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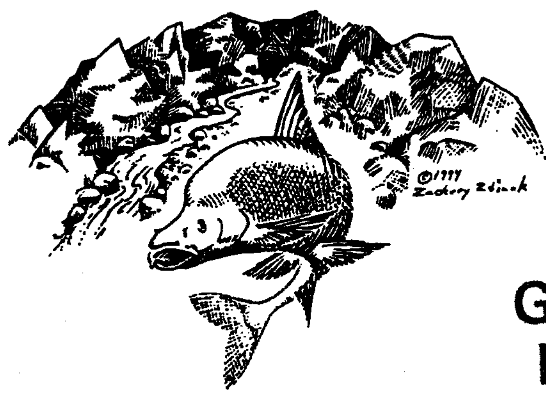
Arizona Fishery Resources Office

Glen Canyon Environmental Studies Phase II Final Report



Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River

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Submitted to:

U. S. Bureau of Reclamation
Glen Canyon Environmental Studies
121 East Birch Street, Suite 307
Flagstaff, Arizona 86001

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Report prepared by:

Owen T. Gorman
U.S. Fish and Wildlife Service
Arizona Fishery Resources Office - Flagstaff
P.O. Box 338
Flagstaff, Arizona 86002

Principal Investigator:

Owen T. Gorman, PhD.
U.S. Fish and Wildlife Service
Arizona Fishery Resources Office - Flagstaff
P.O. Box 338
Flagstaff, Arizona 86002

Co-investigator:

Stuart C. Leon, PhD.
U.S. Fish and Wildlife Service
Arizona Fishery Resources Office - Pinetop
P.O. Box 39
Pinetop, Arizona 85935

Fish and Wildlife Service Supervisor, Arizona Fishery Resources Offices:

James N. Hanson
U.S. Fish and Wildlife Service
Arizona Fishery Resources Office - Pinetop
P.O. Box 39
Pinetop, Arizona 85935

Principal technical support staff:

John M. Seals (Supervisory Technician)
Dennis M. Stone
Zack M. Zdinak

U.S. Fish and Wildlife Service (USFWS)
Arizona Fishery Resources Office (AZFRO) - Flagstaff
P.O. Box 338
Flagstaff, Arizona 86002

Supplementary technical staff for field studies:

John Anderson, USFWS
James Hanson, USFWS
Stewart Jacks, USFWS
Alex Laweka, USFWS
Ron Martinez, USFWS
Daniel Parker, USFWS
John Rogers, USFWS
Lynn Starnes, USFWS
Brent Bristow, USFWS
Allen Hayden, BOR
Norman Jensen, USFWS
Mark Lucas, USFWS
Chuck Minckley, USFWS
Allysa Reischauer, USFWS
Michael Yard, BOR

Cooperators:

U. S. Bureau of Reclamation (BOR), Glen Canyon Environmental Studies (GCES)

Arizona State University (ASU)

Arizona Game and Fish Department (AGFD)

Navajo Fish and Wildlife Department (NFWD)

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INTRODUCTION

The humpback chub (*Gila cypha*) was described in 1946 from a single specimen from an unknown location in the Grand Canyon (Miller 1946). This species has been a long term resident of the Colorado River as evidenced by remains in Indian ruins near Hoover Dam (Miller 1955). Humpback chub historically reached their greatest abundance in inaccessible canyon areas of the mainstream Colorado, and the Green, Yampa, White, and Little Colorado rivers (Smith 1960; Sigler and Miller 1963; Holden and Stalnaker 1970, 1975; Vanicek et al. 1970).

Within its native range, the humpback chub is now restricted to the Green River in Desolation, Gray, and Labyrinth Canyons (Holden and Stalnaker 1975; Holden 1978; Tyus et al., 1982a, 1982b, 1987), in Dinosaur National Monument (Miller 1964; Holden and Stalnaker 1975; Holden and Crist 1980; Miller 1982a; Tyus 1982b), the Yampa River within Dinosaur National Monument (Miller 1964; Holden and Stalnaker 1975; Seethaler et al. 1979; Miller et al. 1982b; Tyus et al. 1982a, 1987), in the Colorado River at Black Rocks, Westwater, and De Beque Canyons (Kidd 1977; Valdez and Clemmer 1982; Valdez et al. 1982; Archer et al. 1985), in Marble and Grand Canyons (Suttkus et al. 1976; Suttkus and Clemmer 1979; Minckley et al. 1981), and in the lower 13 km of the Little Colorado River (Minckley et al. 1981; Kaeding and Zimmerman 1983; Minckley 1987). The reduction in areas of occurrence and population densities have led to the species being declared endangered by the Fish and Wildlife Service.

Much of the habitat use information available for the humpback chub concerns juveniles and adults taken from April through October (Valdez et al. 1987). Adult humpback chub have been reported to be associated with fast current and/or deep channels (Holden and Stalnaker 1975; Kidd 1977; Seethaler et al. 1979). However, Valdez et al. (1982) and the Fish and Wildlife Service (1986) reported preferred habitat of adults to be waters less than 9.1 m deep, over silt, sand, boulder or bedrock, and at water velocities less than 30 cm/s. In the Little Colorado River, Minckley et al. (1981) reported that the species was taken from a variety of habitats, including pools adjacent to eddies, large pools with little or no current, and areas below travertine dams.

Previous studies have concentrated on locating and describing the extent of humpback chub populations; limited information has been collected on the life history and ecology of the species. In the lower Colorado River most, if not all, of the successful spawning takes place in the Little Colorado River (Kaeding and Zimmerman 1983; Minckley 1987). Under the present influence of the Glen Canyon Dam, continued survival of the humpback chub population in the Grand Canyon portion of the Colorado River appears contingent upon the survival of this population.

Although humpback chub may not presently occur in the smaller tributaries of the Colorado River in the Grand Canyon, the likelihood of their presence in these streams or there confluences in the past is very high. Emerging evidence indicates that growth rates and recruitment of juvenile humpback chub in the mainstream Colorado River are quite low and has been attributed to the sustained low temperatures currently prevailing in the River (Kaeding and Zimmerman, 1983; Lupher and Clarkson, 1993; Clarkson et al., 1993). The low temperature regime of the Colorado River is caused by the release of hypolimnetic waters from Lake Powell by Glen Canyon Dam. Seasonally variable hydrology, temperatures, and habitat types in which humpback chub are presently known to reproduce, i.e., Little Colorado River, were approximated in the pre-dam Colorado River of the Grand Canyon (Kaeding and Zimmerman, 1983; Clarkson, et al., 1993). Thus, prior to the closing of Glen Canyon Dam, it is quite likely that humpback chub reproduced in the mainstream Colorado River and in smaller tributaries. The presence of populations of humpback chub in smaller tributaries was probably dependent on regular influxes from a large mainstream population. Therefore, the present absence of humpback chub in smaller tributaries and their confluences with the Colorado River is not an indication of their lack of suitability to humpback chub, but rather a reflection of the decline of the mainstream humpback chub population. It is quite possible that prior to Glen Canyon Dam, smaller tributaries or their confluences provided spawning habitat and nurseries for small fish in those areas of the Colorado River where humpback chub are presently rare or absent.

Surveys by the Arizona Game and Fish Department (AZGFD) and BioWest in the summer of 1993 found evidence of humpback chub spawning in springs along the main channel at river mile 29 (South Canyon reach; AZGFD, 1994; T. Hoffnagle, AZGFD, pers. comm.; R. Valdez, BioWest, pers. comm.). In the largest tributary, the Little Colorado River (LCR) at river mile 61, humpback chub spawn successfully in the lower 14 km (Kaeding and Zimmerman, 1993; AZGFD, 1994). Researchers from BioWest have found evidence that humpback chub may even spawn at the mouth of the LCR (R. Valdez, pers. comm.). Sampling data collected by Arizona State University and U.S. Fish and Wildlife Service indicate that large numbers young-of-year humpback chub remain in the Little Colorado River their entire first year and in winter months many are concentrated in areas more than 10 km upstream from the mouth (Gorman et al. 1991). Most of the remaining adult humpback chub in the mainstream associate with the Little Colorado River and the maintenance of this population appears dependent on reproduction in this tributary (Kaeding and Zimmerman 1983; Rich Valdez, BioWest, pers. comm.).

The success of future recovery efforts that address Conservation Measure #7 for humpback chub in the Grand Canyon must consider the potential role of tributaries in maintaining populations outside the region that includes the Little Colorado River.

CONTRACTED STUDY OBJECTIVES

The purpose of U.S. Fish and Wildlife (USFWS) fishery studies for Glen Canyon Environmental Studies (GCES) Phase II was "to quantify habitat use by humpback chub in the Little Colorado River and other tributaries of the Colorado River, evaluate the potential for establishing a second spawning aggregation and, to the extent possible, evaluate how these populations are affected by the operation of the Glen Canyon Dam which controls the Colorado River environment in the Grand Canyon" (USFWS, 1990). The intent of our research was the collection and analysis of information to partially satisfy GCES Conservation Measures 5, "Conduct Research to Identify Impacts of Glen Canyon Dam Operations on the Humpback Chub in the Mainstem and Tributaries" and 7, "Establish a Second Spawning Aggregation of Humpback Chub in the Grand Canyon" (USFWS, 1990). Our study was designed to "evaluate the specific habitat requirements of various age classes of humpback chub and other native and introduced fish species in the tributaries of the Colorado River and the availability of these habitats at changing discharges" (USFWS, 1990). Tributaries included in the study were the Little Colorado River (LCR), Paria River, and Bright Angel, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks.

The specific objectives of our study (USFWS, 1990) are:

1. Identify and quantify preferred habitats of juvenile and adult humpback chub and other fish species in the LCR.

2. Identify and quantify seasonal habitat use patterns of juvenile and adult humpback chub and other fish species in the LCR.

3. Identify and quantify humpback chub spawning habitat in the LCR.

4. Identify potential humpback chub habitats within the various tributaries of the Colorado River and evaluate suitability of these habitats to recovery efforts.

5. Develop discharge-frequency and flow-duration curves at locations of interest in the LCR to determine how flood stages affect humpback chub habitats.

6. Identify information and future research required for the possible enhancement of environmental conditions to protect and promote fish and wildlife populations in the LCR and other tributaries.

Objective 5 was dropped from the study because of an inability to secure permission to conduct hydrological studies on the Little Colorado River. Our study objectives address the following reasonable and prudent alternatives (RPA) proposed by USFWS (Revision of Reasonable and Prudent Alternative, Draft Biological Opinion, Operation of Glen Canyon Dam, 2-21-93-F-167; USFWS, Arizona Ecological Services Office, Phoenix, Arizona 85019). Most of these RPAs correspond to Conservation Measures outlined in the Glen Canyon Environmental Studies Phase II Draft Integrated Research Plan (GCES, 1990).

2. Protect the humpback chub spawning population and habitat in the LCR by being instrumental in developing a management plan for this river (this corresponds to GCES Conservation Measure 4).

3. Research Program [and Long Term Monitoring]. Determine the responses and impacts on endangered and native fishes in Grand Canyon by experimental flows provided in Element 1 and obtain information necessary to adjust operational criteria so they are beneficial for endangered fishes and other resources affected by Glen Canyon Dam (this corresponds to GCES Conservation Measures 5 and 6)

4. Develop actions that will help ensure the continued existence of razorback sucker [in the Grand Canyon].

5. Make every effort to establish a second spawning aggregation of humpback chub downstream of Glen Canyon Dam (this corresponds to GCES Conservation Measure 7).

6. Reclamation shall determine the feasibility of a selective withdrawal program for Lake Powell waters. If the Service determines from the studies that such an action would be beneficial to endangered fish, Reclamation will take appropriate actions to implement a project for selective withdrawal.

7. Develop an adaptive management plan that will provide for adequate studies to review impacts to endangered and native fishes of the Grand Canyon and recommend actions to further their conservation (this corresponds to GCES Conservation measures 5 and 6).

Our GCES Phase II study program is split into two components to address our study objectives and RPAs listed above:

1. Habitat use by humpback chub and other native fishes in the LCR. The largest concentration of successfully reproducing humpback chub throughout their native range occurs in the LCR. In the LCR our studies focus on describing habitat use by all post larval stages of humpback chub, including spawning habitat. Our findings will serve as a model for evaluating other tributaries in the Grand Canyon for their potential to support secondary reproducing populations of humpback chub.

2. Habitat studies on the smaller tributaries of the Colorado River in the Grand Canyon to evaluate their potential for establishing secondary reproducing aggregations of humpback chub.

Analysis and interpretation of our study objectives pertinent to the LCR were guided by hypotheses from our contract proposal:

Ho_1: Juvenile and adult humpback chub are uniformly distributed throughout all available habitats.

Ho_2: Habitat use patterns of juvenile and adult humpback chub do not vary seasonally.

Ho_3: Habitat use patterns among differing age classes of humpback chub do not vary from uniform.

Ho_4: Habitat availability and consequent habitat use does not vary over a continuum of flow volumes.

The specific tasks addressed in our LCR studies are:

1. Describe and determine the availability of aquatic habitats on a seasonal basis.

2. Describe seasonal patterns of distribution and habitat use by YOY, juvenile, and adult native fishes.

3. Identify humpback chub spawning habitat in the LCR.

4. Predict the effects of seasonal and intermittent high discharges on habitat availability in the LCR by river modeling studies.

The specific tasks addressed in our tributary studies are:

1. Describe and determine the availability of aquatic habitats on a seasonal basis.

2. Determine seasonal patterns of distribution and habitat use by native and exotic fishes.

3. Identify information and future studies required for possible enhancement of environmental conditions to protect and promote fish and wildlife populations in tributaries of the Colorado River.

In our analysis we will mesh information on the impacts of dam operations with habitat availability and critical life history requirements to make recommendations for enhancement of environmental conditions to protect and promote recovery of the humpback chub population in the Grand Canyon. Furthermore, our study will enable us to identify areas with suitable habitat for the establishment of a second spawning aggregation of humpback chub in the Grand Canyon.

METHODS

STREAMS and STUDY AREAS

The following tributaries of the Colorado River in the Grand Canyon were identified as candidates for investigation in GCES Phase II contracted studies to the U.S. Fish and Wildlife (U.S. Fish and Wildlife 1990): Little Colorado River (LCR), Paria River, Bright Angel Creek, Shinumo Creek, Tapeats Creek, Deer Creek, Kanab Creek, and Havasu Creek (Figs. 1, 2).

Little Colorado River

The LCR was the prime focus of our field studies. Our strategy was to conduct a detailed habitat study in the LCR with a focus on the humpback chub and to use our findings as a model for evaluating the potential of other tributaries to support humpback chub populations. The first step in our LCR studies was to sample available habitat throughout the perennially flowing lower 21 km. In the summer of 1991 we chained and flagged transect locations at 20m intervals from the mouth of the LCR (-0.36 km) to Blue

Springs (km 21). We then sampled habitat at 1m intervals along Fish and Wildlife Service (FWS) transects spaced 100m apart (every 5th transect). Data from more than 200 transects allowed us to characterize the available habitat throughout the lower 21 km of the LCR and identify habitat differences among areas were humpback chub were known to occur or were absent.

In September 1992, a formal survey of the LCR canyon bottom from Blue Springs to the confluence was conducted by the Bureau of Reclamation and the Fish and Wildlife Service. The survey team used the highly accurate control traverse method and each FWS transect was located with an accuracy of several cm. The ultimate product of this survey will be a GIS base map showing a detailed topography of the LCR canyon bottom and the locations of all FWS transects. This GIS will give us the capability of locating all of our habitat measures and fish captures in the LCR to within 1-2m accuracy.

The second stage in our LCR studies was to measure habitat at fish sampling nets (hoopnets) set by Arizona State University (ASU) researchers and to evaluate the suitability of that sampling effort for habitat assessment. Habitat measures of ASU hoopnets was conducted monthly/seasonally from July 1991 through March 1993. An analysis of FWS habitat data measured at ASU hoopnets was presented in our 1993 annual report (Gorman, 1994). We determined that the habitat sampled by the nets was not representative of available habitat and therefore were not suitable for habitat use assessment (see Habitat Sampling below). These data will not be considered further in this report.

The third stage in our LCR studies was to establish study reaches where habitat assessment could be investigated under controlled conditions. Two reaches were chosen for study, km 2.5-3.5 (Powell Study Reach) and km 10.5-11.5 (Salt Study Reach) (Figs. 2-3). Boundaries for each study area were chosen so as to include at least two riffle/reef/dam complexes and two pool/runs. Criteria for selection of study areas included representativeness and accessibility to field work. Accessibility was crucial because large amounts of sampling gear had to be hand carried to the sites and field crews were also expected to run nets at night. To assess representativeness we started with the habitat data sampled over the lower 21 km and subdivided it into three reaches: km 0-7.5, km 8-14.5, and km 15-21. PCAs of habitat data were performed for each reach and sample points from the selected study reaches (km 2.5-3.5 and km 10.5-11.5) were projected onto multivariate plots of the km 0-7.5 and km 8-14.5 reaches, respectively. Available microhabitat in the selected study reaches was concordant with available microhabitat in each of the larger river reaches (Gorman et al., 1993). Frequency histograms for depth, current, and substrate characterized the available habitat in each study reach and were compared with available habitat in the LCR as a whole (Gorman et al., 1993). Finally, data for the lower 21 km was divided into 1 km sections and frequency tables for depth, current, and substrate were generated. From these frequency tables, matrices of percent similarity (PS) were generated to compare each 1 km section with all other sections and the selected study reaches (km 2.5-3.5 and km 10.5-11.5) (Gorman et al., 1993). Mean PS for depth, current, and substrate over all 21 river sections was 79, 79, and 66 %, respectively. Mean PS for the 2.5-3.5 km study area with river sections km 1-7 were 80, 79, and 70 % respectively. Mean PS for the 10.5-11.5 km study area with river sections km 8-14 were 79, 79, and 65 % respectively. Given that the average identity of 1 km sections with other local river sections is 79% (depth), 79% (current), and 66% (substrate), our selected study areas are as "representative" as theoretically possible of habitat found in the river (Gorman et al. 1993).

Our 1000 m study reaches were subdivided into two 500 m subreachs or study areas to facilitate sampling efforts. Usually only one 500 m study area was sampled per trip and sampling of lower and upper study areas was alternated over successive trips (this was done in part to reduce sampling impacts on our study areas). Available habitat was sampled along established FWS transects (20 m intervals) throughout each study area. Grids of mini-hoopnets and minnow traps were overlaid on FWS transects to sample fish and assess habitat use (Gorman, 1992). Habitat was measured in small grids around each sampling device and these data were used to assess habitat sampled for fish and to assess habitat use patterns among fishes. Edge habitats were seined to provide samples from habitats too shallow for effective sampling by minihoopnets and minnow traps. When conditions permitted we conducted in situ underwater observational surveys of fish and habitat use. Seine samples and observations also served as baseline sampling methods to evaluate the effectiveness of our minihoopnet and minnow trap sampling (Gorman, 1994). Sampling in FWS study areas was conducted seasonally/monthly from December 1991 through August 1994 (Table 3).

Other tributaries in the Grand Canyon

The fourth stage/component in our studies was to measure habitat and sample fishes in the other tributaries of the Grand Canyon and compare our findings with our LCR study. Our approach was to use the LCR as a habitat model for the smaller candidate streams; the more closely a candidate stream matched conditions found in the LCR, the more likely that stream would be suitable for humpback chub spawning and as nursery areas for young-of-year fish.

Minihoopnets, minnow traps, seining, and direct observation were employed in our studies of other tributaries in the Grand Canyon to evaluate their potential to support additional reproducing populations of humpback chub. However, habitat and fish sampling in other tributaries was less frequent and less focused than in the LCR; the purpose was to characterize available habitat and resident assemblages, not to determine patterns of habitat use.

Available habitat in the tributaries was described from samples taken at transects spaced at 100 m intervals from the confluence to 4-10 km upstream. Fish were sampled by seining and direct observation at 1 km intervals from the tributary confluence to the upstream limit of the habitat transects. Habitat sampled for fish was measured at each fish sampling location. Confluence zones (lower 200 m) were sampled more intensively for available habitat and grids of minihoopnets and minnow traps were deployed in the confluence reaches; LCR sampling protocols were followed.

In June 1993 we conducted field studies of Shinumo, Kanab, and Havasu creeks. In August 1993 we sampled habitat intensively in the lower 500 m of the LCR. In July 1994 we conducted field studies of Bright Angel, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks. Supplementary sampling of the tributaries was conducted under contract by University of Arizona graduate students during 1992 and 1993 (these data are not presented here). The graduate students successfully completed Masters thesis research projects (Allan 1993, Mattes 1993, Weis 1993, Otis 1994) based on their work in the tributaries (Paria, Bright Angel, Shinumo, Tapeats, Deer, and Kanab creeks; Havasu was omitted).

HABITAT SAMPLING

We adopted a *microhabitat* approach to assessing habitat use for stream fishes, e.g., Gorman and Karr (1978). This approach was chosen because this method has been in wide use for many years among fish ecologists for the purpose of describing habitat use patterns in stream fishes. Microhabitats are more readily quantifiable and can be tightly linked to habitat use by stream fishes (e.g., Gorman 1987; 1988a; 1988b). Macrohabitat approaches, i.e., stream classification methods (Platts, 1980; Bisson et al. 1982; Hawkins et al. 1993) are based on the basic pool-riffle-race paradigm. Stream classification is relatively subjective and suffers from imprecise definition and lack of repeatability of measurement (Bisson, 1993). Furthermore, Bisson (1993) argues that the linkage between stream classification and habitat use by fish is relatively ambiguous and applications have not improved understanding of habitat relationships and distribution and abundance of fish. Habitat scale is another problem with classification approaches; most schemes have typically been applied to relatively small streams (typically 3rd order or less). Recognition of boundaries of macrohabitats is less ambiguous in small streams because most are longitudinally arrayed and the terrestrial interface delimits most of the boundary. In larger streams, macrohabitats are distributed in mosaics and boundary determination and subsequent aerial determination is very imprecise.

The Gorman and Karr (1978) microhabitat approach defines microhabitats as multidimensional combinations of the principal habitat variables of stream environments: depth, current, substrate (DCS). Numeric measures of these variables are continuous and therefore amenable to robust statistical analyses. Microhabitat approaches are not affected by habitat scale and are eminently transferable; Gorman (1988b) showed that microhabitat preferences of stream fishes were transferable between field and laboratory aquariums. Macrohabitats can be delimited from microhabitat measures; macrohabitats are represented as supersets of related microhabitats found in pools, riffles, races.

We now describe our strategy for habitat assessment in our model stream, the LCR. The first step in habitat assessment for stream fishes entailed determining habitat availability, secondly, determining habitat sampled for fish, and thirdly, determining habitat use by fishes. Habitat availability (a measure of total or all habitat present) in a given study area to be sampled for fish (500 m subreach) was determined by sampling stream habitat at 1m intervals along established cross-channel transects spaced at 20m intervals; typical sample sizes were ~2000 points/study area/trip (Figure 3-4). Habitat sampled for fish (=sampled habitat) was determined by measuring habitat in sampling grids around capture devices (minihoopnets or minnow traps; Figure 4). Comparison of available habitat versus habitat sampled for fish allowed evaluation of the representativeness of our fish sampling and identified any systematic biases. If the fish sampling design does not attempt to sample available habitat then perceived patterns of habitat use may be largely caused by biases in locations of traps and nets; such biased sampling cannot show where fish do *not* occur and therefore no reliable conclusions can be made about habitat use or preference. Finally, habitat use by fish was determined by weighting habitat data from capture devices by the species and/or size class of fish captured. Comparisons of habitat used with habitat sampled and available habitat provided us with a more accurate picture of habitat use patterns among LCR fishes.

Microhabitat sampling was point-centered. At each sample point the following variables were measured (Table 2, Appendix I): depth in cm (DPH), current velocity (CUR; categorical; Gorman and Karr, 1978), primary substrate (SUB; categorical; Gorman and Karr, 1978), current descriptors (CC; turbulent, eddy, etc.; Gorman, 1993), secondary substrates (SS) and substrate descriptors (SBC; wood, leaves, algae, etc.; Gorman 1993), vertical and overhead structures (OVH; ledges, undercut banks, overhead shade, etc.; Gorman 1993) lateral position measures (LATP, EDG; distance to stream bank and emergent edges), location variables (transect ID, stream km, etc.; Gorman, 1993). Habitat sampled for fish was measured in regular grids around hoopnets (20 pts) and minnow traps (4 pts). Starting in mid-1993 we sampled available habitat along three parallel (triple) transects (1 m spacing) at each FWS transect location (Figure 3-4); this effectively provided a cross-channel sampling grid. The two-dimensional spacing of sample points around hoopnets and minnow traps and from triple transects provided three-dimensional information on the stream bottom or channel.

In the course of this study, other habitat variables beyond the primary DCS and their extensions were developed; some are mentioned above (Table 2, Appendix I). In particular we sought measures that reflected structure of stream habitat that were not always predicted by DCS. The three-dimensional information available from regular spacing of gridded sample points allowed us to determine the slope of the stream bottom; from this we calculated an experimental measure of *vertical structure* (VER) for each sample point (Gorman, 1993). We further calculated a multivariate experimental measure of *cover* (CVR) for each sample point (Gorman, 1993). Other indices of habitat were also developed: vegetation (VEG), precipitated unconsolidated travertine or marl (MAR), consolidated travertine formation (TRA), shade (SHA), debris (DEB) (Gorman, 1993).

Our approach to habitat assessment in the other tributaries was similar to that in the LCR. However, our purpose in studying the tributaries was to characterize available habitat and resident fish assemblages. These data would permit us to evaluate available habitat in the tributaries relative to that in the LCR and identify streams with habitat that matches that used by humpback chub in the LCR. Description of habitat use patterns among fishes in smaller tributaries was not an objective of our contracted study.

Habitat availability in other tributaries was determined by sampling habitat along transects spaced at 100 m intervals over the lower 5-10 km of each tributary. For narrow sections of stream, cross-stream spacing of sample points was reduced to 0.5 m to yield a minimum of 6 points/transect. Available habitat in the confluence reaches (lower 200 m) of each tributary was measured along transects spaced 10 m apart. Habitat sampled for fish was measured at fish sampling sites locationed at 1 km intervals from the confluence to the limit of habitat transects. Fish were seined or observed at these sites. Habitat sampled for fish was usually measured along cross-stream transects spaced at 1 to 5 m to yield a minimum of 100 pts per fish sampling location. Habitat sampled for fish in the confluence reaches was enumerated by measuring habitat in small grids around minihoopnets and minnow traps as was done in the LCR.

FISH SAMPLING

High conductivity, low visibility, extensive travertine structures, boulders, extreme structural complexity, and prolonged periods of flooding and large stream size prohibited conventional approaches to fish sampling and determining habitat use by fishes in the LCR (e.g., seining, electrofishing, direct observation). We developed an experimental passive sampling methodology that would allow us to determine microhabitat use in all stream macrohabitats by adult and young-of-year fishes and to detect diurnal patterns of activity and habitat use (Gorman, 1991). We employed miniature hoopnets (minihoopnets) laid out in grids over our established transects to sample available habitat for fish (Figure 4). In shallow areas, minihoopnets were complemented with standard Gee's minnow traps. Minihoopnets were nominally 1 m long by 0.5 m wide with a 6 mm (0.25") mesh and could fish in water as shallow as 20 cm. deep. The minnow traps were 0.45 m long by 0.23 m wide with 6 mm mesh and could fish in water as shallow as 10 cm deep. The 0-10 cm depth zone is the only inherent gap in our fish sampling.

Minihoopnets were spaced 4-5 m apart across the stream at a FWS transect location (spaced at 20 m intervals). The first and last nets were placed as close to the stream edge possible. Then 2 to 4 minnow traps were placed in the area between the minihoopnet and the edge, starting with the shallowest water where a trap could fish. Usually 1 or 2 successive transects were set in the morning and an additional 1 or 2 successive transects were set that evening (2-4 successive transects sampled). Nets were run (emptied of fish) every 12 hours (morning and evening). After fishing for 24 hours, nets were pulled and a new sequence of transects were set starting 2-3 transects upstream (sequences of set transects were spaced by 2-3 transects). We attempted to sample the entire water column by anchoring nets to the bottom, suspending some at midwater, and floating some at the surface. This methodology was designed to assess habitat use across available stream habitat and minimize biases inherent in passive trap sampling and to minimize impact on the fish (Gorman 1991)

Captured fish were weighed to the nearest gram, measured for total length in millimeters (TL), sexed, and checked for reproductive condition. Fish 100-150 mm were fin-clipped to denote location of capture (lower lobe of caudal and left pelvic (LCLP)= below km 3.5; lower lobe of caudal and right pelvic (LCRP)= above km 3.5; upper caudal left pelvic (UCLP)= below km 10.5; UCRP= above km 10.5. Fish >150 mm were scanned/tagged for internal PIT (passive integrated transponder) tags. Mark/recapture information was shared with other GCES researchers.

To address our inability to sample depth zones <10 cm, we employed seine sampling in edge habitats to complement our passive sampling. We selected small homogeneous sites for seining. Only one seine sweep was made (no block seines were employed) and a grid of habitat points encompassing the sample area was measured (>10 pts). Usually we conducted more than 50 small area seine samples in a study reach per field trip. Additionally, when conditions permitted, we conducted underwater observational surveys of habitat use. We conducted surveys along FWS transects where habitat had been sampled. Fish observations were recorded as to species, estimated size, transect and point location, behavior, and position in water column.

Fish sampling in the other tributaries consisted primarily of seining and/or underwater observations at 1 km intervals from the confluence to the upstream limit of the habitat transects (4-10 km upstream) to characterize resident fish assemblages. At fish sampling locations, approximately 100 m of stream channel was subdivided into seinable units and blocked off with seines. Each channel subunit was depletion seined until the catch had declined to <10% of the total catch (3-8 seine hauls). Separate records of subsets of habitat sampled for fish and matching fish samples were maintained. When conditions and water clarity were suitable, observations were conducted along transects spaced at 2-5 m intervals over a 100 section of stream channel at fish sampling locations. Sampled habitat was measured along the transects at 1 m intervals. Fish observations were recorded as to species, estimated size, location relative to transect and sample point, behavior, and position in water column.

In the tributary confluences (lower 200 m), grids of minihoopnets and minnow traps were set; LCR sampling protocols and methods were followed. Unfortunately, because we were not permitted to do so, we did not sample fish in the confluence of our model stream, the LCR, so we do not have a model fish data set to compare with other tributary confluences.

WATER QUALITY

The following water quality parameters were measured at each study area in the LCR: temperature, dissolved oxygen, pH, conductivity, salinity, oxidation-reduction potential, turbidity and clarity. These measures were taken minimally twice daily (morning and evening). At the Powell study area, an automated water quality recording instrument (Hydrolab II or Hydrolab III) was installed to record water quality parameters hourly for the duration of most field trips (9-10 days each). In addition, daily high and low air temperatures were recorded. Turbidity was measured with a Hach turbidimeter and expressed in NTUs. Clarity was measure with a Secchi disk and expressed in cm.

In the tributaries the following water quality parameters were measured at 1 km intervals (at a 100 m transect location) from the confluence to the upstream limit of sampling (4-10 km): temperature, dissolved oxygen, pH, conductivity. An automated logging water quality instrument (Hydrolab) was installed in the confluence of each tributary above the influence of fluctuating water levels. In the confluences temperature, dissolved oxygen, pH, conductivity, salinity, oxidation-reduction potential, turbidity and clarity were measured twice daily or were recorded hourly by automated logging instruments.

