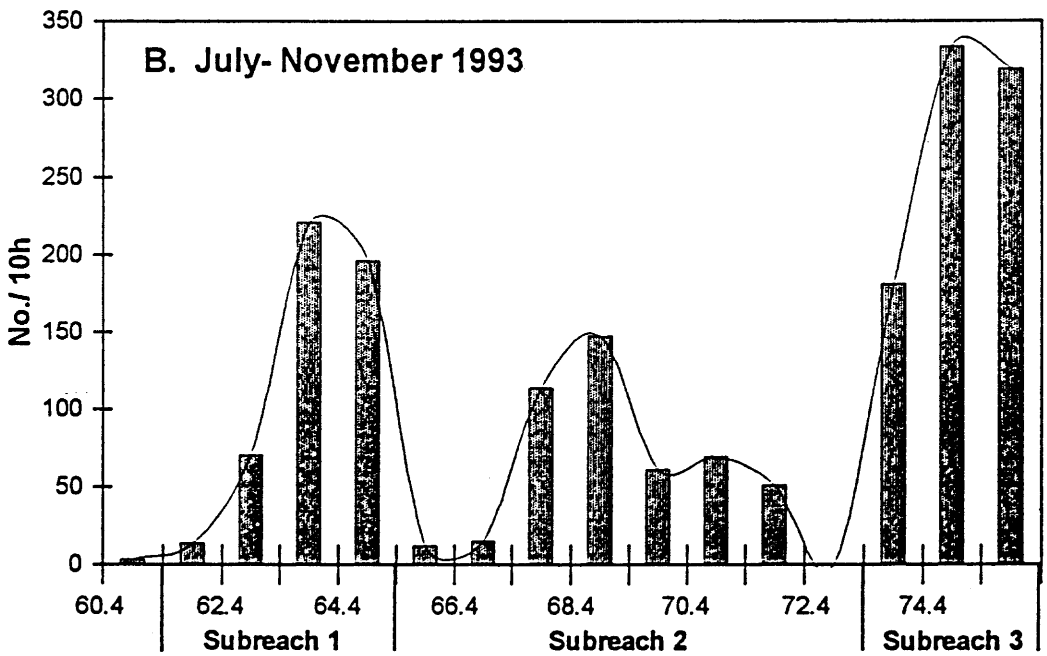
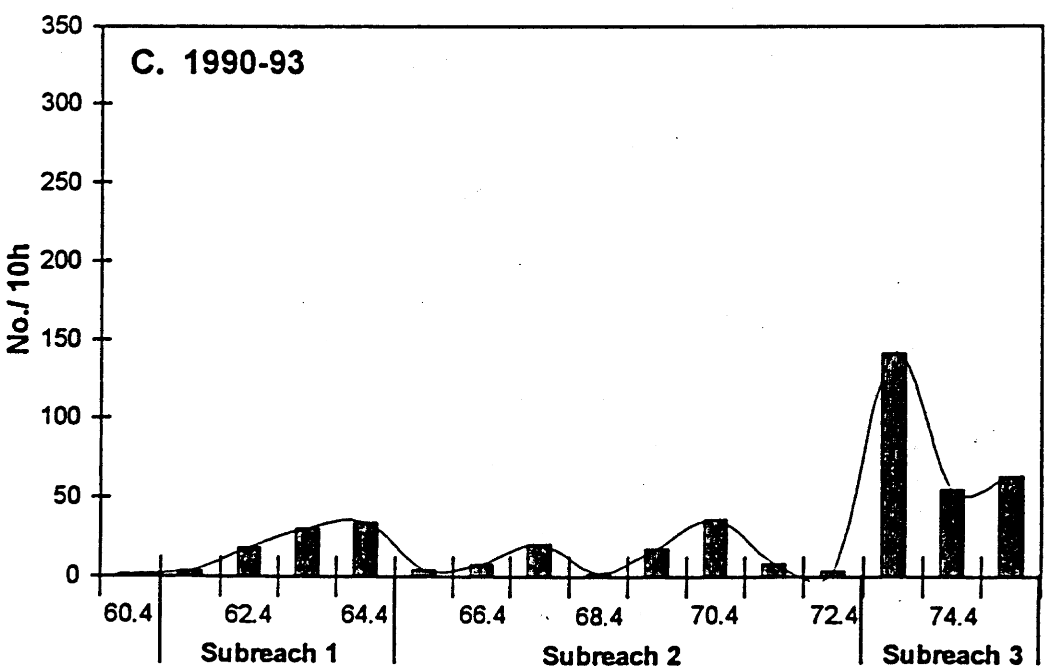


Fig. 7-20. Cumulative surface area of eddies and numbers of adult humpback chub captured from RM 61.4 (LCR inflow) to RM 76.4 (Hance Rapid).


B. July- November 1993
No./ 10h
350
300
250
200
150
100
50
0
60.4
62.4
64.4
66.4
68.4
70.4
72.4
74.4
Subreach 1
Subreach 2
Subreach 3


C. 1990-93
No./ 10h
350
300
250
200
150
100
50
0
60.4
62.4
64.4
66.4
68.4
70.4
72.4
74.4
Subreach 1
Subreach 2
Subreach 3

7-21

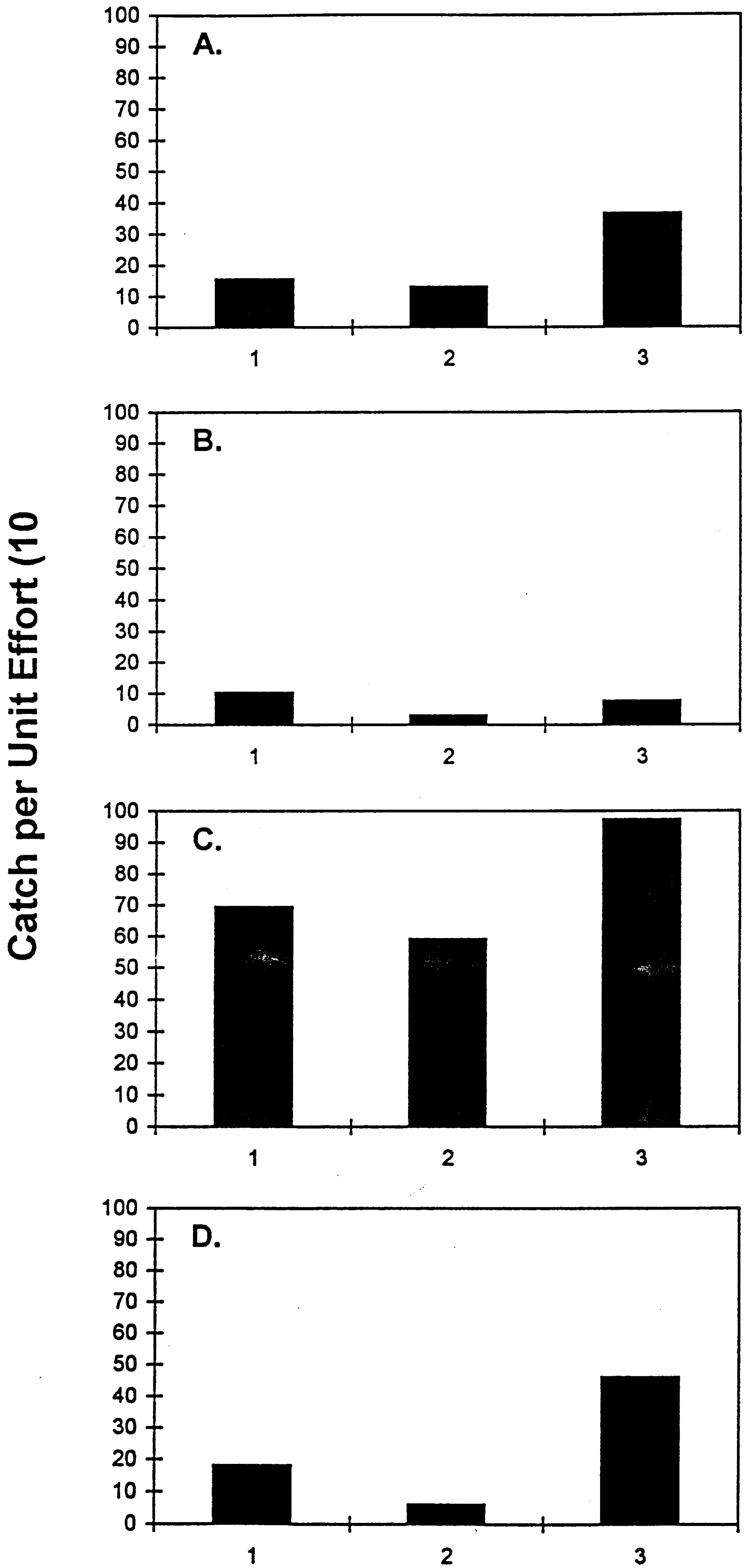


FIG. 7-23

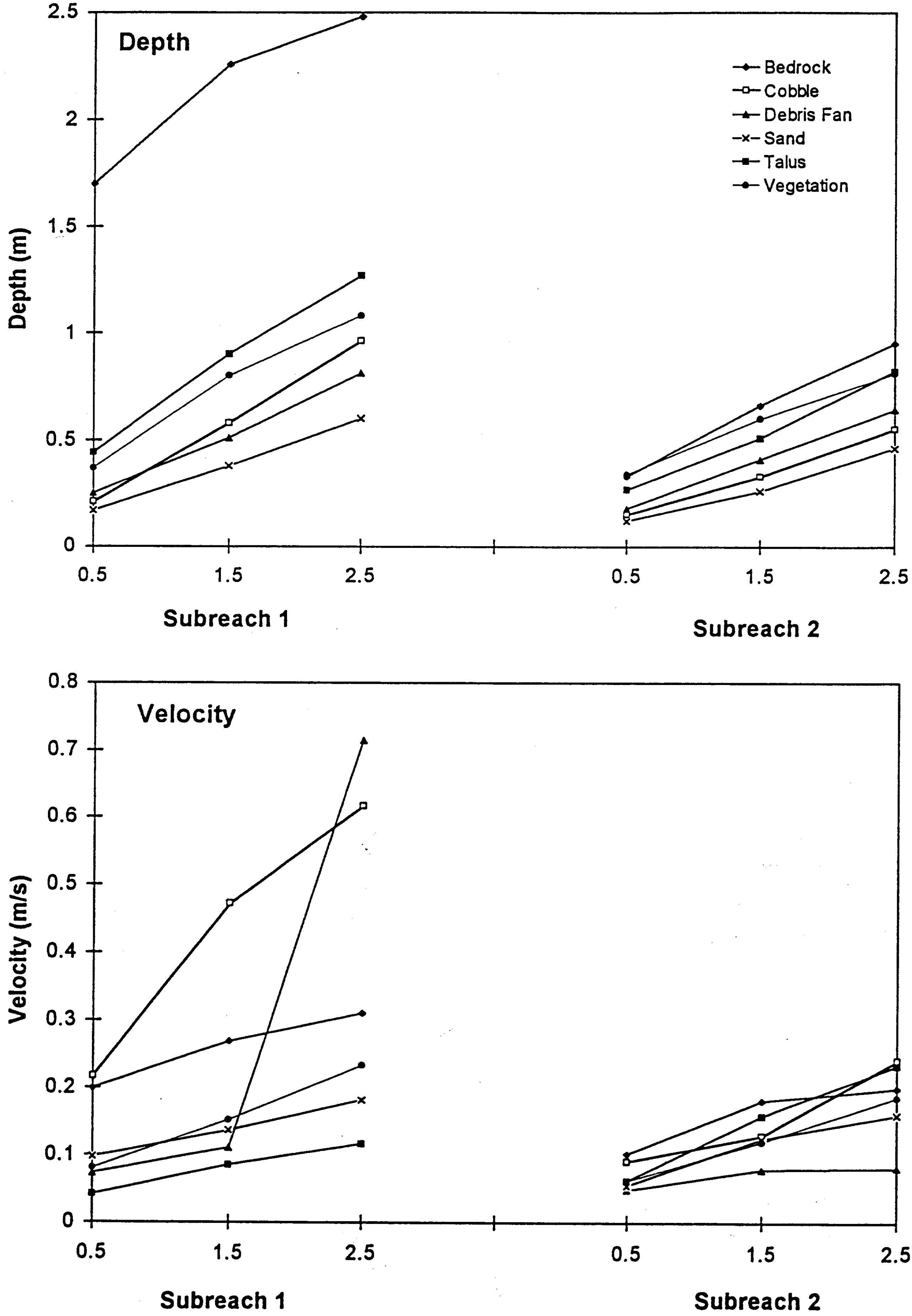

Depth
Bedrock
Cobble
Debris Fan
Sand
Talus
Vegetation
Depth (m)
2.5
2
1.5
1
0.5
0
0.5
1.5
2.5
0.5
1.5
2.5
Subreach 1
Subreach 2
Velocity
Velocity (m/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1.5
2.5
0.5
1.5
2.5
Subreach 1
Subreach 2

FIG. 7-24

CHAPTER 8 - MOVEMENT

INTRODUCTION

Humpback chub move in response to spatial and temporal changes in life-history requirements and habitat attributes, and to daily requirements for food and cover. In this chapter, movements of humpback chub in the mainstem Colorado River were characterized as part of describing life-history attributes for the species. This information was used to infer effects of Glen Canyon Dam operations on humpback chub populations in Grand Canyon.

Prior research on humpback chub in Grand Canyon has not dealt with movements, particularly in the mainstem. Movement of adults from the mainstem into the LCR for spawning was hypothesized (Kaeding and Zimmerman 1983; Angradi et al. 1992), and larval fish had been captured in drift nets and pools at the mouth of the LCR (Valdez 1989; Angradi et al. 1992). Beyond this minimal information, spatial and temporal movements in the mainstem had not been described. Adult humpback chub in Black Rocks and Westwater Canyon in the upper Colorado River, remained in limited areas year-around (Valdez and Clemmer 1982; Kaeding et al. 1990). Significant movements for spawning or between these two populations were not indicated by radiotelemetry or recapture of tagged individuals. This contrasts with sizable movements recorded for three other endemic cyprinids, Colorado squawfish, and razorback sucker, which may move hundreds of kilometers throughout the upper Colorado River basin (Archer and Tyus 1984; Valdez and Masslich 1989; Archer et al. 1985; McAda and Kaeding 1991), and roundtail chub (Kaeding et al. 1990).

Two categories of movements, were identified and described for humpback chub in this study, including long-range movement and local movement. Long-range movements occurred over periods of days to months, and were usually associated with spawning migrations of adults to and from the LCR, movement or dispersal of subadults and adults between aggregations, and juvenile dispersal. Movements of adults between the mainstem and the LCR, and between aggregations were used to identify possible linkages within the population of humpback chub in Grand Canyon. Patterns of long-range movement were used to identify spatial and seasonal movements. Understanding the dispersal of young chubs from the LCR was deemed important in evaluating recruitment potential and the existence of mainstem spawning sites, particularly in lower canyon reaches.

Local movements of adult humpback chub were related to daily activities of feeding, resting, or seeking cover in response to changes in the riverine environment as affected by flow variation. Flow variations were found to be responsible for changes in water quality (See Chapter 4 - WATER QUALITY), arrangement of macrohabitats, and characteristics and distribution of microhabitats (See Chapter 7 - HABITAT). Movement in response to changes in these variables may cost energy, and influence feeding efficiency and predator avoidance. Local movements were hypothesized to be affected by time-of-day, season, turbidity, flow regime, flow level, ramping rates, and magnitude of flow change. Movements related to these changes in the physical environment were assessed to infer effects of dam operations.

METHODS

Movement and activity of humpback chub in Grand Canyon were evaluated with radiotelemetry and recaptures of tagged individuals. Radiotelemetry data were used to identify patterns of long-range and local movements, and to assess responses of chubs to changing flows from Glen Canyon Dam operations. Recapture locations of tagged fish were used to assess long-range movement of humpback chub within the mainstem, and between the mainstem and LCR.

Radiotelemetry

Adult humpback chub were tracked with radiotelemetry in two areas of the Colorado River in Grand Canyon. Seventy-five adults were equipped with radiotransmitters and tracked in an 8-mi (12.9-km) area around the LCR inflow (RM 57-65), from October 1990 through January 1993, and three adults were equipped and tracked in a 4-mi (6.4-km) area in Middle Granite Gorge (RM 125-129) from February through August 1993 (Table 8-1).

Table 8-1. Effort expended for telemetry surveillance and observation of radiotagged adult humpback chub in Region 1 and Middle Granite Gorge (MGG), October 1990-August 1993.

	Telemetry Effort	Day	Night	Total
	Surveillance			
Region 1	Boat Surveillance (mainstem)	285	175	460
	Foot Surveillance (LCR)	73	6	79
	Aerial Surveillance (helicopter)	6	0	6
MGG	Boat Surveillance (mainstem)	21	10	31
	Observations			
Region 1	Implant	-	-	75
	Locate	-	-	58
	2 hour observation	-	-	33
	24 hour observation	-	-	73
	Test flow observation	-	-	21
MGG	Implant	-	-	3
	2-hr Observation	-	-	5
	24-hr Observation	-	-	5

Receivers, Antennas, and Transmitters.

Advanced Telemetry Systems (ATS) Model R2000 and Smith-Root (SR) Model SR-40 receivers were used to monitor humpback chub in Grand Canyon. The ATS Model R2000 was a programmable, sequential-scanning receiver used to monitor radio frequencies of 40 - 41 MHz in omnidirectional searching, directional triangulation, and remote stations. The Smith-Root Model SR-40 was a programmable, simultaneous-scanning receiver used exclusively for omnidirectional searching. The two receivers were frequently used simultaneously to insure thorough searches for radiotagged fish. Larsen-Kulrod omni-directional whip antennas, Smith-Root loop antennas, and directional Proline low band yagi antennas (30-75 MHz) were used for omnidirectional searching, directional searching, and remote stations, respectively. Five remote radiotelemetry stations were established on the banks of the Colorado River in Grand Canyon to constantly monitor presence or movement of radiotagged fish within predetermined receiving zones. Remote stations were equipped with an ATS Model R2000 receiver and a DCC-II Model R5041 data logger. Two stations with directional yagi antennas were operated February through August 1991 and 1992, near the LCR inflow to monitor movement of fish to and from the LCR (Fig. 8-1); one upstream about 50 m (KLCR, RM 61.3) and one downstream about 1200 m (KRSH, RM 62.1). A third station (KILR, RM 60.5), about 600 m above the LCR inflow, was equipped with an omnidirectional antenna to monitor occurrence of radiotagged fish above the signal extinction depth (4.5 m) between RM 60 and RM 61.3. This station was operated from August through December 1991, January 1992, and August through November, 1992. Two omnidirectional stations, established in Middle Granite Gorge, were operated February through September 1993 (KBNE, RM 126.1), and March through September 1993 (KMGG, RM 127.4).

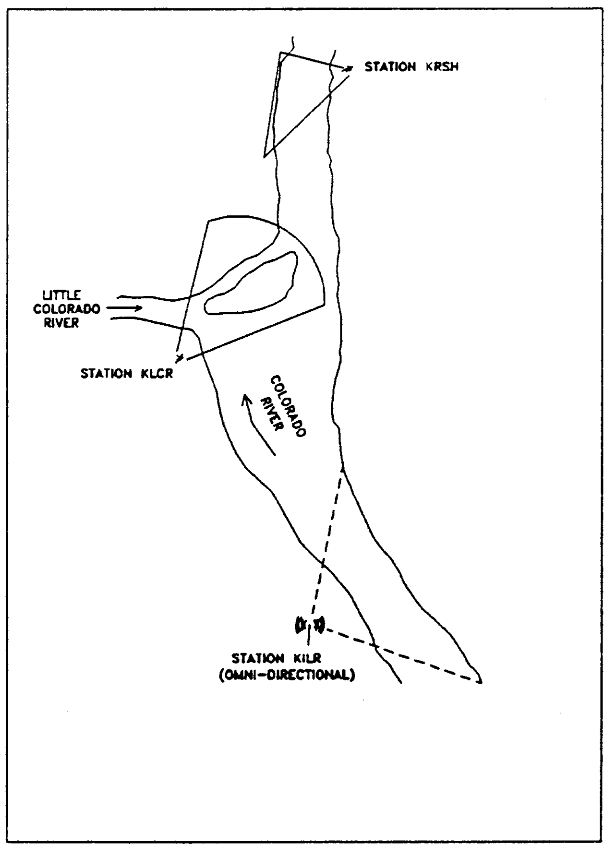


Fig. 8-1. Approximate receiving zones for three remote telemetry stations near the mouth of the Little Colorado River.

Data from remote telemetry stations were downloaded at the beginning and end of each field trip on a portable computer, using the software Procomm Plus Version 1.1B (1987, 1988) communications program. Date were used to evaluate fish movement and near-surface activity relative to season, time of day, river stage, ramping rate, and turbidity. Information collected from station KILR was also used to identify fish signatures (frequency/pulse combinations) in the area to expedite locating radiotagged fish during field trips.

Two models of ATS radiotransmitters were used, including the Model 1 BEI 10-18 (3.8 cm long, 1.3 cm diameter, 9 g, with a life expectancy of 50 d), and the Model 2 BEI 10-35 (6.0 cm long, 1.3 cm diameter, 11 g, with a life expectancy of 75-120 d). Both models were oblong, capsule-shaped transmitters, with an external antenna, 25 cm long and 1.2 mm diameter. Transmitters emitted signals in the frequency range of 40.600-40.740 MHz, and were separated by 10 Hz intervals (i.e., 40.600, 40.610, 40.620, etc.) to distinguish individual transmitters. This 10-Hz separation yielded 15 different frequencies, which in combination with 3 pulse rates (40, 60, and 80 pulses per minute), allowed for a total of 45 unique signatures to identify individual fish. A particular combination of frequency and pulse was reused following expiration of a transmitter.

Yard et al. (1990) reported from field tests in Grand Canyon that radio signals from 9-g external-antenna transmitters were received from a maximum water depth of 4.63 m, at a horizontal distance of 48 m in the Colorado River (10 C, 860 μs/cm), but only 0.91 m depth in the more saline LCR (23 C, 4630 μs/cm). Similarly, radio signals from 11-g external-antenna transmitters field tested for this investigation were received from a maximum water depth of 4.5 m at 50 m distance (11 C, 950 μs/cm). Maximum horizontal reception for an 11-g transmitter 1 m deep was 1200 m (11 C, 950 μs/cm).

Surgical Procedures

A surgical protocol was established from procedures developed by Valdez and Nilson (1982) and Kaeding et al. (1990) for humpback chub; Tyus (1982) for Colorado squawfish; and Valdez and Masslich (1989) for Colorado squawfish and razorback sucker to minimize stress to the fish and prevent bacterial contamination. Fish were selected for radioimplant based on weight, condition, and location of capture. Transmitter weight could not exceed 2% of fish weight (Bidgood 1980, Marty and Summerfelt 1990), such that 9-g transmitters were implanted in fish weighing 450 g or more, and 11-g transmitters were implanted in fish weighing 550 g or more. Care was taken to select fish that were healthy and showed no signs of stress. Females were not implanted from March through May to prevent stress to gravid fish, avoid resorption of eggs from handling, and eliminate the risk of transmitter expulsion from enlargening egg masses (Bidgood 1980, Marty and Summerfelt 1990).

Surgical implants were performed in an enclosed tent at a central processing station in a riverside camp. Two trained members of the B/W staff were designated with the primary responsibility of insuring that all aspects of surgical procedures were followed and monitored. Three people were involved with surgery--a surgeon, an assistant, and an anesthetist to administer anesthesia and monitor respiration of the fish. Fish were anesthetized with Finquel®, a brand of tricaine methanesulfonate (MS-222), at a concentration of 100 mg/l for 2-4 min.

During surgery, gills were bathed with anesthetic at 50 mg/l, as needed, and then with fresh water about half way through the surgery to expedite post-surgical recovery.

A primary incision, 2-3 cm long, was made either along the abdominal midline (linea alba) or lateral to the midline, between the pectoral and pelvic girdles (Fig. 8-2). The radiotransmitter was inserted through the primary incision and positioned on the pelvic girdle with the antenna protruding through the abdominal wall, posterior to the pelvic girdle and anterior to the vent. The antenna was exerted through a small incision in the body wall with the aid of mosquito forceps or punched through the wall with a specially-designed sheathed needle (Masslich et al. 1994). Primary incisions were closed with four or five non-absorbable Gortex® or absorbable Maxon® sutures (Gore Laboratories, Flagstaff, AZ). Antenna incisions were closed with two sutures, and 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 implant. Following surgery, fish were held in a live well until completely recovered--usually 10-30 min--then released at the capture location.