ANALYSIS of DATA

Immense amounts of data were collected in the course of this contracted study (1991-1994). In order to adequately address the objectives of our study within a fixed time frame, we focussed on particular sets of data and types of analyses. Over the course of the study we were plagued by unusual and prolonged flooding throughout 1992 and uncontrollable delays or interruptions in the execution of our field studies. Our most promising and contiguous set of fish habitat use data from the LCR was from May-August 1993. During this time the LCR was very stable (always near or at base flow), was unusually clear, and followed a very successful spawning season. More than 50% of all of our fish capture records were from this period. This period gave us an opportunity to study habitat use among LCR fishes under stable conditions; more importantly, it provided us an opportunity to follow changes in habitat use for young-of-year fishes through the first 6 months of life. To complement this data set we selected spring 1993 and 1994 LCR data sets to describe available habitat and habitat use during the spawning season and habitat use under "brown water" or high flow conditions.

We have chosen to present data only from our minihoopnet and minnow trap grids. We do this because the sampling grids sampled nearly all available habitat and thereby provided the most accurate (least biased) picture of habitat use in the LCR environment. Also, the sampling grids provided comparable data sets for most seasons and years for each study area (subreach), and this method provided habitat use data for both day and night periods. In this report we will present analyses of the following LCR data sets: 1. Available habitat, lower 21 km, summer 1991, 2. Habitat use by fishes in FWS study areas, May-August 1993 (minihoopnet and minnow trap grid data only), and 3. Habitat use by fishes in FWS study areas spring 1993 and 1994 (minihoopnet and minnow trap grid data only).

For the purpose of evaluation of other tributaries relative to the LCR as a model for humpback chub ecology, we have chosen to present data only from FWS field studies. Although University of Arizona graduate students conducted field studies of these streams, their data was not wholly comparable with FWS data and methods of study in the LCR. As the graduate students have evaluated habitat and resident fish assemblages in the tributaries in their completed Masters theses, we have resolved to let their work stand alone as a separate study (Allan, 1993; Mattes, 1993, Weiss, 1993; Otis 1994; Otis and Maughan, 1994).

We will present analyses of the following FWS tributary data sets: 1993: Shinumo, Kanab, and Havasu creeks; 1994: Bright Angel, Shinumo, Tapeats, Deer, Kanab, and Havasu creeks. The only analysis for the Paria River is presented by Weiss (1993). Tributary confluences were analyzed separately from the upstream reaches. We have only one habitat data set for the LCR confluence from August 1993 as a basis for comparison with other tributaries and no comparable fish habitat use data sets for the LCR confluence.

Our primary method of analysis of habitat data is presentation of frequency distributions of habitat variables. This is done for the following reasons. First, frequency histograms of habitat resources is the standard method of presenting stream habitat data. Secondly, most distributions of habitat variables are not normally distributed, but are often multi-modal or strongly skewed and leptokurtic. This renders measures of central tendency relatively disinformative. Thirdly, many habitat variables are measured and presented as categorical data, which usually violates assumptions concerning parametric statistics. Thus frequency distributions provide the most accurate representations of habitat variables. Data from these distributions can be subjected to non-parametric tests of significance and various niche metrics (niche width, overlap, shift) can be directly applied.

With frequency distributions as a foundation for understanding habitat relationships, we performed multivariate analyses of habitat and habitat use to explore multi-dimensional patterns in our data sets. We also used multivariate analyses as a tool to evaluate habitat in other tributaries relative to the model LCR.

DATA ARCHIVING

All data collected by FWS has been entered into dBASE IV computer files. In the future these data will be accessible within the GCES Scientific Information Management data base. Brief descriptions of dBASE variable fields for habitat variables is provided in Appendix I.

RESULTS

USFWS STUDIES IN THE LITTLE COLORADO RIVER

Field studies and sampling effort

Twenty-eight LCR field trips totalling 232 days and 2 Grand Canyon tributary field trips totalling 29 days were completed over the period of this contract (Table 3). Sampling efforts in the LCR included measuring habitat at 981 ASU hoopnets, 3328 FWS minihoopnets, 1917 FWS minnow traps, 549 seine samples, 1097 habitat transects, and 71 fish observation transects (Table 4). Sampling efforts in the tributaries included 111 FWS minihoopnets, 131 minnow traps, 105 seine samples, 742 habitat transects, and 169 observation samples (Table 7).

Fish sampling

The purpose of our study was to determine habitat use patterns for native fishes of the LCR. Thus, our sampling was not designed to provide accurate estimates of population parameters. However, our data is sufficient to provide information on population trends. Over the course of our contracted study we captured 28,837 fish in the LCR, and of this total 17,704 (61.4%) were captured in 1993. Humpback chub was the predominant species, comprising 52.7% of all fish caught (Table 5). The predominance of humpback chub is tied to their reproductive successes in 1991 and 1993; 46.8% of all fish captured were young-of-year (YOY) or juvenile humpback chub (Table 5). Speckled dace were the second most abundant species with 38.7% of all fish caught. Overall, native fishes comprised 98.5% of all fish captured in the LCR (Tables 5). Typically, catches of exotic fishes (channel catfish, fathead minnow, and plains killifish) increased following summer spates (Table 5). Fathead minnow increased noticeably in abundance in 1994 in the LCR and other tributaries, although it was still a rare species (Table 5).

1991

The appearance of a large year class of humpback chub in 1991 indicated successful spring reproduction. High spring flows declined to base flows by early May and remained stable except for minor spates, until December (Append. II). The 1991 year class dominated the humpback chub population in the LCR throughout 1991-1993. As our habitat use studies were first implemented in December 1991, we were unable to obtain enough habitat data to assess habitat use for this cohort in 1991.

1992
Although our habitat study plan was fully implemented in 1992, continued prolonged flooding throughout most of the year (Append. II) resulted in very low catch rates of fish and thereby thwarted our ability to assess habitat use by LCR fishes. Reproduction of native fishes in the LCR was poor in 1992; very few young-of-year fishes were taken during the year or in follow-up sampling in 1993. Speckled dace and the 1991 year class of humpback chub continued to predominate the LCR fish assemblage in 1992. A short period of base flow conditions in June resulted in increased catch rates and thereby permitted our first assessment of habitat use by native fishes. Habitat use data from the Powell study area, June 1992, has been analyzed and discussed previously (Gorman, 1994).

1993
The hydrological pattern of 1993 was very similar to 1991, however, large floods in the winter of 1993 scoured most of the fine sediments from the LCR channel (Append. II). The river returned to base flow by the end of April and remained stable and unusually clear (except for minor spates) until September. Base flow conditions throughout the summer months coupled with successful reproduction by native fishes in the spring months resulted in very fruitful sampling efforts for assessing habitat use by fishes. During April and May, numbers of adult humpback chub and bluehead sucker >200 mm TL peaked (Table 6). This period coincides with the predicted period of peak spawning by humpback chub in 1993 from otolith studies (Hendrickson and Brothers, 1993). However, length-frequency histograms (Fig. 5) do not indicate a large spring influx of large humpback chubs during 1993. The same is true for adult bluehead sucker. These patterns suggest that a portion of the adult populations of humpback chub and bluehead sucker are resident in the LCR. For flannelmouth sucker, more larger individuals were caught during the summer months (Table 6). In comparison to humpback chub, the patterns for bluehead and flannelmouth suckers are less reliable because of small sample size (Table 6). Small YOY fish began to appear in large numbers in June and July and coincided with a decline in relative abundance of adult fish (Table 6). Capture rates of YOY fish declined by November with humpback chub remaining as the most abundant species.

Between the period Feb-May and June-September, the modal size of juvenile (1991 year class) humpback chub increased from 130-160 to 170-190 mm TL. Data for YOY fishes is abundant, especially for humpback chub. YOY fishes first appeared in our sampling in June, when they reach a size (30-40 mm TL) that can be effectively caught in our 1/4" mesh sampling gear. However, the modal size of flannelmouth sucker is about 10 mm larger, suggesting hatching at a earlier date or a larger size.

YOY humpback chub grew rapidly during the summer months. Between June and July, the modal size increased from 35 to 55 mm TL (Fig. 5). After July, modal growth rates decreased and variance in growth rates increased. By August the modal size increased only 10mm over July to 65 mm TL and increased only another 10mm in September. Some YOY humpback chub reached 95mm TL by September while some are still less than 50 mm TL. This large spread in size range may be due to variance in individual growth rates or that spawning occurred over a protracted period of four or more weeks.

The mid-summer period coincides with a shift in the ecology and behavior of YOY humpback chub. During this time, YOY humpback chub move out of shallow edge habitats and begin to co-occupy deeper water habitats with adult humpback chub. Although we do not have weight data to demonstrate, we observed a noticeable decline in condition factors among YOY humpback chub during this period. Both bluehead and flannelmouth sucker showed similar patterns of rapid growth in YOY fishes over the summer months (Fig. 5). Bluehead sucker reached a modal size of 70-80 mm TL by September while flannelmouth sucker reached 100 mm TL. Speckled dace showed a classic size distribution pattern for a fish with a one-year life span. In the early summer, adult fish were the predominant size class in the population, but by September, this cohort had all but disappeared and YOY fish were approaching the size distribution of the adult population it was replacing (Fig. 5).

1994

Two spring and two summer field trips in 1994 were intended to monitor the strong 1993 year class of humpback chub, bluehead sucker, and flannelmouth sucker in the LCR. Usual winter and early spring discharges were much reduced in 1994 (Append. II). A warming period in January may have resulted in early spawning activity by humpback chub, but the size distribution of 1994 YOY suggests that successful spawning occurred following late March-early April floods (Fig 5, Append II). As with the strong 1991 year class of humpback chub in the following years 1992 and 1993, the 1993 year class dominated the humpback chub population through the first half of 1994.

Habitat measures

1991

Stream habitat was evaluated from a set of sample transects taken over the lower 21 km of the LCR (Fig. 2; Append. III; Gorman et al. 1993; Gorman 1994). 201 transects

(6802 sample points) were taken at 100 m intervals from the confluence (0 km) to Blue Springs (km 21). Additional habitat was sampled at 211 additional transects (20 m spacing) between the confluence and km 4.0 and between km 9.0 and 12.0 at 20 m spacing (7148 points); this additional habitat sampling encompassed the FWS study reaches (km 2.5-3.5 and km 10.5-11.5). To provide a picture of available habitat in the LCR we divided the 100 m transect data into four reaches: km 0-4.99, km 5.0-9.99, km 10.0-14.99, and km 15.0-21.0 (Append. III). Changes in habitat are evident from uppermost reach to the confluence. The Blue Springs reach (km 15-21) is characterized by moderate depth (<100 cm), slow to moderate current, sand substrate and reduced vertical structure, cover and travertine. Travertine formation begins at around km 17 and a dramatic increase in precipitated $CaCO_3$ occurs between km 15 and 14. The Atomizer reach (km 10-15) contains all the large travertine dams. This reach contains more areas of deep water, slower currents, more larger substrates, vertical structure, and travertine. The middle reach (km 5-10) shows an increase in current and unconsolidated $CaCO_3$ precipitate ("marl"). The lower reach (km 0-5) shows an increase in moderate depth areas, large substrates, and cover. In comparison with succeeding years, the LCR was shallower, had faster currents, and contained much more sand and marl in 1991 (compare with available habitat frequency histograms for summer 1993 in Appendix V). Following the scouring floods of early 1993, the LCR showed increased depth, slower currents, and greatly reduced amounts of sand and marl.

1992

Stream habitat within USFWS study reaches (km 2.5-3.5 and 10.5-11.5) and the confluence (km 0-1) was sampled along 306 transects (>9000 sample points). An example of available habitat at base flow from the Powell study reach is shown in Appendix IV.

1993

Stream habitat within USFWS study reaches (km 2.5-3.5 and 10.5-11.5) and the confluence (km 0-1) was sampled along 266 transects (>13000 sample points). Examples of available habitat at base flow conditions is shown in Appendix V and VIII.

1994

Stream habitat within USFWS study reaches (km 2.5-3.5 and 10.5-11.5) was sampled at 133 transects (>10000 sample points).

Habitat use by fish

Habitat use data derived from passive sampling gear provides an indirect assessment of habitat use by stream fishes. Unlike point observations, our habitat use data does not precisely define spatial habitat use. Our data provides a description of an array of microhabitat in habitat patches used by stream fish (these patches are not homogeneous); within those patches there might be specific microhabitats or configurations that the fish is selecting. Therefore, a fish that shows an affinity for large substrates and high cover will also show some use or association with microhabitat containing small substrates and low cover. In other words, complex and simple microhabitats are expected to occur together in many of the patches sampled for fish. If a fish shows a habitat use distribution that is relatively different from the available, that fish is selecting habitat patches with different arrays of microhabitat than is available. That portion of the distribution that differs the greatest from the available indicates the habitat category(s) that the fish might be selecting, or the fish is selecting patches that contain occurrences of particular habitat variable categories.

1991

Pilot studies were initiated during the 1991 field season to evaluate methods of assessing habitat use by fishes in the LCR. Initially, habitat use was to be assessed by measurement of ASU hoopnets but this approach was abandoned because a lack of experimental design relative to habitat assessment resulted in biased placement of nets (Gorman, 1994). Experimental seining and minnow trap studies were executed in the summer of 1991. By August 1991 a study plan for assessment of habitat use by fishes was developed and was first implemented during the December 1991 field trip. Our sampling design approach consisted of discrete study areas with systematic sampling of habitat within grids employing mini-hoopnets and minnow traps (Fig 4; Gorman, 1993). The final USFWS study plan for the LCR was distributed in January 1992 (Gorman et al., 1992).

Minihoopnet and minnow trap sampling was conducted in the Powell and Salt study reaches. Additional habitat use data was obtained by small area seine sampling. Habitat use for LCR fishes in 1991 was assessed by 124 minihoopnet sets, 111 minnow traps, and 64 seine samples (Table 4). All of the minihoopnet sets and most minnow traps were conducted during the December 1991 field trip.

1992

Habitat use for LCR fishes in 1992 was assessed by 913 minihoopnet sets, 599 minnow traps and 128 seine samples (Table 4). Because of nearly continuous above base-flow conditions and muddy water (Append. II), catch rates for 1992 sampling were very low despite our intensive sampling efforts (Tables 4, 5). For this reason we have not presented a comprehensive analysis of 1992 data except for the June 1992 example from the Powell study reach (Append. IV).

1993

Habitat use for LCR fishes in 1993 was assessed by 1388 minihoopnet sets, 803 minnow traps and 243 seine samples (Table 4). Prolonged base flow conditions throughout 1993 (Append. II) coupled with successful reproduction by native fishes contributed to high catch rates; 61.4% or 17,704 of 28,837 fish captured during the course of our contracted study were taken in 1993 (Table 5). An analysis of habitat use by LCR fishes for the period May-August is provided in Appendix V. To take advantage of unusually clear water conditions in 1993 we supplemented habitat use sampling with in-situ observational surveys. Observational surveys were further supplemented by underwater photography and videography. Analysis and results of observational survey are not presented in this report.

1994

Study of habitat use by LCR fishes continued at a reduced level in 1994 (Table 4). Field trips were conducted during the spring and summer months to address habitat use by spawning humpback chub and to continue tracking the strong 1993 year class. A lack of usual winter precipitation resulted in a prolonged period of base flow from late December 1993 through mid-March 1994 (Append. II). More typical spring floods occurred in late March through mid-April.

Sampling conducted in the spring months of 1993 and 1994 overlapped with the spawning period of humpback chub. We were able to implement our grid sampling during April 1993 and 1994 to assess habitat use patterns during the spawning season (Append. VI). Our results were compared with observations of spawning by a closely related species, bonytail chub.

Hydrology and Water Quality of the Little Colorado River

Among the tributaries of the Colorado River in the Grand Canyon, the LCR is unique. It is the largest tributary and has unusual water quality conditions (Kubly and Cole, 1979). In addition to being a bicarbonate stream with high levels of travertine deposition, it is saline and relatively warm. High dissolved CO_2 levels appear to delimit the distribution of all but small speckled dace above km 15 (Mattes, 1993). The high levels of chloride salts in the water limit riparian vegetation to salt tolerant species (*Tamarix, Typha, and Phragmites*).

1991

Field studies commenced in July 1991. USGS hydrological data indicated that the winter and spring of 1991 were typical; winter and spring discharges exceeding 1000 cfs ended by April. Except for minor summer spates, the LCR remained at base flow until late December (Table 9; Append. II).

1992

Above base flow conditions prevailed throughout most of 1992. The LCR was muddy during all study trips with the exception of June, the only period of prolonged base flow in 1992 (Table 9; Append. II).

1993

Above base flow conditions continued into early 1993. The winter of 1992-93 was the wettest in 20 years; prolonged flooding scoured much of the finer sediments out of LCR. Three major flood events exceeded 6000 cfs: Jan 3, >7,000 cfs; Jan 13, >17,000 cfs; Feb 23, >15,000 cfs (Table 9; Append. II). The LCR returned to base flow conditions by late April and remained at base flow until late August. During the period of September through December, several smaller floods (<2,000 cfs) of relatively short duration occurred.

Extensive winter flooding in early 1993 affected water quality in the LCR during the summer. The scouring by winter floods deepened pools and resulted in slower currents and clearer water at base flow during the summer months. Turbidities as low as 1.7 NTUs were measured at the Powell camp. Hard travertine formed rapidly during the prolonged baseflow conditions of the summer. The high clarity of the water in the summer months permitted underwater visual working distances exceeding 3 meters.

1994

Relatively dry and warm conditions prevailed during the winter months of early 1994; base flow conditions were regularly achieved throughout the winter (Table 9; Append. II). A warm period occurred in January and most precipitation and runoff occurred in early spring. As a result of this unusual winter weather pattern, some humpback chubs may have spawned during the winter months but successful reproduction occurred following the spring floods (late March-early April). Evidence for successful April spawning is evident in the size distribution of the 1994 year class (Fig. 5).

Other FWS studies and surveys in the LCR

A detailed habitat mapping survey of the confluence (km 0-1) was conducted during August 1993. Habitat was measured in the inflow zone at high and low Colorado River flows (Append. VII). This work complements our earlier habitat mapping in 1991 (Append. III) and 1992. The LCR confluence habitat study was intended to provide a base for comparing the confluences of the smaller tributaries in the Grand Canyon.

Based on work stemming from establishment of USFWS habitat transects in the lower 21 km of the LCR in 1991 and a GCES LCR photo interpreted map dated 28 May 1988, a provisional map of the river channel for lower 15 km was generated. This provisional map shows approximate locations of FWS transects (2 m accuracy) and estimated km values were provided in an accompanying listing of FWS transects (Figure 3 provides examples for USFWS Study Reaches).

During fall 1992, GCES and FWS conducted a formal ground survey of the LCR from Blue Springs to the confluence in conjunction with aerial photo mapping. All FWS transect locations over the lower 21 km were included in the survey. The purpose of this survey was to collect data for the development of a highly accurate base GIS (Geographic Information System) base map (site 15) to assist is assembling information for future LCR studies and analyses (in preparation; Figure 3 provides examples). Ultimately, all FWS transects and sample locations will be tied to the LCR GIS base map.

Other USFWS and GCES sponsored studies in the LCR

Mattes (1993) completed a USFWS/GCES sponsored thesis research in the LCR in 1993. In 1993 Mattes conducted field trips in April, June, and July. His work addressed the factors contributing to the distribution of native fishes in the LCR from Blue Springs to below Atomizer Falls. He found that at base flow, the dissolved CO_2 levels dropped below the published physiological limits (200 mg/l) for trout and carp at Atomizer Falls. This drop matches the upper terminus of humpback chub and sucker distribution in the LCR.

USFWS STUDIES IN OTHER TRIBUTARIES

The small tributaries were sampled throughout 1992 and 1993 by the University of Arizona Cooperative Fish and Wildlife Research Unit (ACFWRU) under subcontract to USFWS and BOR/GCES. Three Masters theses were completed from graduate research projects conducted in the Paria River (Weiss, 1993), and Shinumo Creek (Allen, 1993) and Bright Angel and Kanab creeks (Otis, 1994). A report summarizing ACFWRU field studies of Kanab, Tapeats, and Deer creeks is available (Otis and Maughan 1994).

USFWS personnel conducted detailed surveys of the smaller tributaries in 1993 and 1994 (Table 7). Sampling methods were similar to methods used in the LCR (habitat transects, minihoopnets, minnow traps, and seining) but observations, electrofishing, and angling sampling methods were used in some tributaries where these methods were practical (Table 7). Native fishes were relatively common and abundant in most of the tributaries (Gorman et al., 1993; Gorman 1993; Table 8). Speckled dace and bluehead sucker dominated the assemblages of Bright Angel, Kanab, Shinumo, and Havasu creeks and the confluences these streams were used seasonally by flannelmouth sucker and humpback chub. Several streams, Bright Angel, Shinumo, and Tapeats, supported populations of exotic trout. Rainbow trout were essentially the only fish present in Tapeats Creek. Future studies of these streams should give consideration to renovation and management practices that will allow native fishes to re-establish their former dominance in these streams.

Analyses of available habitat in the smaller tributaries with comparisons to the LCR are provided in Appendices VII and VIII.

DATA BASES AND ANALYSES

<u>USFWS studies</u>

Most of the data from USFWS studies have been entered into dBase IV computer files (Appen. IX: Tables 1, 2). All USFWS data collected up through August 1993 have been entered into dBase computer files and most of these files are ready for archiving. Much of USFWS data collect through August 1994 have been entered into data base files but require further checks before archiving.

Analyses of some USFWS data sets have previously been presented: 1991 habitat transect data for the lower 21 km of the LCR (Gorman et al., 1993, Gorman 1994); ASU hoopnet habitat data for 1991 (Gorman 1994); September 1992 seining data from the Powell study area (Gorman 1993, 1994); June 1992 and June 1993 minihoop-minnow trap-transect habitat data from USFWS study areas (Gorman 1994).

USFWS-GCES sponsored studies

Graduate students from the University of Arizona Cooperative Fish and Wildlife Research Unit (ACFWRU) conducted sponsored research on the Grand Canyon tributaries. Most of the data from their tributary studies have been entered into computer files (Appen. IX: Table 3). Detailed analyses of some tributary data are presented in ACFWRU graduate student theses: Paria River (Weiss, 1993); Bright Angel and Kanab creeks (Otis, 1994); and Shinumo Creek (Allan, 1993). Otis and Maughan (1994) have also written a special report summarizing sponsored research on Tapeats and Deer creeks.

Bill Mattes, ACFWRU graduate student, completed a Master's thesis project (Mattes 1993) that addressed the distribution of fishes in the LCR above Atomizer Falls (km 13.5) in relation to physical habitat and water chemistry.

DISCUSSION

OVERVIEW OF LCR HABITAT STUDIES

Habitat and native fishes in the Little Colorado River

As would be expected, stream habitat characteristics of the LCR changed significantly over the course of the study period. Prolonged base flow conditions in 1991 (Append. II) realized extensive deposition of travertine throughout the lower 14 km of the LCR channel as evidenced by a large proportion of marl (unconsolidated $CaCO_3$ ppt) as a primary substrate (Append. III). In the years prior to 1991, the pattern of discharge maintained or imported large amounts of sand (the predominant primary substrate in 1991) which reduced the depth of pools and holes. The reduced depth of the stream channel resulted in mid-channel currents of 0.2-0.7 m/s (Append III; Gorman et al. 1993; Gorman 1994). Above base flow conditions throughout 1992 followed by prolonged and extensive flooding in the winter of 1992-93 (Append. II) scoured much of the sand and silt out of the stream bed and eroded travertine deposits (Append. III-V). From late April through August 1993 the LCR remained at base flow so that new travertine formation continued uninterrupted for four months and no new sediment was brought into the system. The scouring resulted in deeper pools and slower mid-channel currents throughout the summer of 1993 (typically <0.1 m/s; Append. V). Furthermore, the combination of these factors resulted in unusual water clarity (< 2 NTUs; Table 9; Append. II) throughout the summer months of 1993.

The appearance of YOY fishes in May and June of 1993 indicated that the LCR native fishes (humpback chub, bluehead sucker, flannelmouth sucker, and speckled dace) spawned during or following the declining spring hydrograph in April (Append. II). Humpback chub in particular showed very successful reproductive effort in 1993 (Figure 5). The lack of floods and spates during the summer (Append. II) produced ideal conditions for rearing YOY fishes as indicated by our exceptionally high catch rates and rapid growth rates for 1993 YOY fishes (Fig. 5). Several spates in late August and early September did not appear to affect the status of 1993 YOY; in November 1993 and April 1994 all native fishes, especially the 1993 year class of humpback chub, remained abundant (Table 5; Fig. 5).

Adult humpback chub showed qualitatively similar habitat use patterns in 1992 and 1993 (Gorman, 1994; Append. IV, V). Adults demonstrated an affinity for areas containing deeper water, high cover, and structural complexity during daytime and used more shallow, open areas during the night. Adult humpback chub used habitat somewhat differently in 1992 and 1993. Compared to 1992, adult humpback chub in 1993 used much deeper water habitats (> 2 m) and showed a higher affinity to habitat with high cover and structural complexity during daytime sampling periods. We believe this shift in daytime habitat use between 1992 and 1993 is related to the high clarity of the water and increased abundance of deep water habitat in 1993 and the apparent tendency of adult humpback chub to be negatively phototaxic.

Like humpback chub, bluehead sucker and flannelmouth sucker showed similar patterns of habitat use in 1992 and 1993 (Gorman, 1994; Append. IV, V). The suckers showed and affinity for areas with greater cover and vertical structure during the day and areas with less cover and vertical structure during the night.

Sampling during spring months allowed us to evaluate seasonal differences in habitat use by humpback chub and to describe habitat use during the spawning period (Append. VI). Surprisingly, spring habitat use patterns in humpback chub are very similar to those observed in the summer of 1993 (Append. VI). Moreover, humpback chub do not show unusual habitat use patterns during the spawning season. In the future we will conduct further analyses to describe habitat use by spawning humpback chub in greater detail.

The exceptional reproductive success of humpback chub in 1993 allowed us to track ontogenetic changes in habitat use (Append. V Fig. 5). Our sampling gear permitted capture of humpback chub down to approximately 35 mm TL. YOY humpback chub up to 50 mm TL restricted their distribution to shallow habitats < 1 m from stream edges (early summer; June). These habitats were characterized by extensive cover and algal growths. Our catch rates and observations showed that small YOY humpback chub were diurnally active. Upon reaching 50 mm TL, YOY humpback chub began to move from shallow edge habitats to deep, center channel habitats (mid-summer; July). During this period, YOY humpback chub appeared to be heavily preyed upon by adult humpback chub. By August 1993, many YOY humpback chub appeared to be emaciated and dying; we suppose that this was a consequence of a combination of changing food availability, diets, and habitat use. By late summer (August-September) the densities of YOY humpback chub had declined and their habitat use patterns were merging with that of juvenile humpback chub.

Evaluation of microhabitat use data from FWS study grids

Preliminary analyses of habitat use data from FWS study grids for June 1992 and June 1993, indicated that our passive sampling approach revealed habitat use patterns in humpback chub and other native fishes of the LCR (Gorman 1994; Append. IV, V). If we were unsuccessful in addressing the potential biases in using passive sampling gear to assess habitat use (Gorman 1991), we would not be able to demonstrate clear patterns of habitat use. Our methodology effectively samples the available habitat in the LCR (with the exception of shallow margins < 10 cm deep). Also, our methodology allows us to effectively assess habitat use for day and night periods, a feature not shared with active sampling approaches.

Data from our passive sampling show that the native fish assemblage of the LCR was segregated by habitat use, and there were distinct ontogenetic shifts over time in habitat use by YOY humpback chub and flannelmouth and bluehead sucker (Append. IV, V). In 1993 we began to position nets at specific levels in the water column to assess vertical position habitat use (Gorman 1988). Our analysis showed species-specific patterns in use of vertical position that shifted in some species and size classes between day and night sampling periods (Gorman 1994; Append. V).

Tributaries and confluence studies

Comparison of tributary confluences and upstream reaches with the LCR are provided in Appendices VII and VIII. Of the smaller tributaries of the Colorado River in the Grand Canyon, Havasu Creek was most like the LCR. Although Havasu Creek did not have as much deep water habitat (>100 cm) or was as wide (typically about half the width) as the LCR, it did offer very similar arrays of habitat. It must be noted that the distribution of available depths in Havasu Creek in 1993-1994 was only slightly more restricted than was available in the LCR in 1991 (Append. VIII).

Other tributaries studied (Kanab, Deer, Tapeats, Shinumo, and Bright Angel creeks) were much smaller streams than Havasu Creek and were less like the LCR in habitat configuration. Beyond habitat structure, Kanab Creek had a relatively harsh environment; summer water temperatures exceeded 33° C and dissolved O_2 levels dropped to <4 ppm (Table 10). Tapeats Creek was high-gradient stream with relatively cold summer water temperatures that ranged from 13.8 to 17.4 °C (Table 10).

To evaluate whether Havasu Creek offered an array of habitat suitable for all size classes of humpback chub, we compared available habitat in Havasu Creek in 1993 and 1994 with habitat use patterns of YOY, juvenile, subadult, and adult humpback chub from the LCR in June and July 1993 (Append. VIII). Our analysis suggests that Havasu Creek had a usable range of habitats for YOY to adult humpback chub. More refined analyses are planned to address the suitability of Havasu Creek as a candidate stream for establishing a new population of humpback chub.

We were able to sample some of the smaller tributaries and their confluences twice in the course of this study (Shinumo, Kanab, Havasu). Upstream areas of Shinumo, Kanab, and Havasu creeks showed only minor changes in habitat structure between 1993 and 1994 (Append. VII, VIII). Sponsored graduate student Masters thesis studies provided 1992-1993 seasonal overviews of the Paria River (Weiss, 1993), Shinumo Creek (Allan, 1993), and Bright Angel, Tapeats, Deer, and Kanab creeks (Otis, 1994; Otis and Maughan, 1994).

MANAGEMENT RECOMMENDATIONS

The GCES program has functioned largely to gather information about endangered and native fishes in the Grand Canyon and to provide this information for the development of the Glen Canyon EIS, for refinement of the Biological Opinion on the operation of Glen Canyon dam, and to provide a foundation for developing management and recovery plans for the endangered humpback chub. The intent of GCES Phase II was to expand on the information base of Phase I studies. With the completion of Phase II, we are in a position to propose experimental studies and develop and implement management and recovery plans. As some populations of endangered and native species are in a decline, the need to move forward with recovery efforts becomes paramount.

Our field studies have given us a broad base of knowledge on the habitat ecology of the endangered and native fishes in the Grand Canyon and extensive experience with the problems facing these species. We believe that our experience provides us with a unique perspective of the problems and the capability and expertise to initiate management and recovery plans. The success of management and recovery plans depends on close coordination and integration of efforts among resource management agencies.

Proposed management recommendations take into consideration the GCES Conservation Measures, USFWS Biological Opinion Reasonable and Prudent Alternatives (RPAs), our assessment of current situation in the Grand Canyon and what management initiatives can be implemented in the immediate future.

1. Establish an experimental population of humpback chub in Havasu Creek

This recommendation addresses Conservation Measure 7 and RPA 5, establish a second spawning population of humpback chub in the Grand Canyon.

We recommend moving forward to establish an experimental population of humpback chub in Havasu Creek. Our studies indicate that the Havasu Creek can provide an appropriate array of habitat for all life stages of humpback chub. Establishment of an experimental population of humpback chub may improve the endangered status of the species by serving as a interim measure to guard against further losses in the Grand Canyon population. However, this is not a long-term solution as the Havasu Creek population may require management intervention to maintain. Full recovery of the humpback chub can only be resolved by re-establishment of a spawning mainstem population. Because of the experimental nature of a program to establish humpback chub in Havasu Creek, much valuable hands-on experience with manipulation and management of the species would be gained.

2. Protection of key tributary confluences for native fishes

This recommendation addresses USFWS Biological Opinion RPA 3, research program and long term monitoring; and RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

Humpback chub have been captured in the confluences of the LCR, Bright Angel, Shinumo, Kanab and Havasu Creeks. The LCR confluence supports the largest population of humpback chub and serves as a staging area and possibly a spawning area. At present the tributary confluences provide some of the most productive (and warm) habitat for native fishes of the Grand Canyon. Therefore, management strategies to enhance or stabilize native fish populations in the Grand Canyon must include tributary confluences. Some tributary confluences (in particular the LCR, Bright Angel, Shinumo, and Havasu) are heavily impacted by tourists during summer months. At present we do not know the long-term effects of constant perturbation of these environments on native fishes. However, we suspect that there are impacts, for example, our underwater surveys in the confluence of the LCR suggest that fish appear to avoid areas frequented by tourists. Constant foot traffic in the confluence of Shinumo Creek precludes establishment of periphyton and aufwuchs that would provide food resources for fish. Numerous small dams built by tourists in Bright Angel Creek may frustrate migrating native fishes and enhance predation by exotic trout. As an interim measure, we recommend protection of the lower 500 m of the LCR and the lower 200 m of other tributaries for the period of February-June. This period encompasses the spawning season and early life history stages of native fishes. At other times of the year the amount of traffic and activities of tourists should be controlled to minimize impacts.

3. Management of Grand Canyon tributaries to enhance native fish populations

This recommendation addresses USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

Exotic trouts (rainbow and brown) are common in Bright Angel, Shimumo, and Tapeats creeks. The abundance of exotic trout in these streams may be detrimental to native fishes. However, little is known about the trout populations in the tributaries or of their impact on native fishes. We recommend implementing field studies on exotic trout in these streams to better understand their ecology and provide knowledge critical to their management.

We recommend that trout populations in the tributaries be managed to minimize their impacts on native fishes. For example, unlimited fishing of trout in Bright Angel and Shimumo creeks may reduce impacts of exotics on native fishes. Tapeats Creek appears to be too cold for most native fishes and has perhaps the best trout fishery of all the tributaries; this fishery appears to be relatively unexploited.

4. Pilot study for gene banking and genetic management of humpback chub

This recommendation addresses USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

We recommend implementing a pilot study to develop and fine-tune methods of collection and cryopreservation of humpback chub sperm and production of fish using cryopreserved sperm. Development of these methodologies are necessary for implementing a program for gene banking and genetic management of humpback chub (see recommendations for future studies, below).

5. Implementation of a program to study fish health of Grand Canyon fishes.

This recommendation addresses USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

We recommend implementing a monitoring program to establish a baseline for fish disease epidemiology in the Grand Canyon (see recommendations for future studies below).

6. Implementation of recommendations for future studies

This recommendation addresses USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

See recommendations for future studies, below.

RECOMMENDATIONS FOR FUTURE STUDIES

1. Further habitat/fishery studies on humpback chub in the LCR.

Continued field studies on habitat use in humpback chub are necessary to provide a more complete picture of the ecology of the species. Humpback chub are long-lived (>20 years) and comprehensive ecological studies should be on the same time scale. This is because there is so much year-to-year variation in climate and population dynamics. For example habitat use during a "good" reproductive year might be very different than during a lean year when population densities are much lower. The cumulative effect of cyclic environmental processes over the past decade or longer is what determines the structure and status of the present population. In order to better understand how the environment affects the humpback chub population long-term studies are needed.

Areas where further information on humpback chub is needed are:

spawning ecology and habitat use
contribution of migrating humpback chub to spawning effort/success
habitat use in the confluence (see 2 below)
ecology and habitat use by post-larval fish
habitat use by YOY and juvenile fish at lower population densities
thermal requirements and growth of early life history stages
food resources and diet (seasonal and ontogenetic perspectives)
stream productivity and energy sources (seasonal, year-to-year)

assessment of movement, site fidelity, and home range in relation to age and size

These studies address USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

2. Habitat/fishery studies in other Grand Canyon tributaries

Further studies of other Grand Canyon tributaries are needed to assess year-to-year and seasonal variation in habitat structure and resident fish assemblages. At present we have described available habitat in the tributaries along with their resident fish assemblages only once or twice. This does not provide a long-term picture of the range of conditions and population dynamics in these tributaries. Such information will be critical for identifying candidate streams for introducing humpback chub and for developing management plans for native fishes in Grand Canyon streams (such as protection and enhancement of confluence areas for use by native fishes).

Areas where further information on other Grand Canyon tributaries is needed are:

available habitat in years with different climatic conditions and hydrology
available habitat in confluences (including LCR) on a daily and seasonal basis
fish population structure and dynamics (temporal perspective)
habitat use by resident fishes
food resources and diet of native fishes (seasonal and ontogenetic perspectives)
stream productivity and energy sources (seasonal, year-to-year)

These studies address USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

3. Gene banking and genetic management of humpback chub

The purpose of a genetic management program for humpback chub is to assess the genetic diversity of populations, cryopreserve germplasm as a hedge against loss of genetic diversity through populations bottlenecks and declines, and to use the germplasm to produce genetically appropriate hatchery stocks should the need arise in recovery and management efforts.

Humpback chub, like most endangered species, have reduced and scattered populations. This situation poses a threat to maintenance of the former genetic diversity of the species and may impair the ability of the species to persist over time. The first step in implementing a genetic management plan for humpback chub is to describe the available diversity among populations and to bank germplasm as hedge against genetic losses. These two objectives can be accomplished simultaneously by a program of collection, cryopreservation, and storage of humpback chub sperm from all extant populations. Genetic analysis will allow identification of populations with unique genetic character; these populations would be given high priority for recovery efforts. By using cryopreserved sperm from individuals of known genetic make-up, we can establish or enhance populations that are in the greatest danger of extinction.

This study addresses USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

4. Fish health of Grand Canyon fishes.

As yet there has not been a concerted study of diseases of native fishes of the Grand Canyon. Over the course of GCES Phase II, it has become apparent that native fishes and introduced trouts are suffering from an array of epizootics caused by a variety of parasitic organisms. For example, most fish captured in Kanab Creek in June 1993 carried one or more *Lernaea*. During July 1994, we encountered large numbers of dead or dying fish in Kanab Creek. In August 1993, *Lernaea* were commonly found attached to YOY humpback chub in the LCR. *Lernaea* and Asiatic tapeworm infections were even more prevalent among LCR humpback chub during spring 1994. At present, there is no basis for understanding the causes, dynamics, or ultimate impact of these diseases on fish populations.

Implementing a long-term monitoring program is needed to establish a baseline for fish disease epidemiology in the Grand Canyon. Ideally, this program should be fully integrated into other sampling programs so that fish health variables are related to environmental and populational measures. Should changes in the status of fish health occur in the future, these can be understood in relation to past studies and appropriate management recommendations can be made. The establishment of this baseline will be imperative prior to implementation of stabilized flows and temperature modification of dam discharges.

This study addresses USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

5. Mainstem Colorado River habitat studies

Thus far there have been no studies of available habitat in the mainstem Colorado River of the Grand Canyon that parallel USFWS efforts in the LCR and smaller tributaries. This deficiency impairs our ability to ascertain the potential for the mainstem to support the various life history stages of humpback chub. The LCR is the model stream for understanding humpback chub habitat relations. Therefore, to assure a basis for comparison, the same methodologies employed in assessing habitat in the LCR need to be applied to other areas.

At present, large adult humpback chub are known to occur in the Colorado River mainstem, particularly in the vicinity of the LCR confluence. However, YOY humpback chub that are found in the mainstem do not appear to persist. This apparent loss is explained by arrested growth under cold water conditions in the mainstem (Lupher and Clarkson, 1993). Even if the temperature problem were corrected, YOY humpback chub may not persist because of inappropriate or unstable habitat. To address this concern, available shore and edge habitat in the mainstem needs to be described and quantified. Furthermore, diurnal changes in availability and quantity of this habitat need to be determined. Finally, available habitat in the mainstem needs to be compared with habitat used by humpback chub in the LCR. This last step will indicate the potential for the mainstem to support a reproducing population of humpback chub once other detrimental factors, i.e., low temperature and fluctuating flows, are resolved.

This study addresses USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

6. Historical geochemistry/hydrology/climatology of the LCR

Although the LCR has the largest known reproducing population of humpback chub, there is no historical perspective for the present situation. The presence of humpback chub in the LCR is dependent on maintaining the flow and water chemistry peculiar to that stream. With ever increasing human pressure on water resources in the region, the long-term prospectus for maintaining the current supply of water for the lower LCR is not good.

At the very least an understanding of the distribution of humpback chub in the lower LCR relative to water chemistry and habitat needs to be understood. From this knowledge, predictions of the consequences of changes in the quantity and quality of discharge from springs in the lower 21 km can be made and minimum flow standards can be established to protect the humpback chub population.

The travertine deposits in the LCR provide information about past hydrology, geochemistry, and climatology. An understanding of the past relative to the present will help us to predict the future. For example, and understanding of historical geochemistry may suggest that flow conditions and water quality may have allowed humpback chub to reach Grand Falls, 140 km upstream. Travertine deposits hold a record of the changing hydrology and watershed conditions over the past century or longer. By establishing a baseline of past conditions in the LCR, studies of historical geochemistry can delimit the range of environmental conditions and provide targets or standards for future ecosystem management efforts.

This study addresses USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

<u>7. Assessment of stabilized flows and thermal modification to the mainstem Colorado River</u>

Although it is apparent that cold water and fluctuating flows in the mainstem Colorado River have precluded a reproducing humpback chub population (Clarkson et. al, 1994) the consequences of stabilized flows and increased water temperatures have not been fully evaluated. Stabilization of flows and increased water temperatures may be a necessary first step in the recovery of a mainstem humpback chub population, but other possible consequences include increased incidence of diseases, exotic fish competitors, exotic predators, and a lack of appropriate habitat and food resources.

There is a need to conduct studies on the impact of stabilized flows and increased temperatures in the mainstem on native fishes. These studies should consider:

minimum temperature increase necessary to benefit humpback chub and other native fishes

maximum flow fluctuations that do not disrupt habitat and food resources

pattern of seasonal flows and temperatures
amount of available habitat at various flows usable by humpback chub (baseline studies needed)
changes in fish disease epidemiology (baseline studies needed)
changes in productivity and food resources
changes in abundance of exotic fishes
management strategies that can minimize potential negative impacts

These studies address USFWS Biological Opinion RPA 3, research program and long term monitoring; RPA 5, establish a second spawning aggregation of humpback chub; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

8. Studies of other native fishes in the Grand Canyon

During GCES Phase II a program to PIT tag all native fishes (humpback chub, flannelmouth sucker, and bluehead sucker) > 150 mm TL was implemented. This effort has allowed researchers to track movement and survival of large numbers of native fishes. Because most field sampling efforts have focussed on humpback chub, there has been less attention given to other native fishes. Weiss (1993) has studied flannelmouth sucker in the Paria River and found that large fish move long distances within the Grand Canyon and many return to the Paria during the spawning season. The size structure of the population suggests an aging population without recruitment reminiscent of razorback sucker in Lake Mohave. The implications of Weiss' study is that the flannelmouth sucker population may be declining in the Grand Canyon. To remedy the lack of knowledge of flannelmouth sucker, there should be special efforts to study this species, particularly in the Paria River. Relatively little is known about bluehead sucker in the Grand Canyon. Although most tributaries have large populations of bluehead suckers, fish in these streams are relatively small and reproduce at a small size (Allan, 1993; Otis, 1994). In contrast, large individuals are captured in the mainstem and tributary confluences. The relationships between mainstem and tributary bluehead suckers are unknown. Because flannelmouth and bluehead sucker are already captured and tagged along with humpback chub, expansion of effort to learn more about these suckers should be relatively inexpensive and effortless. These studies should also consider the possible benefits of flow and thermal modification of the mainstem environment to these species.

This study addresses USFWS Biological Opinion RPA 2, development of a management plan for the LCR; RPA 3, research program and long term monitoring; RPA 6, determine feasibility of a selective withdrawal program for Lake Powell; RPA 7, development of an adaptive management plan for native fishes of the Grand Canyon.

EVALUATION OF ACHIEVEMENT OF FWS STUDY OBJECTIVES

Contract study objectives

1. Identify and quantify preferred habitats of juvenile and adult humpback chub and other fish species in the LCR.

   Final Report Appendices IV, V.
   1993 Annual Report

   We have described, in detail, the diel patterns of habitat use in humpback chub in the LCR. Our study has provided detailed descriptions of habitat use for YOY, juvenile, subadult, and adult age classes. Further, by following cohorts in time, we have described in detail the ontogenetic changes in habitat ecology of humpback chub. Finally we have described patterns of habitat use for other native fishes present in the LCR.

2. Identify and quantify seasonal habitat use patterns of juvenile and adult humpback chub and other fish species in the LCR.

   Final Report Appendices IV, V.
   1993 Annual Report

   We have described, in detail, patterns of habitat use in humpback chub and other native fishes during spring and summer months. Changes in habitat use over time by specific cohorts have been tracked and evaluated.

3. Identify and quantify humpback chub spawning habitat in the LCR.

   Final Report Appendix VI

   We have described, in detail, patterns of habitat use by adult humpback chub during periods of reproductive activity.

4. Identify potential humpback chub habitats within the various tributaries of the Colorado River and evaluate suitability of these habitats to recovery efforts.

Final Report Appendix VII, VIII.

We have described, in detail, the available habitat in the smaller tributaries of the Colorado River in the Grand Canyon. Our descriptions treated confluence and upstream areas separately. We have identified Havasu Creek as a candidate stream that resembles the LCR, the habitat model for humpback chub. We have determined the availability of habitat in the candidate stream for YOY, juvenile, subadult, and adult chub.

5. Develop discharge-frequency and flow-duration curves at locations of interest in the LCR to determine how flood stages affect humpback chub habitats.

This objective was dropped from our contract because of an inability to secure permission to conduct a hydrology study of the LCR.

6. Identify information and future research required for the possible enhancement of environmental conditions to protect and promote fish and wildlife populations in the LCR and other tributaries.

Final Report
1993 Annual Report

We have proposed future studies and programs required to promote and realize the management and recovery of native fishes in the Grand Canyon. We made management recommendations in this Final Report to provide immediate improvement in the status of Grand Canyon native fishes.

Other products of the USFWS study

1. Baseline database for native fishes in the LCR, including information on age/size distribution and growth and recruitment of specific year classes.

2. Datasets on home range and site fidelity for native fishes of the LCR.

3. Library of underwater photographs and videos of native fishes in the LCR and their habitat use.

4. New methodologies for conducting habitat studies on stream fishes.

5. Baseline water quality database for the LCR and tributaries

6. Established a regular system of transects in the LCR to provide a framework for integrating data from past and future LCR studies into a GIS data base.

7. Baseline database on habitat and fishes for most of the tributaries of the Colorado River in the Grand Canyon.

8. Four Masters Thesis research projects sponsored by USFWS and GCES on the ecology of native fishes of the Grand Canyon.

> The research topics addressed by these studies were extensions of USFWS project objectives and have served to increase our knowledge of the native fishes and aquatic habitats of the smaller streams of the Grand Canyon (Allan, 1993; Otis, 1994; Weiss, 1993) and in the LCR we have gained a greater understanding of the factors affecting distribution of fishes below Blue Springs (Mattes, 1993).

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TABLE 1. USFWS GCES studies: fish species captured, status, and species codes

species name	common name	status*	species code
CYPRINIDAE (minnows)			
Gila cypha	humpback chub	native SE, LE	HBC
Pimephales promelas	fathead minnow	introduced exotic	FHM
Rhinichthys osculus	speckled dace	native	SPD
Cyprinus carpio	common carp	introduced exotic	CCP
CATOSTOMIDAE (suckers)			
Catostomus discobolus	bluehead sucker	native	BHS
Catostomus latipinnis	flannelmouth sucker	native SC	FMS
ICTALURIDAE (catfishes)			
Ictalurus punctatus	channel catfish	introduced exotic	CCF
Ictalurus melas	black bullhead	introduced exotic	BBH
Ictalurus natalis	yellow bullhead	introduced exotic	YBH
CYPRINODONTIDAE (killifish)			
Fundulus zebrinus	plains killifish	introduced exotic	PKF
PERCICHTHYIDAE (white bass)			
Morone saxatilis	striped bass	introduced exotic	STB
CENTRARCHIDAE (sunfishes)			
Lepomis cyanellus	green sunfish	introduced exotic	GSF
SALMONIDAE (salmon and trout)			
Oncorhynchus mykiss	rainbow trout	introduced exotic	RBT
Salmo trutta	brown trout	introduced exotic	BNT

* SE- state endangered, ST- state threatened, SC state special concern, LE- Federal listed endangered, LT- Federal listed threatened.

TABLE 2. Variables used in USFWS habitat studies.
(full descriptions are contained in Appendix I)

variable	description
primary variables	
DPH	depth in cm
CUR	current velocity, 0-5 categories
SUB	primary substrate particle size (effective particle size), 0-11 categories
LATP	lateral distance from habitat pt to nearest stream edge in cm
CVR	cover at habitat point, -2 to +7 categories (*experimental variable*)
VER	vertical structure at habitat pt, 0-5 categories (*experimental variable*)
RDPH	relative depth of net/trap mouth, % of total depth of water column
TRA	measure of travertine at habitat pt, 0-4 categories (*experimental variable*)
secondary variables	
CC	current descriptors: turbulent, plunge, eddy, fast, slow
SS	secondary substrate
SBC	substrate descriptors
OVH	overhead shade, vertical structure descriptors
EDG	distance from emergent edge, $<=100$ cm
MAR	measure of precip. unconsolidated $CaCO_3$ (marl) (*experimental variable*)
VEG	measure of submergent and emergent vegetation (*experimental variable*)
SHA	measure of overhead shade (*experimental variable*)
DEB	measure of detritus (wood, logs, leaves) (*experimental variable*)

TABLE 3. USFWS LCR studies: summary of field trips.

		Powell Camp		Salt Camp	
Year	Month	Dates	Days	Dates	Days
1991	July	1-13	13	1-13	13
	July	21-03	13	21-03	13
	August	11-24	14	11-24	14
	October	15-22	7	15-22	7
	December	9-16	7	9-16	7
1992	February	12-19	7	12-19	7
	March	--	--	5-10	5
	March	--	--	26-02	7
	April	22-29	7	22-29	7
	June	15-24	9	15-24	9
	July	14-23	9	14-23	9
	August	12-19	7	12-19	7
	September	23-02	9	23-02	9
	November	9-17	9	9-17	9
1993	February	10-17	7	--	--
	March	2-5	3	2-5	3
	March	22-26	4	22-26	4
	April	12-21	9	12-21	9
	May	10-19	9	10-19	9
	June	8-16	8	8-16	8
	July	12-21	9	12-21	9
	August	9-17	8	9-17	8
	September	10-18	8	10-18	8
	November	--	--	4-8	4
1994	April	12-21	9	12-21	9
	May	10-18	8	10-18	8
	June	6-14	8	6-14	8
	August	9-18	9	9-18	9
total	28		223		232

TABLE 4. USFWS LCR studies: sampling effort by year. TRN=habitat transects, MNH=minihoopnet sets, MTP=minnow trap sets, SEN=seine samples, OBS=underwater observation surveys, AHP=ASU hoopnets.

1991	TRN	MNH	MTP	SEN	OBS	AHP
Powell	168	50	56	11	0	147
Salt	224	74	55	43	0	167
total	411	124	111	64	0	314

1992	TRN	MNH	MTP	SEN	OBS	AHP
Powell	156	407	282	103	0	294
Salt	107	292	225	25	0	320
total	263	699	507	128	0	614

1993	TRN	MNH	MTP	SEN	OBS	AHP
Powell	141	750	410	129	38	42
Salt	125	638	393	114	33	10
total	266	1388	803	243	71	52

1994	TRN	MNH	MTP	SEN	OBS	AHP
Powell	69	432	217	101	0	0
Salt	64	471	187	23	0	0
total	133	903	404	304	0	0

1991-1994	TRN	MNH	MTP	SEN	OBS	AHP
Powell	465	1207	748	243	38	483
Salt	456	1004	673	182	33	497
total	921	2211	1421	425	71	980

Table 5. USFWS LCR studies: summary of fish captures by species and year. Totals for size subgroups will not sum to species totals because of missing data for 1991.

species	code	size classes	YEAR and STUDY REACH												totals		
			1991			1992			1993			1994					
			Powell	Salt	both	Powell	Salt	both	Powell	Salt	both	Powell	Salt	both	Powell	Salt	both
humpback chub	HBC	<150				283	398	681	2218	7410	9628	1314	1864	3178	3815	9672	13487
		>=150				62	73	135	223	401	624	219	217	436	504	691	1195
		total	182	326	508	345	471	816	2441	7810	10251	1533	2081	3614	4501	10688	15189
bluehead sucker	BHS	<150				2	11	13	166	783	949	72	122	194	240	916	1156
		>=150				16	25	41	33	59	92	41	132	173	90	216	306
		total	81	113	194	18	36	54	199	842	1041	113	254	367	411	1245	1656
flannelmouth sucker	FMS	<150				10	3	13	167	14	181	10		10	187	17	204
		>=150				10		10	20	15	35	61	26	87	91	41	132
		total	42	6	48	20	3	23	187	29	216	71	26	97	320	64	384
speckled dace	SPD		100	1500	1600	980	653	1633	684	5472	6156	420	1364	1784	2184	8989	11173
channel catfish	CCF		3	4	7	1		1	12		12		6	6	16	10	26
common carp	CCP		31	2	33				2		2	5		5	38	2	40
fathead minnow	FHM		1	2	3	12	10	22	1	23	24	124	85	209	138	120	258
plains killifish	PKF		102	1	103					1	1	1	1	2	103	3	106
yellow/black bullhead	YBH/BBH						1	1	1		1	1	1	2	2	2	4
rainbow trout	RBT		1		1										1		1
total fish by study reach			543	1954	2497	1376	1174	2550	3526	14178	17704	2268	3818	6086	7713	21124	28837

TABLE 6. USFWS LCR studies: 1993 summary of fish captures by size class and sampling date.

A. POWELL CAMP 1993

SPECIES / SIZE CLASS	FEB 7-16	MAR 2-6	MAR 22-26	APR 12-21	MAY 10-19	JUN 7-16	JUL 12-21	AUG 9-18	SEP 13-22	TOTAL
HBC >200	1	4	7	23	27	12	1	3	3	81
HBC 100-200	7	6	16	11	88	59	34	32	12	265
HBC <100	1	0	0	1	0	131	974	706	219	2032
BHS >200	1	0	5	7	2	3	0	2	0	20
BHS 100-200	0	0	2	7	2	1	0	2	1	15
BHS <100	0	0	0	0	0	4	76	73	1	154
FMS >200	0	1	0	0	7	6	0	4	0	18
FMS 100-200	0	0	0	0	6	1	2	1	2	12
FMS <100	0	0	0	0	0	24	51	76	1	152
SPD YOY	0	0	0	0	0	13	135	150	20	318
SPD >60	3	2	9	28	50	146	45	51	2	336
TOTAL	13	13	39	77	182	400	1318	1100	261	3,403

TABLE 6. USFWS LCR studies: 1993 summary of fish captures by size class and sampling date (continued).

B. SALT CAMP 1993

SPECIES / SIZE CLASS	MAR 2-6	MAR 22-26	APR 12-21	MAY 10-19	JUN 7-16	JUL 12-21	AUG 9-18	SEP 13-22	NOV 4-8	TOTAL
HBC >200	0	4	21	60	26	48	23	22	4	208
HBC 100-200	3	4	6	27	57	40	53	17	14	221
HBC <100	0	0	0	0	146	2182	4084	741	205	7358
BHS >200	1	6	5	13	4	3	5	1	0	38
BHS 100-200	0	3	0	8	1	3	4	0	3	22
BHS <100	0	0	0	0	8	365	395	13	1	782
FMS >200	0	0	1	0	3	2	6	1	0	13
FMS 100-200	0	0	0	0	0	0	0	0	5	5
FMS <100	0	0	0	0	5	6	0	0	0	11
SPD YOY	0	0	1	0	116	898	1751	136	134	3036
SPD >60	33	64	87	653	369	368	553	116	34	2277
TOTAL	37	81	121	761	735	3915	6874	1047	400	13,971

TABLE 6. USFWS LCR studies: 1993 summary of fish captures by size class and sampling date (continued).

C. TOTALS

SPECIES / SIZE CLASS	FEB 7-16	MAR 2-6	MAR 22-26	APR 12-21	MAY 10-19	JUN 7-16	JUL 12-21	AUG 9-18	SEP 13-22	NOV 4-8	TOTAL
HBC >200	1	4	11	44	87	38	49	26	25	4	289
HBC 100-200	7	9	20	17	115	116	74	85	29	14	477
HBC <100	1	0	0	1	0	277	3156	4790	960	205	9390
BHS >200	1	1	11	12	15	7	3	7	1	0	58
BHS 100-200	0	0	5	7	10	2	3	6	1	3	37
BHS <100	0	0	0	0	0	12	441	468	14	1	936
FMS >200	0	1	0	1	7	9	2	10	1	0	31
FMS 100-200	0	0	0	0	6	1	2	1	2	5	17
FMS <100	0	0	0	0	0	29	57	76	1	0	163
SPD YOY	0	0	0	1	0	129	1033	1901	156	134	3354
SPD >60	3	35	73	115	703	515	413	604	118	34	2613
TOTAL	13	50	120	198	943	1135	5233	7974	1308	400	17,374

Table 7. USFWS Grand Canyon tributary studies: sampling effort.
TRN = habitat transects, MNH = minihoopnet sets, MTP = minnow trap sets, SEN = seine samples, OBS = observation surveys, ELC = electrofish samples

1993	TRN	MNH	MTP	SEN	OBS	ELC
Bright Angel Creek						
Shinumo Creek	53	27	34	0	5	33
Deer Creek						
Tapeats Creek						
Kanab Creek	184	15	8	37	7	7
Havasu Creek	150	15	15	52	1	
total	387	57	57	89	13	40

1994	TRN*	MNH	MTP	SEN	OBS	ELC
Bright Angel Creek	93	10	13	1	106	
Shinumo Creek	59	10	13			
Deer Creek	28				7	
Tapeats Creek	45	10	20		43	
Kanab Creek	65	14	16	8		
Havasu Creek	65	10	12	7		
total	355	54	74	16	156	0

*all habitat transects sampled in 1994 were triple transects

Table 8. USFWS Grand Canyon tributary studies: summary of fish captures by species and year.

1993					
species	code	Shinumo	Kanab	Havasu	total
brown trout	BNT	2			2
rainbow trout	RBT	41		1	42
common carp	CCP		1		1
humpback chub	HBC		3		3
speckled dace	SPD	211	820	228	1259
fathead minnow	FHM		1		1
flannelmouth sucker	FMS	1	42	9	52
bluehead sucker	BHS	25	95	386	506
channel catfish	CCF				
plains killifish	PKF			1	1
striped bass	STB			1	1
green sunfish	GSF				2
total		280	964	626	1870

1994							
species	code	Bright Angel	Shinumo	Tapeats	Kanab	Havasu	total
brown trout	BNT						
rainbow trout	RBT	1	2	19			22
common carp	CCP						
humpback chub	HBC	8	4				12
speckled dace	SPD	411	843	1	84	100	1439
fathead minnow	FHM	4	20		11	1	36
flannelmouth sucker	FMS		10		8		18
bluehead sucker	BHS	2	7		18	210	237
channel catfish	CCF						
plains killifish	PKF						
striped bass	STB						
green sunfish	GSF				4		4
total		426	886	20	125	311	1768

TABLE 9. USFWS LCR: summary of water quality measures, 1991-1994.

A. POWELL		1991		1992				1993				1994	
		Sum	Fall	Win	Spr	Sum	Fall	Win	Spr	Sum	Fall	Spr	Sum
temp	min	21.6	18.2	8.6	16.2	17.9	13.5	7.7	7.8	18. 9	17.3	16.1	19.3
°C	max	27.1	22.1	16.2	24.0	25.8	17.2	11.5	23.9	26.1	22.2	22.3	24.8
	mean	24.2	20.2	12.4	20.1	21.7	15.3	9.6	15.4	22.5	19.3	19.2	22.0
pH	min	7.29	7.43	7.85	7.17	6.90		7.7	6.3	6.4	7.3	7.25	7.67
	max	8.26	8.31	8.13	7.52	7.85		7.9	7.8	8.8	8.1	7.89	8.89
	mean	7.77	7.87	7.99	7.35	7.38		7.7	7.1	7.6	7.7	7.57	8.28
cond	min	4850	4340	2640	1739	1489	3079	961	832	4700	1342	3127	4709
uS	max	5250	5240	4600	3109	5110	4769	2560	4700	5190	4813	4680	5009
	mean	5050	4790	3620	2420	3299	3924	1448	2766	9890	3319	3903	4859
DO	min	7.5	8.0	5.2	9.3	6.8	10.1	10.3	8.3	6.1	7.1	6.8	6.6
ppm	max	8.5	8.9	10.5	11.1	9.8	11.9	13.5	12.9	9.9	8.1	9.2	8.4
	mean	7.9	8.5	7.7	10.2	8.3	11.0	12.5	10.6	8.0	7.6	8.0	7.5
salinity	min	2.4	2.4	1.4	0.4	0.3	1.2	0.0	0.0	2.2		1.7	2.7
%	max	2.4	2.4	1.5	1.2	2.4	2.2	0.9	2.1	2.4		2.1	2.9
	mean	2.3	2.4	1.4	0.8	1.3	1.7	0.4	1.1	2.3		1.9	2.8
ORP	min	.048	.051	.121	.109	.224		.213	.073	.017	.241	.318	.432
	max	.152	.094	.145	.263	.338		.389	1.53	.397	.313	.516	.535
	mean	.113	.073	.133	.186	.280		.300	.800	.200	.298	.420	.480
turbid	min							1280	12	1.7	400	85	2
NTUs	max							15920	22940	4.2	21700	1000	4
	mean							8600		2.9			3

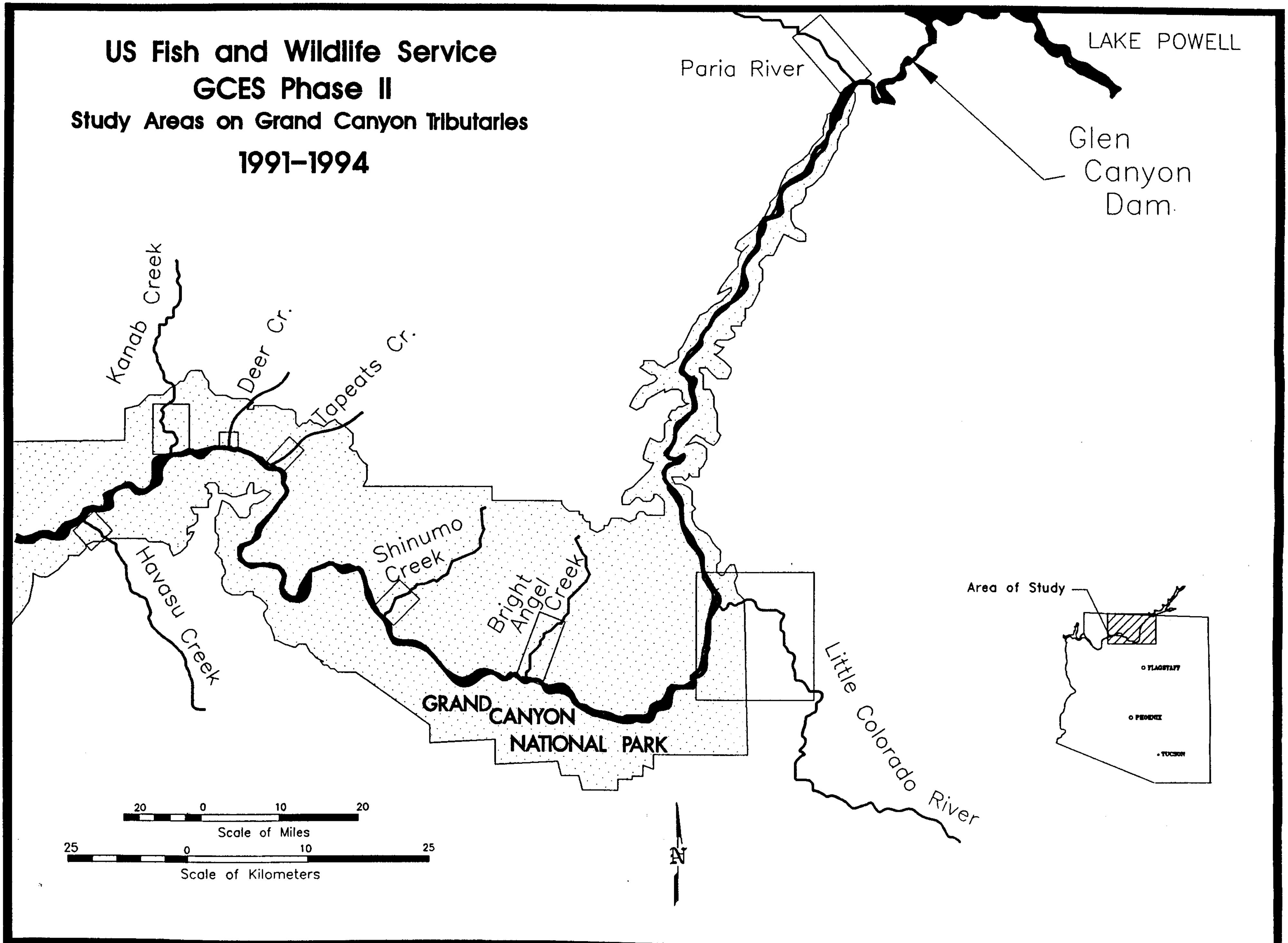
TABLE 9. USFWS LCR: summary of water quality measures, 1991-1994 (continued).