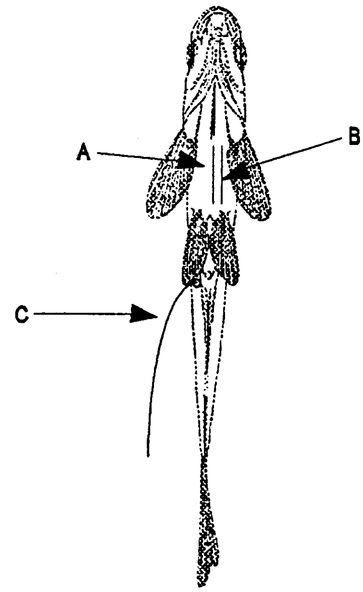


Fig. 8-2. Primary abdominal incision along the linea alba (A) or lateral to the midline (B), and external antennae (C) of implanted radiotransmitter in adult humpback chub.

Recaptured radiotagged fish were weighed and measured, and examined to document recovery or complications associated with radioimplant procedures. Photographs were taken of the fish to document general condition, and of the primary incision and antenna exit to document rate and degree of healing or signs of necrosis. Protruding antennae, from expired transmitters, were cut approximately 1-2 cm from the body wall to remove frictional drag of the antennae and reduce stress to the fish. Expired radiotransmitters were not removed from fish. An evaluation of radiotelemetry procedures is presented in Chapter 10.

Surveillance

Surveillances were conducted twice daily, during day and night to characterize daily pattern in near surface activity, and longitudinal long-range movement of radiotagged fish. Each surveillance was conducted by 2-3 researchers from a 16-ft Achilles research boat moving slowly through a 12.9-km subreach (RM 57.5-65.5) while radioreceivers were monitored. Aerial surveillances by helicopter were conducted three times, but discontinued because fidelity by radiotagged fish to specific areas precluded the need for widespread searches.

Signal locations were marked on 1:2400-scale aerial photographs, and a confidence level of 1 (high, <10 m), 2 (medium, 10-100 m) or 3 (low, 100-400 m) was assigned to each location as an index of observer confidence for range of location accuracy, i.e., triangulation was usually inaccurate at night, in proximity to canyon walls, during inclement weather, and with faint or inconsistent signals. Ambient light, weather, and an ocular estimate of turbidity (high or low) were recorded for each surveillance, and habitat type was recorded at each radiocontact location. Water clarity was measured at least once daily with a Secchi disk, and beginning in March 1992, turbidity as NTU's (as nephelometric turbidity units, NTU; Hach Model 2100P turbidimeter) was measured daily.

Fish movements of greater than 0.08 km (0.05 mi) were detectable with surveillance. Because surveillance was not continuous in time, displacement was used as an index to movement (Fig. 8-3). "Net displacement" was defined as longitudinal distance from release site to last contact site, while "gross displacement" was defined as cumulative distance between successive contact points for an individual fish and "mean displacement" was the average distance between contact points. Net displacement was also expressed as distance upstream or downstream. Only surveillance locations with confidence levels of 1 or 2 were used for analysis.

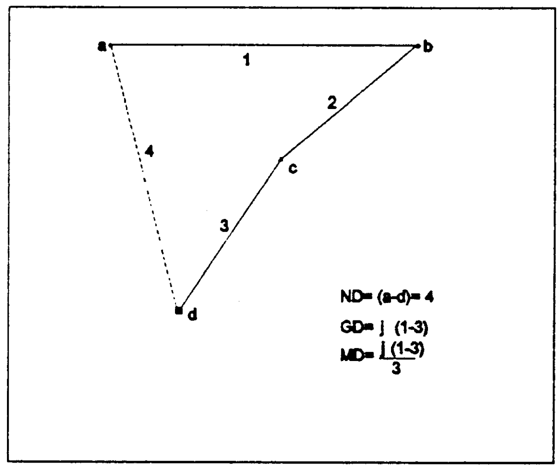


Fig. 8-3. Schematic to define movement of radiotagged fish at net (ND), gross (GD), and mean (MD) displacement between contact points. Contact points are a-d, and distance between consecutive contact points are 1-3. Distance 4 is linear distance from first to last contact.

An index of near-surface activity was also determined from telemetry surveillance of radiotagged adult humpback chub. Fish contacts above the extinction depth of radio signals, approximately 4.5 m (Yard et al. 1990), were used to indicate near-surface activity. During surveillances, it was assumed that fish below this depth could not be contacted, but were within the range of radio coverage based on previous contacts. Average proportion of fish located (APFL) was used as an index to express near surface activity:

$$APFL = FL/FE \qquad \text{(Equation 8-1)}$$

where: FL = fish located, or the number of radiotagged fish located in the surveillance area (above 4.5 m depth),
FE = fish expected, or the probable number of fish in the area based on release records of radiotagged fish, previous surveillances, and remote telemetry data.

APFL was compared between seasons, time-of-day, and high and low turbidity. Seasons were designated by 3-month periods (winter: December-February, spring: March-May, summer: June-August, fall: September-November). Spawning period (February-May) was also distinguished from non-spawning period (June-January).

The period of spawning was inferred from observed movement of radiotagged fish into the LCR, and was similar to that reported by Kaeding and Zimmerman (1983). Time-of-day was divided into day (sunrise to sunset) and night (sunset to sunrise), with sunrise and sunset calculated for a date in the middle of each monthly trip (Sun and Moon Events Worksheet, Heizer Software, Inc., Palo Alto, CA). Turbidity, as measured with a Secchi disk, was classified as low (≥ 30 NTU, 0.5 m) or high (< 30 NTU, 0.5 m) (See Chapter 4 - WATER QUALITY).

Surveillance records from radiotagged chubs were used to calculate net and gross movements in Region 1 and MGG. Of the 75 radiotagged humpback chub released in Region 1 between October 1990 and November 1992, 69 were used to evaluate long-range movement (Appendix H-1). Six fish were excluded from analysis: five were only tracked 2 weeks following implant, and aerial locations for the sixth were not ground confirmed. Three humpback chub radiotagged in 1993 were used to evaluate movements of fish in the MGG aggregation.

Remote Telemetry

Directional remote telemetry was used to evaluate use of the LCR confluence by identifying specific times in which radiotagged fish were present. Two directional stations were used to monitor radiotagged humpback chub between RM 61.2 and RM 61.5 (KLCR), and between RM 61.9 and RM 62.2 (KRSH) (Fig. 8-1). All fish contacted by a station were assumed to be within the respective receiving range. Effective antenna range was determined by deploying test tags at a 1-m depth at increasing distances up- and downstream from the station until contact was lost, and included a reach of approximately 0.5 km for both stations. Upstream or downstream movement to and from these monitored areas was inferred from surveillance locations collected before and after contact by a station. Season and duration use of the LCR confluence, and specific timing of movements by adults between the mainstem and LCR, were determined with this monitoring system.

Data from three omni-directional remote telemetry stations were used to assess near-surface activity of radiotagged fish in the LCR inflow aggregation (KILR) and the Middle Granite Gorge aggregation (KBON and KMGG). Although antenna ranges were not established for KBON or KMGG, effective ranges were assumed to be similar to KILR. To permit comparisons with telemetry surveillance data, only remote telemetry data collected during field trips (when turbidity data were collected) were analyzed. Average proportion of radiotagged fish contacted (APRC) was used as an index to near surface activity:

$$APRC = CO/CE \qquad \text{(Equation 8-2)}$$

where: CO = number of contacts with a radiotagged fish within a specified time period
CE = number of possible contacts within the same time period

Mean APRC was related to turbidity and time-of-day, but seasonal effects could not be evaluated because KILR was operated only during non-spawning periods, and an appropriate spawning season could not be identified for the Middle Granite Gorge aggregation. Diel periods and high-low turbidity levels were the same as defined for telemetry surveillance. For statistical analysis, values of APRC and APFL were arcsin transformed (Sokal and Rohlf 1969).

Observation

Individual radiotagged adult humpback chub were observed for periods of 2 to 72 h (x=14.5 h) to assess local movement by season, time-of-day, turbidity, flow, ramping rate, and magnitude of flow change. Local movement or activity was defined as movement within macrohabitats or habitat complexes, and was represented two-dimensionally as horizontal movement. Sequential observations of radiotagged fish were conducted with relocation attempts approximately every 0.5 h.

The location of a selected radiotagged fish--determined by triangulation from the nearest bank (Fig. 8-4)--was marked at 30-min intervals on a mylar overlay on 1:2400-scale aerial photographs, and river stage and fish macrohabitat (e.g., eddy, run, pool, riffle) were simultaneously recorded. Locations (dots) and movements (lined arrows) were transferred to GIS as a record of movement of radiotagged adult humpback chub relative to other environmental parameters, e.g., channel bathymetry, fish macrohabitat, substrate type, temperature regimes, and occurrence of other fish species (See Chapter 7 - HABITAT).

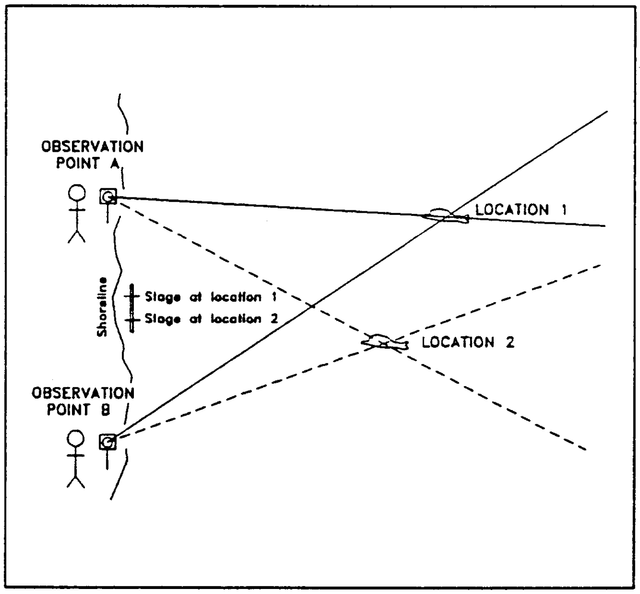


Fig. 8-4. Location of radiotagged adult humpback chub by triangulation and relationship to river stage.

Observation periods were divided into blocks for analysis, each covering the time between consecutive locations of a target fish. A given observation period was usually composed of many blocks, each representing a sample of movement by the fish under specific conditions. To standardize blocks for analysis, only those with elapsed time of 0.25-1.0 h were used, and included 1831 blocks (90% of total) with a total elapsed time of 962.8 h. Detectable fish movement during a block was defined as movement ≥5 m. Movements of <5 m were considered with the range of observer triangulation error. The proportion of movement (Pm) was used as an index of fish movement or activity where:

$$P_m = BM/BT \qquad \text{(Equation 8-3)}$$

where: BM = number of blocks with movement, and
BT = total number of blocks

Categories of season, time-of-day and turbidity were the same as described for surveillance. Mainstem flow in 30-min intervals was determined from the Colorado River USGS gaging station (#9383100) just above the LCR confluence. Flow was classified as high (≥ 10,000 cfs) or low (< 10,000 cfs), with the dividing point close to the mean flow during observations (mean: 10,874 cfs; range: 4778 - 29,916 cfs). Absolute ramping rates (cfs/h) were calculated from flow measurements nearest the start and end times of an observation period, and were classified as high (≥ 300 cfs/h) or low (< 300 cfs/h). Ramping rates ranged from 0 to 8833 cfs/h and averaged 454 cfs/h during observations. Periods of continuous observations for 24 h were used to evaluate fish movement under research and interim flow regimes, since flow changes typically cycled through 24 h. Proportion of movement from 24-h observations was also related to the magnitude of flow change, i.e., the difference between high and low flows within a flow cycle.

Radiotelemetry in Middle Granite Gorge was used primarily for tracking movement and dispersal of adults from a small disjunct aggregation of humpback chub prior to the expected spawning period of April and May. The area was surveyed and radiotagged fish were monitored in the same manner as described for the LCR inflow area.

Recaptures of Marked Fish

Adults and Subadults

Displacement by PIT-tagged humpback chub recaptured by electrofishing, netting, and seining were also used to evaluate long-distance movement. Sampling efforts used to capture these fish were described in Chapter 5 - DISTRIBUTION AND ABUNDANCE. Net movement was defined as displacement between successive captures. Humpback chub recaptured with Carlin dangler tags or Floy tags, marked during previous studies, were also used to assess long-distance movement, although original capture information was not available for all fish (See Chapter 10 - EVALUATION OF SAMPLE DESIGN).

Juveniles

A joint marking program was conducted by ASU in the LCR and B/W in the mainstem to determine dispersal of subadult (TL <150 mm) humpback chub. Fish marked with fin clips or punches (N=186) by ASU were used to evaluate movements of juvenile humpback chub from the LCR into the mainstem. Fin-clip combinations (codes) and associated reaches in the LCR (river kilometers, RK, from mouth) where fish were originally marked were:

- RK 0 to RK 3.1 - lower caudal lobe, left pelvic (LCLP),
- RK 3.1 to RK 7.5 - lower caudal lobe, right pelvic (LCRP),
- RK 7.5 to RK 10.8 - upper caudal lobe, left pelvic (UCLP), and
- RK 10.8 to RK 14.8 - upper caudal lobe, right pelvic (UCRP).

In 1992-93 BIO/WEST marked 1042 subadults in the mainstem with the following four fin-punch combinations (codes) used to identify the subreach where fish were originally captured, marked and released.

- RM 57 to RM 65.4 - dorsal fin (DP)
- RM 65.5 to RM 76.6 - lower lobe caudal fin (LCP)
- RM 76.7 to RM 156.6 - upper lobe caudal fin (UCP), and
- RM 156.7 to RM 225.5 - upper and lower lobe caudal fin (ULCP)

RESULTS

Long-range Movement

Long-range movement of humpback chub was evaluated for the mainstem Colorado River between the mainstem and LCR, and between aggregations. The extent and timing of these movements were related to flow regime, season, and age of fish.

Mainstem Movement

Mean net displacement of 69 adult humpback chub in Region 1 (Fig. 8-5, Appendix H-1) was 1.49 km (range: 0.00-6.11 km). Mean gross displacement was 5.13 km (range: 0.32-16.93 km), with a mean displacement of 0.26 km between contacts. Time between release date and last contact ranged from 30-170 d and averaged 93 d. All observed movements in Region 1 were within a 14-km subreach of the mainstem (RM 57.0-65.4) and the lower 5 km of the LCR, although movement information from radiotelemetry within the LCR was minimal, since the highly conductivity water interfered with signal transmission. Net (t=0.341, p=0.734, df=63) and gross (t=0.073, p=0.942, df=63) movements were not significantly different between males and females.

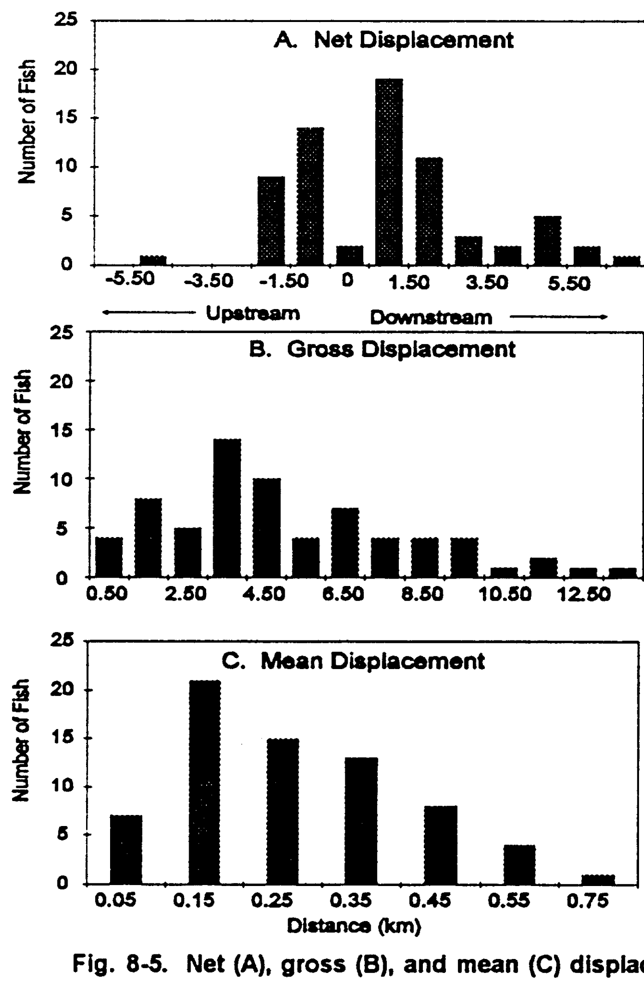


Fig. 8-5. Net (A), gross (B), and mean (C) displacement between contacts of 69 radiotagged adult humpback chub in Region 1, November 1990-November 1992.

Movements of three radiotagged adult humpback chub in Middle Granite Gorge

(MGG) were similar to those in Region 1, with mean net and gross displacements of 1.88 and 3.38 km, respectively (Appendix H-1). Net displacement was not significantly different from fish in Region 1 (t=0.38, p=0.704, df=70). Displacement between contacts averaged 0.20 km, and was not significantly different from mean displacement in Region 1 (t=0.76, p=0.450, df=70). Movements by these fish were confined to a 4-km reach (RM 126.1-128.5), the approximate boundaries defined for this aggregation (See Chapter 5 - DISTRIBUTION AND ABUNDANCE).

Strong spatial fidelity was exhibited by radiotagged adult humpback chub. Of 69 fish radiotracked in Region 1, net displacement of 35 (51%) was less than 1 km, and net displacement 58 (84%) less than 3 km. Despite strong spatial fidelity, adults moved considerably between eddy complexes following spawning periods, as illustrated by movements of two radiotagged adults during portions of 3 months (Fig. 8-6). Fish spent one to several days within an area before moving, and tended to reoccupy specific sites after periods of absence.

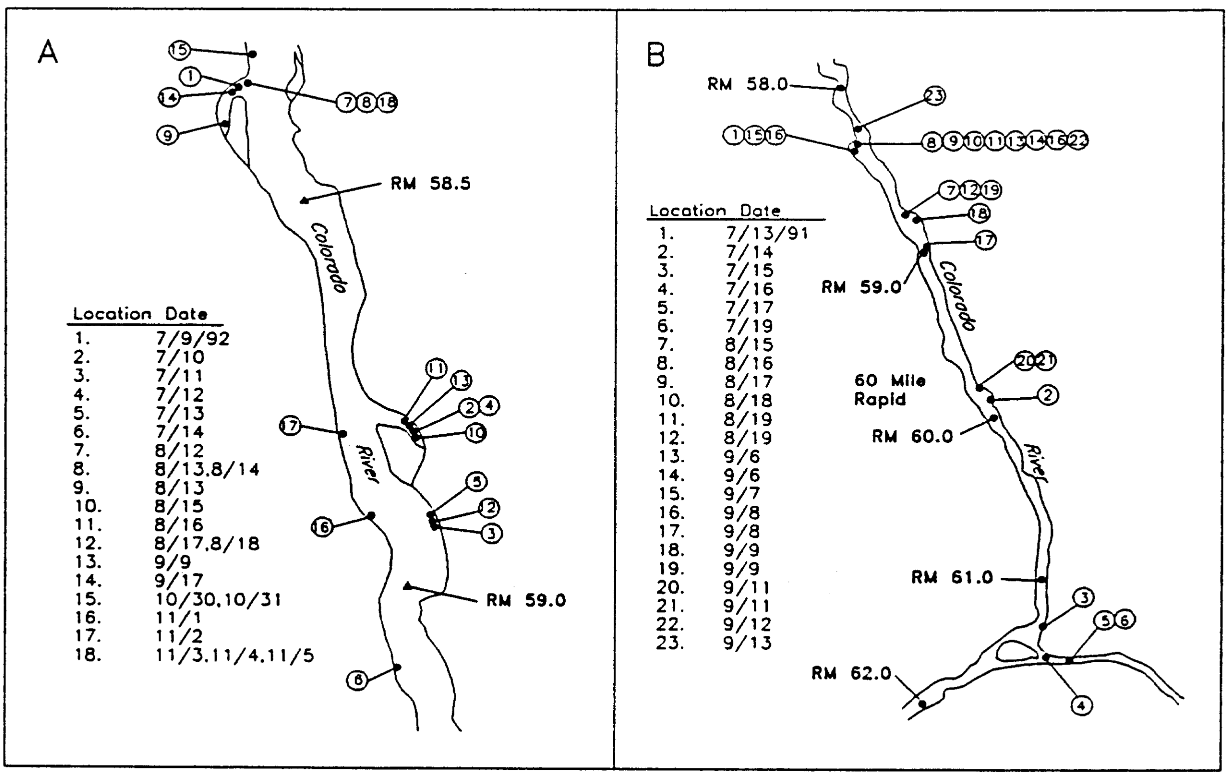


Fig. 8-6. Locations of two radiotagged adult humpback chub determined from telemetry surveillance in Region 1, July 9-November 5, 1992 (A) and July 13-September 13, 1991 (B). RM = river mile

Similar movement was reported for 188 PIT-tagged humpback chub (TL ≥150 mm). Net displacement within the mainstem between consecutive captures of 238 marked fish (285 movements) averaged 1.64 km (range: 0.0-99.8). To remove biases of fish caught a few hours to days apart, net displacement was calculated for consecutive captures separated by ≥20 d (188 fish, 225 movements). A slightly higher net displacement of 1.94 km (range: 0.0-99.8) resulted. Net displacement for 185 PIT-tagged fish (222 movements) was 0.99 km (range: 0.0-8.9) when three net movements over 9 km (movements between aggregations) were omitted. For periods of ≥20 d, displacements were equally divided between upstream and downstream movements, with 85% of net displacements less than 2 km (Fig. 8-7). Mean net displacements were not significantly different for captures separated by 20-120, 121-365, and 366-1065 d (ANOVA, F=0.80, p=0.45, df=2, 291), with net movements averaging 0.85 km (range: 0.0-8.9), 1.10 km (range: 0.0-4.8) and 1.02 km (range: 0.0-5.6) for the three respective periods. Net displacement of ≥20 was not significantly different (t=1.66, p=0.098, df=192) between male (mean: 0.89 km, range: 0.0-4.9) and females (mean: 1.22 km, range: 0.0-8.9). Net displacements of PIT-tagged humpback chub were similar to those calculated of 69 radiotagged fish (t=0.17, p=0.867, df=352).

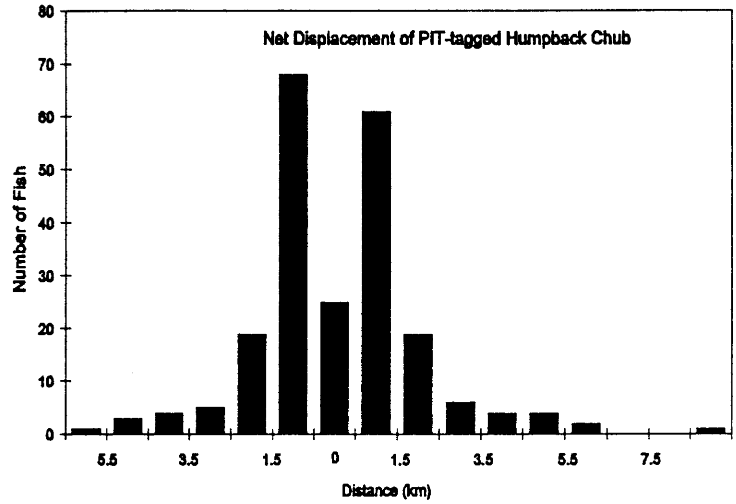


Fig. 8-7. Net movement of 188 PIT-tagged humpback chub (225 movements) between consecutive captures separated by ≥20 d within Region 1, October 1990-November 1993.

Estimated net displacement was greater for PIT-tagged humpback chub in Reach 1 than in MGG. Net displacement of 1.11 km (range: 0.0-8.9) in Reach 1 for 166 movements was significantly greater (t=3.11, p=0.0022, df=209) than 0.64 km (range 0.0-2.8) for 45 movements in MGG. Differences in net displacement between aggregations may have been related to the reach size, since greater net movement in Region 1 was related to a much larger area of suitable habitat (34.4 km) than in MGG (3.9 km).

Movement between Mainstem and LCR

Extent of Movements. Numerous radiotagged fish moved from the mainstem to the LCR or LCR inflow during this investigation. High conductivity in the LCR precluded adequate relocations of radiotagged fish in that tributary. Of 69 fish monitored, 35 (51%) were found in the LCR or LCR inflow (RM 61.3-61.4) at least once during the period of contact, despite having been captured, implanted, and released in the mainstem Colorado River. Timing of these movements corresponded with spawning activity in the LCR (See next section--Timing of Movements). Even with movements to the LCR, these fish demonstrated strong spatial fidelity, i.e., net displacement of 70% of fish was less than 2 km.

Net displacement of PIT-tagged fish between the mainstem Colorado River and LCR also showed substantial movement between the two systems. PIT-tagged humpback chub captured and released in the mainstem were recaptured up to 14.6 km into the LCR, with 44% more than 3 km, and 36% more than 5 km from the mouth (Fig. 8-8). Mean net displacement of 419 PIT-tagged chub (431 movements) from the mainstem to LCR was 6.4 km (range, 0.10-20.0 km), with mean displacement in the mainstem of 2.0 km (range, 0.0-6.5 km) and LCR of 4.4 km (range, 0.0-14.6 km). Mean net displacement from the mainstem to LCR was similar between males (6.5 km) and females (5.8 km) (t=1.41, p=0.075, df=370).

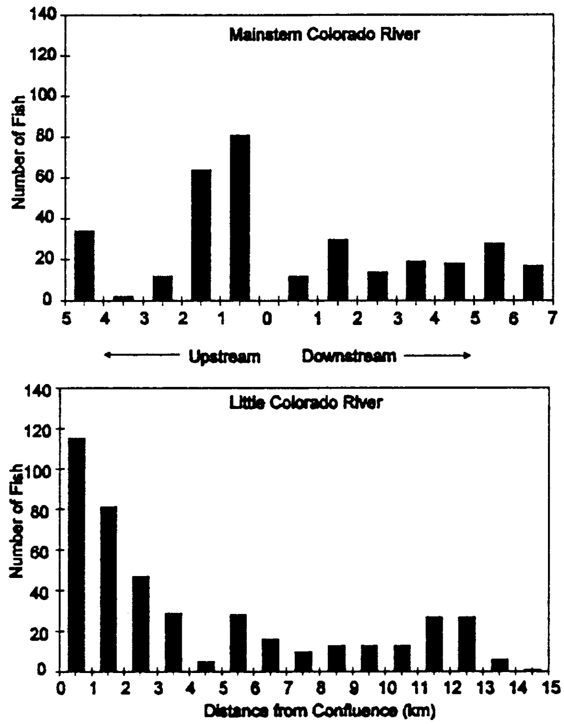


Fig. 8-8. Capture locations of 419 PIT-tagged humpback chub (431 movements) in mainstem Colorado River (A) and recapture location in LCR the (B), October 1990-November 1993.

Net displacements were determined for PIT-tagged fish captured in the LCR and recaptured in the mainstem (Fig. 8-9). Fish captured between river kilometer (RK) 0.0 and RK 14.6 in the LCR were recaptured in the mainstem up to 4.9 km upstream and 24.2 km downstream of the confluence, with 24% recaptured more than 3 km from the confluence, but only 8% more than 5 km. Mean net displacement of 401 fish (415 movements) from the LCR to the mainstem was 7.2 km (range, 0.08-34.1 km), with mean displacement of 5.3 km (range, 0.0-14.6km) in the LCR and of 1.9 km (range, 0.0-24.2 km) in the mainstem. Mean net displacement from the LCR to the mainstem was nearly identical for males (7.4 km) and females (7.2 km) (t=0.30, p=0.76, df=357). Mean net displacements were significantly greater (t=9.96, $p<0.00005$, df=1129) for total movement of PIT-tagged fish between the mainstem and LCR (6.72 km) than for all movements within the mainstem (1.64 km).

Over 99% of PIT-tagged fish captured in both systems remained within a 13-km subreach of the mainstem, i.e., 6.5 km upstream to 6.5 km downstream of the LCR confluence (Fig. 8-8 A, Fig. 8-9 B). Based on these recaptured fish, the range of the mainstem component of the LCR population of humpback chub was approximately 28 km, 13 km in the mainstem and 15 km in the LCR. Although the majority of fish remained within this range, three (2 juveniles , 1 adult) moved further downstream including one that moved 34.1 km in 359 d between recaptures (from RK 9.8 in LCR to RM 76.4 in the mainstem). However, the largest cumulative displacement was entirely within this 13-km range, i.e., 54.9 km for a fish recaptured six times in 626 d, twice moving between RK 10.0 in the LCR and RM 58.3 in the mainstem. Both movements were during spawning periods.

Fidelity of PIT-tagged humpback chub to specific locales or reaches in the mainstem was similar to that observed for radiotagged fish. In total, 73 PIT-tagged fish moved from the mainstem to the LCR and back to the mainstem. Of these, 59 (81%) exhibited some degree of fidelity to specific locales in the mainstem; 38 (64%) were recaptured in approximately the same location in the mainstem after leaving the LCR (Fig. 8-10), while only 5 (7%) failed to return to the same locale.

PIT-tagged humpback chub moving between the mainstem and LCR tended to be large individuals. Mean total length of 362 chubs caught in both systems was 331 mm, while 8536 fish originally tagged in the LCR

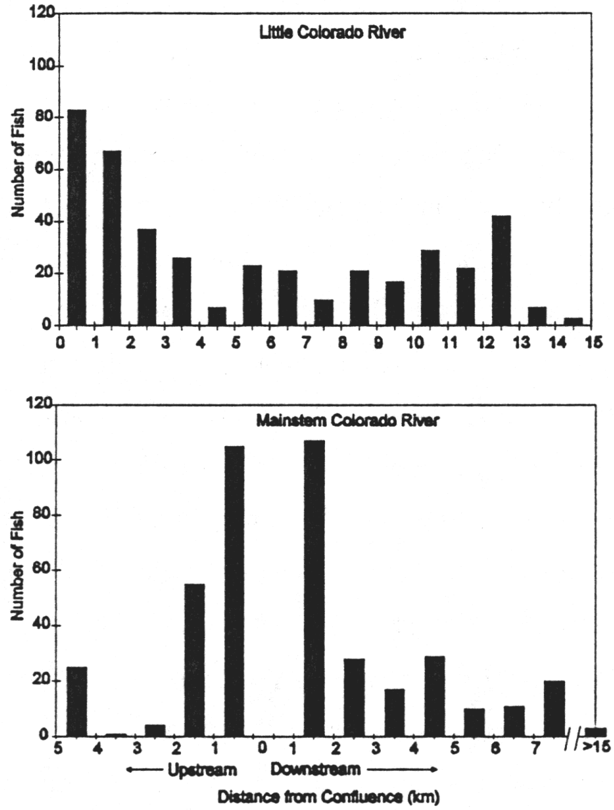


Fig. 8-9. Capture locations of 415 PIT-tagged humpback chub in LCR (A) and recapture location in mainstem Colorado River (B), October 1990-November 1993.

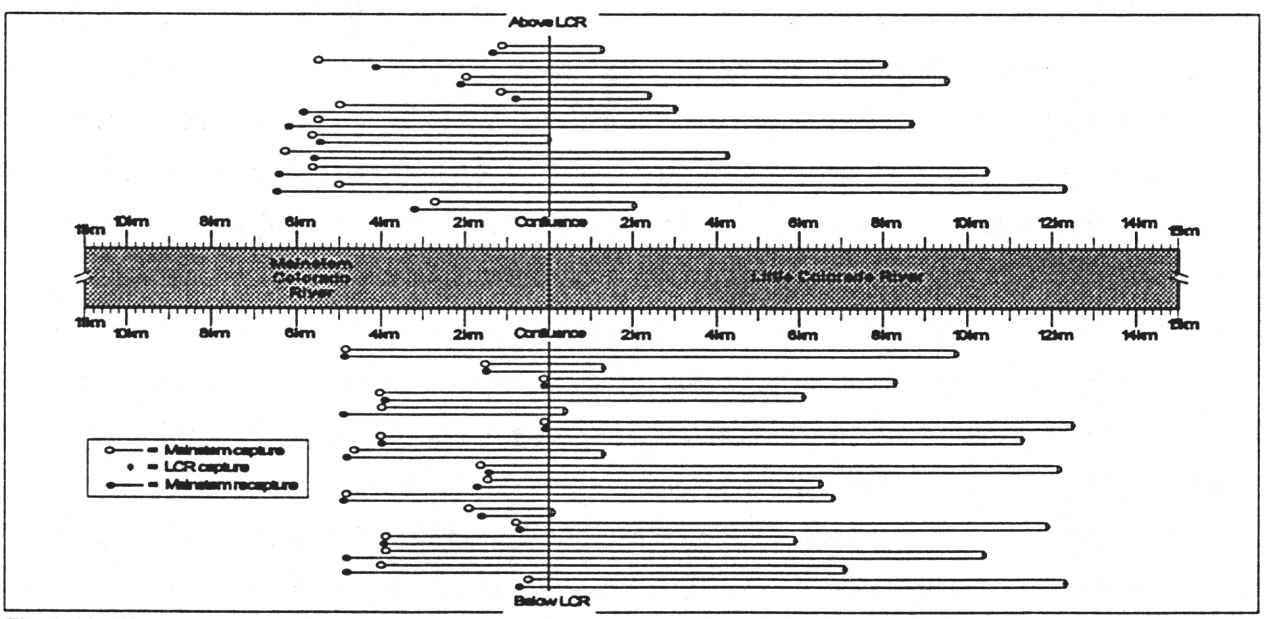


Fig. 8-10. Fidelity of 38 PIT-tagged humpback chub in the mainstem Colorado River following presumed spawning in the LCR, October 1990-November 1993.

0averaged 254 mm TL (ASU data), and 823 fish first tagged in the mainstem averaged 315 mm TL. Most individuals (81%) caught in both systems were 300 mm TL or greater (Fig. 8-11), and many of these mature fish may have been moving between the mainstem and LCR for spawning.

A total of 92 humpback chub, originally marked by other investigators, were recaptured in the mainstem bearing Carlin dangler tags or Floy tags. Original tagging records for 50 of these fish showed that all were originally tagged in the LCR by AGF, between the confluence (RK 0.0) and RK 9.0 during 1980-90, and 49 (98%) were recaptured in the mainstem (Region 1), between RM 57.0 (6 km above LCR) and RM 65.0 (5 km below LCR), in the period October 1990 to November 1993 (Fig. 8-12). Average distance between original capture and recapture was 4.29 km, (range, 0.1-14.4 km). Average elapsed time between captures was 2990 d (range, 304-4496 d). Humpback chub recaptured with Floy and Carlin tags were dispersed approximately evenly above and below the LCR (25 fish upstream, 21 downstream, and 4 at the confluence).

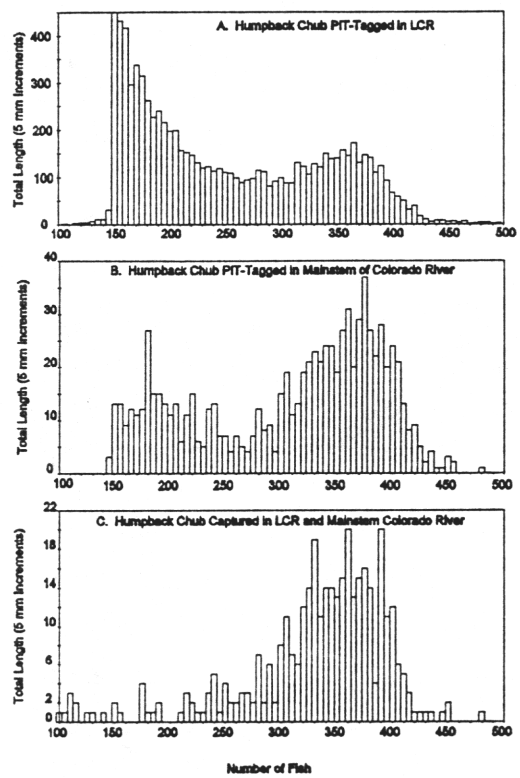


Fig. 8-11. Length frequency of humpback chub initially captured in the LCR (A), initially captured in Region 1 of Colorado River (B), and captured in both LCR and Region 1 (C), October 1990-November 1993.

Timing of Movements. Timing of movements to and from the LCR was evaluated using remote and surveillance telemetry, and recaptured PIT-tagged fish. Average number of contacts of radiotagged fish by the remote telemetry station at the LCR confluence (KLCR) was highest from February through April (Fig. 8-13), indicating that movements between the mainstem and LCR were not direct, but preceded by a period of staging in the confluence area. In 1991 and 1992, 39 fish were continuously contacted an average of 17.1 d (range, 1-64 d) by KLCR (Appendix H-2), an estimate of the time spent by radiotagged fish in the confluence staging area. Lowest contact rates, from May to August corresponded to periods when many fish were in the LCR, and may also have reflected rapid post-spawning dispersal.

Movements of 35 radiotagged humpback chub from the mainstem to the LCR confluence and, into the lower LCR, were documented by telemetry surveillance in1991 and 1992. Spawning-related movements

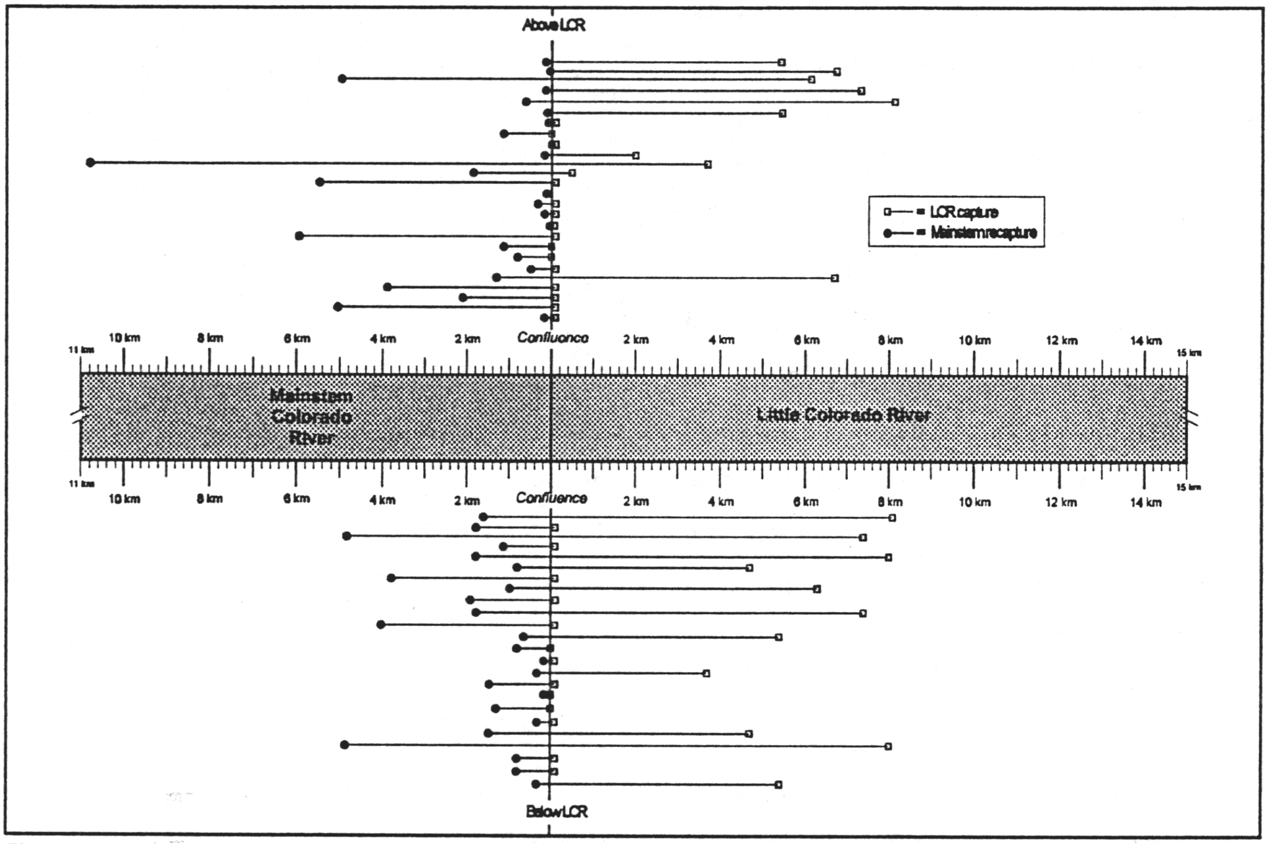


Fig. 8-12. Net displacement of 50 Floy- and Carlin-tagged humpback chub originally tagged by AGF in the LCR 1980-90 and recaptured in Region 1, October 1990-November 1993.

appeared to occur in four phases, with the first marked by local aggregations in mainstem eddy complexes in February. The second phase was long-distance movements to staging areas near the LCR confluence from March to May. Largest aggregations of radiotagged fish in the mainstem were observed in March and April of 1991, and March of 1992 (Fig. 8-14). Peak numbers occurred on March 8 and 11 of 1991, and March 11 of 1992 when 60% of radiotagged fish were located in deep mainstem eddies just above the LCR confluence.

The third phase of spawning-related movements was ascent from the confluence into the

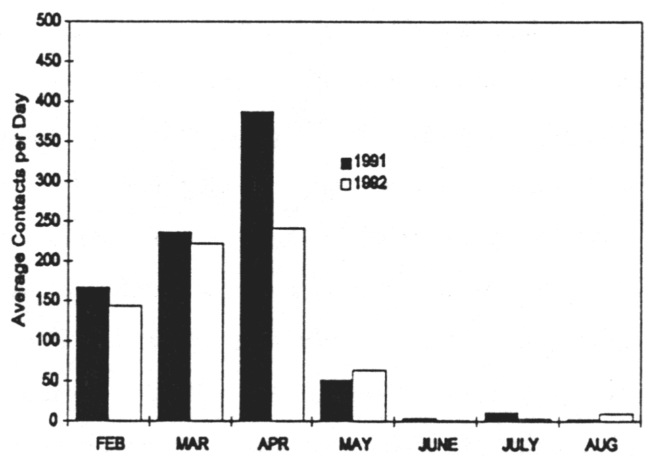


Fig. 8-13. Average number of radiotagged adult humpback chub contacted per day by remote telemetry station KLCR, February-August in 1991 and 1992.

LCR, usually between February and August. During 1991 these movements of radiotagged fish were irregular, with several fish moving between the mainstem and LCR two or more times during March and April, although most movement into the LCR was completed by May. Fish appeared to respond to floods in the LCR during this period, returning to the mainstem when LCR flow volume and turbidity increased substantially. In 1992, most radiotagged fish moved into the LCR between mid-March and mid-April (Fig. 8-14), and less movement, occurred between the mainstem and LCR, coincident with lower flow fluctuations in the LCR than in 1991.

The fourth stage of migration involved the return of fish to the mainstem after spawning. Timing of these movements were not clearly documented, since the battery life of radiotransmitters did not span the full period of activity in the LCR. Detected movements of fish from the LCR were generally early in the spawning season, and associated with movements between the LCR and mainstem staging areas in response to high LCR flows. Several fish captured in the staging area during September of 1991 and 1992 may have been fish moving out of the LCR.

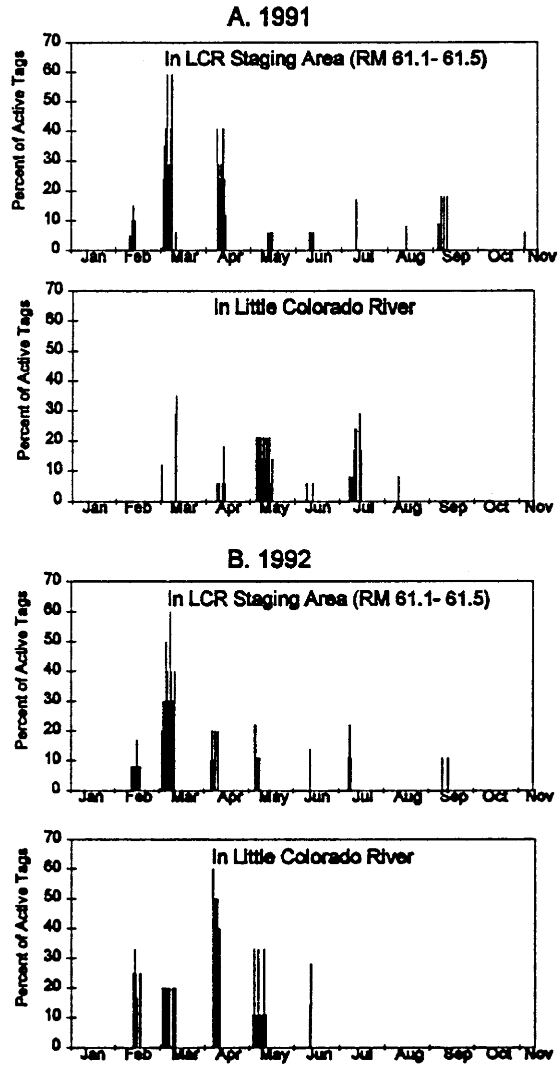


Fig. 8-14. Percent of radiotagged adult humpback chub with active radiotransmitter (tags) located during telemetry surveillance in the LCR staging area (RM 61.1-61.5), during 1991 (A) and 1992 (B).

Timing of movements of 20 radiotagged fish into the LCR appeared related to falling or steady low flows and rising temperatures. Eleven (55%) of these movements into the LCR, occurred during falling hydrographs (i.e., decreased flow in LCR), at a flow range of 213-1760 cfs, seven (30%) occurred during steady low flows ranging from 198-276 cfs, one occurred during rising flows at 1220 cfs, and one occurred during a small flow peak of 1140 cfs (Fig. 8-15). Seventeen movements (74%) were made during rising temperature trends and four during steady temperatures. LCR temperatures during these movements into the LCR ranged from 9.6 to 22.7° C.

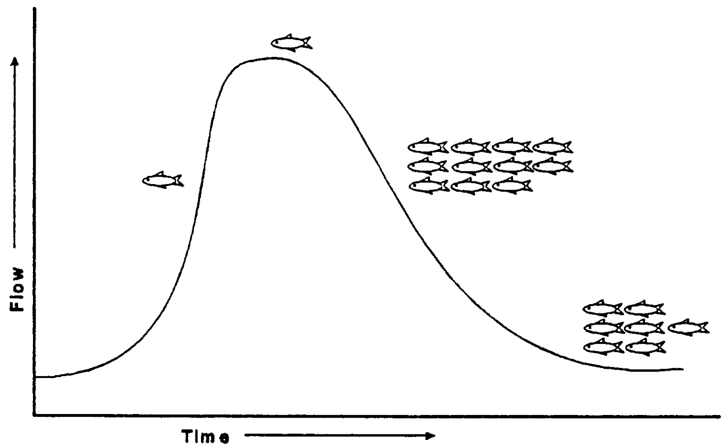


Fig. 8-15. Conceptual flow spike in the LCR illustrating the timing of movements by 20 radiotagged adult humpback chub into the LCR from the mainstem Colorado River.

Timing of movements between the mainstem and LCR were also identified for 23 PIT-tagged humpback chub captured in the mainstem and recaptured in the LCR, and 17 captured in the LCR and recaptured in the mainstem (Fig. 8-16). Only fish that were at large less than 30 d were considered for this analysis. Movements occurred primarily during spawning season (February through June). Only 3 of 23 fish (13%) moved into the LCR during the remainder of the year. Most movements from the LCR for 17 chubs were later in the year than movements into the LCR with 15 fish (88%) moving out from May through November.

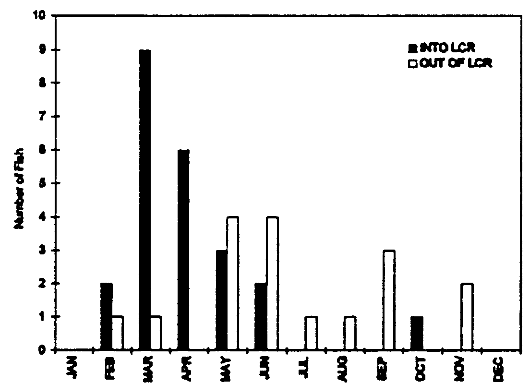


Fig. 8-16. Timing of movement for 23 PIT-tagged humpback chub between mainstem Colorado River and LCR, October 1990-November 1993.