B. SALT		1991		1992				1993				1994	
		Sum	Fall	Win	Spr	Sum	Fall	Win	Spr	Sum	Fall	Spr	Sum
temp	min	20.5	18.0	6.4	12.3	16.9	13.7		7.2	17.3	12.3	13.2	17.7
°C	max	26.8	21.2	16.8	20.9	23.9	21.0		22.4	23.7	20.7	24.4	26.5
	mean	23.7	19.6	11.6	16.6	20.4	17.4		14.8	20.3	16.5	18.8	22.1
pH	min	7.76	7.52	7.75	7.24	6.87	6.77		7.3	7.2	7.0	7.54	7.02
	max	8.01	7.55	7.90	8.75	8.03	8.11		8.3	8.0	8.0	8.66	7.85
	mean	7.89	7.54	7.83	8.00	7.45	7.44		7.8	7.6	7.5	8.10	7.44
cond	min	3840	4220	2380	423	3300	1780		729	4410	1690	3050	4100
uS	max	4980	4600	4540	3460	4370	4240		4850	5250	5390	4380	5160
	mean	4410	4410	3460	1942	3835	3010		2790	4830	3540	3715	4630
DO	min	7.7	6.7	9.2	7.9	5.3	7.2		6.0	4.2	7.3	8.1	6.0
ppm	max	8.9	8.0	11.8	11.3	7.8	9.3		11.6	8.0	10.5	10.7	8.1
	mean	8.3	7.6	10.5	9.6	6.6	8.3		8.8	6.1	8.9	9.4	7.1
salinity	min	1.6			0.0								2.2
%	max	2.3			0.9								2.3
	mean	1.95			0.5								2.2
ORP	min	.027			.081								.315
	max	.161			.281								.420
	mean	.094			.181								.370
turbid	min									3.0	6.0	112	6.5
NTUs	max									9.7	22272	3400	16.3
	mean	50								6.4			12.0

TABLE 10. **USFWS Grand Canyon tributary studies: summary of water quality measures.** confl=location near confluence above inflow of mainstem (100-200 m upstream); upstr=upstream locations (0.1-10 km). If only one measure was taken, no min/max is recorded.

		June 1993							July 1994									
		Shinumo		Tapeats	Deer	Kanab	Havasu		Bright Angel		Shinumo	Tapeats	Deer	Kanab		Havasu		
		confl	upstr	confl	confl	upstr	confl	upstr	confl	upstr	confl	confl	confl	confl	upstr	confl	upstr
temp	min		15.9	15.87		19.4	19.98	20.0	18.2	18.5	19.9	13.8	17.7	26.7	30.2	21.4	28.3
°C	max		18.7	16.58		28.7	23.98	22.9	25.8	27.5	24.5	17.4	18.7	31.6	33.9	24.9	30.2
	mean	15.9	17.79	16.23	16.7	25.41	22.78	21.68	22.2	23.1	21.79	15.1	18.1	28.6	31.4	22.9	28.9
pH	min		7.90	8.44		7.10	8.29	7.67	8.26	8.61	8.21	8.26	8.35	8.19	8.32	8.03	8.31
	max		8.42	8.48		8.12	8.44	8.48	8.67	9.01	8.65	8.52	8.38	8.25	8.39	8.20	8.46
	mean	8.42	8.11	8.46	8.48	7.69	8.34	7.98	8.46	8.79	8.34	8.36	8.37	8.22	8.36	8.11	8.39
cond	min		264	341		109	726	663	347	321	319	340	430	1081	1180	669	797
uS	max		306	344		130	768	726	386	336	375	358	438	1209	1210	774	809
	mean	379	285	343	416	124	750	693	367	326	355	353	434	1155	1197	729	802
DO	min		6.40	8.71		4.20	5.17	6.10	7.1	6.0	7.39	8.82	8.12	6.23	3.38	6.17	
ppm	max		9.30	8.82		8.20	7.68	4.30	8.4	7.2	8.24	9.57	8.28	6.76	4.0	7.77	
	mean	7.92	7.37	8.77	8.30	5.91	6.62	5.35	7.5	6.7	7.82	9.32	8.21	6.55	3.7	7.0	
salinity	min								.171		.155	.167	.216	.6		.344	
%	max								.192		.186	.177	.219	.6		.401	
	mean								.182		.175	.174	.218	.6		.377	
ORP	min						171		328		372	399	477	478		507	
	max						249		388		426	426	508	495		584	
	mean	149		112	106		214		356		405	413	495	490		559	
turbid	min																
NTUs	max																
	mean	<10	<10	3.0	4.5	<10	<20	14									

FIGURE 1. USFWS GCES Phase II: Study Areas in Grand Canyon Tributaries, 1991-1994.



VSaylor 9-27-94

FIGURE 2. USFWS GCES Phase II: Study Reaches in the Little Colorado River.

U.S. FISH & WILDLIFE SERVICE
Study Areas on the Little Colorado River

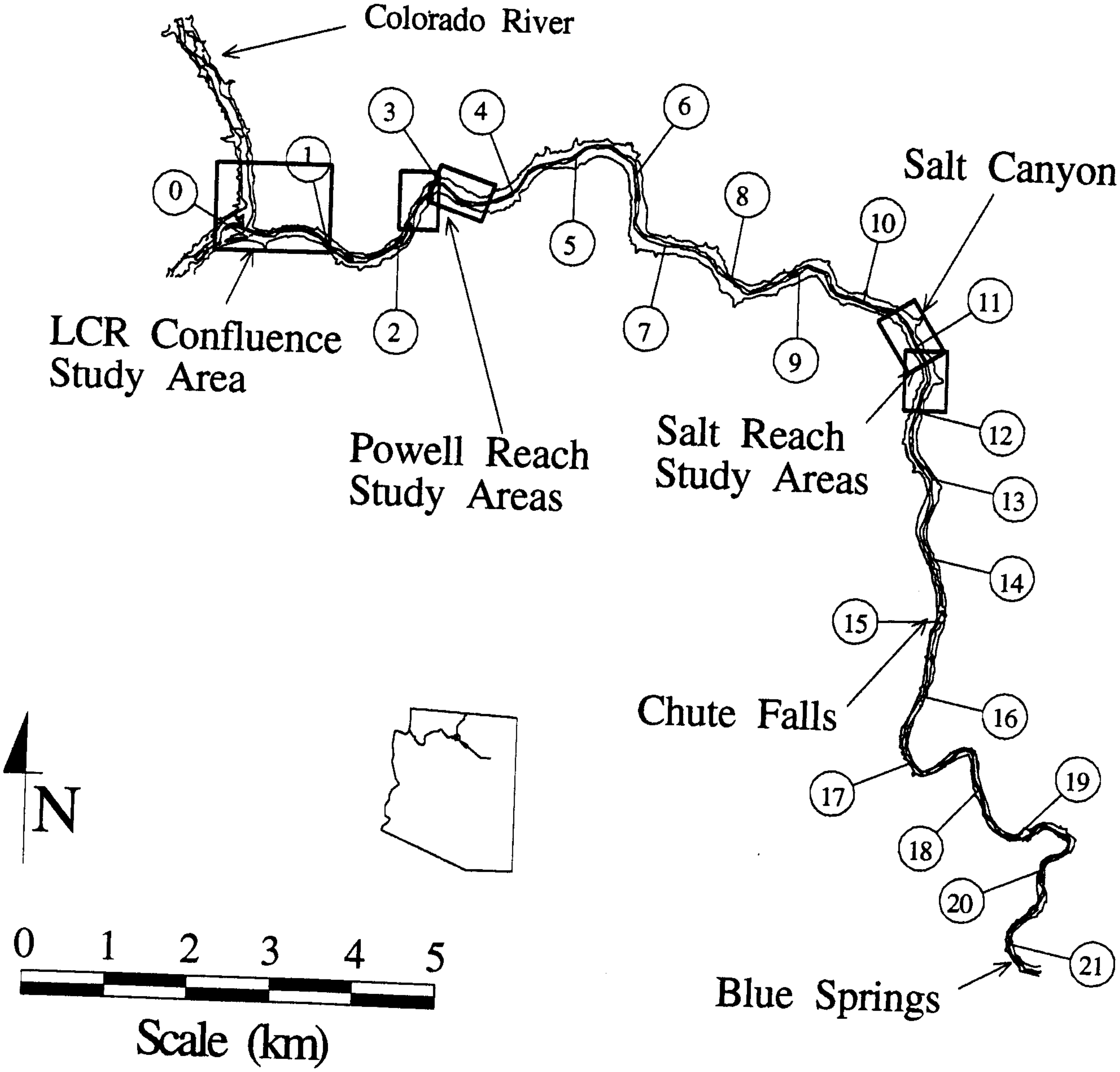


FIGURE 3. USFWS GCES Phase II: Study Reaches and Study Areas with transects in the Little Colorado River

Panel 1. Confluence Study Reach, km 0.0-0.5

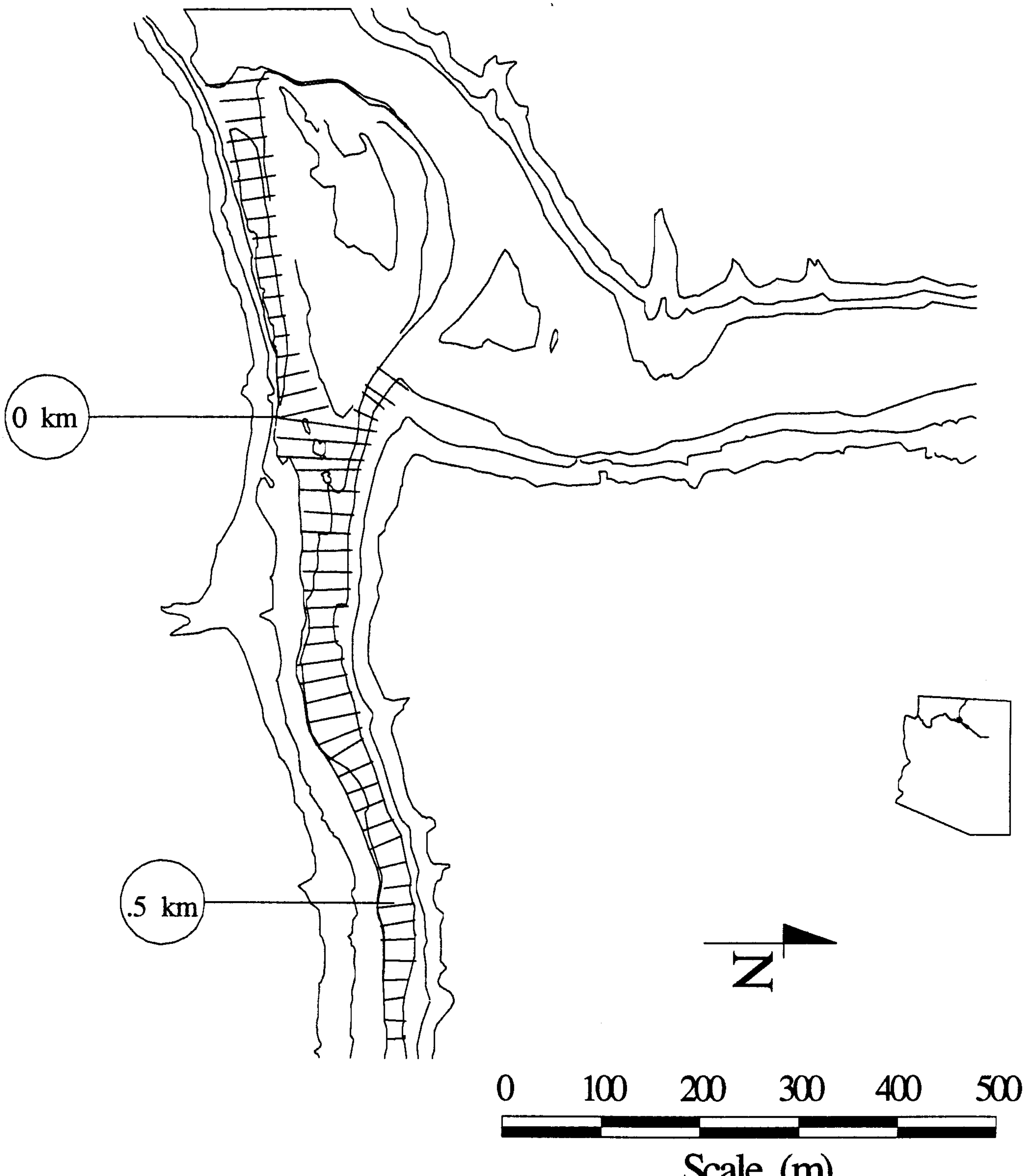
Panel 2. Powell Study Reach, lower study area, km 2.5-3.0

Panel 3 Powell Study Reach, upper study area, km 3.0-3.5

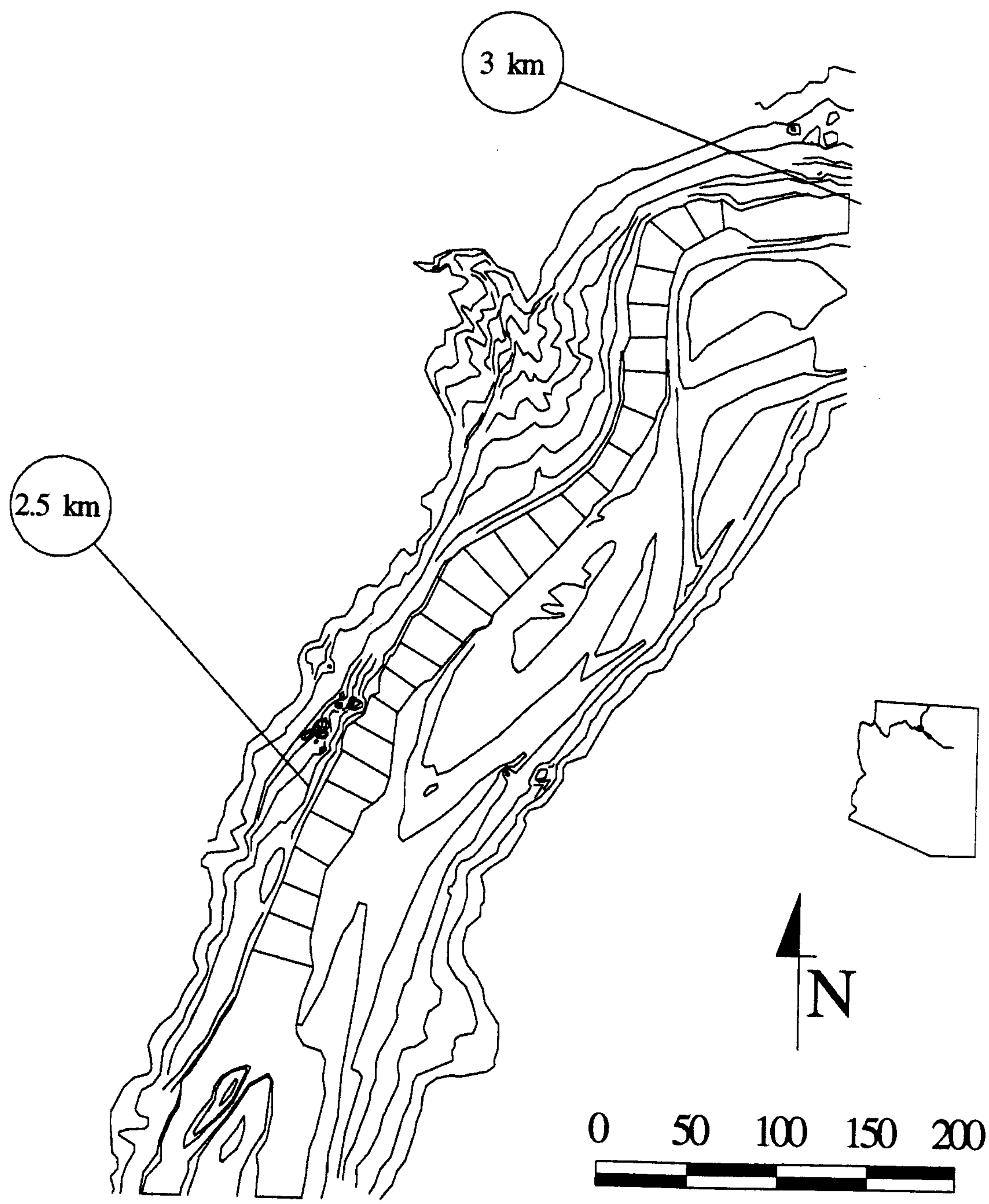
Panel 4 Salt Study Reach, lower study area, km 10.5-11.0

Panel 5 Salt Study Reach, upper study area, km 11.0-11.5

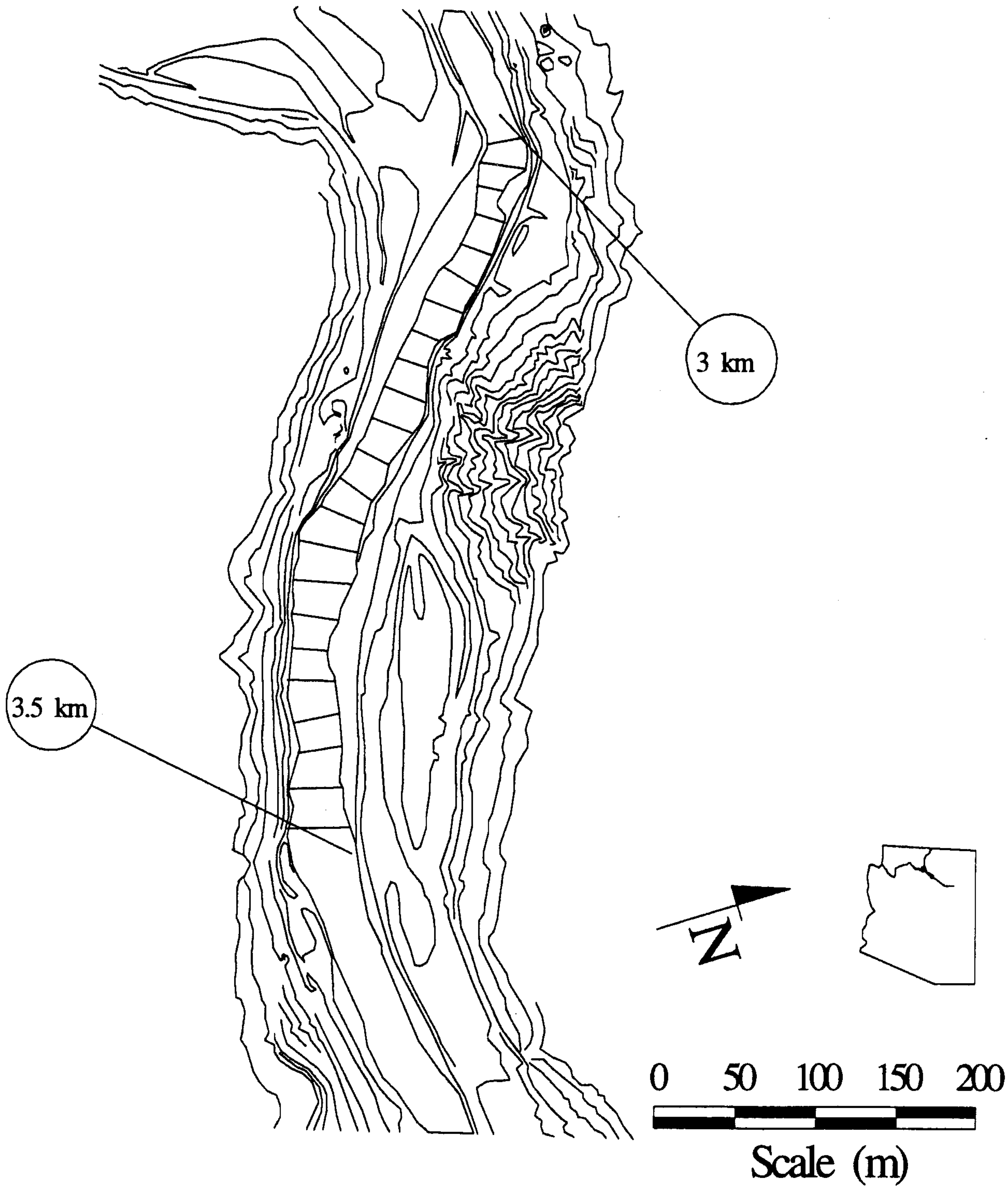
U.S.F.W.S. Confluence Study Reach with transects on the Little Colorado River



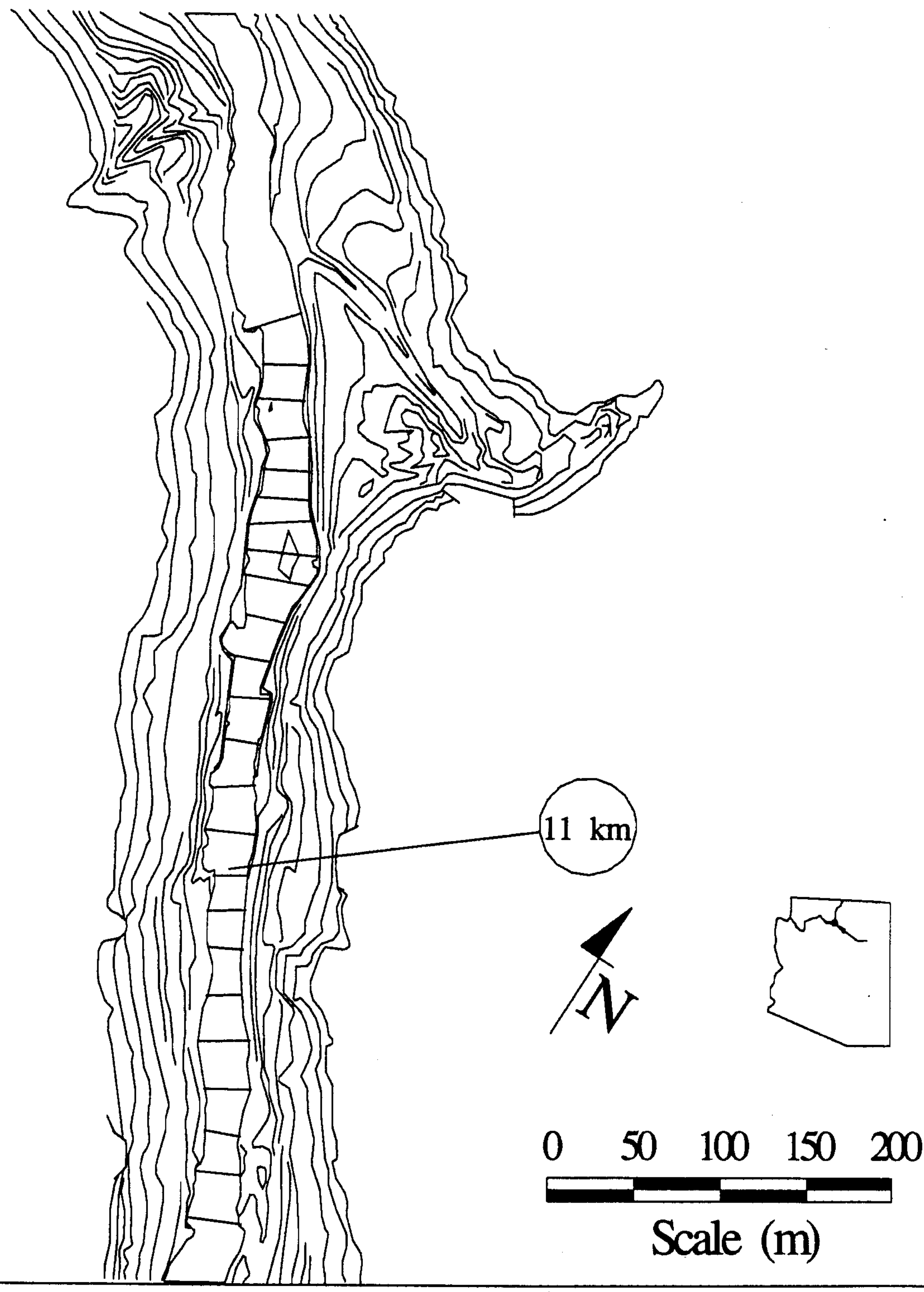
U.S.F.W.S. Powell Study Reach
lower study area
with transects on the Little Colorado River



U.S.F.W.S. Powell Study Reach
upper study area
with transects on the Little Colorado River



U.S.F.W.S. Salt Study Reach
lower study area
with transects on the Little Colorado River



U.S.F.W.S. Salt Study Reach upper study area with transects on the Little Colorado River

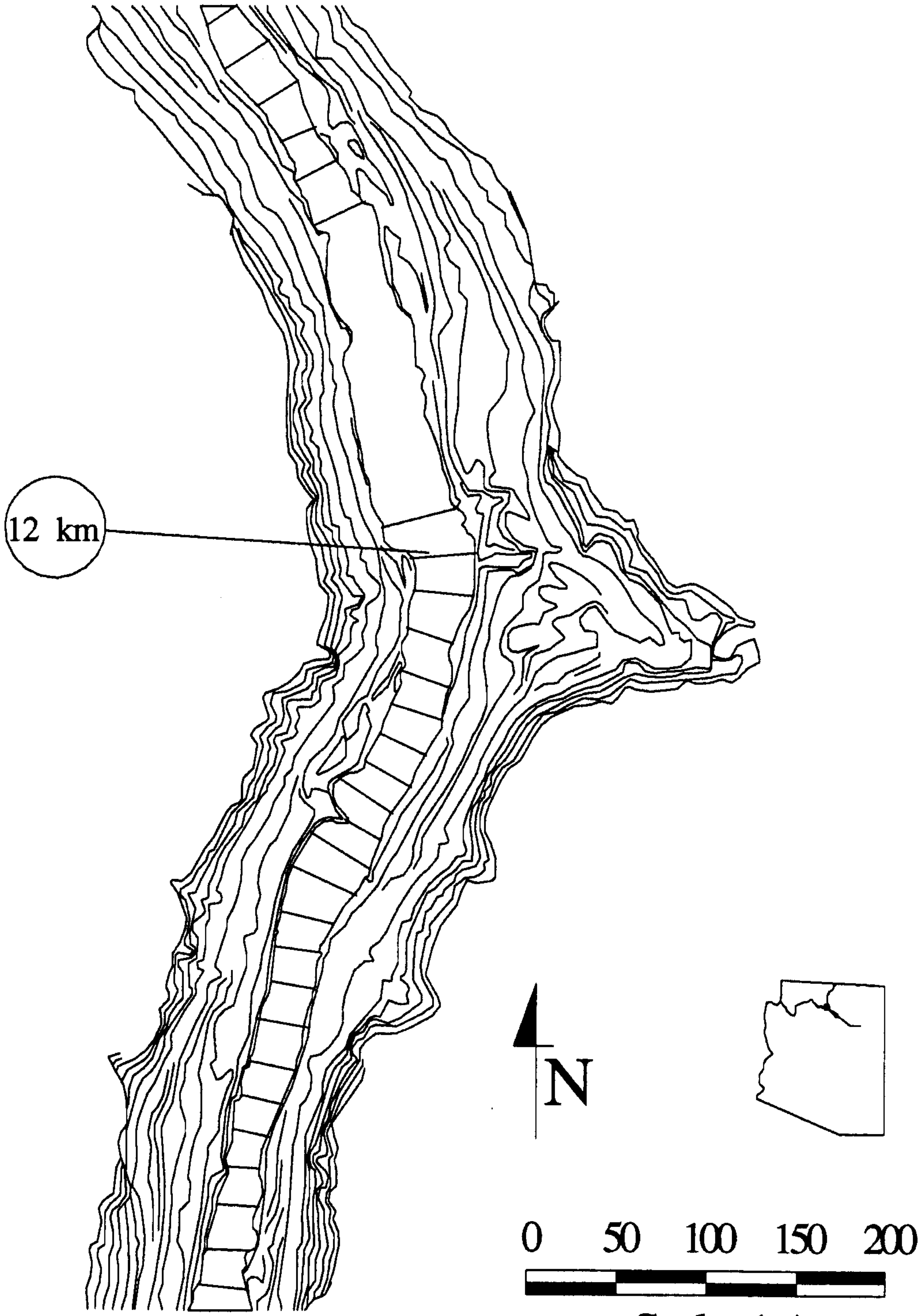


FIGURE 4. USFWS GCES Phase II: Schematic of USFWS fish sampling grid.

TRN=FWS transect, MTP=minnow trap, MNH=minihoopnet.

USFWS fish sampling grid schematic

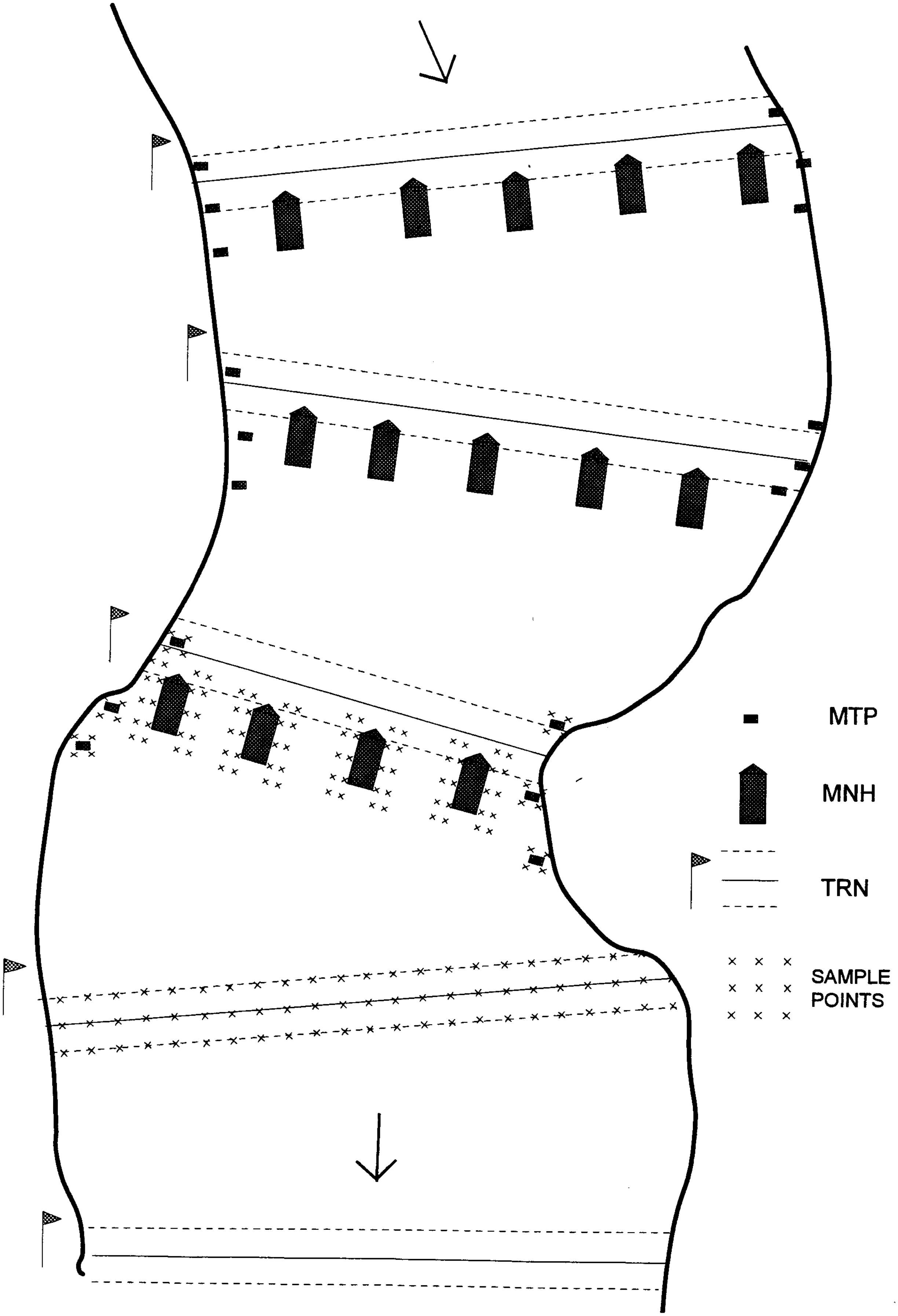
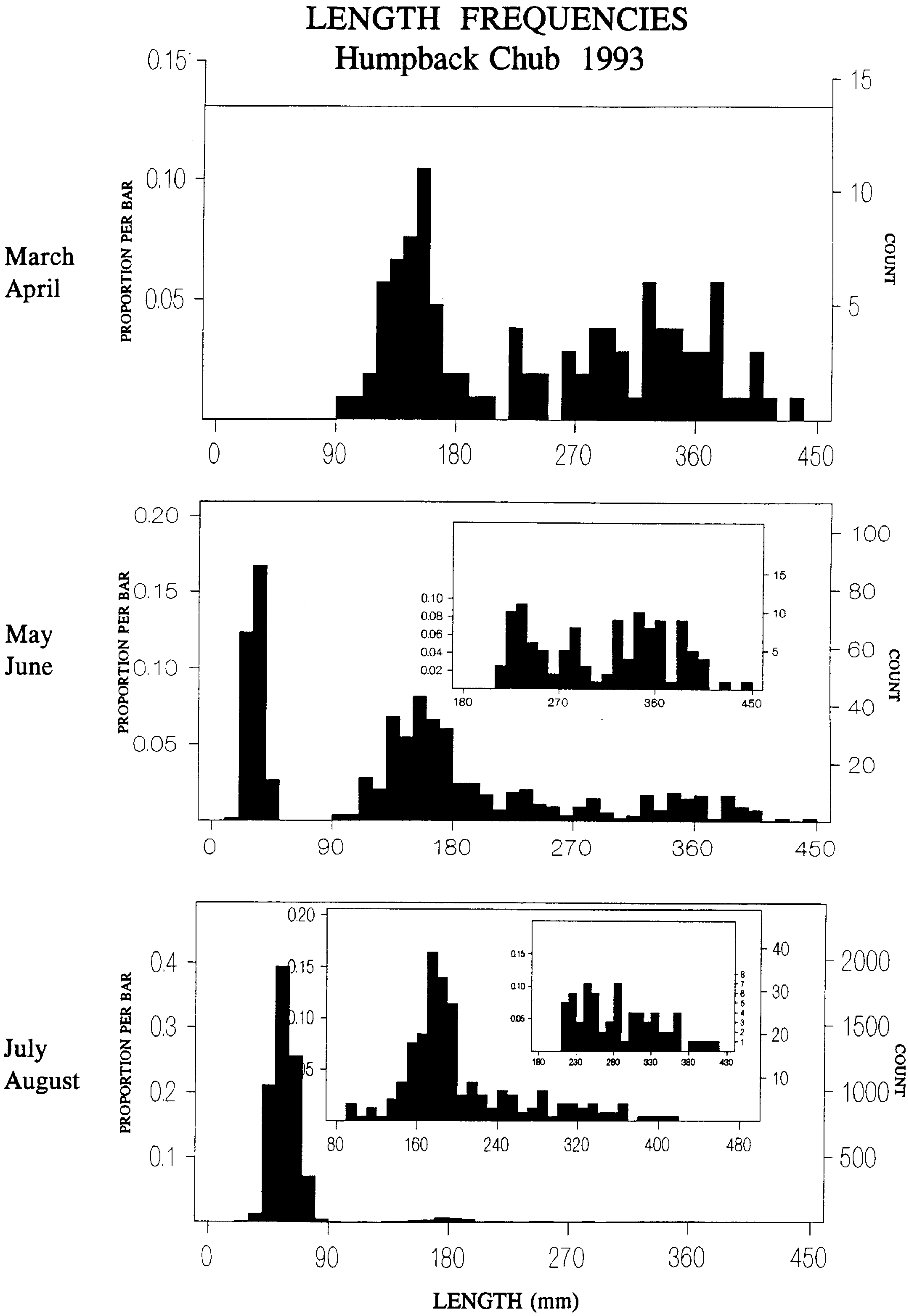


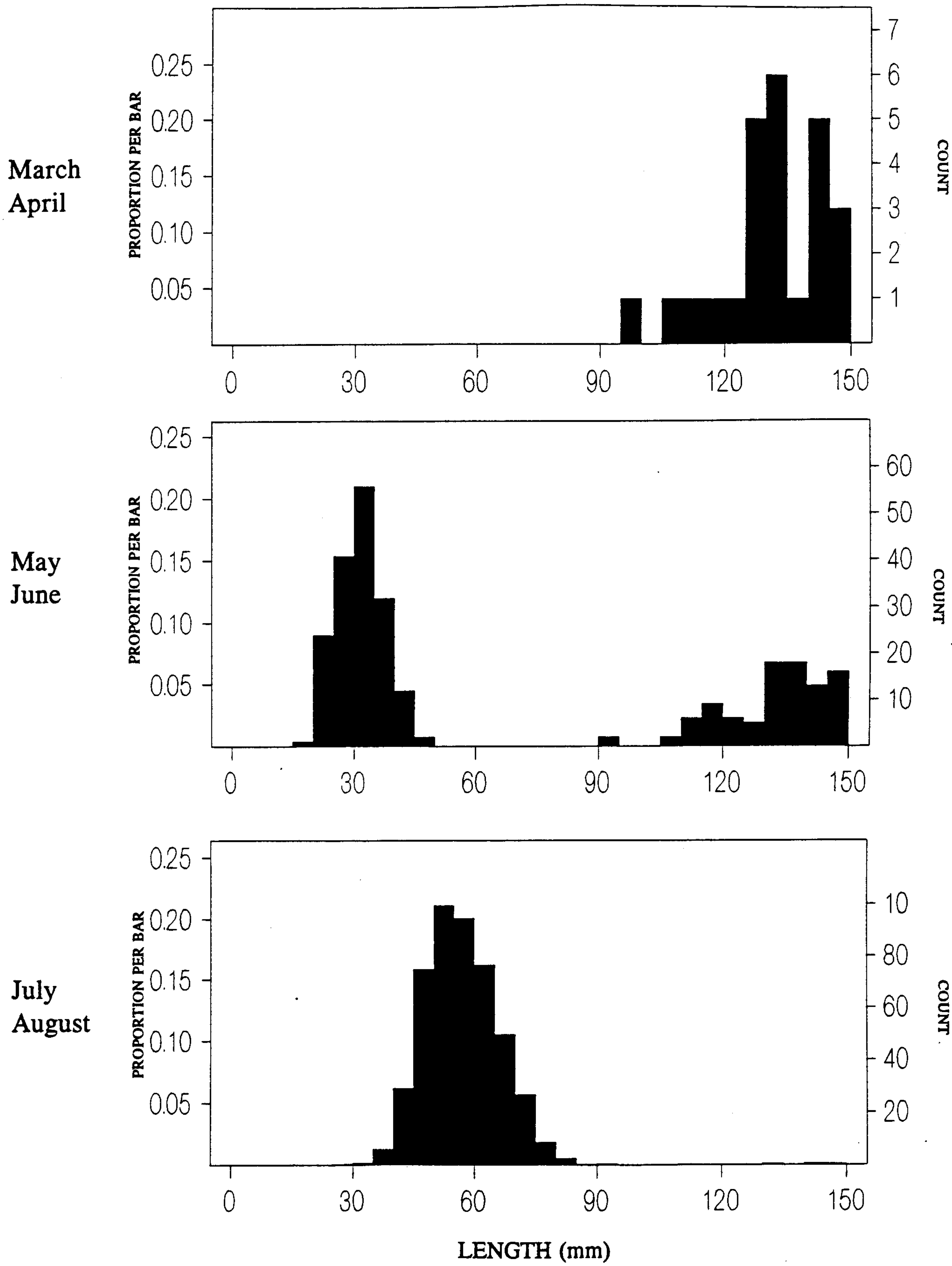
FIGURE 5. USFWS GCES Phase II: Length-frequency histograms for LCR fishes, 1993-1994.

Shown are length-frequency histograms for humpback chub, speckled dace, bluehead sucker, flannelmouth sucker.



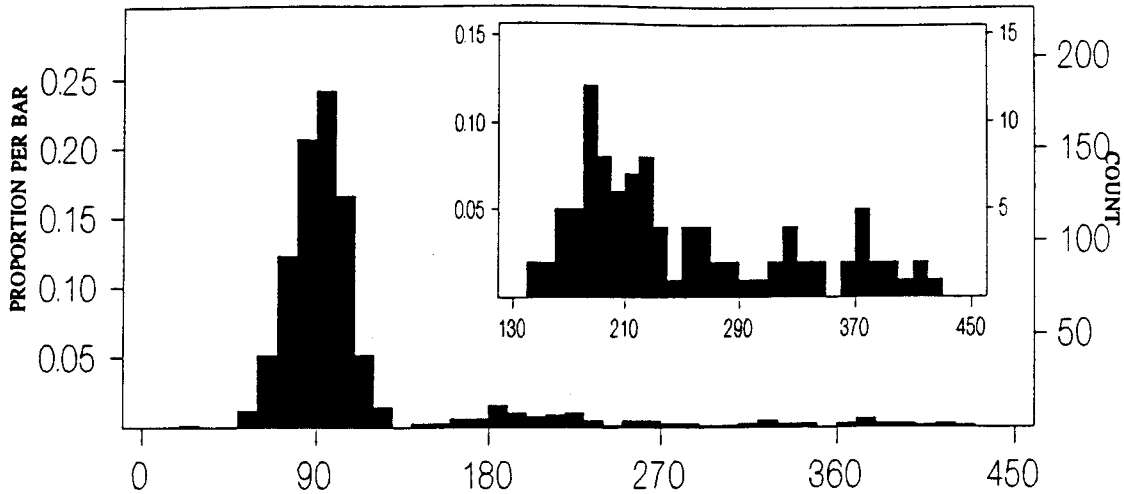
LENGTH FREQUENCIES
Humpback Chub 1993
March
April
May
June
July
August
PROPORTION PER BAR
COUNT
LENGTH (mm)
0.15
0.10
0.05
0.20
0.4
0.3
0.2
0.1
15
10
5
100
80
60
40
20
2000
1500
1000
500
0
90
180
270
360
450
80
160
240
320
400
480
230
280
330
380
430