Movements between Aggregations

Movement between nine aggregations of humpback chub (See Chapter 5 - DISTRIBUTION AND ABUNDANCE) was rare with only 7 PIT-tagged fish captured in different aggregations (Fig. 8-17). Four of these fish moved downstream from the LCR aggregation to aggregation A-3 (RM 65.7 to RM 76.3), suggesting that some individuals may move between these relatively close aggregations. Two other fish made extensive downstream movements from the LCR aggregation, including one with gross displacement of 99.8 km, to the MGG aggregation (RM 127.0). This radiotagged fish exhibited normal behavior during 57 d of tracking in Reach 1, but may have moved as a result of delayed effects of the radio-implant. The other large downstream

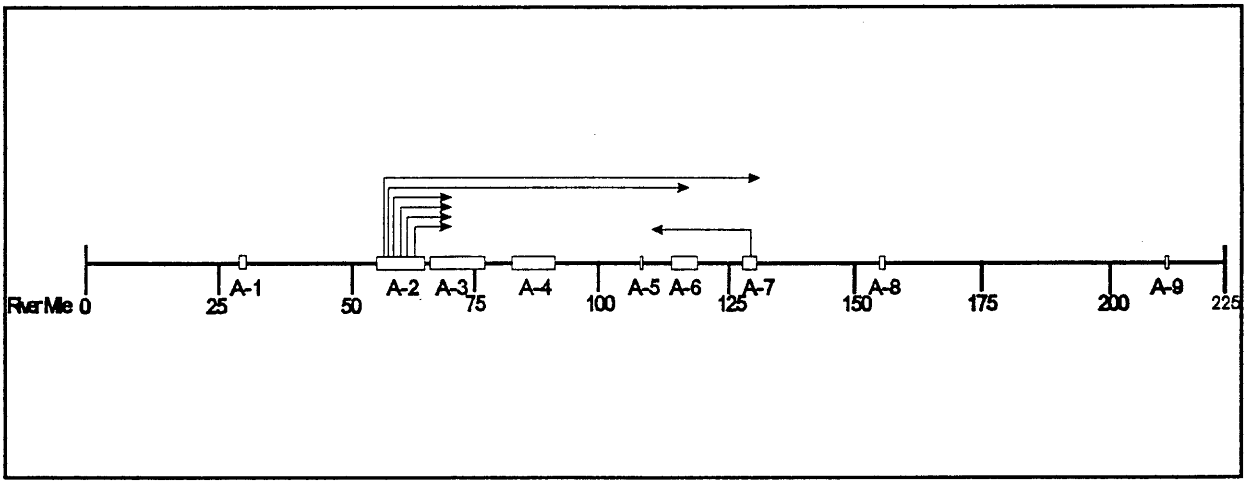


Fig. 8-17. Movement of 7 PIT-tagged humpback chub between mainstem Colorado River humpback chub aggregations.

displacement was 87.6 km, from the LCR aggregation to the A-6 aggregation (RM 119.1). Upstream movement between aggregations was observed for only one fish that moved 30.7 km, from RM 127.6 (MGG aggregation) to RM 108.5 (A-5 aggregation). These displacements between aggregations involved only 7 of the 238 (2.9 %) PIT-tagged humpback chub captured at least twice in the mainstem.

Movement Related to Flow Regime

Movements of radiotagged adult humpback chub, monitored with surveillance, were compared between the two flow regimes observed during the study period i.e., research flows, (June 1, 1990 to July 29, 1991) and interim flows (after August 1, 1991) (See Chapter 3 - HYDROLOGY). No significant differences in mean net displacement ($t=0.777$, $p=0.440$, $df=52$) or mean gross displacement ($t=0.253$, $p=0.802$, $df=52$,) were observed between research flows and interim flows.

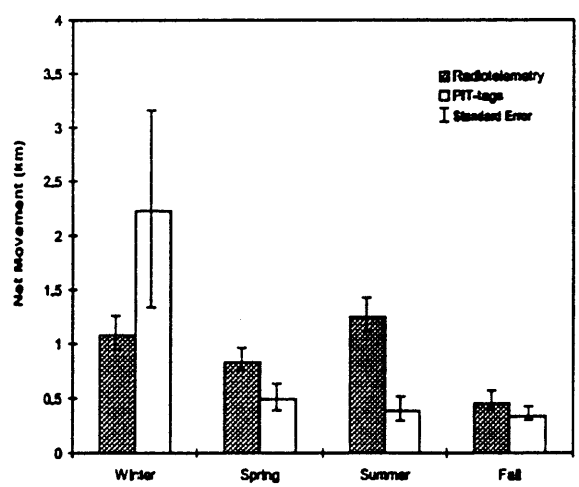


Fig. 8-18. Net displacement by season of radiotagged and PIT-tagged adult humpback chub in Region 1, October 1990-November 1993.

Seasonal Movements

Seasonal net displacement of radiotagged humpback chub, measured during surveillance in Region 1, were similar in winter, spring and summer, but significantly less (ANOVA, $F=3.15$, $p=0.027$, $df=3, 122$) in fall (Fig. 8-18). Absolute differences by season were not great with mean net displacements in fall only 0.4-0.8 km less than other seasons. Net up- and downstream movement

movement for these fish was not significantly different from zero for each season (t-test, p>0.05), indicating no seasonal net up- or downstream displacement. Similar results were found from consecutive captures of PIT-tagged chubs in the mainstem (Fig. 8-18), although no significant differences were found between seasons (log-transformed data: ANOVA, F=2.46, p=0.091, df=3, 21).

Movement of YOY and Juveniles

Movement of YOY and juvenile humpback chub in the mainstem were assessed from recaptures of marked individuals, since these fish were too small to radioimplant. A total of 31 YOY and juvenile humpback chub marked with fin-punches or fin-clips were recaptured during this investigation. Ten fish were excluded from analysis because of incomplete clip combinations or fin clip combinations that did not conform to known protocols. Of the remaining 21 fish, 11 were marked by ASU in the LCR beginning in January 1992 and recaptured in the mainstem in 1993. These fish dispersed from three of the four LCR reaches (RK 0-3.1, RK 7.5-10.8, RK 10.8-14.8) originating from as high as 14.8 km in the LCR. Five fin-clipped fish were recaptured in January, two in April and one each in March, May, and October, below the confluence of the LCR between RM 61.9 and RM 64.9, and one was recaptured in July, 1.8 km above the confluence at RM 60.2 (Table 8-2). These fish were recaptured in the mainstem in 1993, despite the initiation of fin-clipping in the LCR in August 1991 (P. Marsh, ASU, pers. comm.). The appearance of these fin-clipped fish in the mainstem coincided with the appearance of numerous young chubs in the mainstem in early 1993, concurrent with large floods from the LCR in January and February (See Chapter 5 -DISTRIBUTION AND ABUNDANCE).

Table 8-2. Numbers, by month, of YOY and juvenile humpback chub fin-clipped in the LCR[a] and recaptured in Region 1 of the mainstem Colorado River.

Month	LCLP	UCLP	UCRP	Total
January	2	1	2	5
March	0	1	0	1
April	1	0	1	2
May	1	0	0	1
July	1	0	0	1
October	0	1	0	1
Total	5	3	3	11

[a] Fin-clip combination for the LCR
LCLP = lower caudal lobe, left pelvic, RK 0.0-3.1
UCLP = upper caudal lobe, left pelvic, RK 7.5-10.8
UCRP = upper caudal lobe, right pelvic, RK 10.8-14.8

Only 10 of 1228 (0.8%) YOY and juvenile humpback chub fin-punched in the mainstem during this investigation were recaptured to evaluate movement or dispersal between reaches in the mainstem. All of these fish were recaptured in the reach of initial capture, and time between mark and recapture, as well as length of time in the reach, could not be determined. Ten recaptured fish were considered an insufficient sample to assess movement of young chubs in the mainstem. Additional information on dispersal of young humpback chub, based on catch rates, is discussed in Chapter 5 - DISTRIBUTION AND ABUNDANCE, and Chapter 7 - HABITAT.

Local Movement

Local movement of adult humpback chub in the mainstem Colorado River was related to spawning/non-spawning seasons, time-of-day, turbidity, flow level, flow regime, ramping rates, and magnitude of flow change. Vertical and horizontal movements were used to assess these relationships. Evaluation of vertical movement was based on occurrence of radiotagged fish within 4.5 m of the water surface (radio signal extinction depth) and termed near-surface activity. Horizontal movement was based on locations recorded during telemetry observations of radiotagged adults.

Effect of Season, Time-of-day, and Turbidity

Near-surface activity was expressed as average proportion of radiotagged fish located (APFL) during telemetry surveillances for each trip, and related to season, time-of-day, and turbidity. Data were pooled over years, since no significant differences were found for APFL (ANOVA, F=0.80, p=0.371, df=1, 441) between years. Turbidity had a significant influence on near-surface activity (ANOVA, F=99.41, p<0.00001, df=1, 441), with mean APFL greater during high turbidity (Table 8-3). Near-surface activity was also significantly higher during spawning than non-spawning season (ANOVA, F=19.97, p<0.00001, df=1, 441). Smaller but insignificant differences (ANOVA, F=2.16, p=0.141, df=1, 441) were found for APFL between day and night (Table 8-3). APFL was highest under conditions of high turbidity, regardless of season and time-of-day, and was higher during spawning than nonspawning season at similar turbidity and time-of-day (Fig. 8-19). Although nighttime near-surface

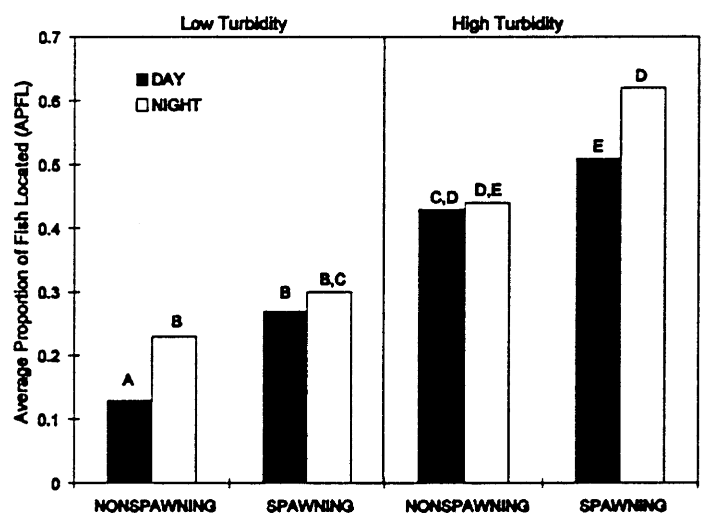


Fig. 8-19, APFL for radiotagged adult humpback chub located with telemetry surveillance in Region 1 under different turbidity levels, season and time-of-day, November 1990-November 1992. (Bars with same letter were not significantly different at =0.05 with Fisher's LSD test after significant ANOVA).

Table 8-3. Near-surface activity of radiotagged adult humpback chub as average proportion of fish located (APFL) during spawning and nonspawning periods, between day and night, and under low and high turbidity. Fish were located during telemetry surveillance in the mainstem, November 1990 - November 1992. N=number of observations, S.D. = standard deviation.

Factor	N	APFL	S.D.
Spawning[1]	148	0.40	0.31
Non-Spawning[1]	295	0.25	0.27
Day	280	0.28	0.29
Night	163	0.33	0.30
Low Turbidity[2]	288	0.20	0.25
High Turbidity[2]	153	0.48	0.29

[1,2] Pairs of factors with the same number are significantly different at □ = 0.05.

activity was consistently higher under all conditions, APFL was significantly lower in the day under low turbidity and during non-spawning periods. While a diel pattern may have existed, is was less pronounced during spawning and high turbidity.

Average proportion of radiotagged fish contacted (APRC) was also related to time-of-day and turbidity using remote telemetry in Region 1. No significant differences were found between trips for APRC in 1991 and 1992 (ANOVA, F=2.35, p=0.128, df=1, 138) and data were pooled for analysis. APRC was significantly greater (ANOVA, F=28.46, p<0.001, df=1, 138) during high turbidity (Table 8-4), but there was no significant difference (ANOVA, F=2.37, p=0.126, df=1, 138) between day and night. APRC was significantly higher under high turbidity during both day and night, and lowest during the daytime under low turbidity (Fig. 8-20). These patterns of

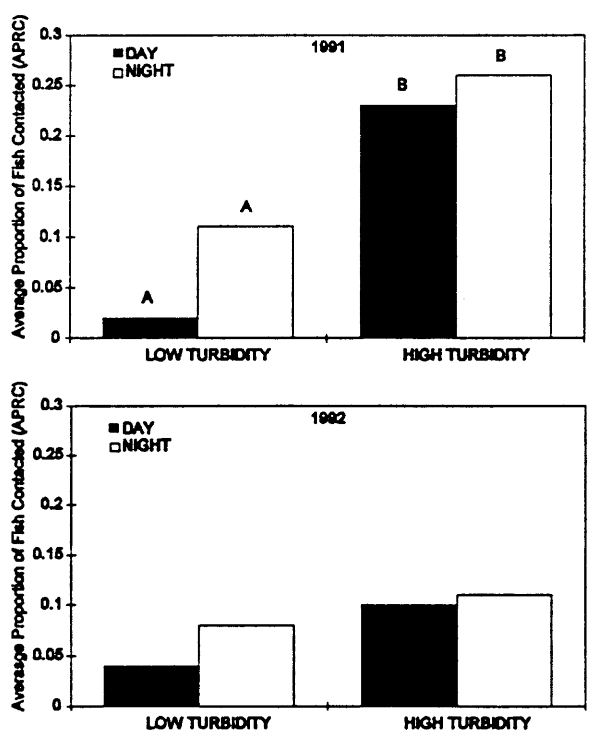


Fig. 8-20. APRC for radiotagged adult humpback chub at low and high turbidity, during day and night, for fish contacted by remote telemetry station KILR in Reach 1. (Bars with same letter were not significantly different at =0.05 with Fisher's LSD test after significant ANOVA).

Table 8-4. Near-surface activity of radiotagged adult humpback chub as average proportion of fish contacted (APRC) during low and high turbidity and between day and night. Data were collected by remote telemetry station (KILR) in Region 1, August 1991 - December 1991 and August 1992 - December 1992.

Factor	APRC	S.D.
	Turbidity	
Low[a]	0.06	0.13
High[a]	0.18	0.23
	Time of Day	
Day	0.09	0.17
Night	0.14	0.20

[a]Factors with same letter are significantly different at □ = 0.05.

increased near-surface activity during high turbidity and at night were consistent with observations made with telemetry surveillance.

Remote telemetry was also used to calculate APRC for three radiotagged fish in Middle Granite Gorge. As with fish in Region 1, APRC for fish from MGG was higher during periods of high turbidity, but diel patterns of near-surface use were opposite of those observed in the LCR group (Fig. 8-21). Although not significant, APRC for MGG fish was greater during the day under both high and low turbidity. Since daily flow patterns in MGG were opposite those near LCR (i.e., mainstem flows at MGG were typically high at night and low during the day, whereas flows near the LCR were usually high in the day and low at night), flows may have influenced near-surface activity more than ambient light condition.

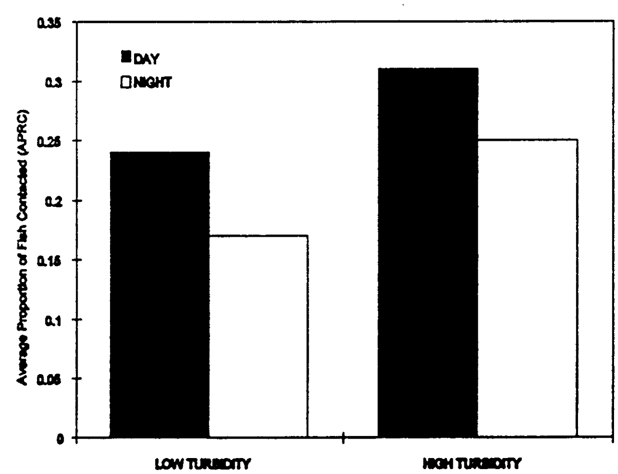


Fig. 8-21. APRC for radiotagged adult humpback chubs at low and high turbidity, during day and night, for fish contacted by remote telemetry stations in MGG, February 1993-September 1993. (ANOVA was not significant at =0.05).

Telemetry observations of radiotagged chubs were used to relate horizontal movement to season, time-of-day and turbidity (Table 8-5). Horizontal movement was indicated by the proportion of times fish moved (Pm) during observation blocks. Significantly higher movement were recorded during spawning season than non-spawning season in Region 1 (□^{2}=22.25, p<0.00001, df=1). Proportion of movement was significantly higher during high turbidity (□^{2}=10.89, p=0.001, df=1), but no difference was detected between day and night (□^{2}=0.02, p=0.887, df=1). Proportion of movement in the MGG group was similar during day (16%) and night (13%)

Table 8-5. Horizontal activity of radiotagged adult humpback chub as proportion of movement (> 5 m) during spawning and nonspawning periods, between day and night and under low and high turbidity. Fish were monitored November 1990 - November 1992. N=number of observations.

Factor	N	No. Movements > 5 m	Proportion of Movement > 5 m
Spawning[1]	705	151	0.21
Non-Spawning[1]	1,126	147	0.13
Day	947	153	0.16
Night	884	145	0.16
Low Turbidity[2]	651	81	0.12
High Turbidity[2]	1180	217	0.18

[1,2] Factors with the same number are significantly different at $\propto = 0.05$.

($\square^2=0.30$, p=0.58, df=1), and overall Pm of the MGG group (17%) and the LCR group (16%) were similar ($\square^2=0.61$, p=0.436, df=1). Influence of turbidity on fish movements in MGG could not be examined because all observations in this reach were conducted during of high turbidity. Patterns of horizontal movement from telemetry observations of radiotagged fish were consistent with measurements of near-surface activity in Region 1 (Fig. 8-19, 8-20; Tables 8-3, 8-4), with more movement observed under high turbidity and during spawning season.

Effect of Flow, Ramping Rate and Magnitude of Flow Change

Observations of radiotagged adult humpback chub were used to relate horizontal movement (Pm) under different flow regimes, flow levels, ramping rates and magnitude of flow change. Magnitude of flow change was defined as the difference between highest and lowest flows in a daily cycle, while ramping rate was the hourly rate of flow change in cubic feet per second. Implementation of interim flows in August 1991 resulted in a substantial decrease in ramping rate and magnitude of flow change. Average ramping rate during telemetry observations was 886 cfs/h (s.d.=1230) prior to interim flows (November 1990 - July 1991), and 378 cfs/hr (s.d.=379) during interim flows (August 1991 - November 1992). Magnitude of daily flow change during telemetry observations decreased from an average of 5643 cfs (s.d.=5144) during research flows to an average of 4014 cfs (s.d.=1991) during interim flows. Hydrological differences between research and interim flows were described in detail in Chapter 3 - HYDROLOGY.

Proportion of movement of radiotagged adult humpback chub varied with different flow regimes and flow characteristics. When observations were pooled by flow regime, Pm was significantly higher during research flows than during interim flows ($\square^2=5.18$, p=0.023, df=1) (Table 8-6). Horizontal movement also differed with flow level (Table 8-7), with Pm approximately 3 times higher at flows above 10,000 cfs ($\square^2=39.31$, $p<0.00001$,

Table 8-6. **Comparison of horizontal activity of radiotagged adult humpback chub as proportion of movements (> 5 m) during research and interim flows in Region 1 of the mainstem, October 1990 - November 1992. N=number of observations.**

	N	No. Movements >5 m	Proportion of Movement > 5 m
Pre-interim flows	310	66	0.21
Interim flows	1715	275	0.16

Table 8-7. Horizontal movement of radiotagged adult humpback chub as proportion of movement (> 5 m) at high and low flows, and high and low absolute ramping rates as monitored during telemetry observation, November 1990 - November 1992. N=number of observations.

Flow (cfs)[1]	Absolute Ramping Rate (cfs/hr)[1]	N	No. Movements > 5 m	Proportion of Movement > 5 m
<10,000	<300	318	16	0.05
	>300	130	10	0.08
>10,000	<300	353	55	0.16
	>300	463	97	0.21

[1]Flows and ramping rates measured at Colorado River USGS gage # 9383100 (RM 61.2 above Little Colorado River)

df=1). Pm was also higher when ramping rates were greater than 300 cfs/h during both high and low flows (Fig. 8-21), but this relationship was statistically significant only for flows greater than 10,000 cfs (ANOVA, F=15.37, p<0.00005, df=3, 1260). Only telemetry observations during non-spawning season were used in this analysis, since it was assumed that higher movement rates during spawning season would bias fish response to flow.

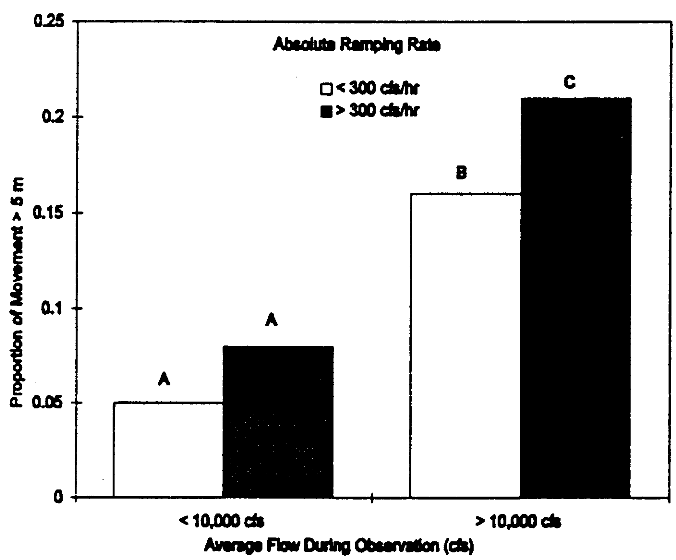


Fig. 8-21. Fraction of telemetry observation time blocks with horizontal movement of radiotagged adult humpback chub in Region 1 as related to ramping rate and flow, November 1990-November 1992. (Bars with same letter were not significantly different at =0.05 with Fisher's LSD test after significant ANOVA).

Horizontal movement rates of adult humpback chub varied with the daily hydrograph (Fig. 8-22). Pm was highest (0.21) during the rising and falling limbs of the high-flow portion of the daily hydrograph during both research and interim flow regimes. Pm remained high (0.16) during the steady high portion of the flow cycle, and during the low flow period, Pm was substantially less (0.06). Ramping during the low flow portion of the hydrograph did not markedly increase horizontal movement (Pm = 0.08).

Less movement observed during interim flows (Table 8-6) may have been related to the reduced magnitude of daily flow changes and lower ramping rates. Although the daily regularity of high and low flows were similar under research and interim flow regimes, the magnitudes of flow change were substantially different. Mean daily flow change observed in Region 1 during research flows (October 1990 - July 1991), was approximately 6500 cfs, but only 3000 cfs during interim flows (August 1991 - November 1992) (Fig. 8-22). Reduced fluctuations in daily flow under interim flows corresponded to shorter intervals of high flows (>10,000 cfs) and high ramping rates (>300 cfs/hr), periods when Pm was greatest. Hourly averages of flow from gage number 9383100 were used to calculate average flow cycles during research (October 1990-July 1991) and interim (January 1992-December 1992) flows.

The total distance traveled by adult humpback chub during telemetry observations was greater with higher magnitude of flow change. When total fish movement was related to magnitude of flow change during observations, a general trend of increased total movement with greater fluctuations was found (Fig. 8-23), particularly when the daily difference between high and low flows exceeded 4000 cfs.

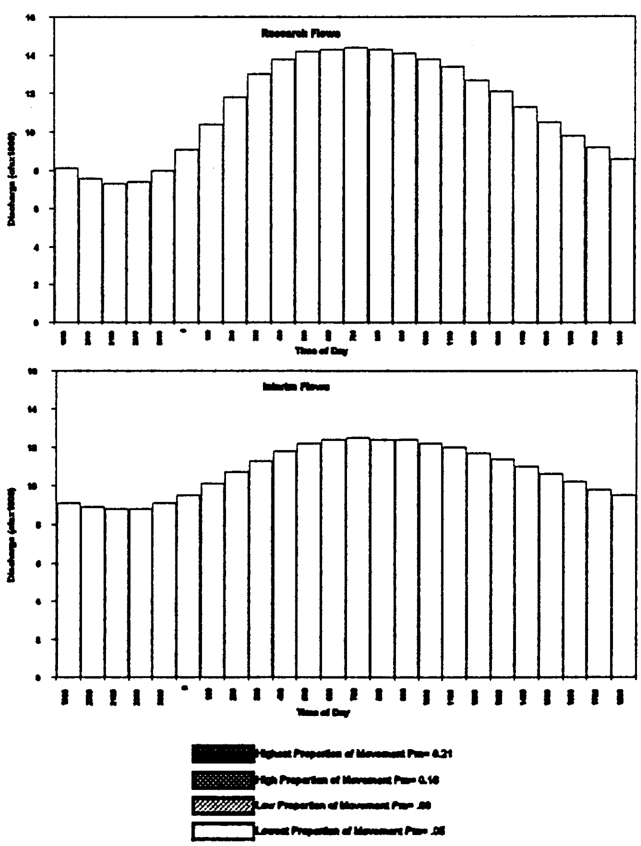


Fig. 8-23. Fraction of telemetry observation time blocks with horizontal movement of radiotagged adult humpback chub in Region 1 during average research and interim flow cycles.

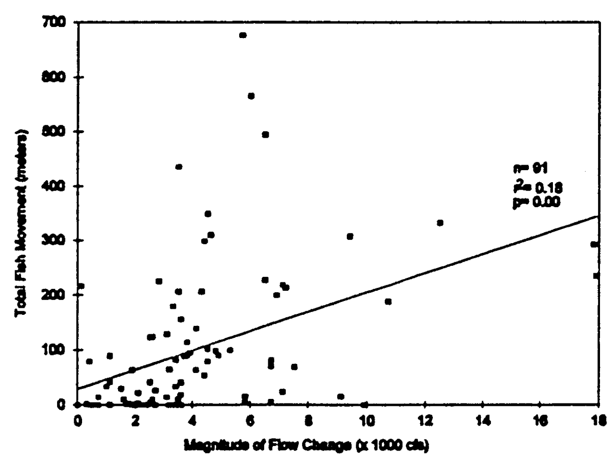


Fig. 8-24. Total horizontal movement of radiotagged adult humpback chub related to magnitude of flow change during telemetry observations in Region 1, November 1990-November 1992.

DISCUSSION

Long-range Movement

Long-range movements of adult and subadult humpback chub, as monitored with radiotelemetry and PIT-tags, were restricted to relatively small areas within the mainstem Colorado River in Grand Canyon. These limited movements were observed for fish even over periods of several years. While chubs were not stationary (e.g., see Fig. 8-6), movements of marked individuals were often within small areas of the mainstem, despite adjoining areas of seemingly suitable habitat. Strong spatial fidelity for a few discrete locations was observed for radiotagged fish following sizable movements up- or downstream. Such fidelity may have been associated with an affinity for specific habitats or habitat complexes, as areas utilized by radiotagged fish often included large recirculating eddies and associated eddy return channels (See Chapter 7 - HABITAT).

Movements of humpback chubs within the mainstem Colorado River in Grand Canyon were similar in extent to those reported for humpback chub in Black Rocks, a turbulent deepwater reach of the Colorado River in the upper basin. Net displacement for chubs in Region 1 of this study averaged 1.49 km for radiotagged adults from release to last contact, and 0.99 km for PIT-tagged fish between captures. Mean maximum movements of humpback chub in Black Rocks were 0.8 km for radiotagged adults and 1.67 km for Carlin-tagged adults (Valdez and Clemmer 1982), and mean net and maximum displacement of radiotagged adults was 0.8 and 1.4 km, respectively (Kaeding et al. 1990). Similarities in net movements for males and females of the Grand Canyon population was also observed in Black Rocks (Kaeding et al. 1990). The strong spatial fidelity observed in the mainstem Colorado River in Grand Canyon may be indicative of the strong homing ability reported by Kaeding et al. (1990) in Black Rocks.

Movements of humpback chub in Grand Canyon were substantially less than reported for other Colorado River cyprinids. Mean maximum displacement of 28.7 km was reported by Archer et al. (1985) for radiotagged adult Colorado squawfish, while mean maximum displacements of 33.9 km were reported for roundtail chub by Kaeding et al. (1990). Relatively small movements by humpback chub, during all seasons, may be attributed to the proximity of feeding, resting and cover habitat within small reaches of river. Specifically, eddy complexes trap food pockets of slackwater adjacent to rapidly moving currents may concentrate food by depositing drifting invertebrates and algae, and provide sufficient resting and cover habitat (See Chapter 7 - HABITAT).

Although most movements observed for adult and subadult humpback chub in the mainstem were over short distances, a few movements of substantial distances occurred, the longest up to 99.8 km. Large but infrequent movements have also been documented for humpback chub in the Upper Colorado River Basin (Valdez and Clemmer 1982, Kaeding et al. 1990) i.e., three fish moved 22 km between populations in Black

Rocks and Westwater Canyon. These large movements, observed in a few individuals, may be a dispersal mechanism for these relatively sedentary fishes, and may be more prevalent with high population densities. Long-distance dispersal of humpback chub from Region 1 may represent the primary source of individuals to other aggregations in Grand Canyon, particularly those downstream.

While adult humpback chub exhibited limited movements and strong spatial fidelity within the mainstem Colorado River in Grand Canyon, sizable movements of fish from the mainstem into the LCR were observed. Mean net displacements of PIT-tagged fish between the mainstem and LCR were significantly greater than mean net displacement within the mainstem. Movements of radiotagged adults from mainstem locations to the LCR occurred predominately from February through April, and were likely associated with spawning activities within the LCR, reported primarily as March through July (Suttkus and Clemmer 1977, Minckley et al. 1980, Kaeding and Zimmerman 1983). Staging behavior by adults was also observed in the LCR confluence area, with movement into the LCR primarily under declining flows and rising temperatures, conditions presumably favorable for spawning. Although not well documented, movements from the LCR after spawning appeared to occur over an extended period, without individuals spending extended periods in the LCR confluence area. Movements from the LCR coincided with reduced captures of adults in hoop nets in the LCR in fall (Angradi et al. 1992). Significant spatial fidelity was observed for individuals migrating to the LCR, i.e., these fish tended to return to similar mainstem locations once leaving the LCR.

Movements from the mainstem to the LCR for spawning were dissimilar to that observed for humpback chub in Black Rocks, and more similar to those observed for Colorado squawfish (Tyus 1985). Kaeding et al. (1990) suggested that suitable habitat for spawning was found within the confined reaches of Black Rocks, while Kaeding and Zimmerman (1983) hypothesized that suitable temperature were not available in the mainstem Colorado River near the LCR for survival of embryonic and larval humpback chubs. Thus, successful spawning habitat for humpback chub in Region 1 was likely limited to the LCR, necessitating migrational movements to suitable habitat. Also, adults living year-round and spawning in the LCR may have eventually exploited the mainstem when populations in the LCR became large enough to limit resources, but returned to the LCR to spawn. These movements suggest homing behavior for spawning in humpback chub, as hypothesized for Colorado squawfish (Tyus 1985), or may simply result from the quest for suitable spawning habitat, limited in Region 1 by water mainstem temperatures.

Movement of YOY humpback chub from the LCR to the mainstem was documented with marked individuals. Such movement had been presumed (e.g., see Kaeding et al. 1983, Angradi et al. 1992) as large numbers of YOY have been observed in the mainstem despite an apparent lack of successful spawning. Based on catch rates of young chubs (See CHAPTER 5 - DISTRIBUTION AND ABUNDANCE) and recapture records, large movements of YOY and juveniles from the LCR to the mainstem was associated with flood events in the LCR. This study did not determine whether this movement was passive or active. Passive movement may occur when flows are sufficient to involuntarily move fish from suitable habitat, while active movement may involve opportunistic use of high flows to disperse to more favorable habitat. John (1964) and Harvey (1987) found that larvae and small post-larvae were most susceptible to passive downstream transport, and that for young cyprinids, vulnerability was greatly reduced for individuals 10-25 mm in length (Harvey 1987). If susceptibility to passive transport was similar for humpback chub the bulk of young fish observed in the mainstem after floods from the LCR were actively moved. However, LCR floods may be sufficient to passively transport young chubs from the LCR to the mainstem.

Dispersal of young chubs from the LCR to the mainstem may be the major contributor of fish to downstream aggregations. YOY and age-I chubs found in lower reaches probably dispersed from the LCR, since evidence of successful spawning did not occur within these reaches. However, young chubs marked in the LCR or Region 1 were not subsequently captured in these lower reaches, but small numbers of marked fish, short duration of fin-clips and punches, and probable high mortality of young fish in the mainstem contributed to low probability of recapture. Although successful spawning in these lower reaches could not be documented and larvae were not captured, significant numbers of young chubs could have been produced locally if environmental conditions were favorable. Pattern of dispersal below the LCR was consistent with major dispersal of young from a single source--the LCR.

Long-range movements of radiotagged adult humpback chub in Region 1 were not different between research and interim flow regimes. Also, there were no apparent large-scale movement of adults when flow regimes were changed, a phenomenon that may have occurred if major habitat changes had occurred. Instead, relatively stable geomorphic features, and similarities in gross habitat complexes were observed between flow regimes (See Chapter 7 - HABITAT). Kaeding et al. (1983) speculated that common to all humpback chub habitats was the occurrence of large, angular boulders and shoreline rock outcrops that cause rapid changes in current velocity and direction. Flow regimes observed in this study did not change basic habitat characteristics of Region 1, and suitable habitat was apparently available for the numbers of adult chubs observed.

The effects of flow regime on dispersal and movement of young humpback chub were not clearly determined. Relatively low densities of juveniles were observed in the mainstem during research flows (i.e., 1991), and low (i.e., 1992) and high (i.e., 1993) densities were observed during interim flows. These variable densities precluded evaluation under the two flow regimes. If young chubs were passively transported in large numbers under high flows from the LCR, it is likely that high flows in the mainstem would have a similar effect. Two unanswered questions, however, are: 1) what flow levels, ramping rates and magnitude of flow changes are necessary to passively transport large numbers young chubs in the mainstem; and 2) at which point in the mainstem are transported young chubs unable or unlikely to return to Region 1 as young or adults, and thus be lost from the reproducing population? Within Black Rocks and Westwater Canyon of the upper basin, numbers of young chubs were found in areas within or adjacent to reaches inhabited by adults, with few juveniles found in reaches several km from population centers (Valdez and Clemmer 1982). Recruitment of young chubs may be dependent on their ability to hold and mature in habitats near to those of adults.

Local Movement and Activity

Relationships between near-surface activity of adult humpback chub and turbidity were consistent with negative phototactic behavior of juveniles in the laboratory (Bulkley et al. 1982) and in hatchery troughs (R. Hammon, USFWS, pers. comm.). Near-surface activity was highest under conditions of high turbidity and lowest during daylight hours when turbidity was low. Adults apparently used shallow habitats or the upper portion of the water column more often when cover was provided by turbidity or darkness. Although larger subadults and adults were minimally susceptible to predation by large brown trout (See Chapter 6 - DEMOGRAPHICS), they were also vulnerable to avian predators, primarily osprey (Pandion haliaetus) and bald eagle (Haliaeetus leucocephalus). An osprey was observed to capture an adult humpback chub near the LCR confluence in May of 1991(Wasowicz and Yard 1993).

The pattern of near-surface activity for adult humpback chub in Grand Canyon differed from that reported for adults in the upper basin. When turbidity was consistently high, and flows relatively constant, patterns of near-surface activity of adults in Black Rocks varied by time-of-day. Valdez and Nilson (1982) found adults in shallow shorelines (<5 m) during crepuscular periods, in slightly deeper waters in the midmorning and late afternoon (5-7 m), and in deepest waters (>7 m) during the night and midday hours. In Grand Canyon, near-surface activity appeared to be related to flow and thus availability of food (i.e., drifting macroinvertebrates), but was significantly reduced at low turbidity, suggesting use of turbidity as cover.

YOY and juveniles were also negatively phototactis, opportunistically moving into habitats when cover was available. While movements of young chubs could not be followed throughout the day, higher catch rates along shorelines at night and during high daytime turbidity indicate use of low light as cover for feeding and possibly escape from predators. Tabor and Wurtsbaugh (1991) observed similar behavior by juvenile rainbow trout in two Utah reservoirs, in which the young avoided sand and gravel inshore habitats during the day, and used these unsheltered habitats only at night.

Adult humpback chubs exhibited highest rates of daily horizontal movement under conditions associated with research flows, i.e., high ramping rates, high magnitude of flow change, and high flows. Higher movement rates may have resulted from chubs moving to more favorable microhabitats after flow changes altered conditions at the original position. Microhabitat changes could involve changes in cover (through fluctuations in water depth) and local hydraulics. Higher local movement rates did not translate to greater long-range movements as net long-range displacement of adults did not differ between research and interim flows.

Local movements of YOY and juvenile humpback chub as related to ramping rates, magnitude of flow change and flow level were not assessed because of inadequate marking techniques for young fish. If movements of young chubs were higher under the greater fluctuations of research flows as with adults, exposure to predation and potential for downstream transport likely increased. Movement of young chubs between habitats with favorable cover exposed these small fish to predation by both rainbow trout and brown trout, particularly if movements were through areas with minimal cover. Movement between favorable habitats also exposed these young fish to mainstem currents and possible downstream transport. Daily occurrence of high fluctuating flows may repeatedly expose these young fish to increased predation and downstream transport.

The effect of greater daily movement by adult humpback chub could be increased energy expenditure and risk of predation. Energy costs would be associated with movements between areas of suitable habitat, and could result from reduced feeding efficiency. High condition factors for adults during research flows (See Chapter 6 -DEMOGRAPHICS), indicate no negative energetic affect from increased energy demands. Increased predation of adults could be associated with higher movement rates when fish leave protective cover, but present predator size indicates low risk to adults.

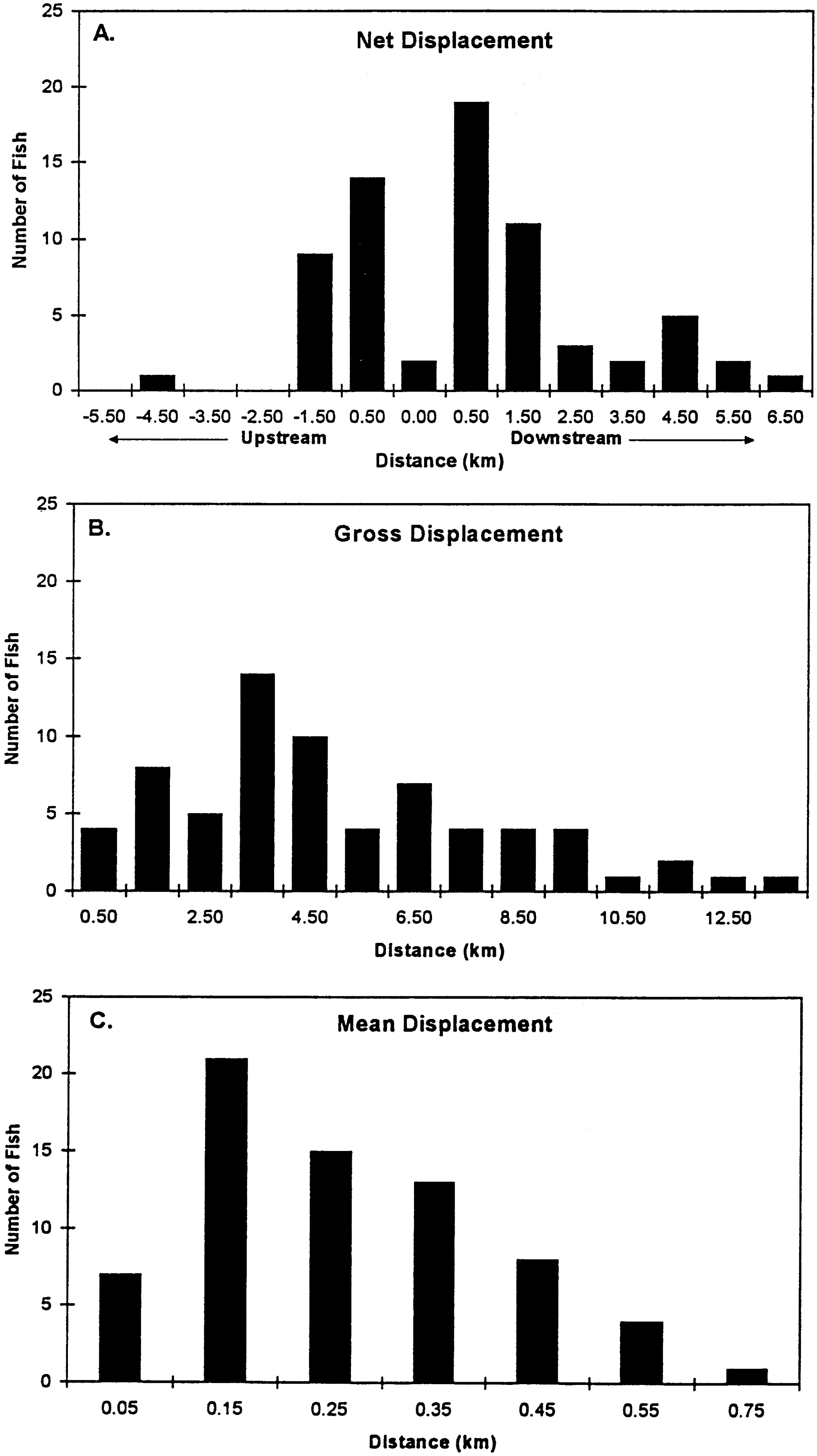

A.
Net Displacement
Number of Fish
25
20
15
10
5
0
-5.50 -4.50 -3.50 -2.50 -1.50 0.50 0.00 0.50 1.50 2.50 3.50 4.50 5.50 6.50
Upstream
Downstream
Distance (km)
B.
Gross Displacement
Number of Fish
25
20
15
10
5
0
0.50 2.50 4.50 6.50 8.50 10.50 12.50
Distance (km)
C.
Mean Displacement
Number of Fish
25
20
15
10
5
0
0.05 0.15 0.25 0.35 0.45 0.55 0.75
Distance (km)

FIG. 8-5

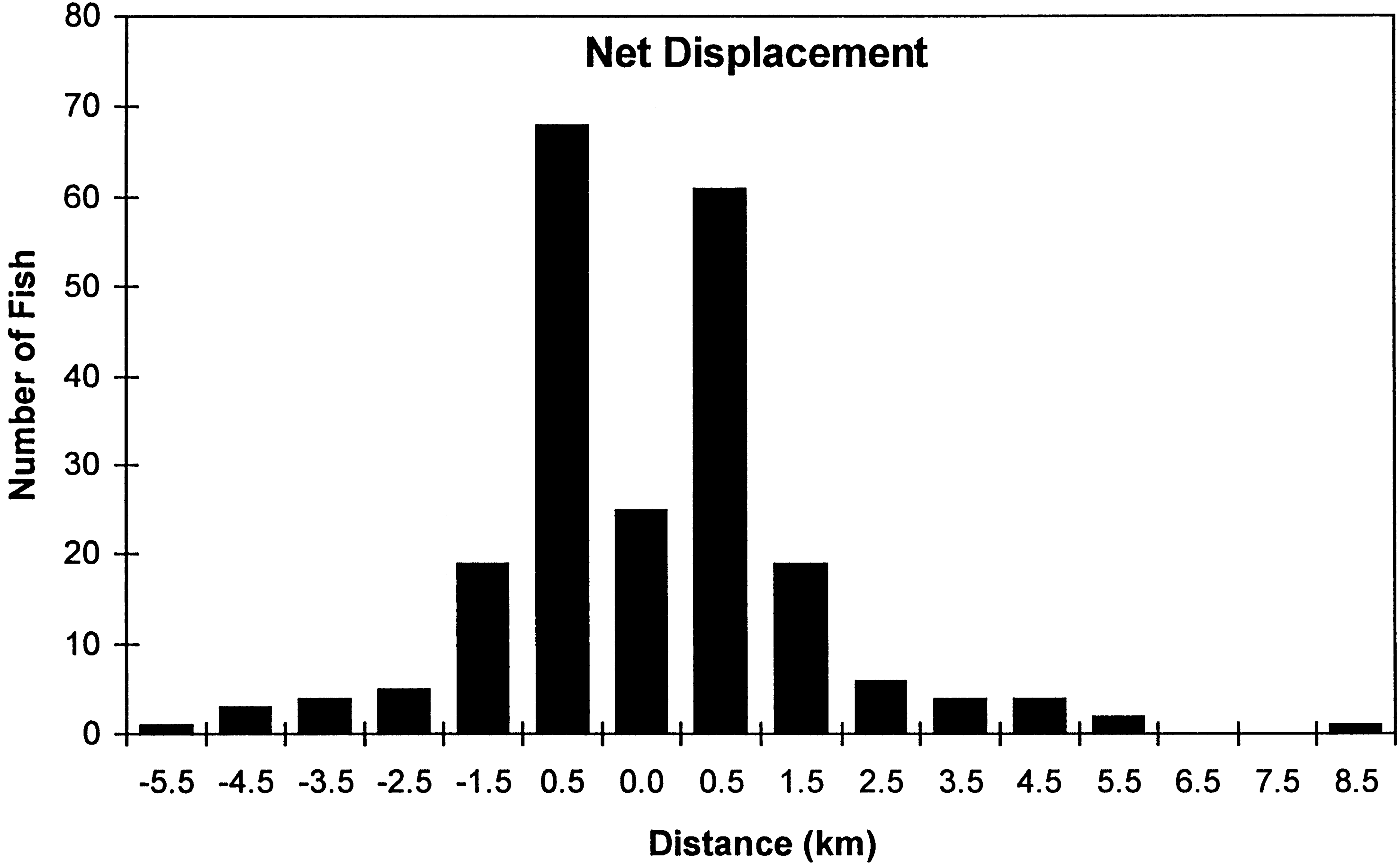
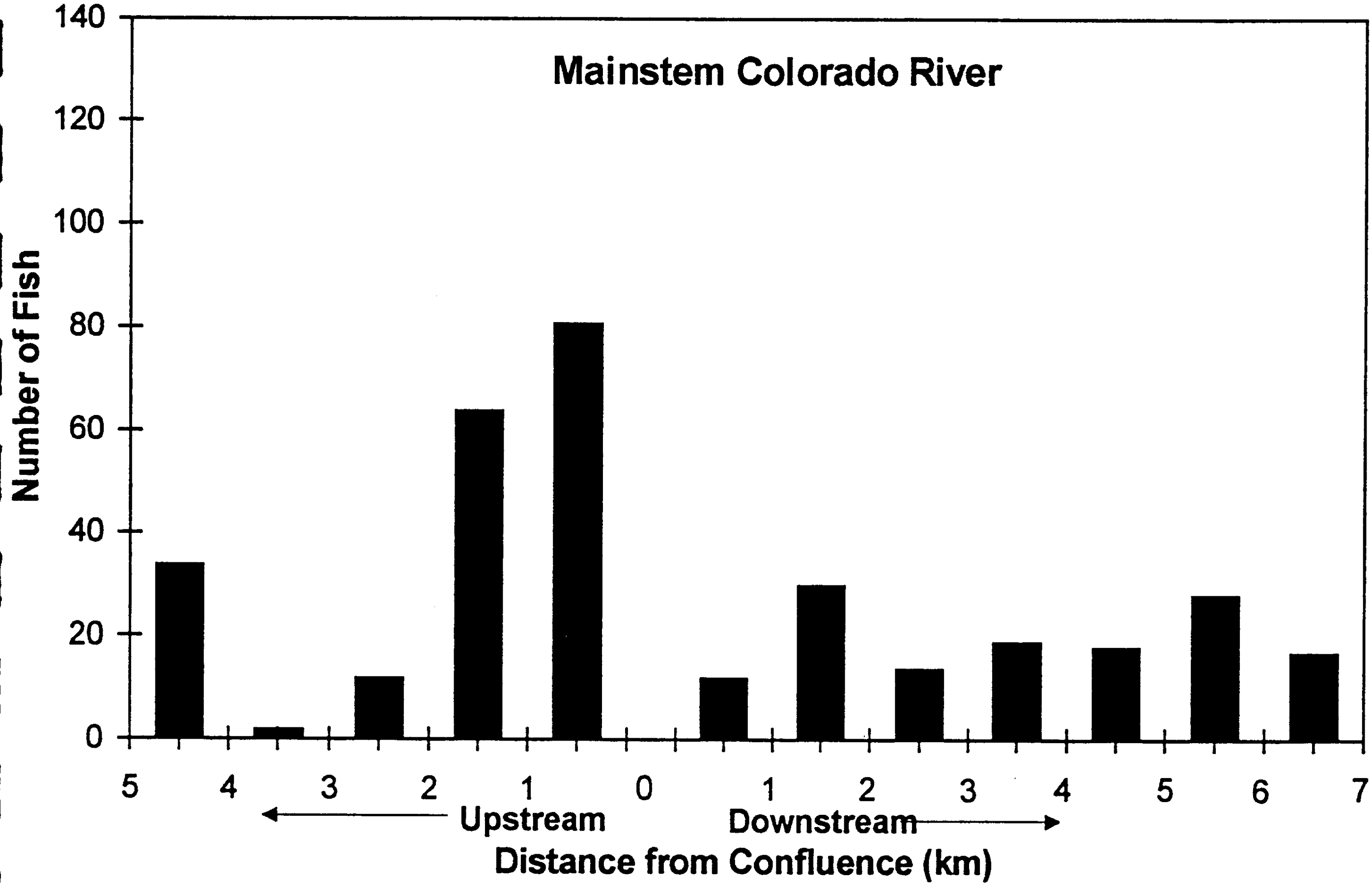
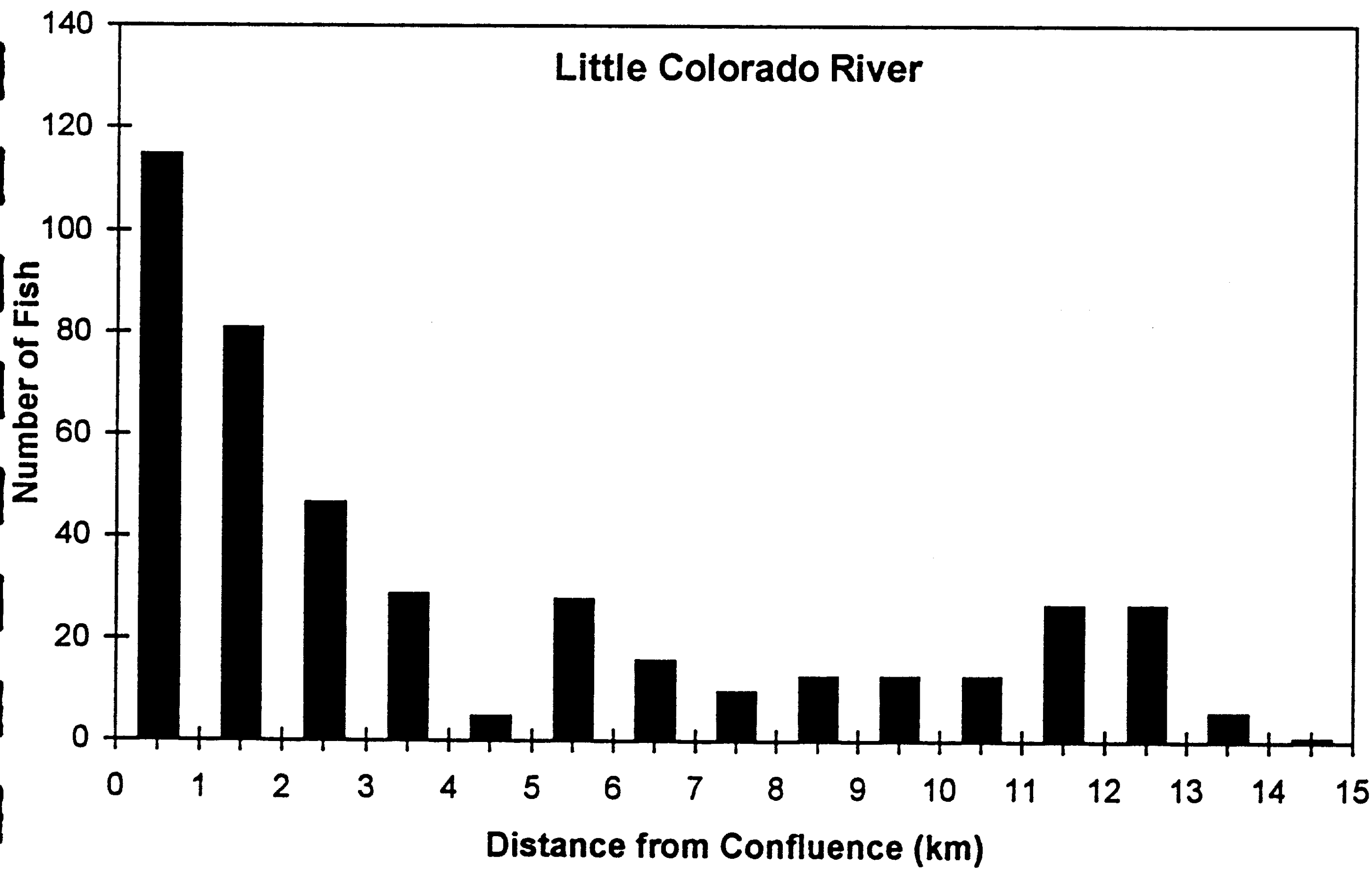