LENGTH FREQUENCIES
Humpback Chub < 150mm 1993

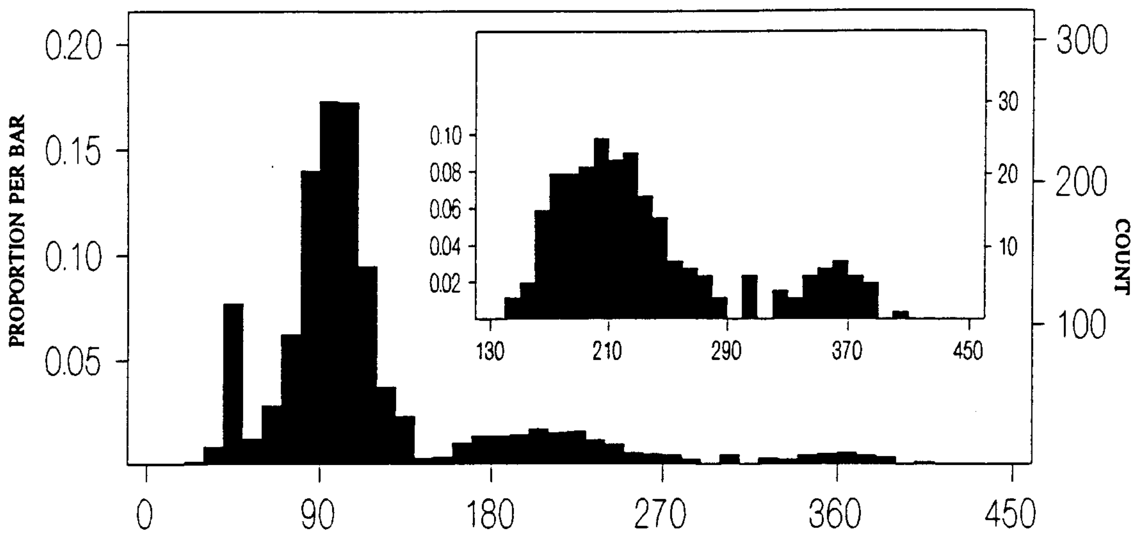


LENGTH FREQUENCIES
Humpback Chubs 1994

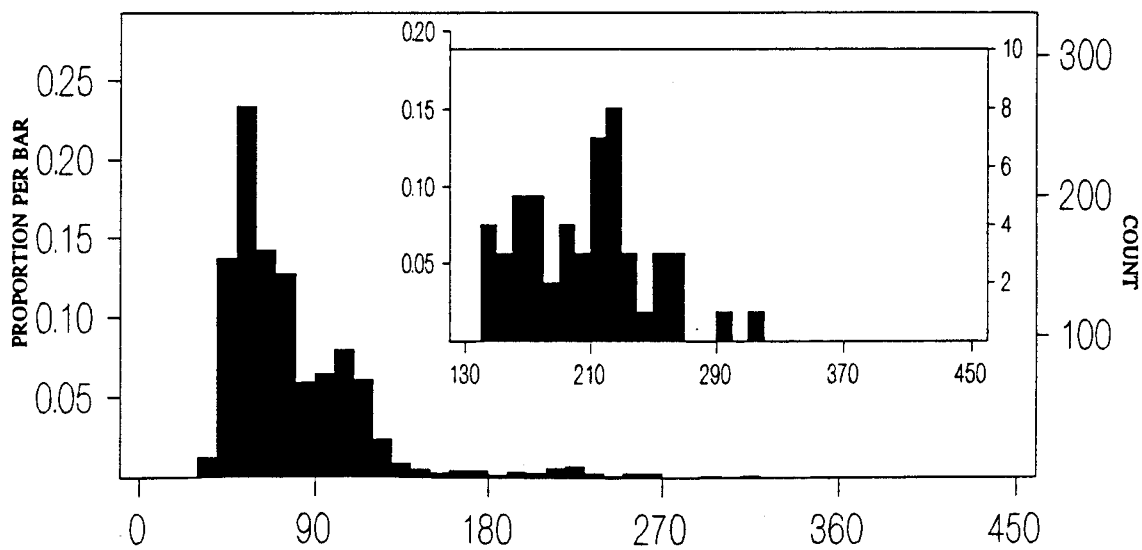
April



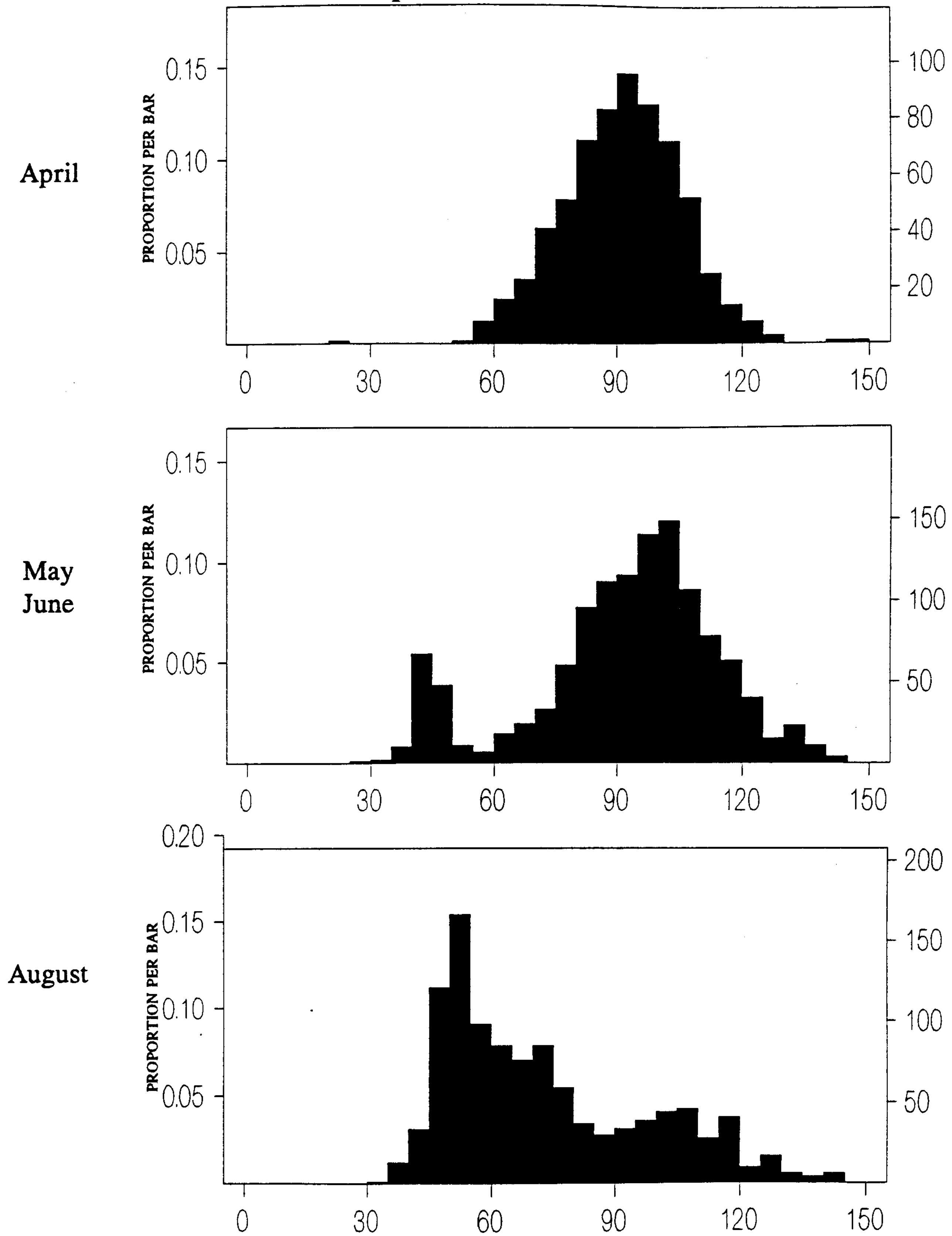
May
June



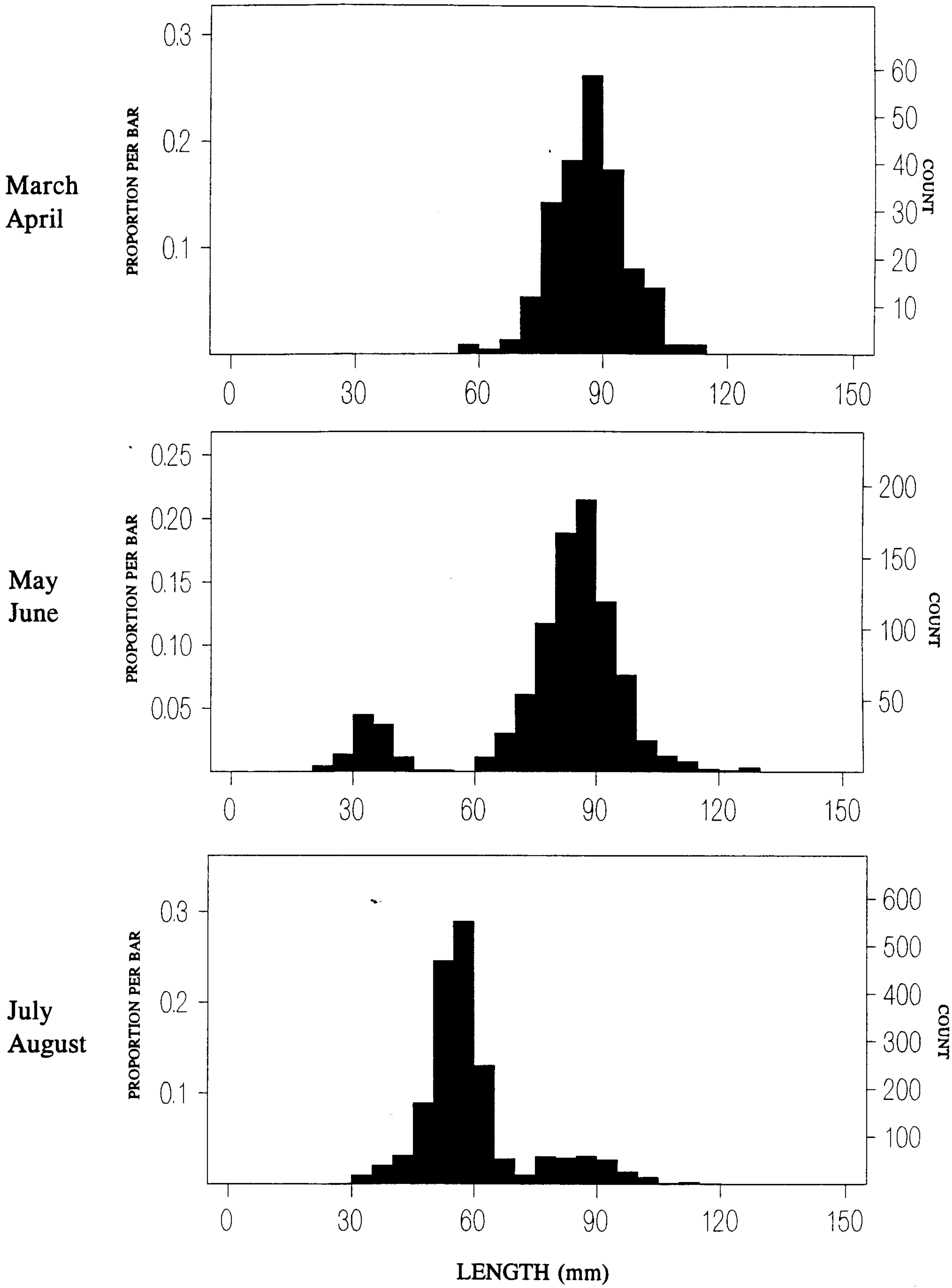
August



LENGTH FREQUENCIES
Humpback Chubs < 150mm 1994



LENGTH FREQUENCIES
Speckled Dace 1993

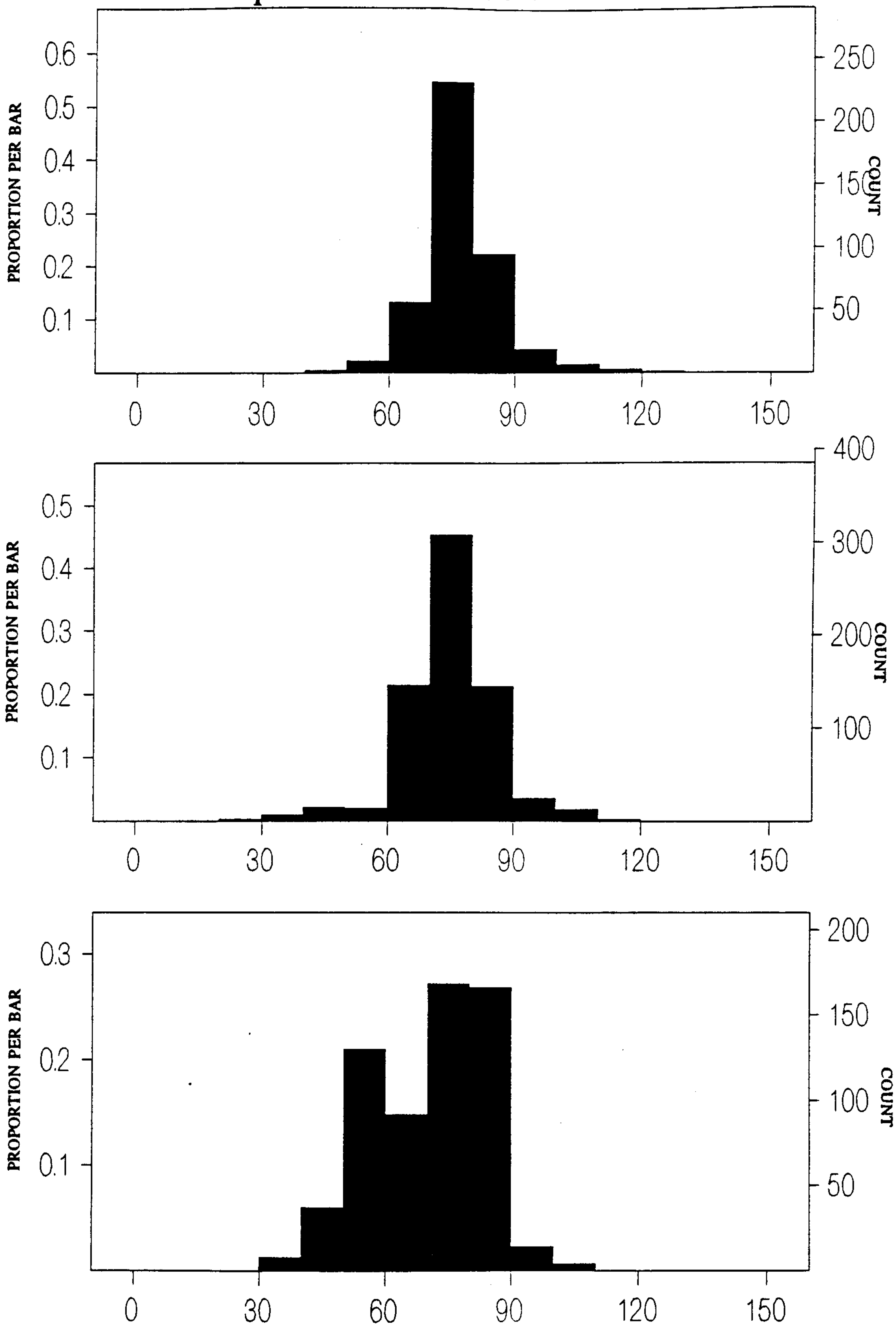


LENGTH FREQUENCIES
Speckled Dace 1994

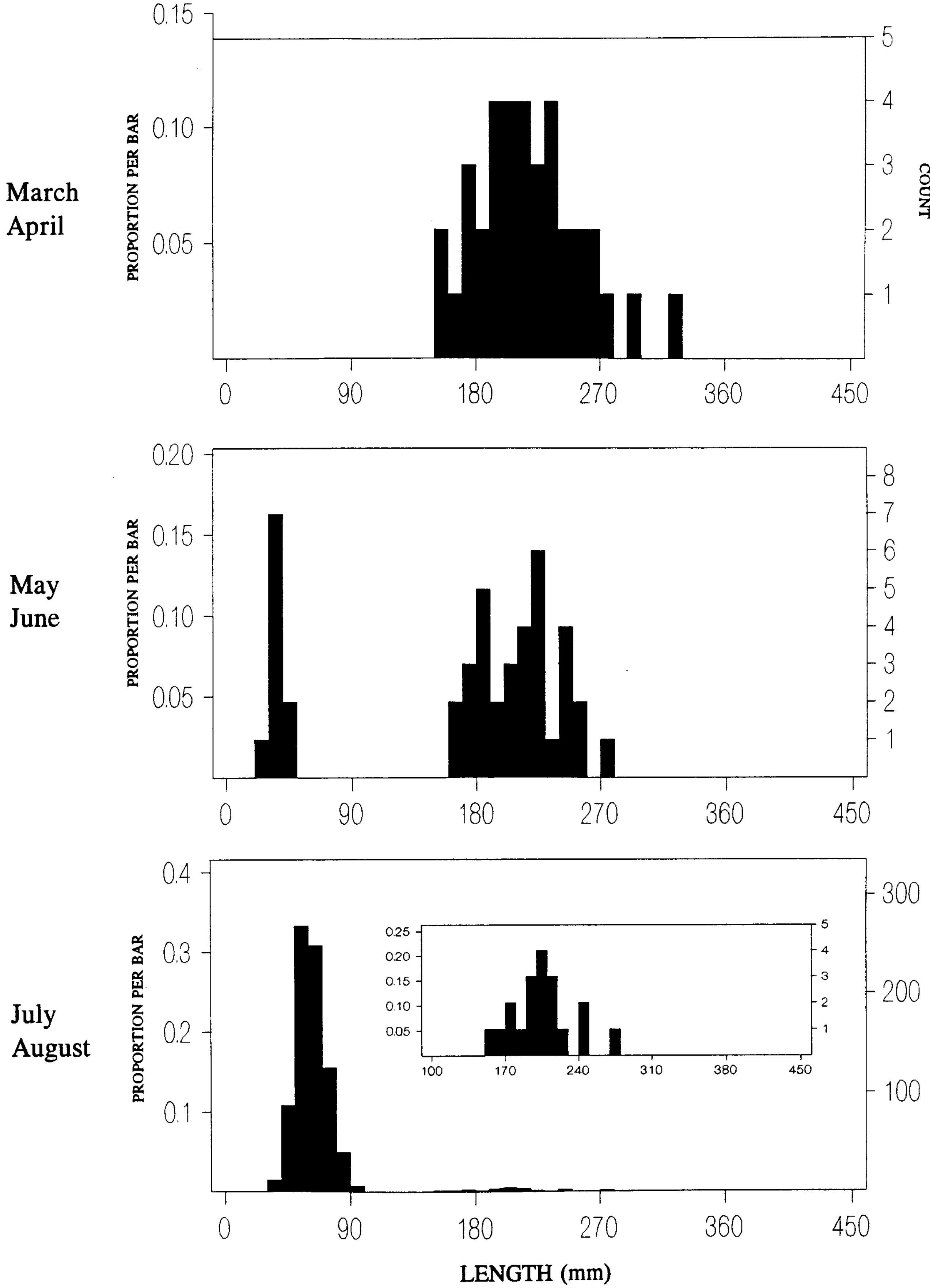
April

May
June

August

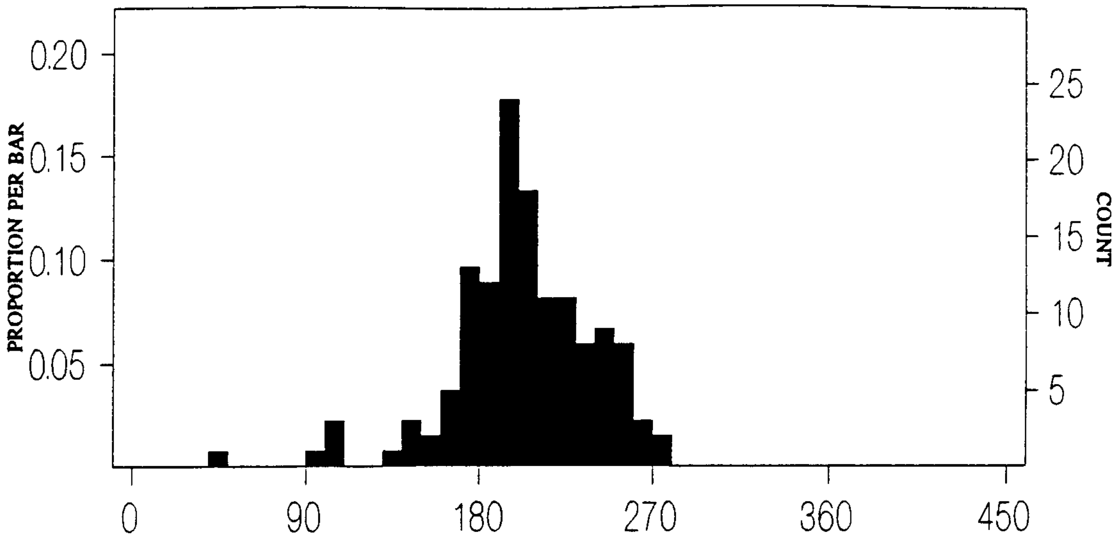


LENGTH FREQUENCIES
Bluehead Suckers 1993

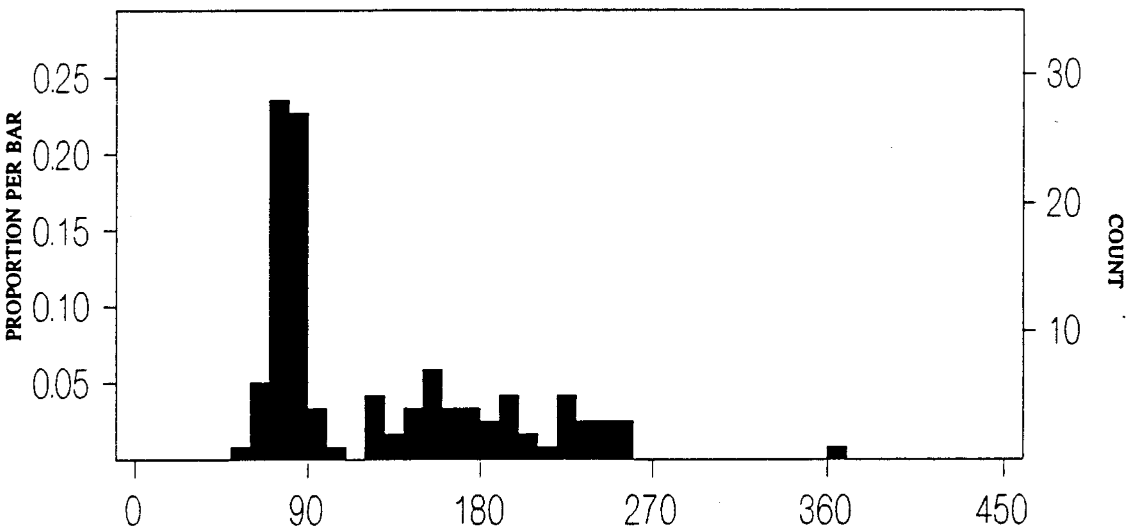


LENGTH FREQUENCIES
Bluehead suckers 1994

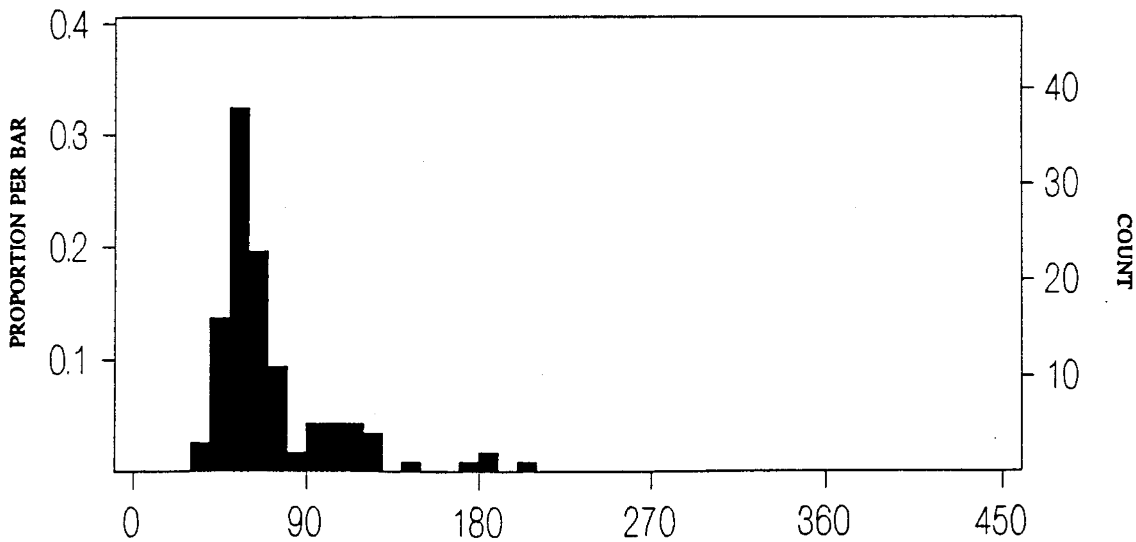
April



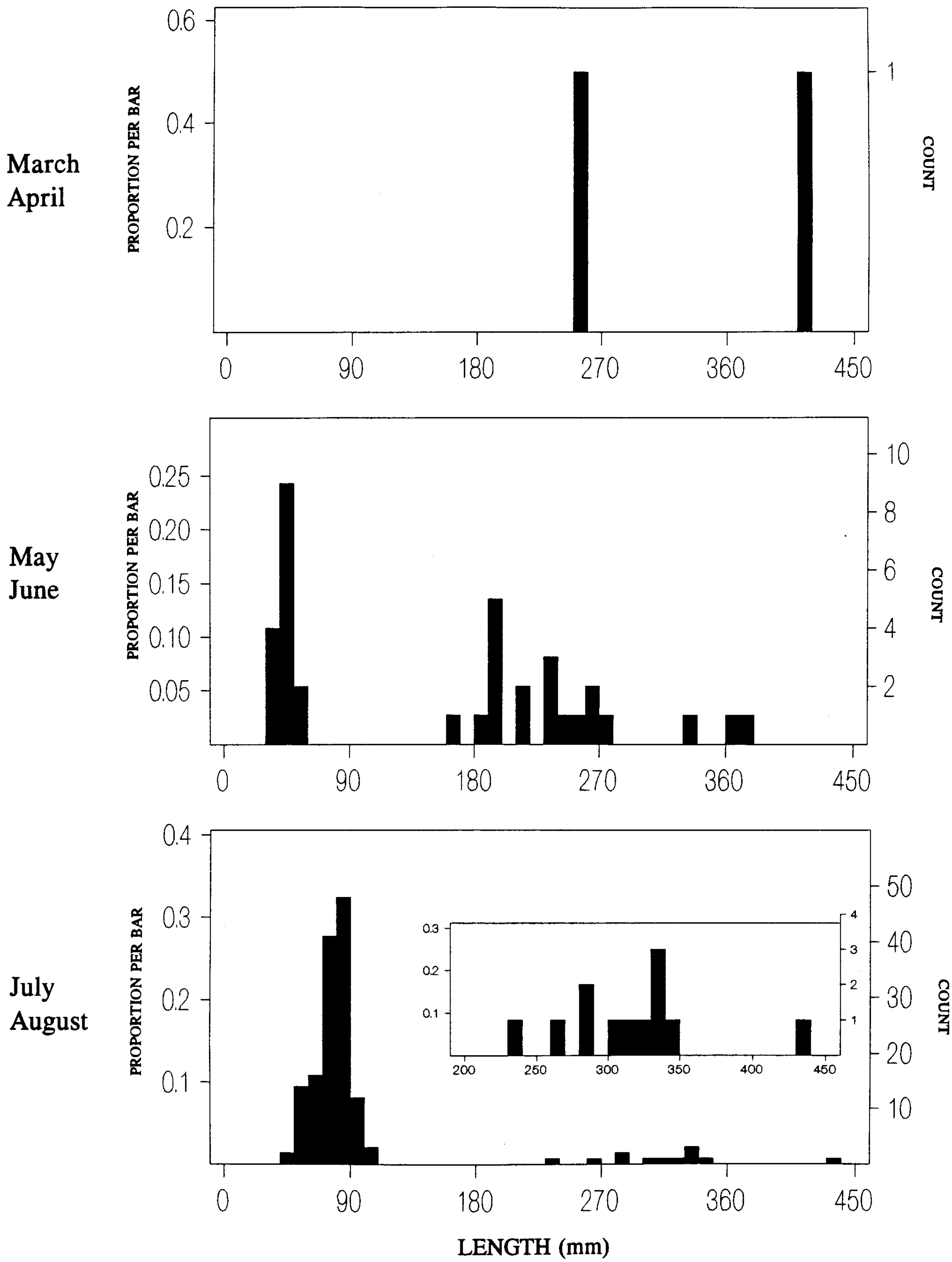
May
June



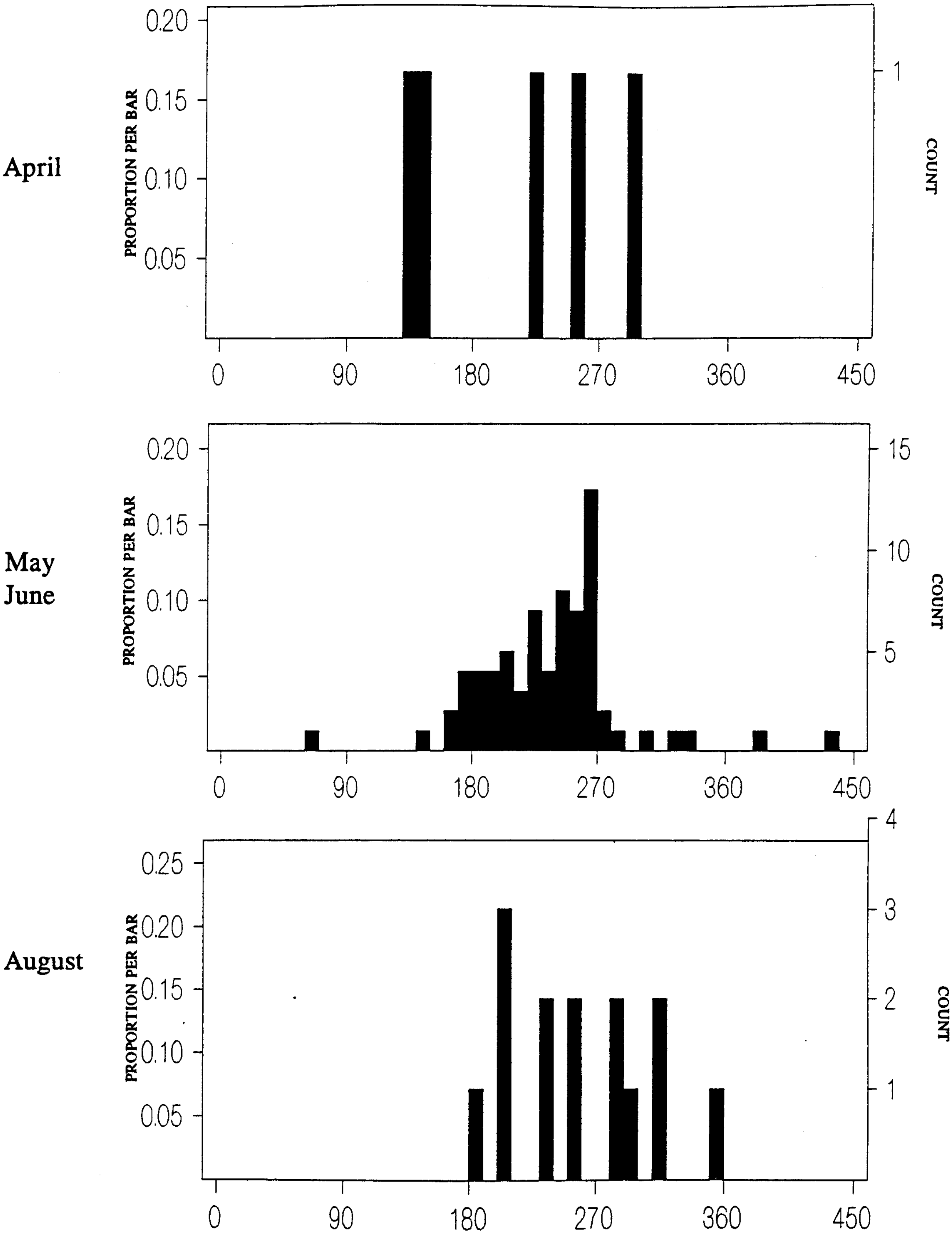
August



LENGTH FREQUENCIES
Flannelmouth Suckers 1993



LENGTH FREQUENCIES
Flannelmouth Suckers 1994



United States Department of the Interior
FISH AND WILDLIFE SERVICE
Arizona Fishery Resources Office

Glen Canyon Environmental Studies Phase II Final Report

PROVISIONAL

Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River

VOLUME II
APPENDICES

October 1, 1994

submitted to:
U.S. Bureau of Reclamation
Glen Canyon Environmental Studies
Flagstaff, Arizona

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Arizona Fishery Resources Office

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Colorado River

GCES Phase II Final Report

APPENDIX I

USFWS STREAM HABITAT STUDIES
DESCRIPTION OF VARIABLES

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USFWS STREAM HABITAT STUDIES
DESCRIPTION OF VARIABLES

HABITAT VARIABLES

DBASE field name	variable name	type	width
	Common variables for all habitat samples:		
STREAM	name of stream	char	8
SITE	stream reach	num	1
KM	km from confluence(XX.XXX)	dec	6
TRID	transect ID (as flagged)	char	6
ID	sample location ID	char	8
DATE	MM/DD/YY	date	8
TIME	24 hr clock	num	4
GEAR	sample type	char	3
	Common variables for net/trap/seine samples:		
LATDS	lateral distance to set (cm)	num	4
GEARD	gear description	num	5
SETD	set date	date	8
SETT	set time (24 hr clock)	num	4
PULD	pull date	date	8
PULT	pull time (24 hr clock)	num	4
UPDN	distance from transect	num	4
MO	depth at mouth of net/trap	num	3
MTH	depth, top of trap/hoop	num	3
PO	depth at point of net	num	3
PTH	depth at top of first hoop	num	3
T	transect/row of net grid	char	1
P	point/column of net grid	num	1
	Common variables for each habitat point:		
ELV	change in elevation: (+,- cm)	num	4
EDG	dist. (cm) when edge <=100	num	3
DPH	depth (cm)	num	3
CUR	current category 0-5	num	1

CC	current comments	char	2
SUB (SUB1)	primary substrate 0-11	num	2
SS (SUB2)	secondary substrate 0-11	char	2
SBC	substrate descriptors	char	6
OVH	overhang, vert. edge	char	5

Variables specific for transect measures:

M	20 or 100 m transect	num	1
TR	transect row (triple transect)	char	1
PT	point along transect (L to R)	num	3
DBT	spacing between transect rows	num	3
DBP	spacing between sample points	num	3

Variables specific to seine samples only:

SNSZ	L x W seine dimensions (m)	char	7
MESH	seine mesh, 100s of inches	num	2
L	length of area seined (m)	num	3
W	width of area seined (m)	num	2
AREA	area seined (m^2)	num	3
SWPS	number of sweeps in sample	num	1

Common variables modified by DBASE program

OVH	overhang, vert. edge	char	5

Common variables created by DBASE program

LATP	dist. to nearest bank/edge	num	4
DPH2	10 cm dpth intervals, max=200	num	3
ECUR	expanded current categories	dec	3
CURV	current velocity, m/s	dec	4
EPS	effective particle size	num	2
MXPT	max. number pts/transect	num	3

Common *experimental* variables created by DBASE program

CVR	cover	num	2
CCV	current corrected CVR	num	2
VER	vertical structure	num	2
VRC	current corrected VER	num	2
VEG	vegetation	num	2
MAR	marl	num	2

TRA	travertine	num	2
SHA	shade	num	2
DEB	debris	num	2

DESCRIPTION OF HABITAT VARIABLES

STREAM Name of stream. LCR (Little Colorado River), PARIA, B.ANGEL, SHINUMO, TAPEATS, DEER, KANAB, HAVASU.
DBASE character field [8]

SITE Study reach of river. 0= confluence (up to 200m), 1= upstream. In LCR 1=Powell study reach, 2=Salt study reach.
DBASE numeric field [1]

KM Distance in km from the confluence. There is a database of km values for all transects that can be linked to habitat databases.
DBASE numeric decimal field [6.3]

M "1" in this field indicates a 100 m transect. Habitat was measured across the stream channel at 100m intervals from the confluence to Blue Springs (21 km) in July August 1991. The 100 m transects are a subset of the 20 m transects (M=0). All 20 m transects were flagged from the confluence to Blue Springs in July-August 1991. Habitat has been measured at approximately 1/2 of all 20 m transects.
DBASE numeric field [1]

TRID TRANSECT "ID" (alphameric/character string) up to 8 characters. Provides the transect ID as labeled in the field and on FWS provisional maps of the LCR channel.
DBASE character field [8]

ID Location "ID" (alphameric/character string) up to 8 characters. Provides unique identifier for each transect or sampling location. Incorporates TRID and has unique extensions indicating type of sample and its relative location.
DBASE character field [8]

DATE Date sampling was conducted. DBASE date field [8]

TIME Time of day (24 hr clock) sampling was conducted
DBASE numeric field [4]

GEAR Sampling method/device: ASU hoopnet=AHP, FWS minihoopnet= MNP, FWS minnow trap= MTP, FWS seine= SEN, FWS transect= TRN
DBASE character field [3]

LATDS Distance in cm from nearest stream bank (L or R) to midline of net or trap. LATDS for seine samples is the distance to point A1.
DBASE numeric field [4]

GEARD Sampling gear description (hoopnets and traps) mesh (25 for 1/4", 50 for 1/2"), # hoops (e.g., 4, 5, 6, 7), hoop diameter (cm, typically 50, 60, 70, 80, or 90 cm). Example: 50590 is a 1/2" mesh, 5 hoop, 90 cm diameter net. If data is not available leave field empty or enter a "0".
DBASE numeric field [5]

SETD Date net/trap was set.
DBASE date field [8]
SETD Time of day (24 hr clock) net/trap was set.
DBASE numeric field [4]

PULD Date net/trap was pulled.
DBASE date field [8]
PULT Time of day (24 hr clock) net/trap was pulled.
DBASE numeric field [4]

MO Depth in cm at the mouth of net.
DBASE numeric field [3]

MTH Depth in cm to top hoop at mouth. "-" in front of number means top of hoop is above water. Dbase numeric fields do not accept "+" symbols.
DBASE numeric field [3]

PO Depth in cm at the "point" (upstream end or closure of hoopnet).
DBASE numeric field [3]

PTH Depth in cm to the top of the first hoop nearest the "point". A "-" in front of value means the hoop is out of the water. Dbase numeric fields do not accept "+" symbols.
DBASE numeric field [3]

POS Depth (cm) to top of minnow trap. Analogous to MTH or PTH.
DBASE numeric field [3]

SNSZ Dimensions of seine used for sampling (L x W in cm).
DBASE character field [7]

MESH Mesh of seine in 100s of inches.
DBASE numeric field [2]

L Length of seined area in cm.
DBASE numeric field [4]

W Width of seined area in cm.
DBASE numeric field [4]

SWPS Number of seine hauls in a sample
DBASE numeric field [1]

T Transect or row (letters A-E) for hoopnet habitat grid or transect row for triple transects (letters A-C). For nets, rows start 1 m below mouth to 1 m above net.

This is the "y" coordinate for the habitat sample point grid.
DBASE character field [1]

TR Transect or row converted to numbers.
DBASE numeric field [1]

P Point or column (numbers 1-4) for hoopnet habitat grid. Points are numbered from left to right facing upstream. This is the "x" coordinate for the habitat sample point grid.
DBASE numeric field [1]

ELV Change in water surface elevation or level between points in cm when sampling in a L to R direction. The default is positive values. A "-" indicates a drop in water level. "0" or blank field indicates no change.
DBASE numeric field [4]

PT Habitat sample point number for cross channel habitat transects.
DBASE numeric field [3]

LATP Distance in cm from habitat sample point to the nearest bank or edge (edges < =100 cm away; see EDG). These values are generated by a dbase program.
DBASE numeric field [4]

EDG Distance in cm to nearest edge from a habitat point when < =100 cm. Edges can be stream banks, emergent #8 or #9 rocks, emergent sand/gravel bars, etc. Points on the edge of the stream are measured within 5 cm interval of the true edge (depth=0). A "0" or an empty EDG indicates a point > 100 cm away (dbase converts empty numeric fields to 0s).
DBASE numeric field [3]

DPH Depth of water column at sample point, 0 to 999 cm. Points out of the water are left blank or filled with "0"s (0 indicates ground). See elevation for changes in water surface level.
DBASE numeric field [3]

DPH2 Depth of water column at sample point in 10 cm depth intervals from 0-10 cm to > 200 cm (21 intervals). This variable is created by a dbase program using DPH values.
DBASE numeric field [3]

CUR Current at sample point, OTG categories 0-5:

0 none	0 - .02 m/s
1 very slow	.02 - .10 m/s
2 slow	.10 - .30 m/s
3 moderate	.30 - .70 m/s
4 fast	.70 - .1.20 m/s
5 very fast-torrent	>1.20 m/s

DBASE numeric field [1]

CC Current comment or descriptor. "E" indicates backcurrent or eddy; "T" indicates turbulent flow; "P" indicates plunge pool or waterfall; "+" indicates upper range of a current category; "-" indicates lower range for a current category.
DBASE character field [2]

ECUR Expanded current categories. Subdivides each current category into 3 subcategories (slow, median, fast) based on CUR and CC information.
DBASE decimal field [3.1]

CURV Estimated current velocity in m/s based on median values of ECUR categories.
DBASE decimal field [4.2]

SUB (SUB1) Substrates are visualized as to relative aerial coverage within a 10 cm diameter disk. The primary substrate is that substrate under the point of the pole and has the most extensive aerial coverage within the imaginary 10 cm disk. Secondary substrates (if present) are recorded in decreasing order of relative dominance.

Primary substrate/bottom type:

0 silt	<.06 mm
0 marl, or M (primary)	see subcom, below

1 silt-sand	.07 - .10 mm
2 sand	.11 - 2.0 mm
3 gravel	2.1 - 15 mm
4 pebble	16 - 31 mm
5 rock	32 - 100 mm
6 cobble	101 - 256 mm
7 small boulder	256 - 1000 mm
8 boulder	1 - 3 m
9 large boulder (8+),	> 3 m

10 or T travertine (primary) subcom, below
11 bedrock (encountered in Blue Springs reach)
DBASE numeric field [2]

SS (SUB2) Secondary or subdominant substrate (use SUB1 categories above). SS may be imbedded in the SBC field (below) and are extracted with a dbase program.
DBASE numeric field [2]

SUB3, SUB4, SUB5. Subdominant substrates in order of decreasing abundance.
DBASE numeric field [2]

EPS Effective particle size for SUB1. A dbase program estimates the effective substrate size relative a Wentworth scale. EPS will vary from SUB1 only in streams dominated by travertine structures.
DBASE numeric field [2].

SBC Substrate comments or descriptors (apply to primary substrate or affect the 10 cm area):

M marl covered (substrates 2-10)
M with substrate 0: deep marl; primary substrate
M with substrate 1: silty/sandy marl
T travertine covered or coated (substrates 4-9)
H rough or horny travertine; DEFAULT (with substrate 10)
Q travertine dam or terrace (with substrate 10, travertine)
B smooth or bottom/basement travertine (with substrate 10)
V vegetation (could be anything! Check for context.)
A algae

P pondweed
R roots
F phragmites stems
C cattail (typha) stems
S shrubs or small tree
D detritus (very small dead woody or fine vegetative material, includes leaves)
W wood (dead sticks and logs)
L leaves
G dry ground or land
Z particle is composed of solid travertine
(e.g., coded as "T7", "T8", "T9" in field notebook)

DBASE character field [6]

OVH Overhang, edge, vertical structure coding for each habitat point. Above water overhang from rocks, ledges, vegetation, etc. produces shade. Below water submerged ledges, undercut banks, and submerged logs produce overhangs and enhanced vertical structure/cover. Edge: points < = 100 cm from stream edges or island/boulder margins. Vertical structure/cover (1 m sample spacing): points < = 100 cm from sharp vertical drop-offs (> =.5 slope; > = 50 cm increase in depth/1m lateral distance). Vertical structure for minihoopnets with .5 meter grid spacing: points < = 50 away from vertical dropoffs (> = .5 slope; > =25 cm increase in depth/.5m lateral distance).

OVH
Overhang from:

Above water structures:
S shade from vegetation (> 50% shading)
O above water ledges, overhanging logs, bank (100% shade)

Below water structures:
U undercut bank
L submerged ledge
W submerged logs (>30 cm dia) producing an overhang.

Edge:
E located within 1m (< =100 cm) of the stream edge or island boulder margin

Vertical structure:

V Points following a sharp vertical drop off (> =50 cm/100 cm slope)

Vertical structure: these points are the lowest point following an increase in depth of more than 50 cm/m. Most often these conditions are met for points > = 50 cm depth with more than a 50 cm increase in depth but can occur for points in shallow water but the drop off must be much closer (<.5 m for points 26-50 cm depth and <.25 m for points 11-25 cm depth). Vertical structure is also associated with points of >25 cm depth within 1 m of a 25 cm decrease in surface elevation. This last example occurs around travertine dams and reefs. For points < =10 cm depth, vertical structure does not provide any enhancement (see Cover table). DBASE character field [5]

EXPERIMENTAL HABITAT VARIABLES

The following variables are generated from primary habitat variables by DBASE programs. These variables are *experimental* and therefore are still under development.

CVR and **CCV** (*experimental habitat variable*)
COVER and CORRECTED COVER

Cover is generated by a DBASE program and is determined by a combination of substrate, substrate comments, depth, and cover enhancement. The effect of current on cover is considered in current corrected cover values (CCV) below. Note: M or T SUBCOM have no effect on cover. The following descriptions are not up-to-date; consult OTG dbase program and program notes for changes. DBASE numeric field [2]

<u>0 none</u>: substrates 0-4, M (no subcom); any depth
substrates 0-4, M (any subcom); > 50 cm depth
substrates 7-9, T(10); < =10 cm depth, flat, pool-edges
substrate T-smooth (10-B); any depth
all substrates, any subcom, < 5 cm deep

Includes: open water areas with flat bottoms and small substrates, and very shallow exposed areas without structure; flat, pooled, very shallow edge areas with 7-9, or T (10) substrate; smooth travertine bottoms- flat bedrock-like (10B).

1 slight: substrates 0-4,M (any subcom ex m,t); < =10 cm depth
substrates 0-4,M (w/subcom a,p,d,l,v); 11-50 cm depth
substrates 5-6; depths < =10 cm
substrate 5; depth > 50 cm
substrates 7-9, T(10); < =10 cm depth, vertical-edges
substrate T-rough (10H,Q); 11-25 cm; > 100 cm depth

Includes edge, open and very shallow water habitats with fine substrates and vegetative structuring; somewhat deeper areas (shallow-intermediate) with fine substrates and small vegetation structuring (a,p,d,l,v) have only slight cover; rocky (5-6) substrates in very shallow edges and 5 substrate in deep water areas (>50 cm); 7-9, T(10) substrates along very shallow shelves or terraces with sharp vertical drop off into deep water; t-rough substrate (10H,Q) in shallow 11-25 cm waters and very deep areas >1 m.

2 little: subs. 0-4, m (with subcom r,f,c,w); 11-50 cm depth
substrate 5 (any subcom); 11-50 cm depth
substrate 6 (any subcom); > 50 cm depth
substrates 6-9 (any subcom); depth 11-25 cm
substrate T-rough (10H,Q); depth > 26-100 cm

Includes open water areas of shallow to intermediate depth with fine substrates and coarse vegetation structuring or rocky (5) substrates; deeper areas with cobble substrates (6); shallow edge habitats with large substrates (6-9); shallow and deeper areas with rough T substrate (10H,Q).

3 moderate: substrate 5 (w/large "w" subcom); 11-50 cm depth
substrates 6-9; depth 26-50 cm

Includes shallow to intermediate rocky areas with large woody debris (> 25 cm size); intermediate depth open water areas with larger substrates (6-9); large intrusive travertine particles (6-9) in deep water and around dams.

4 extensive: substrates 7-9; depth > 50 cm
Includes large substrates in deep water habitats (> 50 cm).

5-8 deep water cover Achieved in deep water habitats (>50 cm) with large substrates (7-9), overhang, vertical edges, and little current.

Negative Values: unsuitable habitat generated by Corrected Cover (CCV) DBASE program to account for the negative effect of fast currents or extremely shallow depth. See COVER SUMMARY TABLE.

Cover Enhancement: The cover value of a particular habitat point can be enhanced by undercut banks, overhanging rock or travertine ledges, overhead shade from f,c,w, etc.). Slightly less enhancement occurs when the point is close to a sharp vertical edge (see Overhang section, above). Extremely shallow habitats ($<=10$ cm deep) are relatively unaffected by the scale of these enhancements. Enhancement is calculated as part of the net cover value (COVER) by a DBASE program.

Corrected Cover (CCV): These are cover values modified by consideration of the negative effect of current. See cover summary table. CCV is generated by a DBASE program.

DBASE numeric field [2]

Interpreting Cover (CVR) and CCV Values

Range of Cover (CVR) and Corrected Cover (CCV) values:

The primary cover value (CVR) does not account for the negative effect of current on cover. The range of possible values are -2 to +8. With the addition of CCV the range is expanded from -7 to +8.

Habitat points with negative cover values represent microhabitats that are unsuitable for fishes. Negative values reflect habitats that are very shallow, have fine substrates, little structuring, no overhang, and none to very fast currents.

Habitats with 0-2 cover values have little or no cover for larger fishes (>100 mm TL). Areas with 0-2 cover may be shallow with fine to coarse substrates and some structuring or they may be areas of deeper water, large substrates but fast currents.

Habitats with 2-4 cover values have moderate cover for larger fish (> 100 mm TL)

Habitats with >4 cover values offer extensive cover for larger fish (>100 mm TL). These areas are typically deep (>50 cm), with large substrates (7-9), have overhangs or are at vertical edges, and have zero to slow currents.