Net Displacement
Number of Fish
80
70
60
50
40
30
20
10
0
-5.5
-4.5
-3.5
-2.5
-1.5
0.5
0.0
0.5
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
Distance (km)

FIG. 8-7

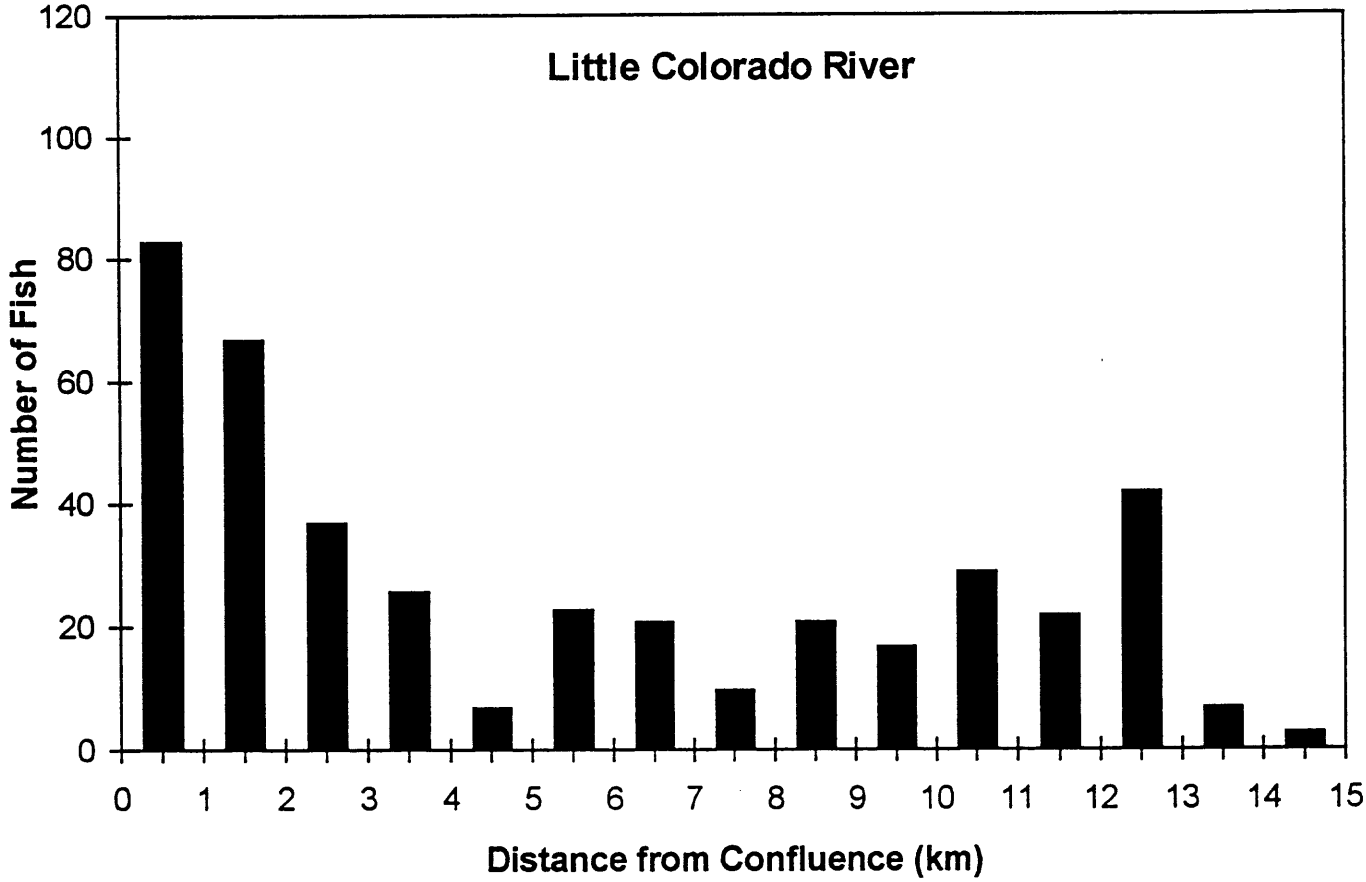


Mainstem Colorado River
Number of Fish
140
120
100
80
60
40
20
0
5
4
3
2
1
0
1
2
3
4
5
6
7
Upstream
Downstream
Distance from Confluence (km)



Little Colorado River
Number of Fish
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Distance from Confluence (km)

I.G.8-8


Little Colorado River
Number of Fish
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Distance from Confluence (km)

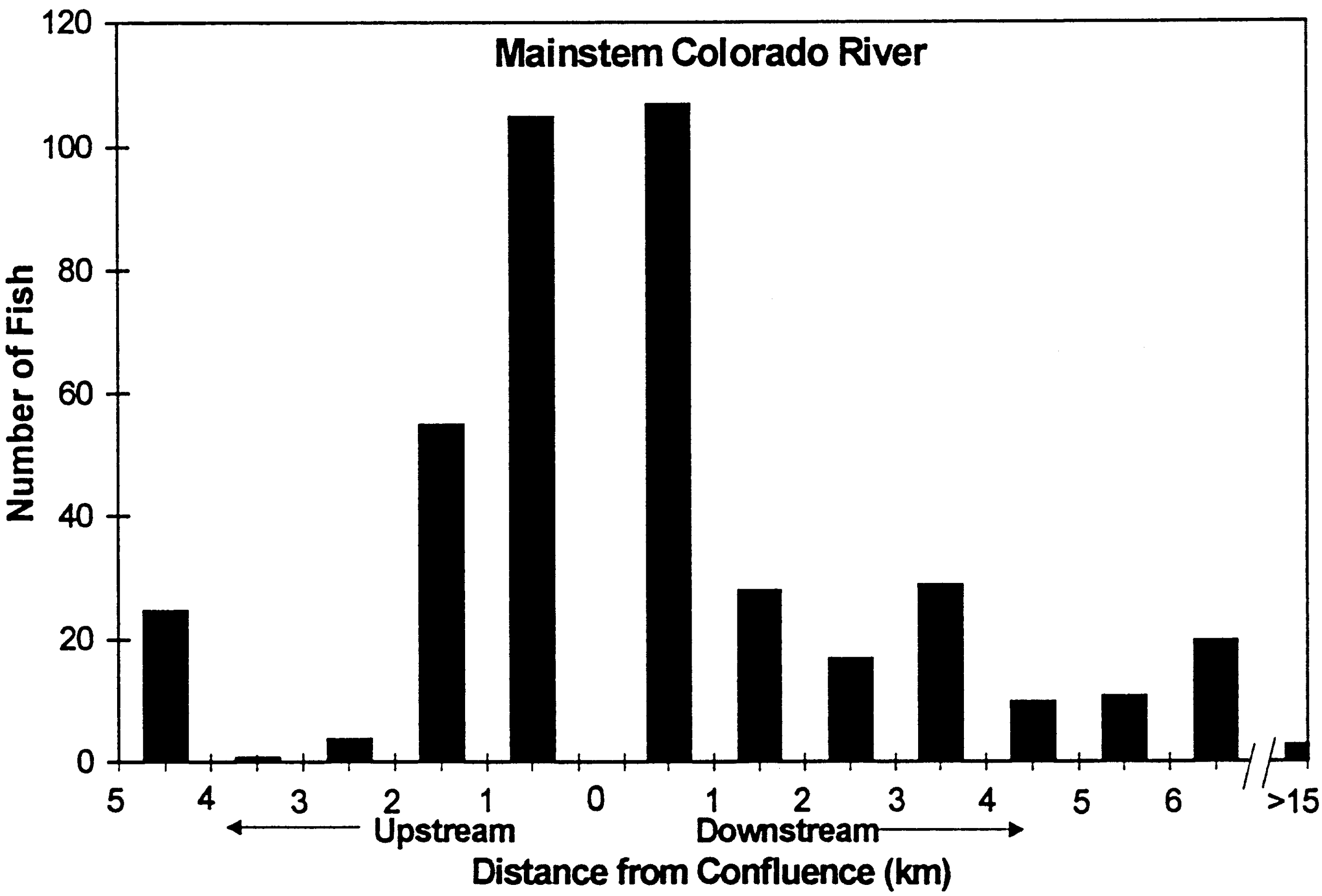

Mainstem Colorado River
Number of Fish
120
100
80
60
40
20
0
5 4 3 2 1 0 1 2 3 4 5 6 >15
Upstream
Downstream
Distance from Confluence (km)

FIG. 8-9

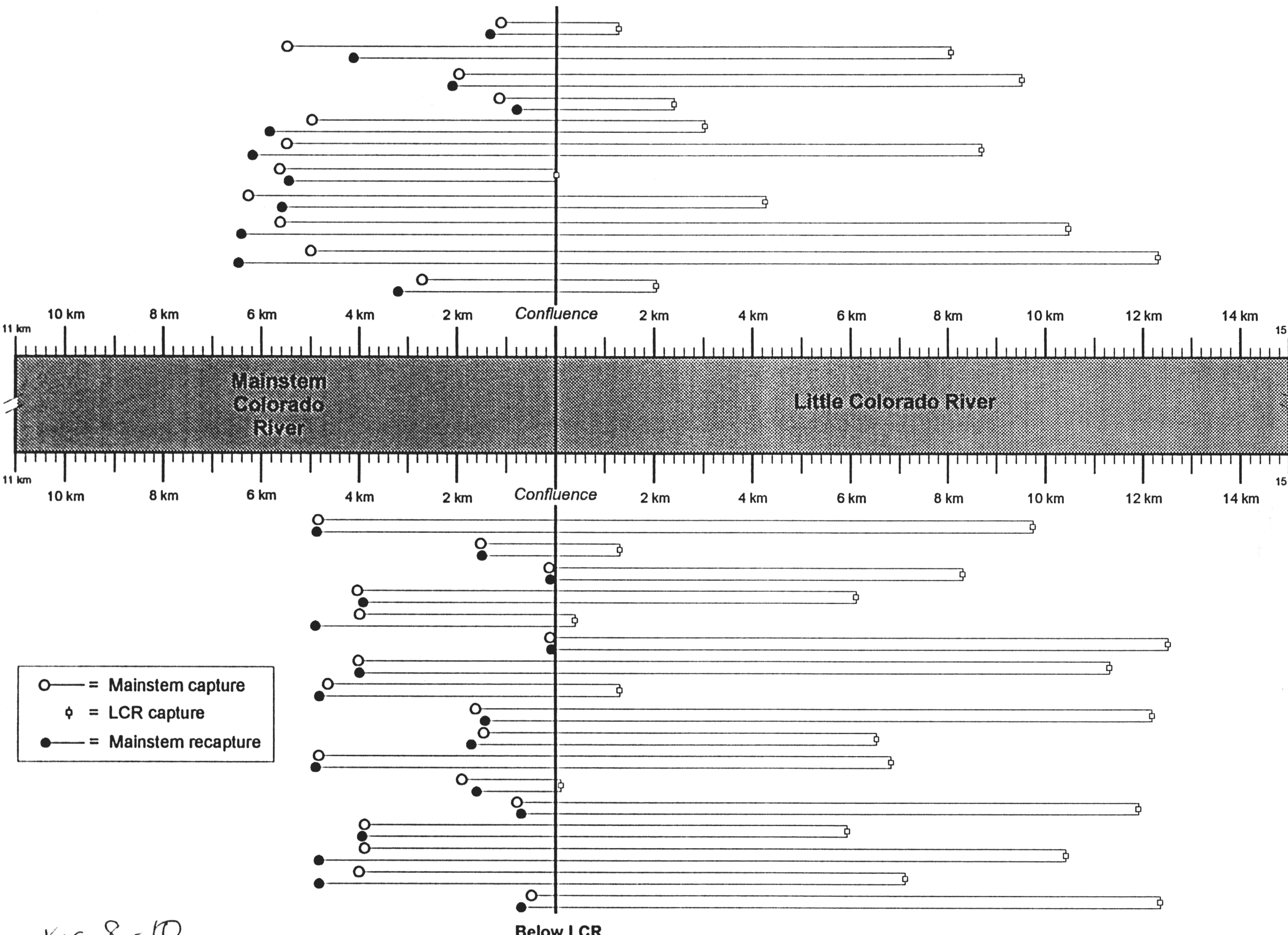
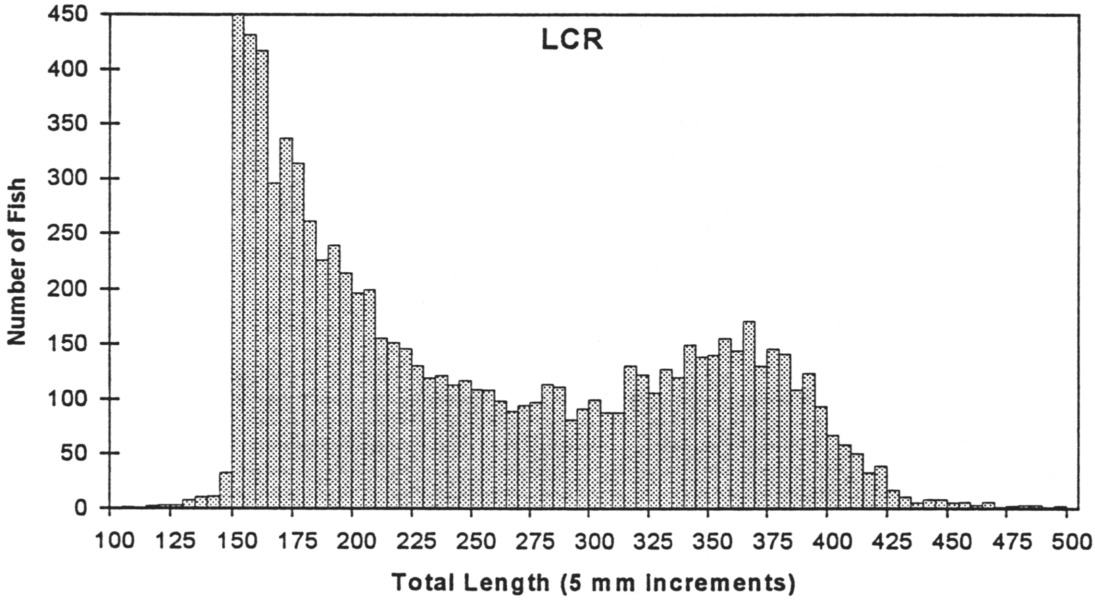
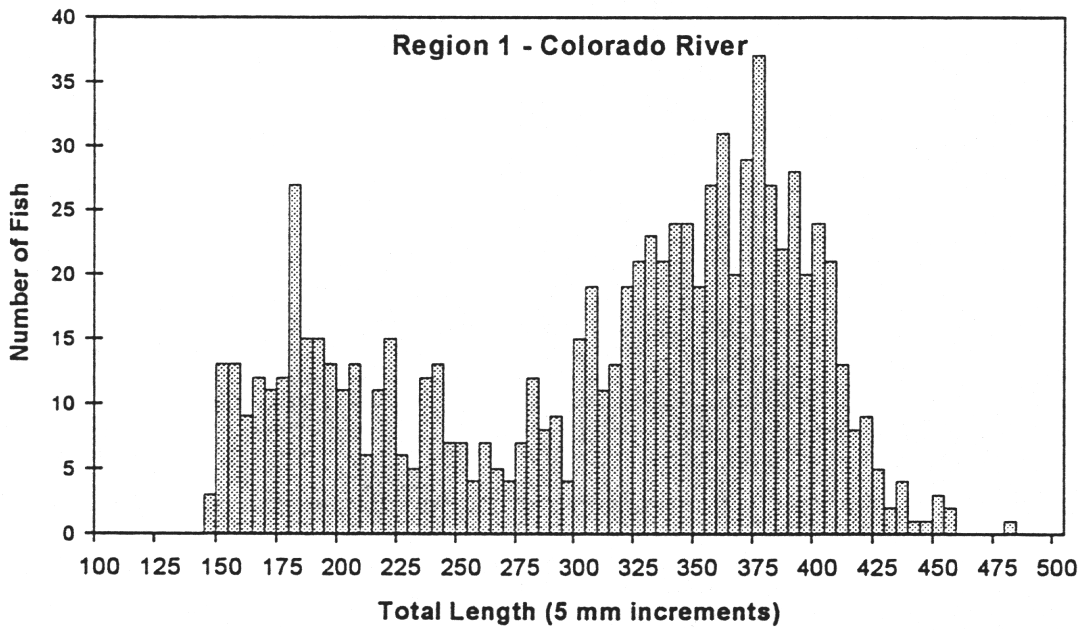
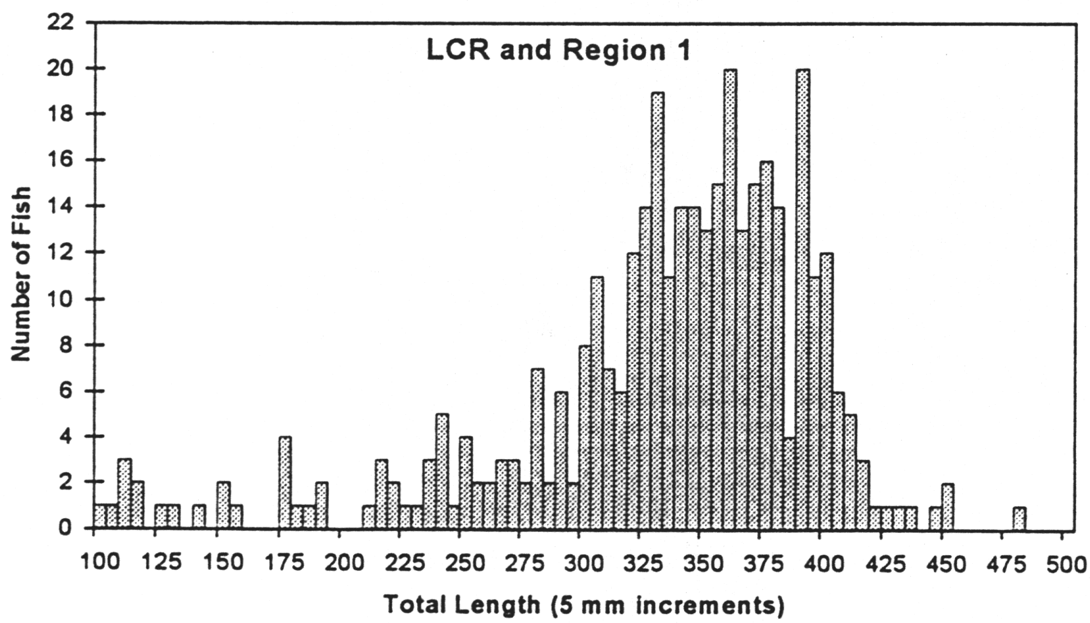

Confluence
Mainstem Colorado River
Little Colorado River
11 km
10 km
8 km
6 km
4 km
2 km
2 km
4 km
6 km
8 km
10 km
12 km
14 km
15 k
Below LCR
= Mainstem capture
= LCR capture
= Mainstem recapture

FIG. 8-10


LCR
Number of Fish
0
50
100
150
200
250
300
350
400
450
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (5 mm increments)


Region 1 - Colorado River
Number of Fish
0
5
10
15
20
25
30
35
40
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (5 mm increments)


LCR and Region 1
Number of Fish
0
2
4
6
8
10
12
14
16
18
20
22
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Total Length (5 mm increments)