VER (*experimental variable*) A measure of vertical structure at a habitat sample point (0-5 scale):

0 no vertical structure
1 V in OVH and depth 10-25 cm
2 V in OVH and depth 25-50 cm
3 V in OVH and depth 50-100 cm
4 V in OVH and depth >100 cm
+1 E and O,L,U, or W in OVH, and depth>25 cm

DBASE numeric field [2]

VRC (*experimental variable*) Current corrected VER:

-1 CUR=3 and SUB1<6 (silt to rock) or CUR=4
-2 CUR=4 and SUB1<7 (silt to cobble) or CUR=5
-3 CUR=5 and SUB1<7 (silt to cobble) or CUR>5

DBASE numeric field [2]

VEG (*experimental variable*) A measure of vegetation density and size at a habitat sample point (0-3 scale):

0 no vegetation
1 small macrophytes or filamentous algae (A,P in SBC field)
2 roots and small emergent vegetation, rushes (V, R in SBC)
3 large emergent vegetation (F-phragmites, C- cattails/typha, S-shrubs in SBC field)

DBASE numeric field [2]

MAR (*experimental variable*) A measure of the thickness of unconsolidated $CaCO_3$ precipitate at habitat sample points (0-3 scale):

0 no marl
1 mixture or marl and silt or sand (SUB=1,2 and SBC=M)
2 marl coating on larger substrates 3-11
3 thick marl deposit as primary substrate (SUB=0, SBC=M)
DBASE numeric field [2]

TRA (*experimental variable*) A measure of the quantity and type of deposited travertine present at a sample point (0-4 scale):

0 no travertine
1 travertine coated primary substrates 4-9
2 smooth (SBC=B) or rough (SBC=H) travertine with effective particle size >4
3 travertine with effective particle size >5 (cobble size and larger) and associated with travertine dams and reefs (SBC=Q) or solid travertine (SBC=Z)
4 travertine with effective particle size >6 (boulder size and larger) and associated with travertine dams and reefs (SBC=Q) or solid travertine (SBC=Z)

DBASE numeric field [2]

SHA (*experimental variable*) A measure of the degree of shade present at a sample point (0-3 scale):

0 <10% or no shade
1 10-50% shade (F, C, S in SBC field)
2 50-75% shade (S in OVH field)
3 > 75% shade (O,U,L with S in OVH field)

DBASE numeric field [2]

DEB (*experimental variable*) A measure of amount and type of debris present at a sample point (0-3 scale):

0 no debris
1 detritus and leaves (SBC= D or L)
2 sticks and small logs (SBC=W)
3 large submerged logs (OVH=W)

DBASE numeric field [2]

SUMMARY TABLE: HABITAT COVER CATEGORIES (OTG 2/24/92)

substrate/depth	subcom*	cover value 0	1	2	3	4
0-4,M /all depths	none	0				
0-4,M / <=10 cm	any ex. M,T		1			
0-4,M / 11-50 cm	A,P,D,L,V		1			
0-4,M / 11-50 cm	R,F,C,W			2		
0-4,M / > 50 cm	any	0				
5-6 / <=10 cm	none/any		1			
5 / 11-50 cm	none/any			2	**	
5 / > 50 cm	none/any		1			
6 / > 50 cm	none/any			2		
7-9 / <=10 cm,pool-edge,none/any		0				
7-9 / <=10 cm,vert-edge,none/any			1			
6-9 / 11-25 cm	none/any			2		
6-9 / 26-50 cm	none/any				3	
7-9 / > 50 cm	none/any					4
T*** smooth/any depth, none,any		0				
T rough/<=10 cm,pool-edge,none/any		0				
T rough/<=10 cm,vert-edge,none/any			1			
T rough/> 11-25 cm	none/any		1			
T rough/ 26-100 cm	none/any			2		
T rough/ >100 cm	none/any		1			
T large/ >50 cm	none/any				3	
Cover enhancement ****						
Overhang						
any / <=10 cm	none/any	+0				
any / 11-25 cm	none/any		+1			
any / 26-50 cm	none/any			+2		
any / 51-100 cm	none/any				+3	
any / > 100 cm	none/any					+4
Near vertical edge						
any /<=10 cm w/in .25 m vert edge		+0				
any /11-25 cm w/in .25 m vert edge			+1			
any /26-50 cm w/in .5 m vert edge			+1			
any / 51-100 cm w/in 1 m vert edge				+2		
any />100 cm w/in 1 m vert edge					+3	

Negative effect of current on cover (substrate from cover value)

<u>Substrates 0-5, M; any depth:</u>

currents 0-2	0
current 3	-1
current 4	-3
current 5	-5

<u>Substrates 6-9, T; any depth:</u>

currents 0-3	0
current 4	-2
current 5	-4

Negative effect of shallow depth on cover (sub. from cover value)

<u>depths >0, <3 cm</u>
-2

<u>depths >2, <5 cm</u>
-1

* T or M subcom have no effect.

** with large woody debris (> 25 cm size) counts as cover 3.

*** "T" (10) as a primary substrate refers to nascent travertine, i.e., recently formed or actively forming travertine that completely covers and consolidates old substrates, i.e., they are no longer recognizable as 6, 7, etc. The default "T" substrate is rough (SBC=H); the effective substrate size is recorded as 5 or 6. Smooth bottoms of consolidated travertine are coded as 10B (effective particle size = 4). Solitary or detached large chunks of old or fossil travertine dams that have been re-exposed and moved should be treated as substrate particles, usually in the size range of 8-9. Large pieces of travertine that protrude greatly into the water column should estimated at to effective particle size in the 7-9 range. Note that "T" associated with travertine dams/terraces/reefs (SBC=Q) has the same value as 10H but may provide overhanging cover (O) and vertical structure (V).

**** overhanging cover: from overhanging vegetation (overhead shade) on bank, undercut bank, or overhanging ledge, etc. Vertical edges (large 7-9 rocks), undercut banks, overhanging ledges within .25 m for habitat points 11-25 cm depth, .5 m of point for 26-50 cm depth, and within 1 m for points with depth >50 cm (> 50 cm change in depth per 100 cm horizontal distance).

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Arizona Fishery Resources Office

Habitat use by humpback chub, *Gila cypha*,
in the Little Colorado River and other tributaries of the
Colorado River

GCES Phase II Final Report

APPENDIX II

SUMMARY OF WATER QUALITY AND HYDROLOGY FOR THE LITTLE COLORADO RIVER, 1991-1994

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SUMMARY OF WATER QUALITY AND HYDROLOGY FOR THE LITTLE COLORADO RIVER, 1991-1994

A. Water quality, Little Colorado River

Explanation of water quality measures

Basic water quality measures were taken at Powell Camp (km 3.1) at one hour intervals with a Hydrolab Surveyor 2 with attached data logger. These data were supplemented with manual readings taken twice daily (approx. 0700 and 1700 hrs). In 1994 we replaced the Hydrolab Surveyor 2 with a Hydrolab Surveyor 3; the new instrumentation provided more reliable autologging. Water quality measures at Salt Camp (km 10.7) were taken manually an ICM model 51100 water analyzer twice daily (approx. 0700 and 1700 hrs). Turbidity was measured at both camps with a Hach model 16800 or 2100P analog nephelometer. Standard 8" black and white secchi disks were used at both camps. Ambient temperatures were recorded using min-max thermometers. River stage was estimated by taking USGS gauge readings at Cameron, AZ, and adding 250 cfs (the estimated discharge from Blue Springs).

Key to water quality parameters

High-highest recorded value for the particular measure
Low-lowest recorded value for the particular measure
Mean-arithmetic mean
Median-midpoint of range of readings
SD-standard deviation of the sample
Amb-ambient temperature in degrees Fahrenheit
Temp-water temperature in degrees Celsius
pH-pH units
Cond-conductivity in μS/cm
DO-dissolved oxygen in mg/l
Sal-salinity in grams/l
ORP-oxidation-reduction potential in mV
Secc-secchi disk measure in cm
Turb-turbidimeter measure in NTU's
Stage-discharge of the river in cubic feet/second

WATER QUALITY PARAMETERS 1991 POWELL CAMP

Trip date July 1-13

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		27.1	8.26	5250	8.5	---	----	-----	.152
Low		21.6	7.29	4850	7.5	---	----	-----	.074
Median		24.4	7.77	5050	7.9	---	----	-----	.113

Trip date July 1-August 7

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		24.3	8.37	5240	8.3	2.4	----	-----	.100
Low		22.3	8.21	5220	8.0	2.4	----	-----	.048
Median		23.3	8.29	5230	8.2	2.4	----	-----	.074

Trip date August 12-23

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		26.2	8.19	5110	8.4	2.4	----	-----	.083
Low		21.3	7.70	5030	7.5	2.3	----	-----	.049
Median		23.7	7.95	5070	7.9	2.3	----	-----	.066

Trip date October 15-22

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		22.1	8.31	5240	8.9	2.4	----	-----	.094
Low		18.2	7.43	4340	8.0	2.4	----	-----	.051
Median		20.2	7.87	4790	8.5	2.4	----	-----	.073

Trip date December 9-17

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		16.2	8.13	4600	9.8	---	----	+31cm	---
Low		8.6	7.85	2640	5.2	---	----	0	---
Median		12.4	7.99	3620	7.5	---	----		---

WATER QUALITY PARAMETERS 1992 POWELL CAMP

Trip date February 12-19

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		14.8	8.03	3729	10.5	1.5	----	-----	.145
Low		13.9	7.99	3489	10.3	1.4	----	-----	.121
Median		14.4	8.01	3607	10.4	1.4	----	-----	.133

Trip date April 22-29

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		24.0	7.52	3109	11.1	1.2	----	-----	.263
Low		16.2	7.17	1739	9.3	0.4	----	-----	.109
Median		20.1	7.35	2420	10.2	0.8	----	-----	.186

Trip date June 15-24

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		25.6	7.85	5110	8.3	2.4	----	-----	.263
Low		17.9	7.60	4850	6.8	2.2	----	-----	.225
Median		21.7	7.73	4980	7.6	2.3	----	-----	.244

Trip date July 14-23

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High		25.8	7.31	4250	9.7	1.9	2cm	+14cm	.332
Low		20.8	7.10	2250	8.5	0.7	.5cm	-1cm	.260
Median		23.3	7.20	3250	9.1	1.3			.296

Trip date August 12-19

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		25.8	7.30	3689	9.8	1.5	----	-----	.338
Low		21.7	6.90	1489	8.6	0.3	----	-----	.226
Median		23.7	7.10	2589	9.2	0.9	----	-----	.282

Trip date November 9-17

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		17.2	---	4769	11.9	2.2	----	-----	---
Low		13.5	---	3079	10.1	1.2	----	-----	---
Median		15.3	---	3924	11.0	1.7	----	-----	---

WATER QUALITY PARAMETERS 1993 POWELL CAMP

Trip date February 10-17

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	90	11.8	7.9	2560	13.5	0.9	15920	2788	.280
Low	40	7.7	7.7	961	10.3	0.0	1280	546	.213
Mean		9.0	7.7	1448	12.5	0.2	7599	1513	.261
SD		1.4	0.2	546	0.8	0.3	5702	712	.023

Trip date March 2-5

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	90	11.5	7.7	1450	10.2	0.2	22940	6318	.389
Low	40	7.8	7.7	1185	8.9	0.1	4814	1383	.349
Mean		9.6	7.7	1352	9.5	0.2	12238	5516	.367
SD		1.5	0	106	0.5	0.0	9497	1104	.014

Trip date March 22-26

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	93	16.4	7.6	1125	9.3	0.0	16384	2320	1.53
Low	57	11.9	6.3	832	8.3	0.0	5824	2175	.286
Mean		14.1	6.5	928	8.8	0.0	9143	2211	.419
SD		1.3	1.7	71	0.5	0.0	4888	43	.234

Trip date April 12-21

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	97	18.2	7.8	2900	9.4	1.1	2748	897	.326
Low	48	13.0	7.5	1500	7.7	0.3	1088	505	.073
Mean		15.6	7.7	2042	8.5	0.6	1953	684	.292
SD		1.6	0.5	400	0.7	0.2	552	127	.038

Trip date May 10-19

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	104	23.9	7.5	4700	12.9	2.1	68	348	.320
Low	65	18.7	7.2	4450	10.3	2.0	12	342	.213
Mean		21.2	7.4	4598	11.6	2.1	29	345	.258
SD		1.5	0.1	59	0.7	0.0	21	2	.034

Trip date June 8-16

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	113	24.5	8.8	5190	8.6	2.4	4.2	250	.298
Low	69	18.9	7.2	4790	6.1	2.2	2.0	250	.017
Mean		21.7	7.5	4953	6.6	2.3	2.9	250	.130
SD		1.5	0.5	126	0.6	0.1	1.2	0	.094

Trip date July 12-21

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	109	25.1	7.8	4920	7.9	2.2	2.5	250	.157
Low	80	21.4	7.5	4830	6.9	2.2	1.7	250	.047
Mean		22.4	7.7	4877	7.6	2.2	2.0	250	.123
SD		1.1	0.1	28	0.2	0.0	0.4	0	.040

Trip date August 9-17

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	110	26.1	7.7	5069	9.9	---	2.9	250	.397
Low	70	20.3	6.4	4700	7.7	---	2.3	250	.082
Mean		22.4	7.4	4950	8.8	---	2.5	250	.259
SD		1.9	0.5	100	1.0	---	0.3	0	.042

Trip date September 10-18

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	103	22.2	8.1	4813	8.1	---	21700	1457	.313
Low	64	17.3	7.3	1342	7.1	---	400	250	.241
Mean		19.3	7.7	3319	7.6	---	5730	435	.298
SD		1.5	0.5	1374	1.0	---	7317	316	.017

WATER QUALITY PARAMETERS 1994 POWELL CAMP

Trip date April 12-21

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		21.9	7.89	3818	8.3	2.1	1000	-----	.437
Low		16.1	7.75	3127	7.4	1.7	85	-----	.318
Mean		18.7	7.80	3485	7.8	1.9		-----	.397

Trip date May 10-18

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	102	22.3	7.46	4680	9.2	---	1000	-----	.516
Low	60	17.7	7.25	3397	6.8	---	85	-----	.475
Median	81	20.0	7.37	4038	8.0	---		-----	.496

Trip date June 6-14

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	121	24.1	8.89	5009	8.4	---	4.0	-----	.531
Low	74	19.3	8.54	4709	6.6	---	2.0	-----	.432
Median	98	21.7	8.72	4859	7.5	---	3.0	-----	.482

Trip date August 9-18

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	110	24.8	7.93	5266	--	2.9	4.5	-----	.535
Low	80	22.6	7.67	4981	--	2.7	4.0	-----	.438
Median	95	23.7	7.80	5134	--	2.8	4.25	-----	.487

WATER QUALITY PARAMETERS 1991 SALT CAMP

Trip date July 1-13

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		23.9	7.89	3930	8.8	1.7	----	-----	.077
Low		20.5	7.78	3840	7.9	1.6	----	-----	.027
Median		22.2	7.85	3885	8.4	1.6	----	-----	.050

Trip date July 21-August 3

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		26.5	8.00	3910	8.9	1.7	50	-----	.115
Low		21.7	7.76	3840	7.7	1.6		-----	.067
Median		24.1	7.88	3875	8.3	1.6		-----	.090

Trip date August 11-24

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		26.8	8.01	4980	8.5	2.3	----	-----	.161
Low		21.9	7.85	4820	7.8	2.2	----	-----	.067
Median		24.4	7.93	4900	8.2	2.2	----	-----	.011

Trip date October 15-22

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		21.2	7.55	4600	8.0	---	----	-----	---
Low		18.0	7.52	4220	6.7	---	----	-----	---
Median		19.6	7.54	4410	7.6	---	----	-----	---

Trip date December 9-16

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		16.8	7.90	4540	11.8	---	----	-----	---
Low		6.4	7.75	2380	9.2	---	----	-----	---
Median		11.6	7.83	3460	10.5	---	----	-----	---

WATER QUALITY PARAMETERS 1992 SALT CAMP

Trip date March 5-10

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High		18.2	8.75	2640	11.3	0.9	----	-----	.237
Low		12.2	8.02	424	10.7	0.0	----	-----	.212
Median		15.2	8.36	1532	11.0	0.5	----	-----	.225

Trip date March 26-April 2

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High		15.3	8.88	1130	11.3	0.1	<1	-----	.281
Low		12.3	7.24	423	10.5	0	0	-----	.081
Median		13.8	8.06	777	10.9	0		-----	.181

Trip date April 22-27

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High	85	20.9	8.17	3460	11.3	---	5cm	-----	---
Low	63	15.9	7.67	2150	7.9	---	2cm	-----	---
Median	74	18.4	7.92	2805	9.6	---	3.5cm	-----	---

Trip date June 15-24

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High		23.5	7.20	4370	7.8	---	35cm	-----	---
Low		16.9	6.87	4130	5.3	---	20cm	-----	---
Median		20.2	7.04	4250	6.6	---	28cm	-----	---

Trip date August 12-19

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High	103	23.9	8.03	3600	6.8	---	0.5cm	-----	---
Low	80	21.9	7.70	3300	6.0	---	.25cm	-----	---
Median	92	22.9	7.87	3450	6.4	---	.35cm	-----	---

Trip date September 23-October 2

	Amb	Temp	pH	Cond	DO	Sal	Secchi	Stage	ORP
High	111	21.0	8.11	4000	8.1	---	2cm	-----	---
Low	64	16.6	6.77	1780	7.2	---	1cm	-----	---
Median	88	18.8	7.44	2890	7.7	---	1cm	-----	---

Trip date November 9-17

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	74	16.2	7.73	4240	9.3	---	---	-----	---
Low	43	13.7	7.67	2500	8.5	---	---	-----	---
Median	59	14.9	7.70	3370	8.9	---	---	-----	---

WATER QUALTIY PARAMETERS 1993 SALT CAMP

Trip date March 2-5

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	80	10.3	8.1	1240	11.6	----	----	6318
Low	44	7.2	7.9	1180	9.1	----	----	1383
Mean		8.4	8.0	1220	10.5	----	----	5516
SD		1.3	0.1	22	0.9	----	----	1104

Trip date March 22-26

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	84	13.4	8.3	867	10.8	----	----	2320
Low	51	12.2	7.8	729	8.9	----	----	2175
Mean		13.0	8.1	802	10.1	----	----	2211
SD		0.4	0.2	48	0.6	----	----	43

Trip date April 12-21

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	92	17.3	8.3	2062	10.8	----	----	879
Low	47	12.3	8.1	1740	7.7	----	----	505
Mean		15.2	8.2	2052	9.1	----	----	684
SD		1.6	0.1	90	1.0	----	----	127

Trip date May 10-19

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	106	22.4	7.6	4850	8.9	234	----	348
Low	64	18.7	7.3	4320	6.0	24	----	342
Mean		20.5	7.5	4567	7.2	82	----	345
SD		1.3	0.1	147	0.7	60	----	2

Trip date June 8-16

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	109	23.7	8.0	4880	8.0	350	3.6	250
Low	63	17.3	7.3	4410	6.1	320	3.0	250
Mean		20.3	7.7	4627	6.9		3.3	250
SD		2.2	0.2	125	0.5		0.3	0

Trip date July 12-21

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	108	22.9	7.6	5010	7.1	----	6.5	250
Low	74	18.8	7.2	4480	4.7	----	3.2	250
Mean		20.6	7.4	4721	6.1	----	4.7	250
SD		1.6	0.1	129	0.8	----	1.2	0

Trip date August 9-17

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	108	23.0	7.7	5250	7.7	300	9.7	250
Low	68	18.2	7.3	4700	4.2	200	3.1	250
Mean		20.2	7.5	4951	5.7	254	5.8	250
SD		1.5	0.1	151	1.0	34	2.0	0

Trip date September 10-18

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	102	20.7	8.0	4690	10.5	----	22272	1457
Low	58	15.5	7,0	1690	7.3	----	38	250
Mean		17.8	7.5	3633	8.1	----	5763	435
SD		1.6	0.3	1176	0.9	----	8348	316

Trip date November 4-8

	Amb	Temp	pH	Cond	DO	Secc	Turb	Stage
High	78	15.5	7.6	5390	10.4	142	8.4	250
Low	44	12.3	7.0	4920	7.9		6.0	250
Mean		14.0	7.4	5084	9.4		7.3	250
SD		1.1	0.3	150	1.0		1.0	0

WATER QUALITY PARAMETERS 1994 SALT CAMP

Trip date April 12-21

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	102	24.4	8.66	4280	--	---	577	-----	---
Low	56	13.2	8.13	3240	--	---	112	-----	---
Median	79	18.8	8.40	3760	--	---	345	-----	---

Trip date May 10-18

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	98	22.8	7.93	4380	10.7	---	3400	-----	---
Low	59	17.2	7.54	3050	8.1	---	161	-----	---
Median	78	20.0	7.74	3715	9.4	---		-----	---

Trip date June 6-14

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	111	24.9	7.85	4930	--	---	6.5	-----	---
Low	71	19.3	7.65	4100	--	---	4.0	-----	---
Median	91	22.1	7.73	4515	--	---	5.3	-----	---

Trip date August 9-18

	Amb	Temp	pH	Cond	DO	Sal	Turb	Stage	ORP
High	102	26.5	8.86	5160	8.1	2.3	16.3	-----	.420
Low	79	17.7	7.02	4670	6.0	2.2	6.5	-----	.315
Median	91	22.1	7.94	4915	7.1	2.3	12.0	-----	.370

APPENDIX II

SUMMARY OF WATER QUALITY AND HYDROLOGY FOR THE LITTLE COLORADO RIVER, 1991-1994

B. 1 October 1989 - 1 October 1994 hydrographs

Overview of hydrology of the Little Colorado River, 1989-1994.

Seasonal patterns of discharge in the Little Colorado River (LCR) over the period 1989-1994 do not show much consistency. Except for one 2000 cfs spate in March 1990, there was no discharge from LCR upstream of Blue Springs over the period of mid-October 1989 through early July 1990. Note that base flow in the lower 21 km of the LCR is maintained by a constant discharge of ~250 cfs from the Blue Springs complex at km 21. From July through October 1990 the LCR experienced regular spates >2000 cfs and discharge was elevated for more than half that time. There were elevated flows in Spring 1991 that declined in early May and remained at base flow until some ~1000 cfs spates in September. Throughout 1992 there were frequent spates (many exceeding 2000 cfs) and long periods of elevated discharge. From January through April 1993 discharge in the LCR remained above 1000 cfs. During January and February, three flood events with discharge exceeding 10,000 cfs occurred. From May until September 1993 the LCR remained at base flow. Like the winter of 1990, there was little upstream discharge in the winter of 1994. A short period of spring flooding occurred in March and April 1994 and except for a small spate in June (<500 cfs), remained at base flow until September.

Inspection of length-frequency histograms for humpback chub over the period 1991-1994 reveal the effects of the timing, duration, and intensity of discharge on reproduction and recruitment (Fig 4.). Sampling data for 1991 does not suggest a large 1990 year class; recruitment was probably hampered by the frequent mid-summer floods in 1990. However, spawning may have commenced in early winter that year so that some YOY fish may have been 6 months old and >100 mm TL (yearling size fish) by the time the summer flooding started. A combination of a protracted spawning period and broad size class of YOY fish in 1990 makes evaluation of reproductive success ambiguous from the perspective of 1991 catch data. Conditions in 1991 were ideal for reproduction; high spring flows were followed by more than 3 months of base flow conditions. The very successful 1991 year class of humpback chub dominated the population until summer 1993. Throughout 1992 the LCR was peppered with flooding and more than half the time discharge was well above base flow (and muddy). Humpback chub reproduction in 1992 failed to produce new fish; however the 1991 yearlings were able to persist despite the regular flooding. The large floods of winter 1993 did not appear to impact the resident humpback chub, but the floods modified the available habitat in the river channel by scouring most of the finer sediments (see Append. III-V). High spring discharge declined to base flow by May 1993 and remained stable for four months. This pattern is similar to that observed in 1991, and in 1993 as in 1991, humpback chub showed good reproductive success. The pattern in 1994 once again was similar to that in 1991, and humpback chub appeared to have had good reproductive success. The common elements to successful reproduction in LCR humpback chub are: elevated spring discharge that drops to base flow by late April-early May and remains at base flow for 3 or more months of the summer. After this period, YOY fish are of sufficient size (65-85 mm TL) to withstand and not be displaced by typical flooding events in the LCR.

Figure 1. **USFWS LCR fish habitat studies:**
Hydrograph, Little Colorado River at Cameron, AZ.

Maximum daily discharge data (MAXQ) is plotted for the period 1 October 1989 through 1 October 1994. Date scale is shown in two-week steps. Flattened steps in hydrograph usually indicates that the gauge was clogged with sediment and/or was temporarily inoperative. In order to provide a constant scale of reference, maximum discharge is fixed at 10,000 cfs. The three January-March 1993 flood events exceeded 10,000 cfs. The Cameron gauge malfunctioned during those floods so that the duration and timing of the peak flows is not accurate. Based on data from the Grand Falls gauge on the Little Colorado River and the Bright Angel gauge downstream on the Colorado River, the peak discharge in early January 1992 exceeded 17,000 cfs and the peak discharge in late February 1992 exceeded 15,000 cfs (see Figs. 2-3).

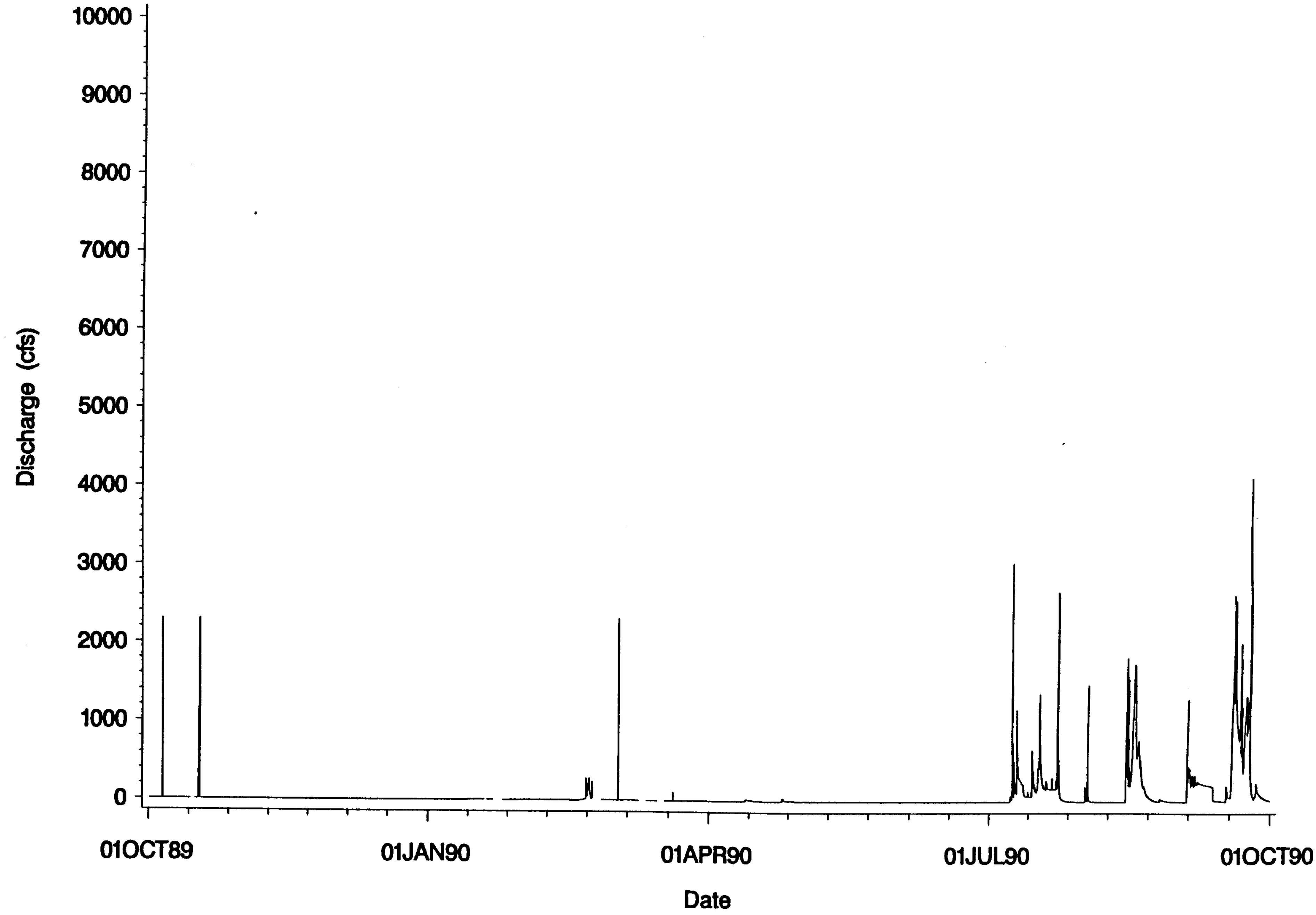
Data for these hydrographs was collected by US Geological Survey.

Hydrographs were produced for USFWS by Bureau of Reclamation/GCES.