C-11

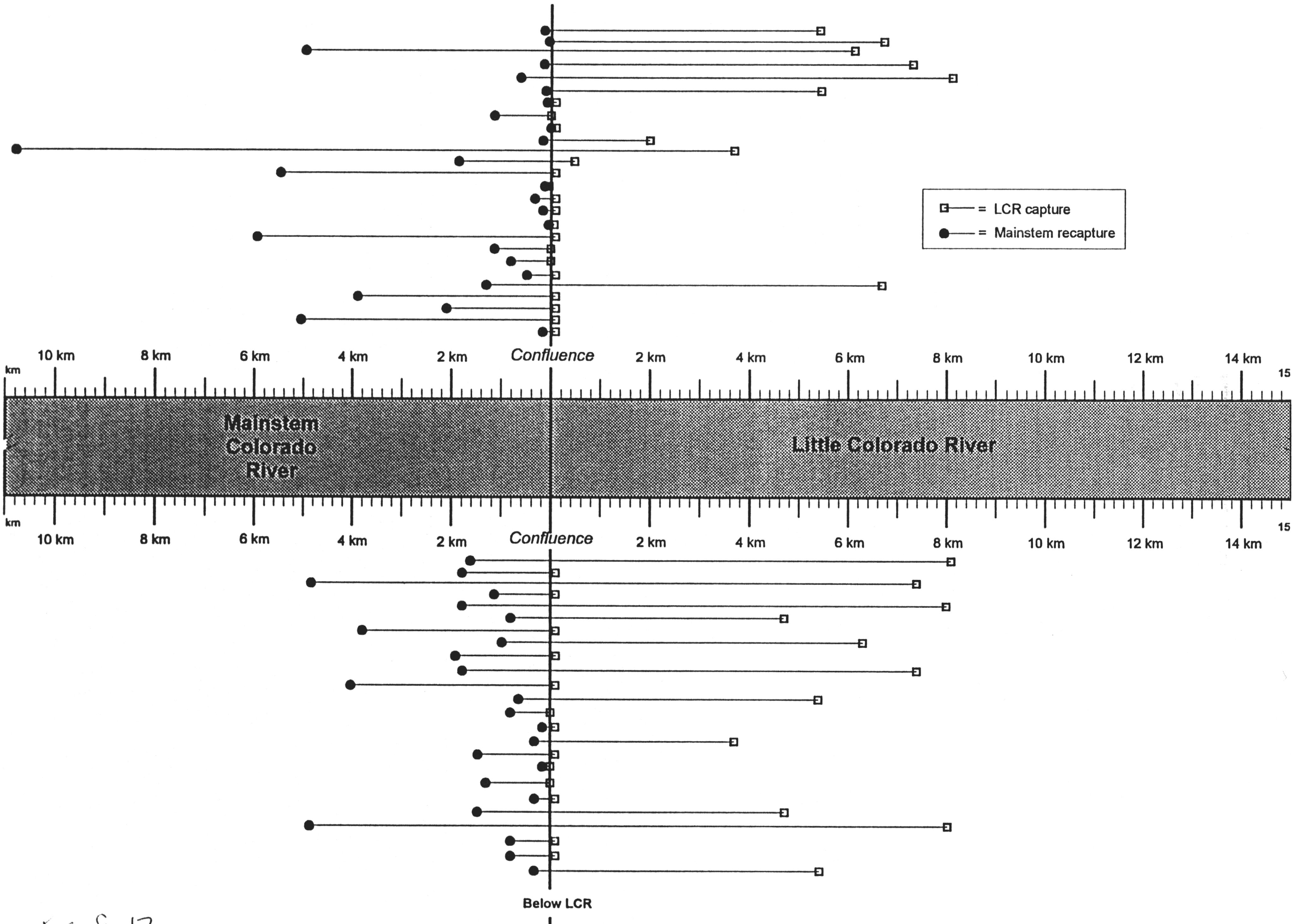
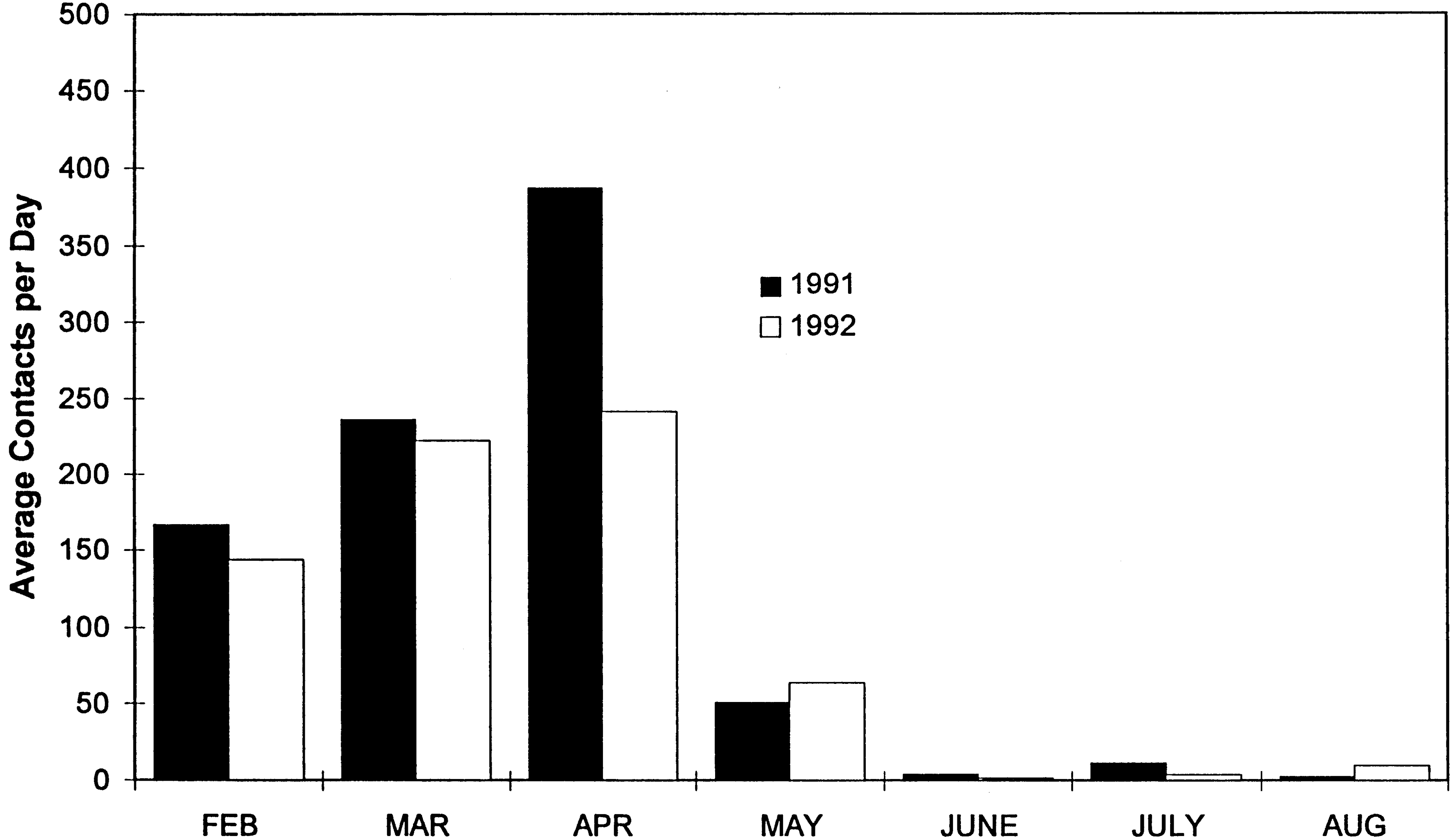
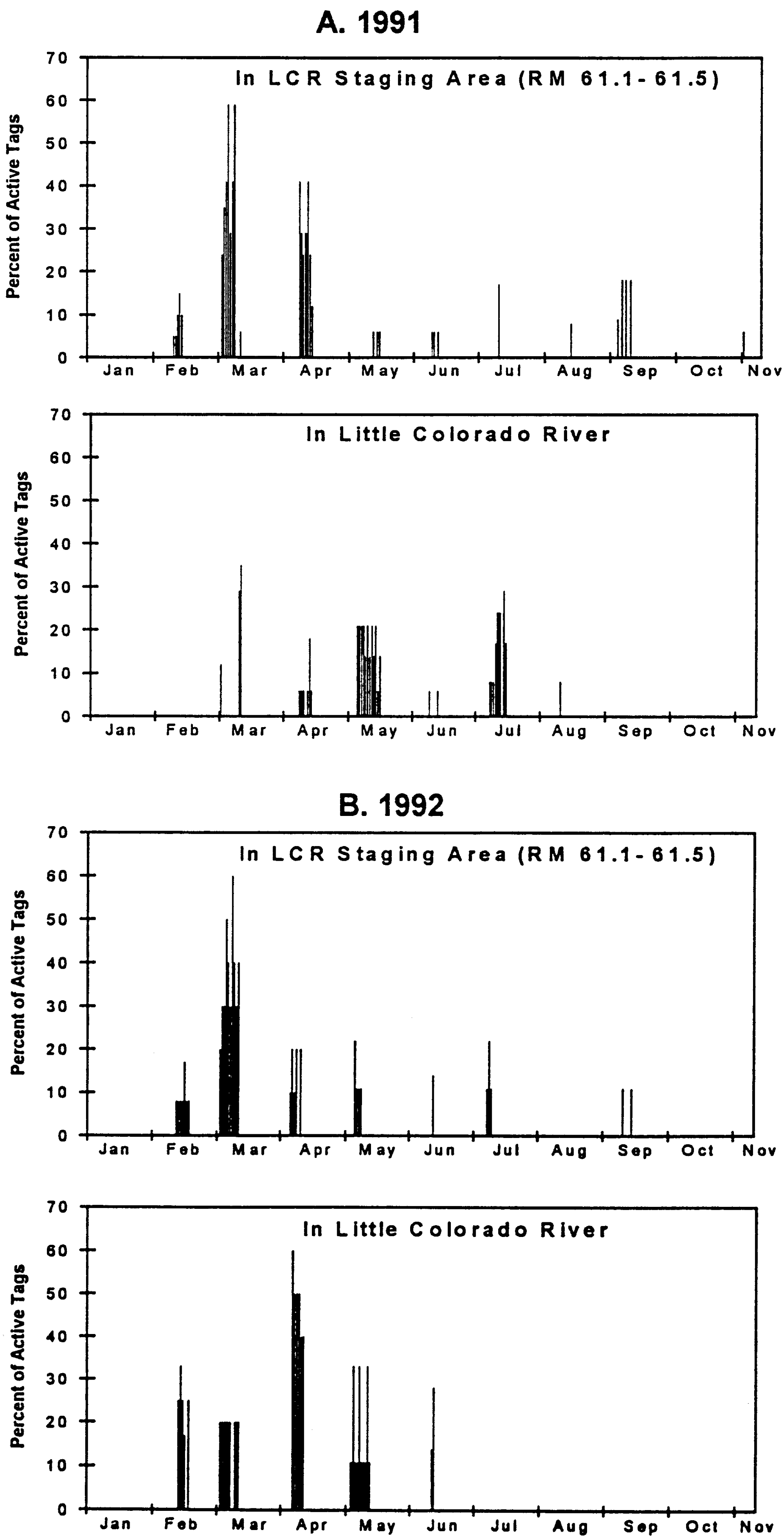

ove
= LCR capture
= Mainstem recapture
10 km
8 km
6 km
4 km
2 km
Confluence
2 km
4 km
6 km
8 km
10 km
12 km
14 km
15
km
Mainstem Colorado River
Little Colorado River
Below LCR

FIG. 8-12


Average Contacts per Day
500
450
400
350
300
250
200
150
100
50
0
1991
1992
FEB
MAR
APR
MAY
JUNE
JULY
AUG

2-13



A. 1991
In LCR Staging Area (RM 61.1-61.5)
In Little Colorado River
B. 1992
In LCR Staging Area (RM 61.1-61.5)
In Little Colorado River
Percent of Active Tags
0
10
20
30
40
50
60
70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Fig. 8-14

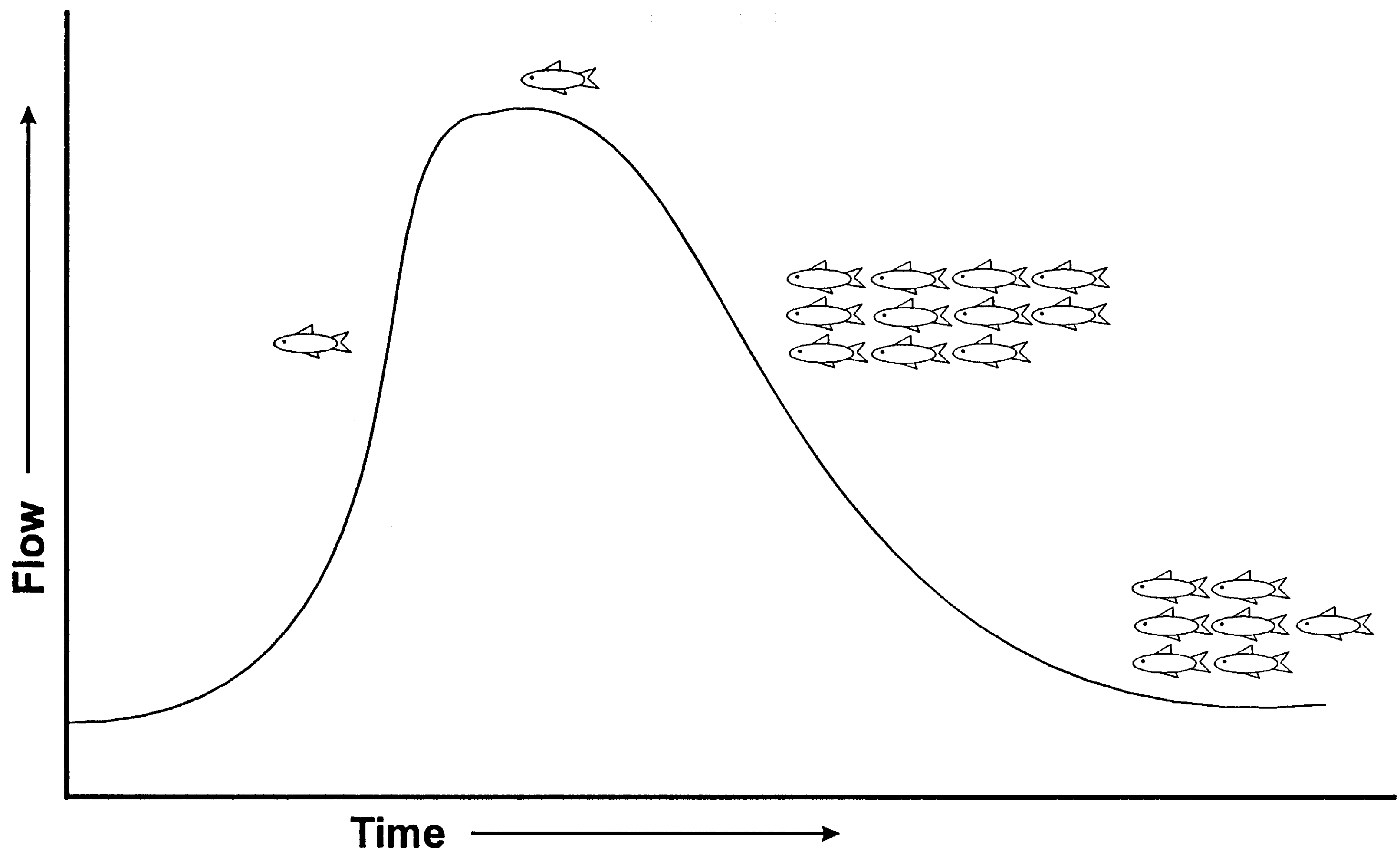
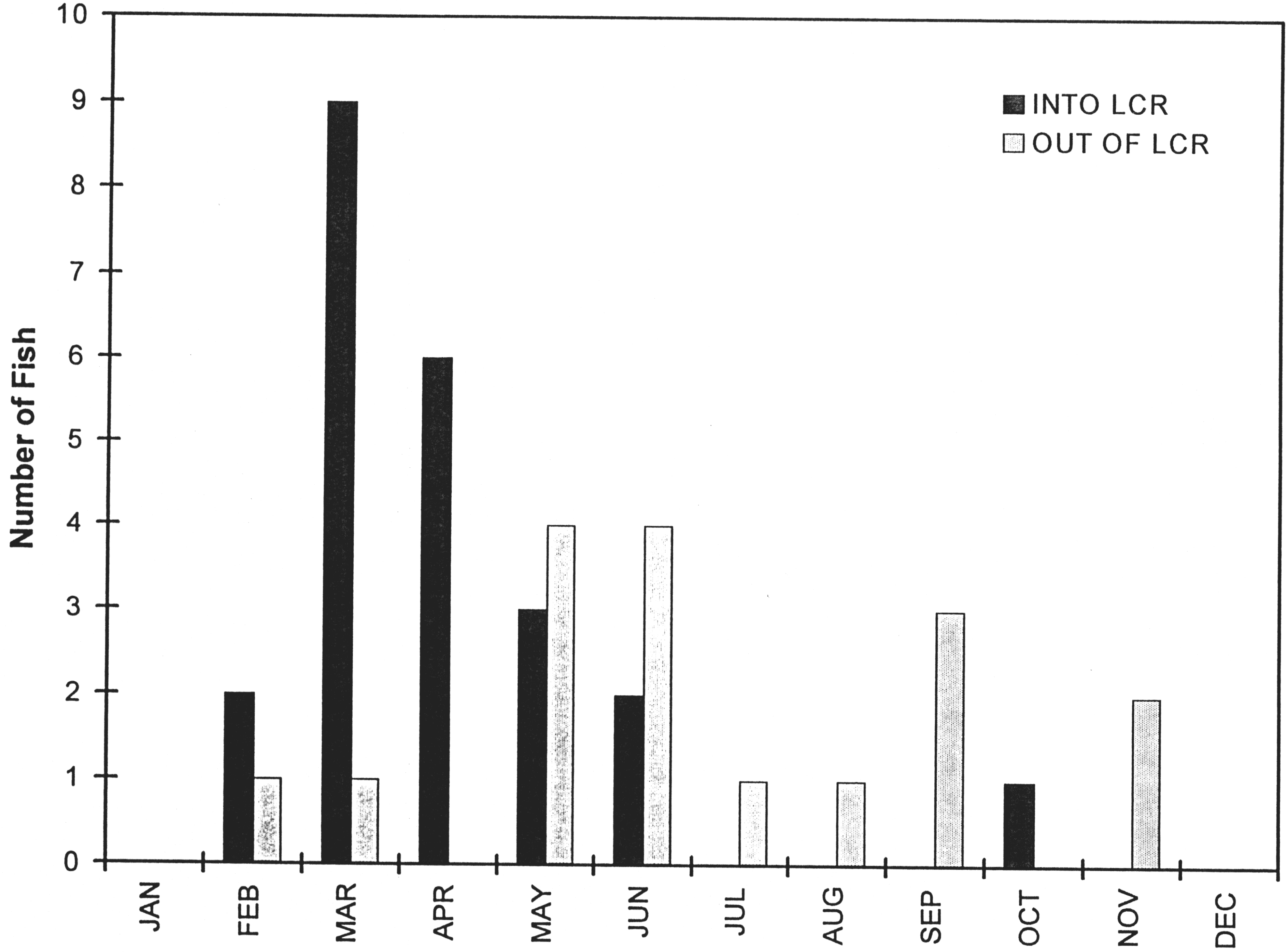
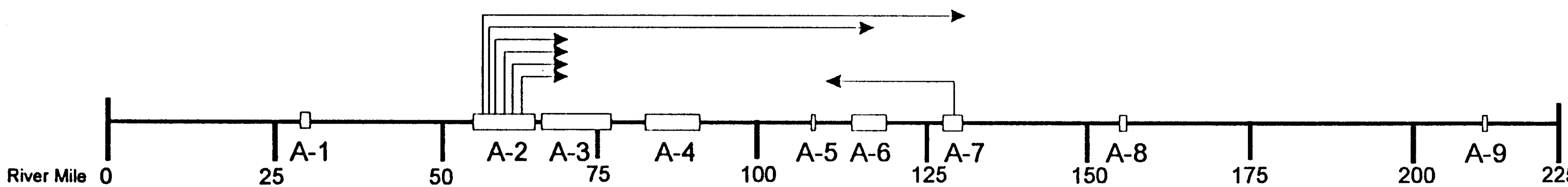


FIG. 8-15


INTO LCR
OUT OF LCR
Number of Fish
0
1
2
3
4
5
6
7
8
9
10
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

8-16



River Mile
0
25
50
75
100
125
150
175
200
225
A-1
A-2
A-3
A-4
A-5
A-6
A-7
A-8
A-9

FIG. 8-17

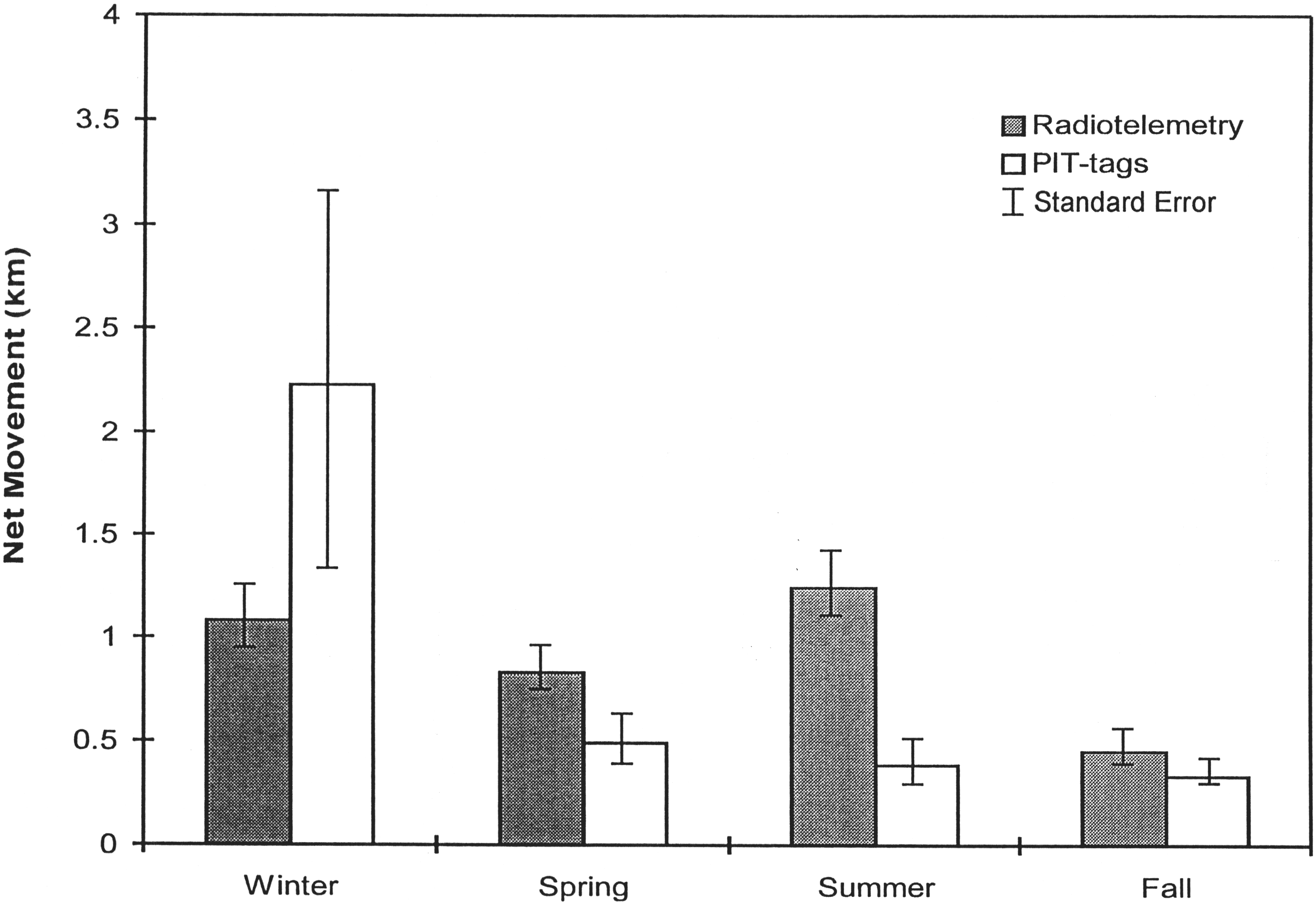
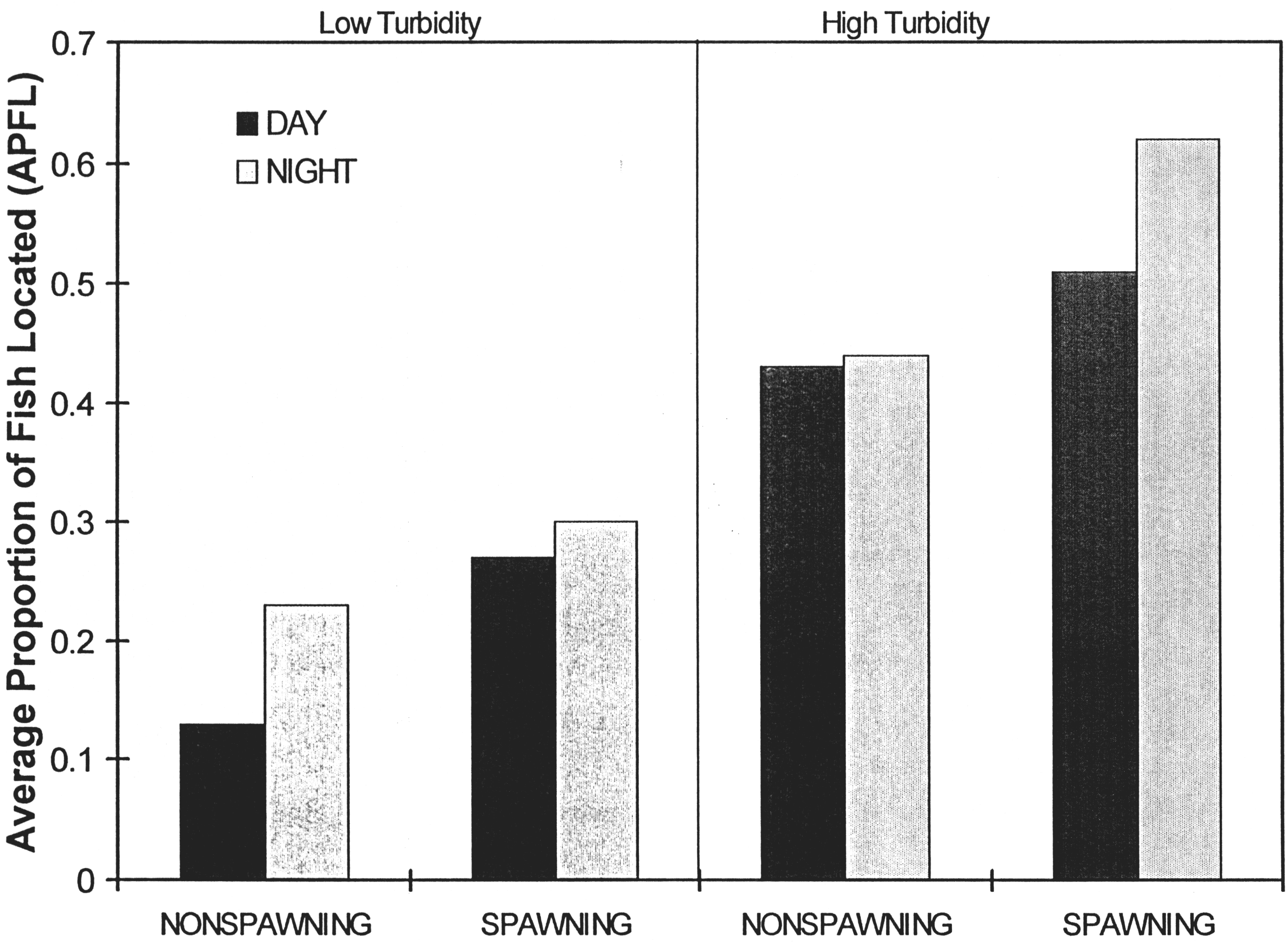
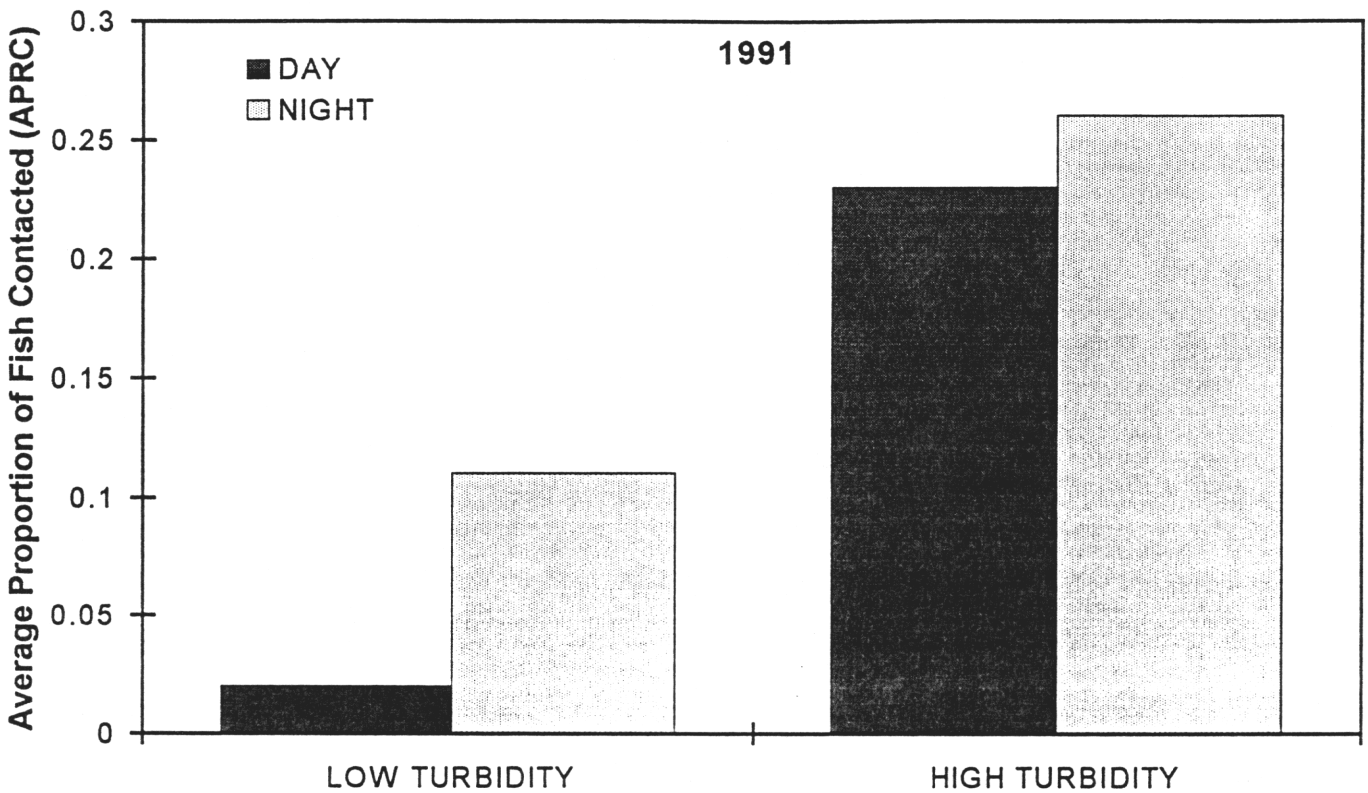
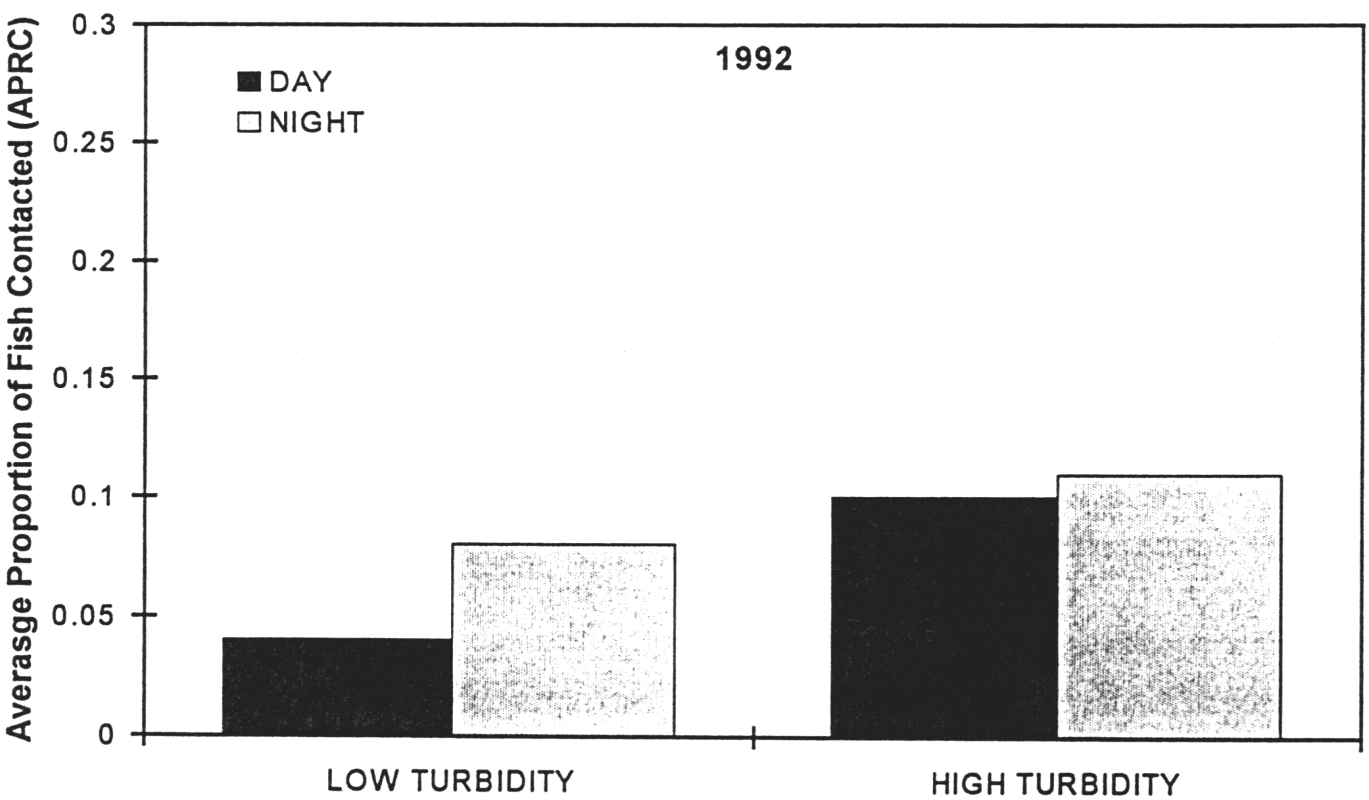

Radiotelemetry
PIT-tags
Standard Error
Net Movement (km)
4
3.5
3
2.5
2
1.5
1
0.5
0
Winter
Spring
Summer
Fall

FIG. 8-18

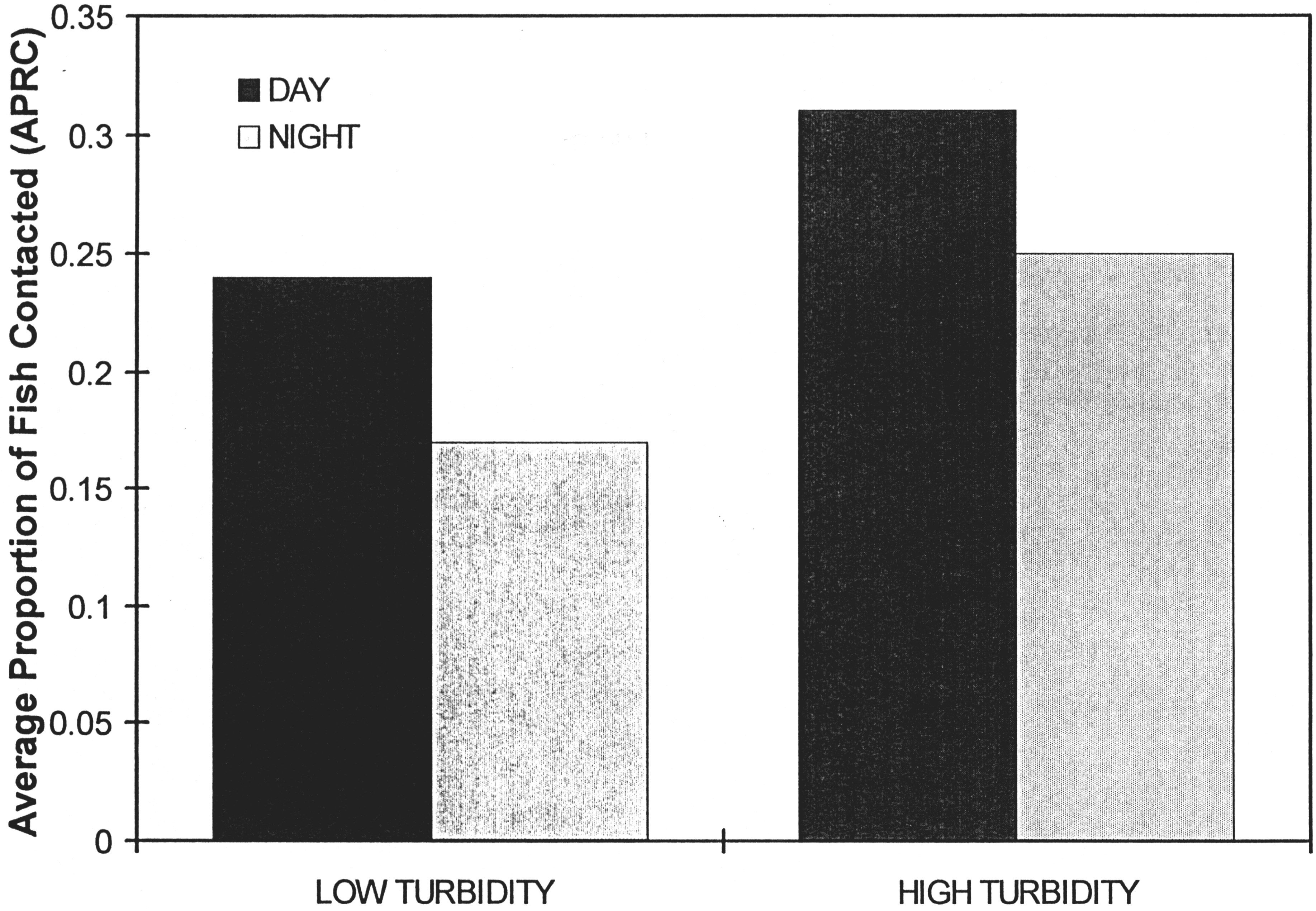

Low Turbidity
High Turbidity
DAY
NIGHT
Average Proportion of Fish Located (APFL)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NONSPAWNING
SPAWNING
NONSPAWNING
SPAWNING

8-19


1991
DAY
NIGHT
Average Proportion of Fish Contacted (APRC)
0.3
0.25
0.2
0.15
0.1
0.05
0
LOW TURBIDITY
HIGH TURBIDITY

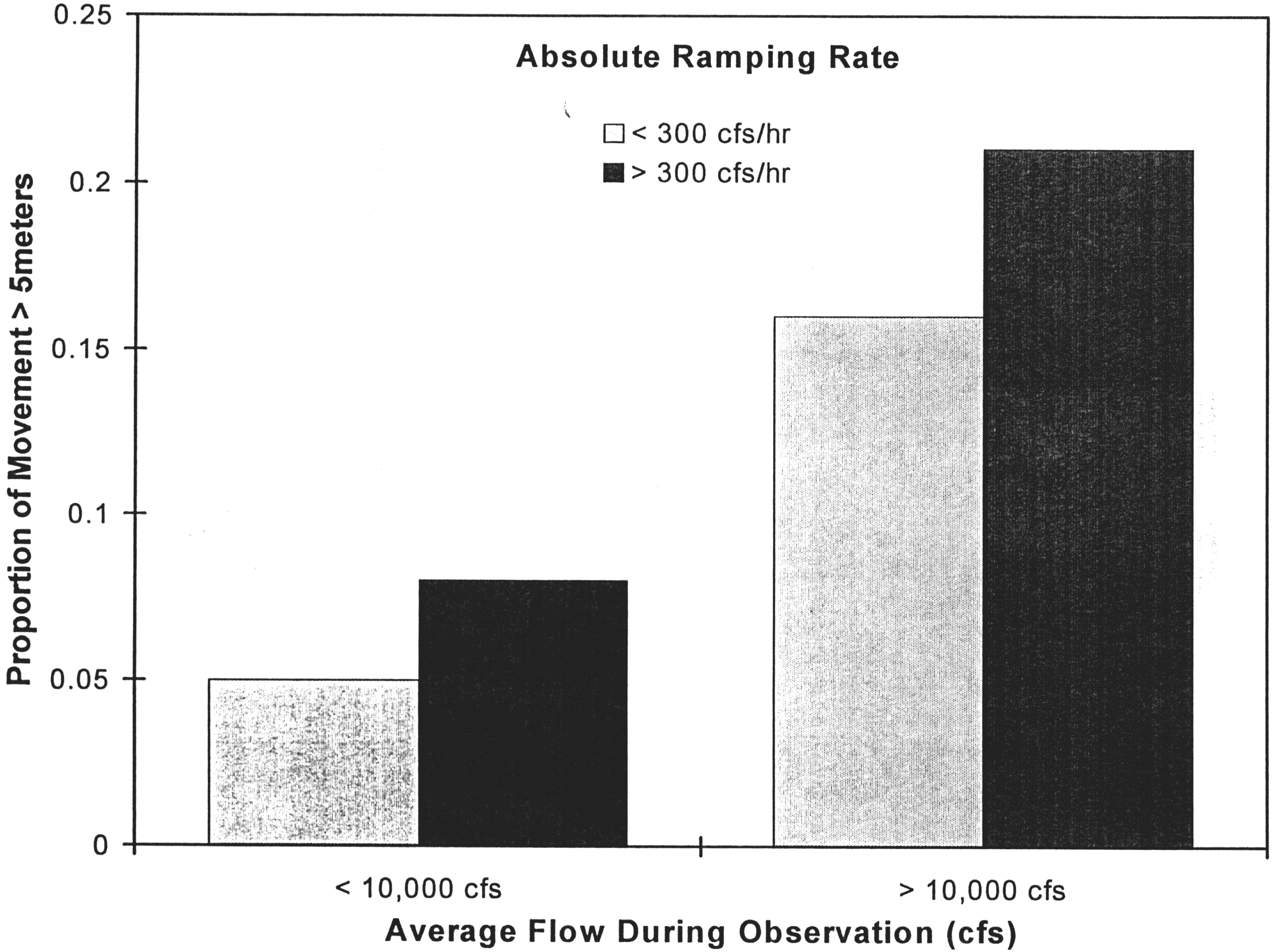

1992
DAY
NIGHT
Averasge Proportion of Fish Contacted (APRC)
0.3
0.25
0.2
0.15
0.1
0.05
0
LOW TURBIDITY
HIGH TURBIDITY

8-20

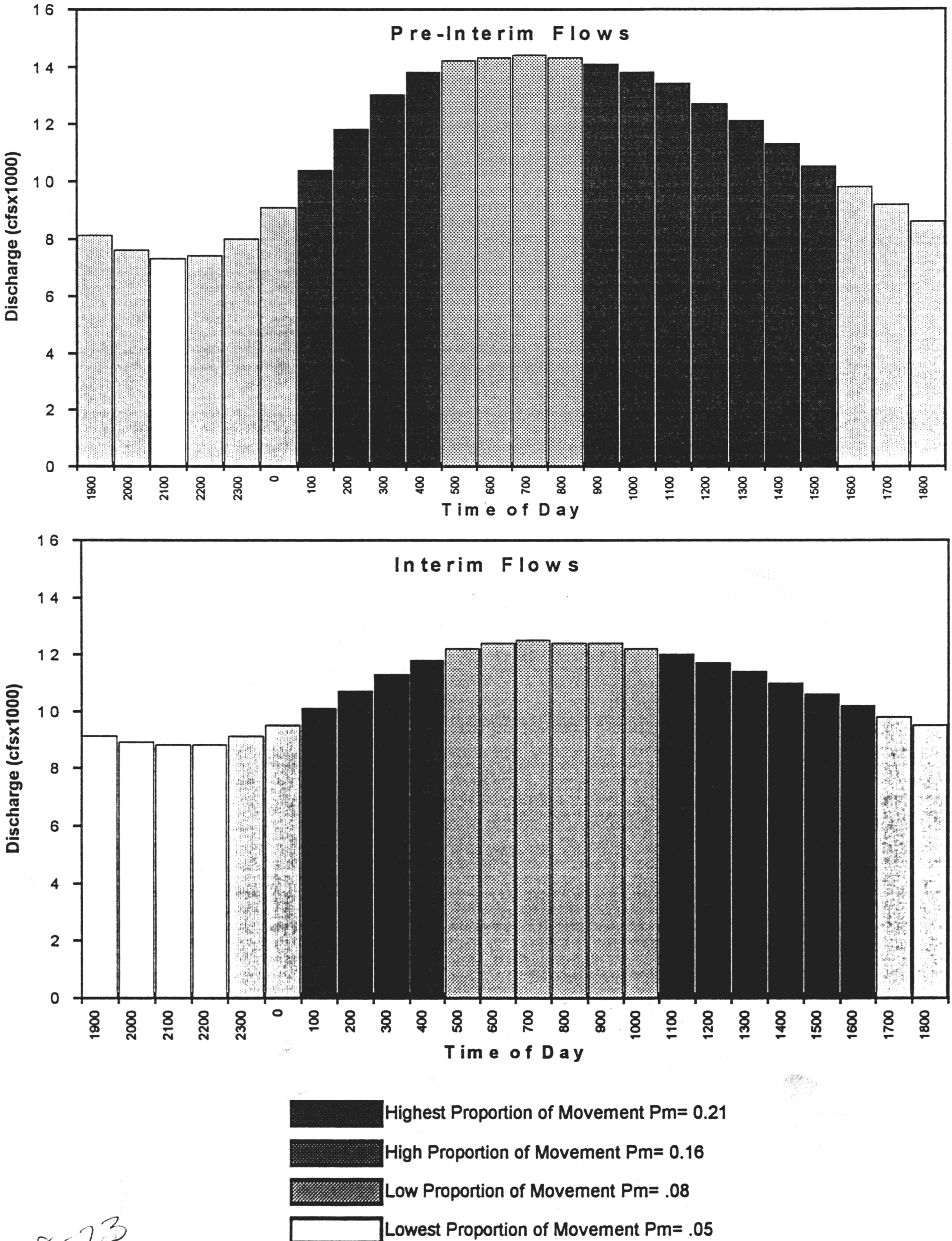


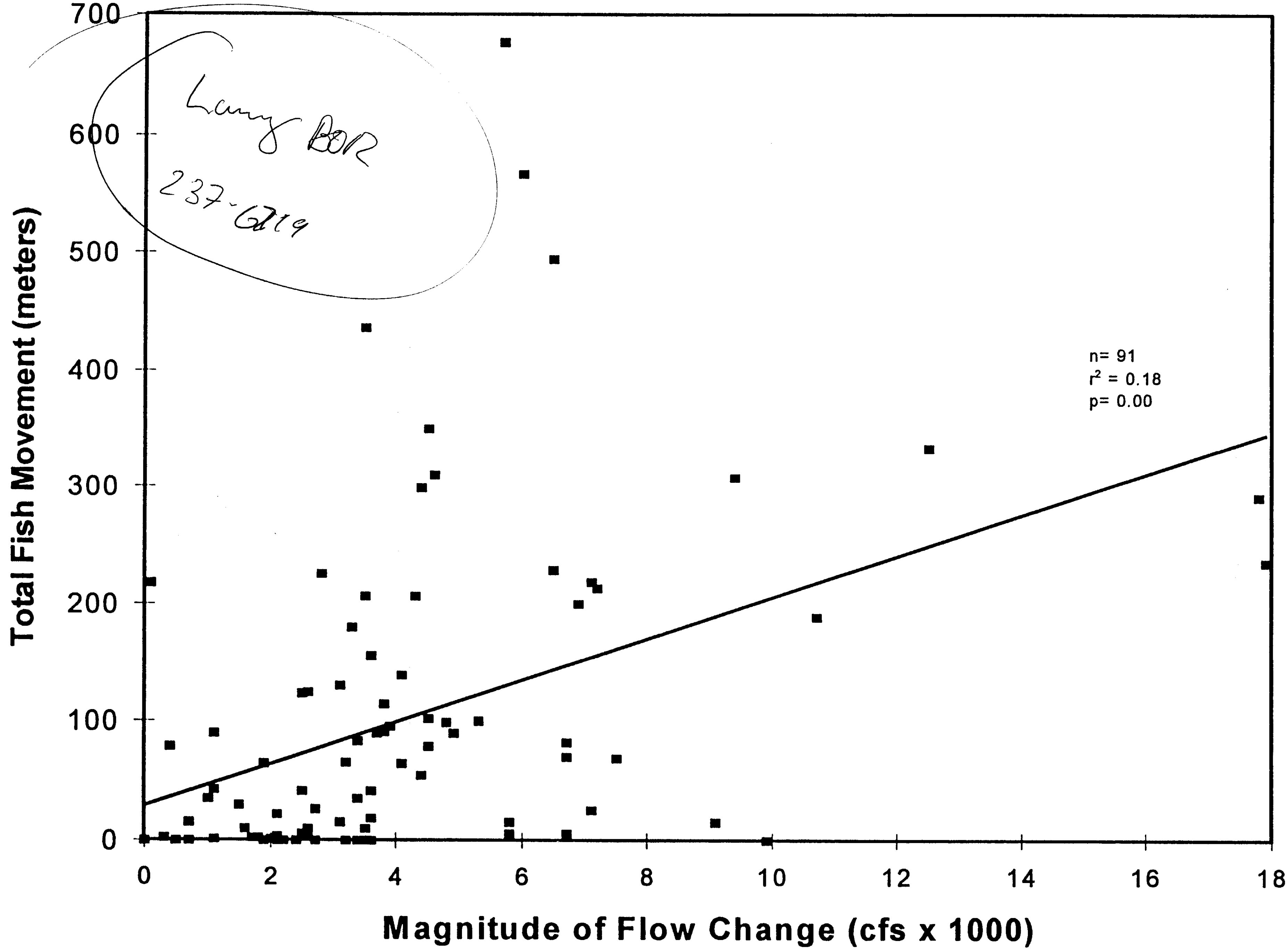
Average Proportion of Fish Contacted (APRC)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
DAY
NIGHT
LOW TURBIDITY
HIGH TURBIDITY

8-21


Absolute Ramping Rate
< 300 cfs/hr
> 300 cfs/hr
Proportion of Movement > 5meters
0.25
0.2
0.15
0.1
0.05
0
< 10,000 cfs
> 10,000 cfs
Average Flow During Observation (cfs)

8-21


Pre-Interim Flows
Discharge (cfsx1000)
16
14
12
10
8
6
4
2
0
1900
2000
2100
2200
2300
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time of Day
Interim Flows
Discharge (cfsx1000)
16
14
12
10
8
6
4
2
0
1900
2000
2100
2200
2300
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time of Day
Highest Proportion of Movement Pm= 0.21
High Proportion of Movement Pm= 0.16
Low Proportion of Movement Pm= .08
Lowest Proportion of Movement Pm= .05



n= 91
r^2 = 0.18
p= 0.00
Total Fish Movement (meters)
0
100
200
300
400
500
600
700
0
2
4
6
8
10
12
14
16
18
Magnitude of Flow Change (cfs x 1000)

8-24