Little Colorado River near Cameron, AZ

Station: 09402000

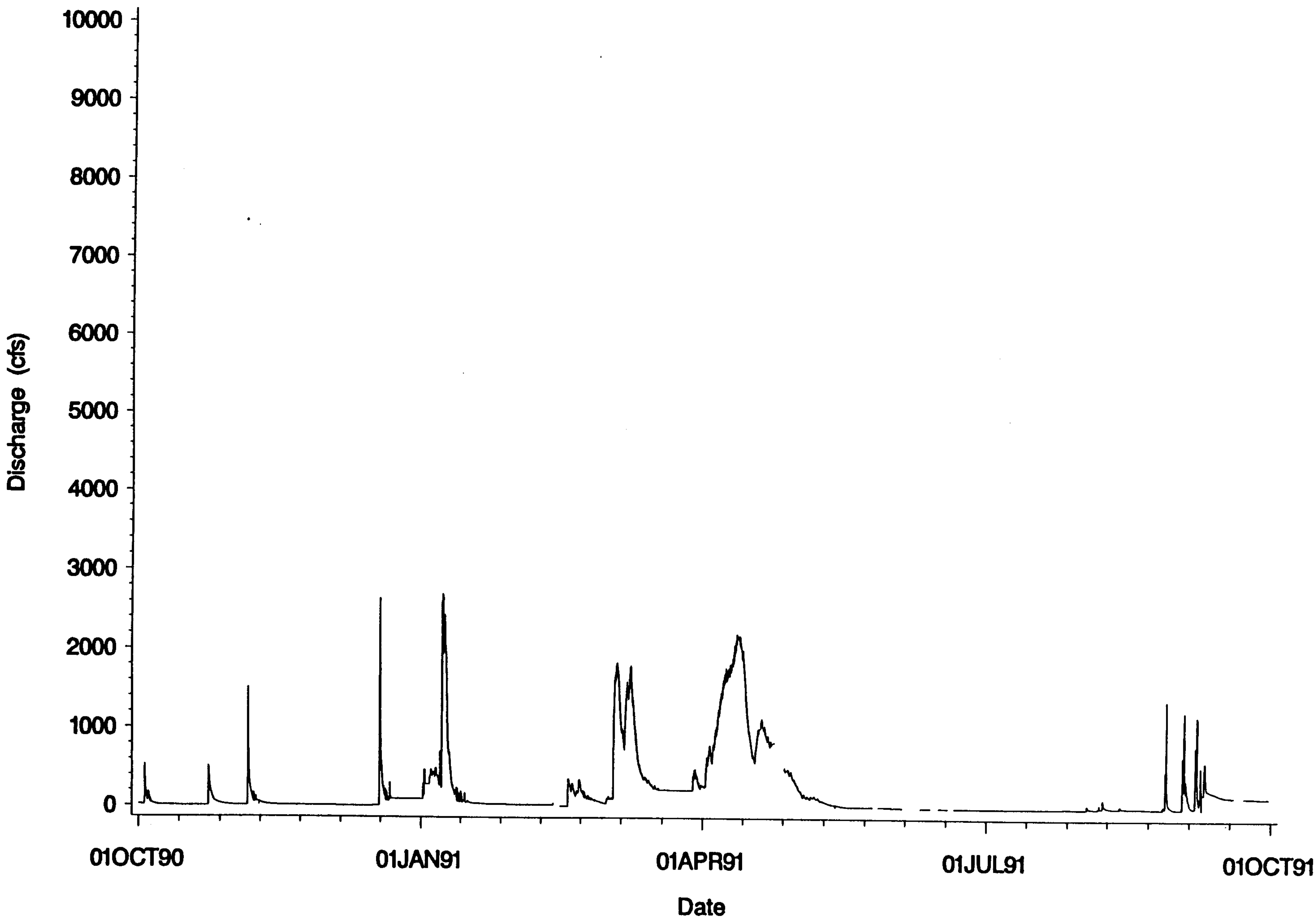
USGS Gaged Discharge – Provisional Data



Little Colorado River near Cameron, AZ

Station: 09402000

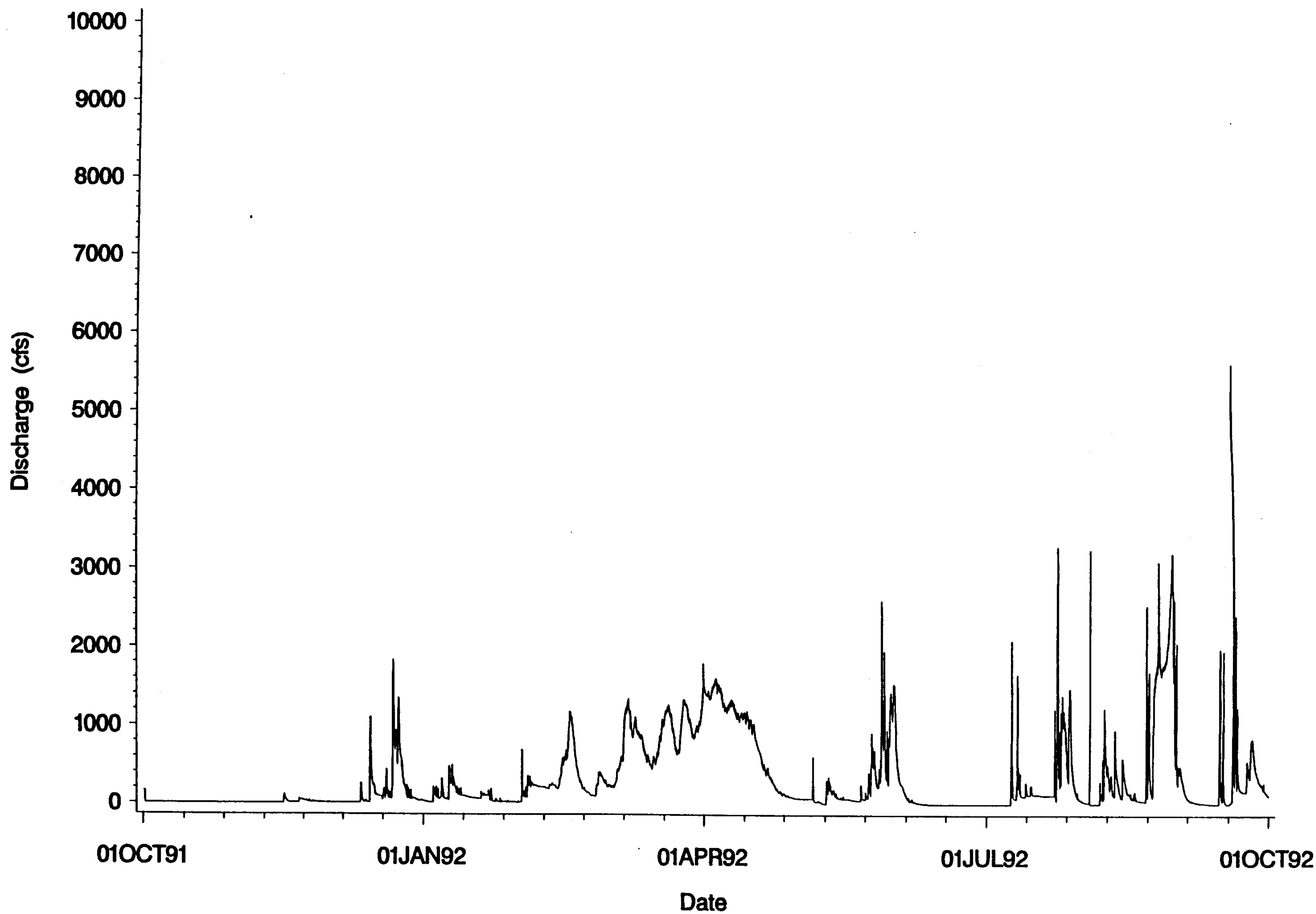
USGS Gaged Discharge – Provisional Data



Little Colorado River near Cameron, AZ

Station: 09402000

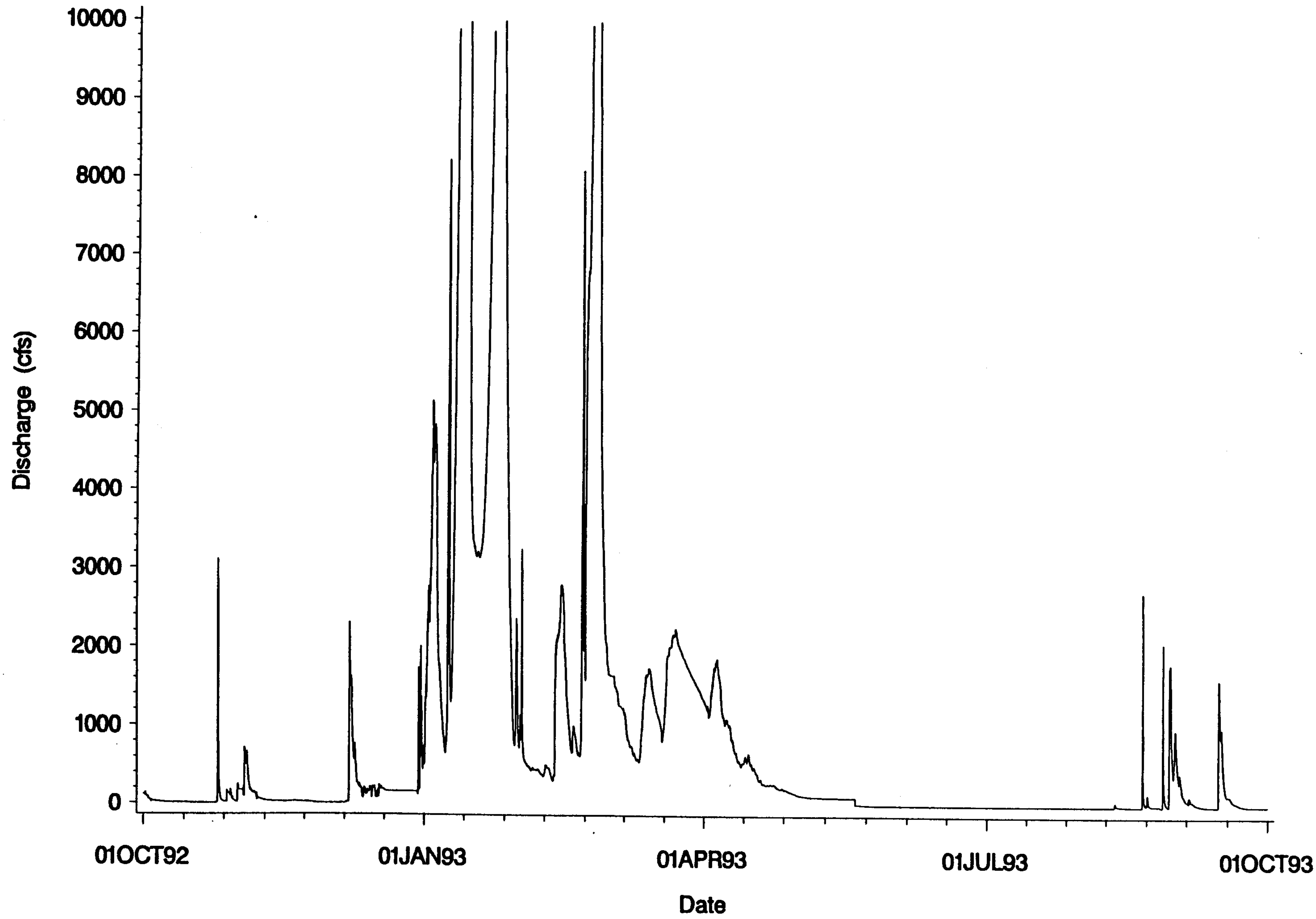
USGS Gaged Discharge – Provisional Data



Little Colorado River near Cameron, AZ

Station: 09402000

USGS Gaged Discharge — Provisional Data



Little Colorado River near Cameron, AZ

Station: 09402000

USGS Gaged Discharge – Provisional Data

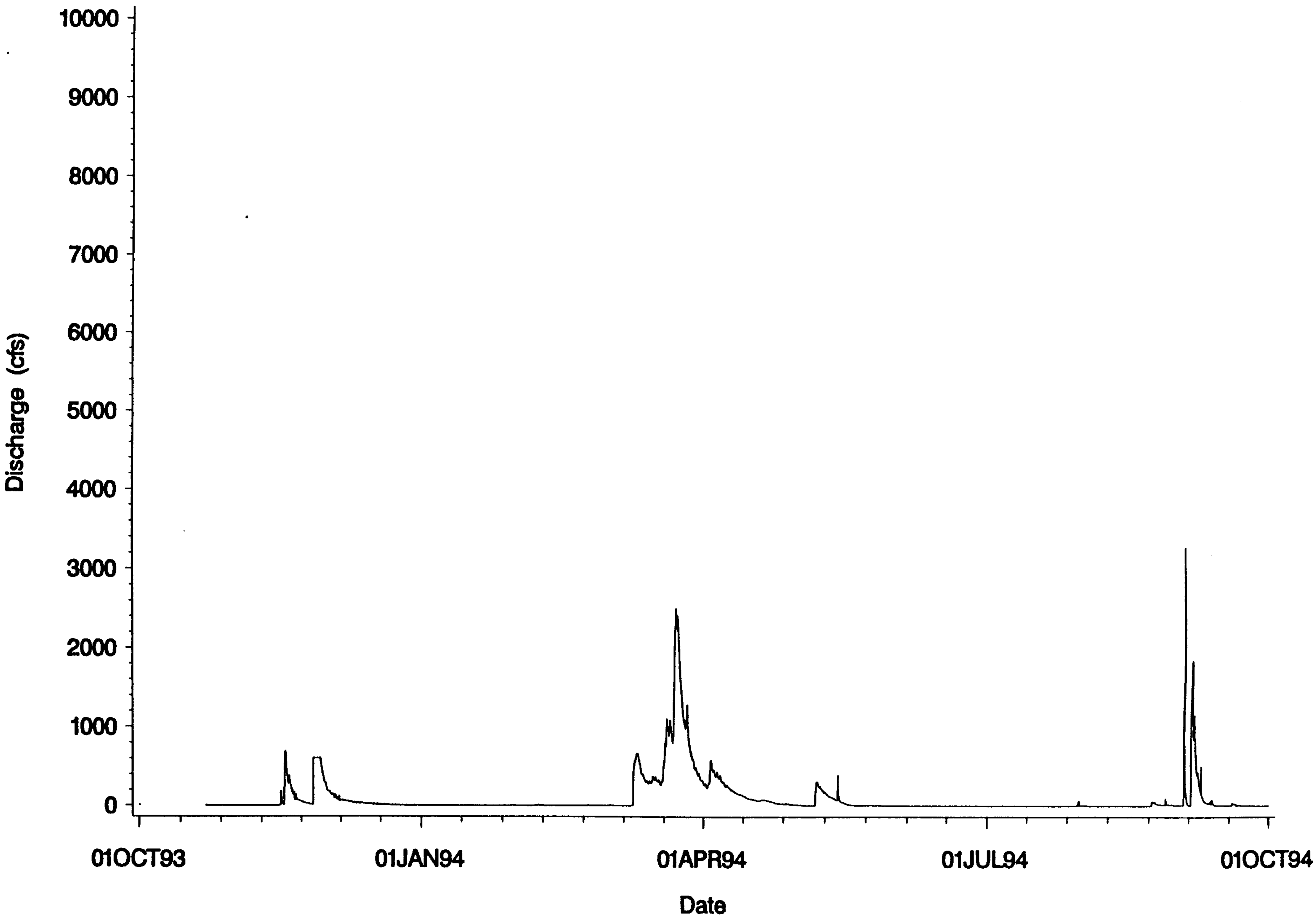


Figure 2. **USFWS LCR fish habitat studies: Composite Hydrograph, Little Colorado River at Grand Falls and Cameron, AZ.**

Maximum daily discharge data (MAXQ) is plotted for the period 1 October 1992 through 1 December 1993. Discharge from the Grand Falls gauge does not include that from Moenkopi and San Francisco washes. Note that the peak discharge at the Grand Falls gauge for the late February flood is near 15,000 cfs.

Data for these hydrographs was collected by US Geological Survey.

Hydrographs were produced for USFWS by Bureau of Reclamation/GCES.

Maximum Daily Discharge in Little Colorado River
1993
USGS Gaged Discharge – Provisional Data

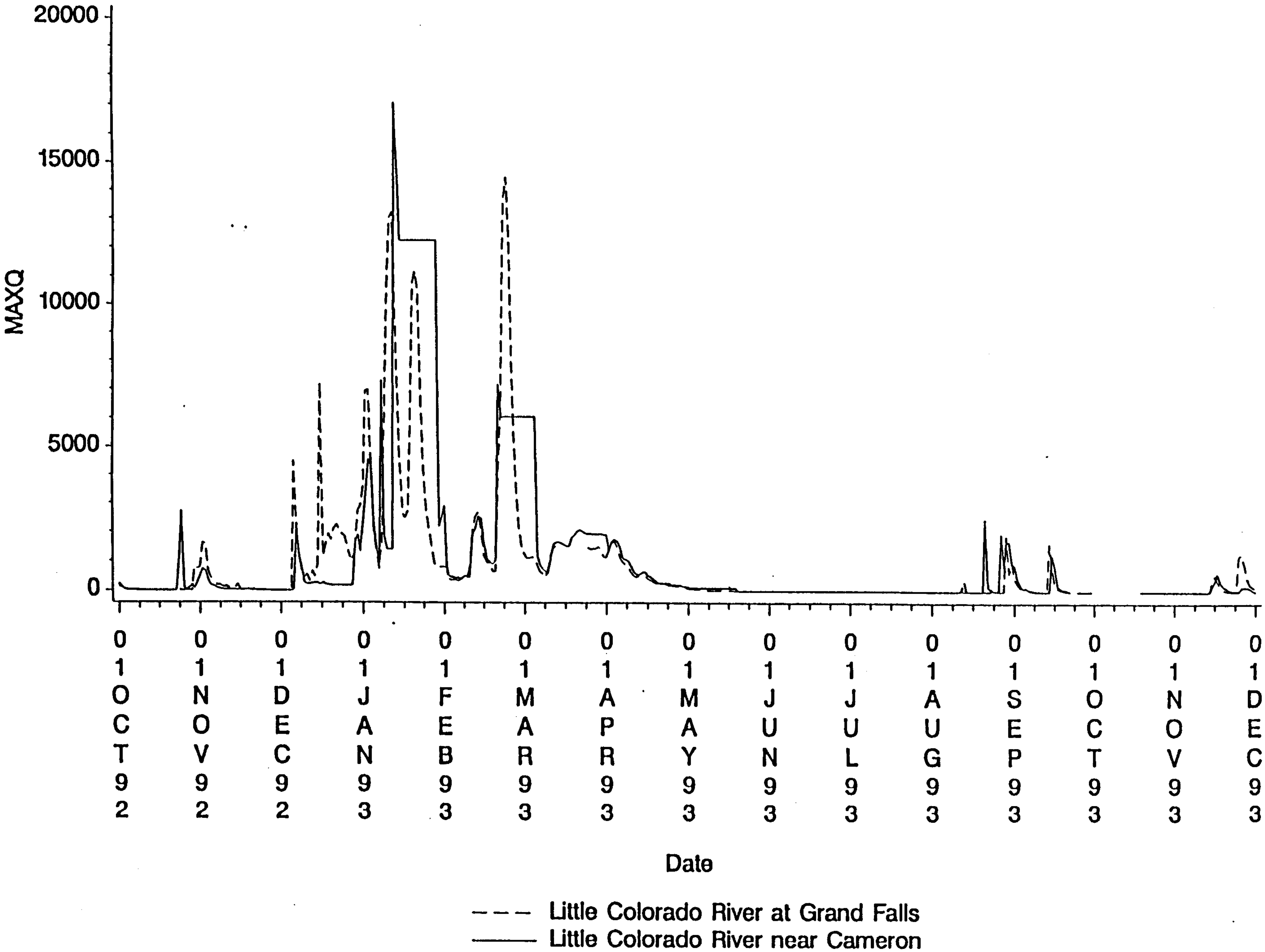


Figure 3. **USFWS LCR fish habitat studies: Hydrograph, Colorado River at Lees Ferry and Phantom Ranch, AZ.**

Maximum daily discharge data (MAXQ) is plotted for the period 1 October 1992 through 1 December 1993. This plot is a superimposition of discharge data from Lees Ferry and Phantom Ranch. The difference shows the discharge contribution to the Colorado River by the Little Colorado River. Note the three spike flood events during January through March, 1993.

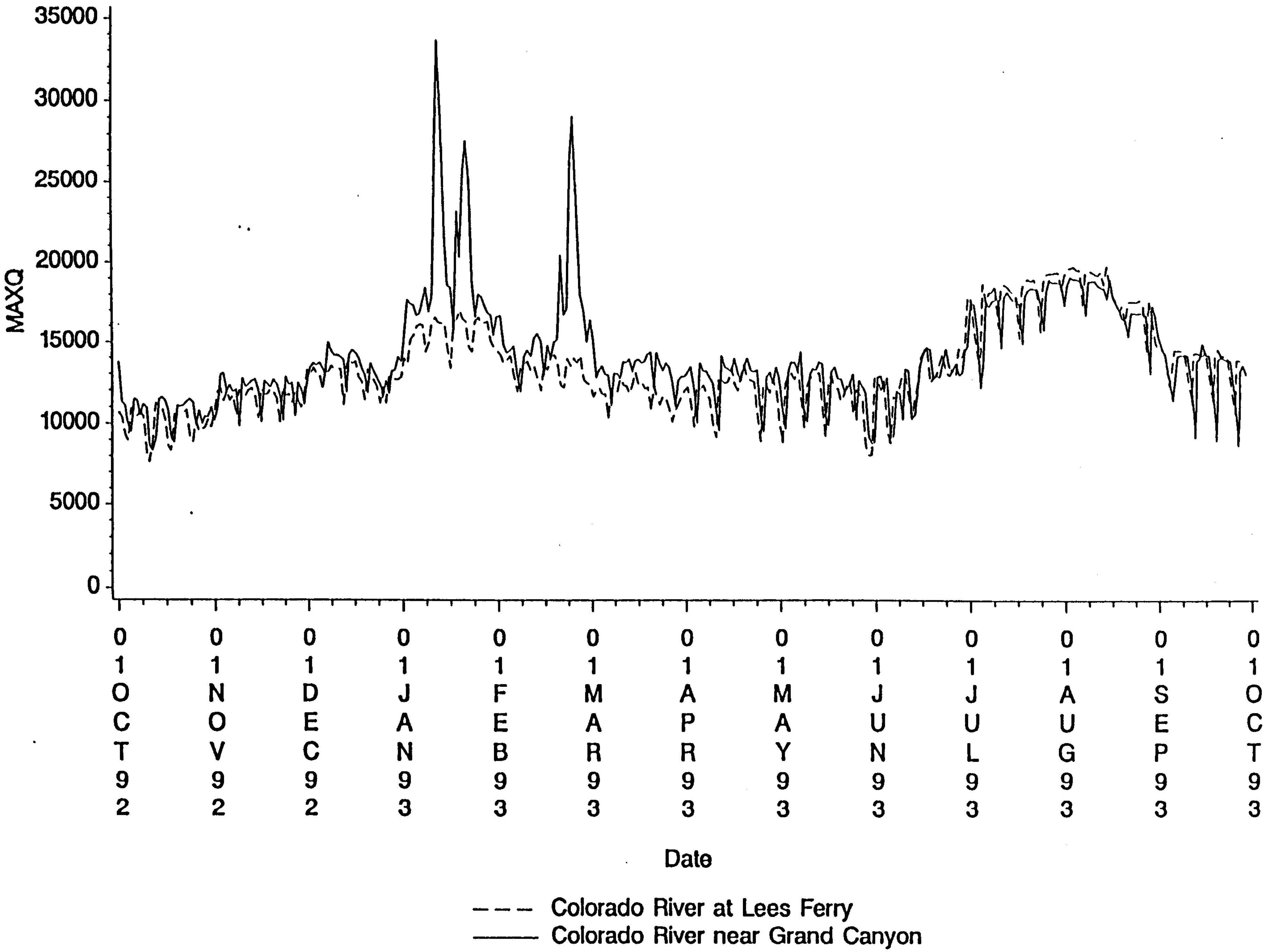
Data for these hydrographs was collected by US Geological Survey.

Hydrographs were produced for USFWS by Bureau of Reclamation/GCES.

Maximum Daily Discarge at Lees Ferry and Phantom Ranch

1993

USGS Gaged Discharge – Provisional Data



United States Department of the Interior
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Arizona Fishery Resources Office

Habitat use by humpback chub, *Gila cypha,*
in the Little Colorado River and other tributaries of the
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APPENDIX III

1991 AVAILABLE HABITAT IN THE LITTLE COLORADO RIVER, KM 0-21

APPENDIX III.

1991 AVAILABLE HABITAT IN THE LITTLE COLORADO RIVER, KM 0-21

Data shown represents available habitat in the Little Colorado River (LCR) in summer 1991. USFWS transects were established at 20 m intervals from the confluence (0 km) to Blue Springs (km 21). Available habitat was determined from sampling transects at 100 m intervals (every 5th transect) over the 21 km reach. At each transect, habitat sample points were spaced at 1 m intervals across the stream channel. Sample size: 210 transects, 6,802 sample points.

The first panel shows frequency histograms of available habitat for the entire 21 km reach. The 2nd-5th panels show available habitat in 5 km sections of the LCR starting from the confluence reach (km 0-4.99).

The array of habitat present in 1991 was very different than in 1993. This is because large floods over the winter of 1993 scoured most of the sand out the LCR channel. The result in 1993 was deeper pools, slower currents, increased amount of exposed cobbles, boulders and travertine substrates, and less sand and marl.

Description of available habitat

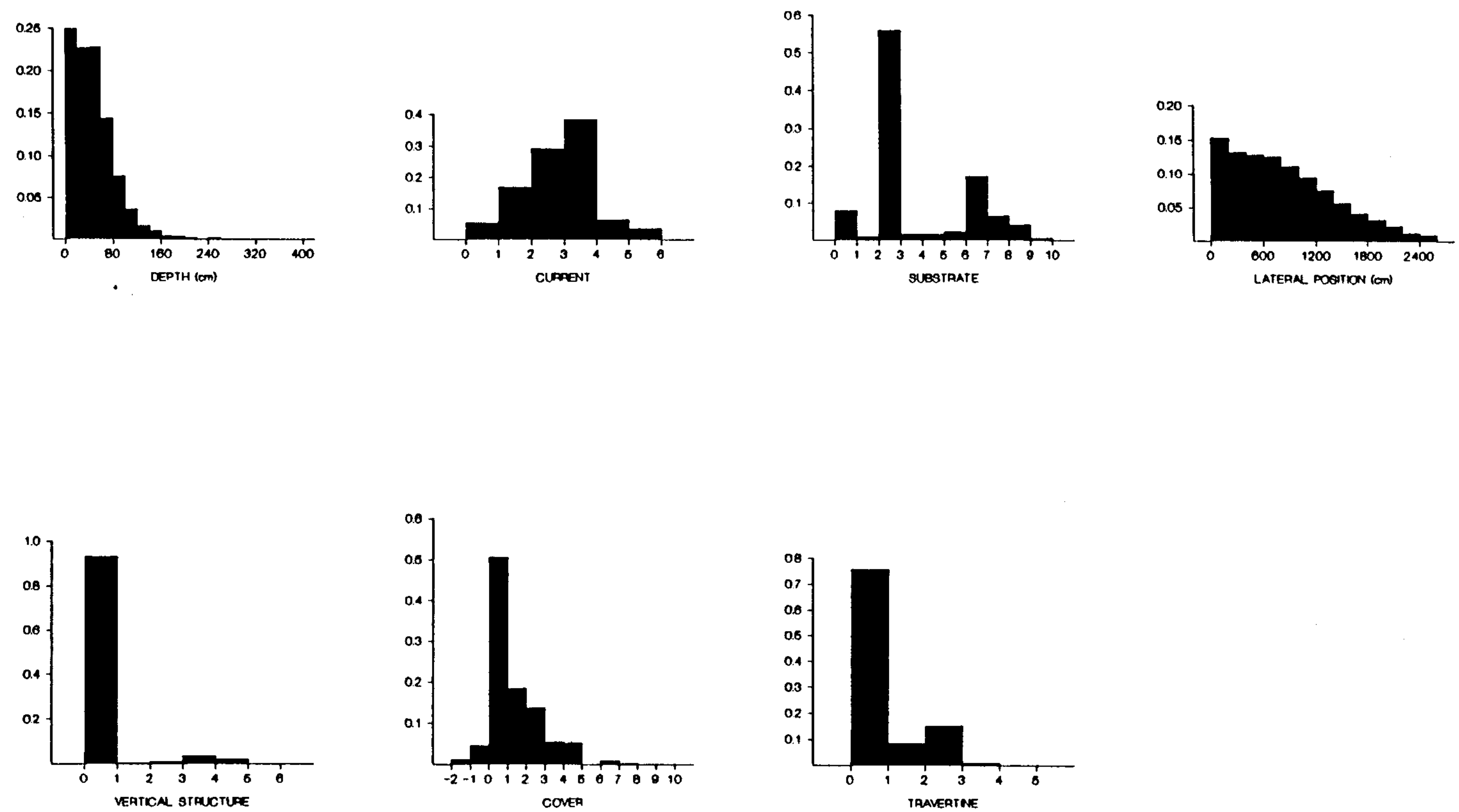
PANEL 1. km 0-21. The LCR is moderately deep (most areas >50 cm but < 150 cm deep), characterized by moderate to slow currents (CUR=2-3; 0.1-0.7 m/s), contains mostly sand and cobble substrate (most of the "cobble" is consolidated travertine), and is wide (>600 cm wide). Areas of high vertical structure (VER>2) are relatively rare as are areas of high cover (>3).

PANEL 2. km 0-4.99. Compared to overall, the lowermost reach of the LCR has more large boulders (SUB>7) and an increase predominance of moderate current (CUR=3; 0.3-0.7 m/s). Travertine is limited to incrustation of alluvial substrates.

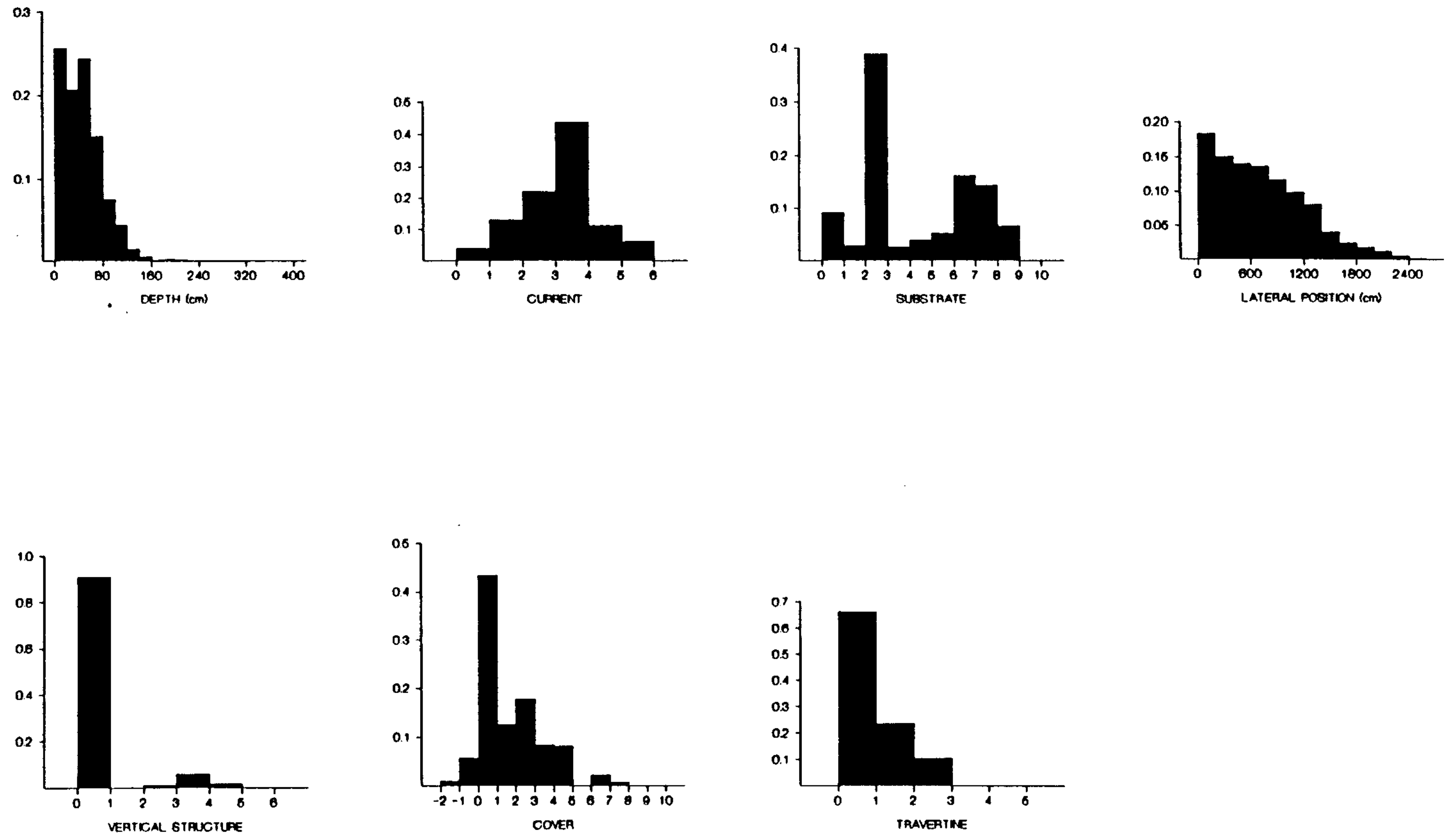
PANEL 3. km 5.0-9.99. The lower-middle reach has an increased amount of unconsolidated travertine precipitate ("marl"; represented as substrate 0), there are more areas with wider channel, vertical structure and cover are reduced, and there is more consolidated travertine deposits (TRA>1) but less boulder substrate (substrate>6).

PANEL 4. km 10.0-14.99. The upper-middle reach contains most of the travertine dams and reefs in the LCR. As a result of the ponding effect of the many dams, currents are reduced with slow (CUR=2) being modal (0.10-0.30 m/s). There is a reduction in marl substrate (SUB=0), fewer large boulders, fewer wide channel sections, more vertical structure, and increased amounts of consolidated travertine (TRA=2) and travertine in the form of dams and reefs (TRA=3).

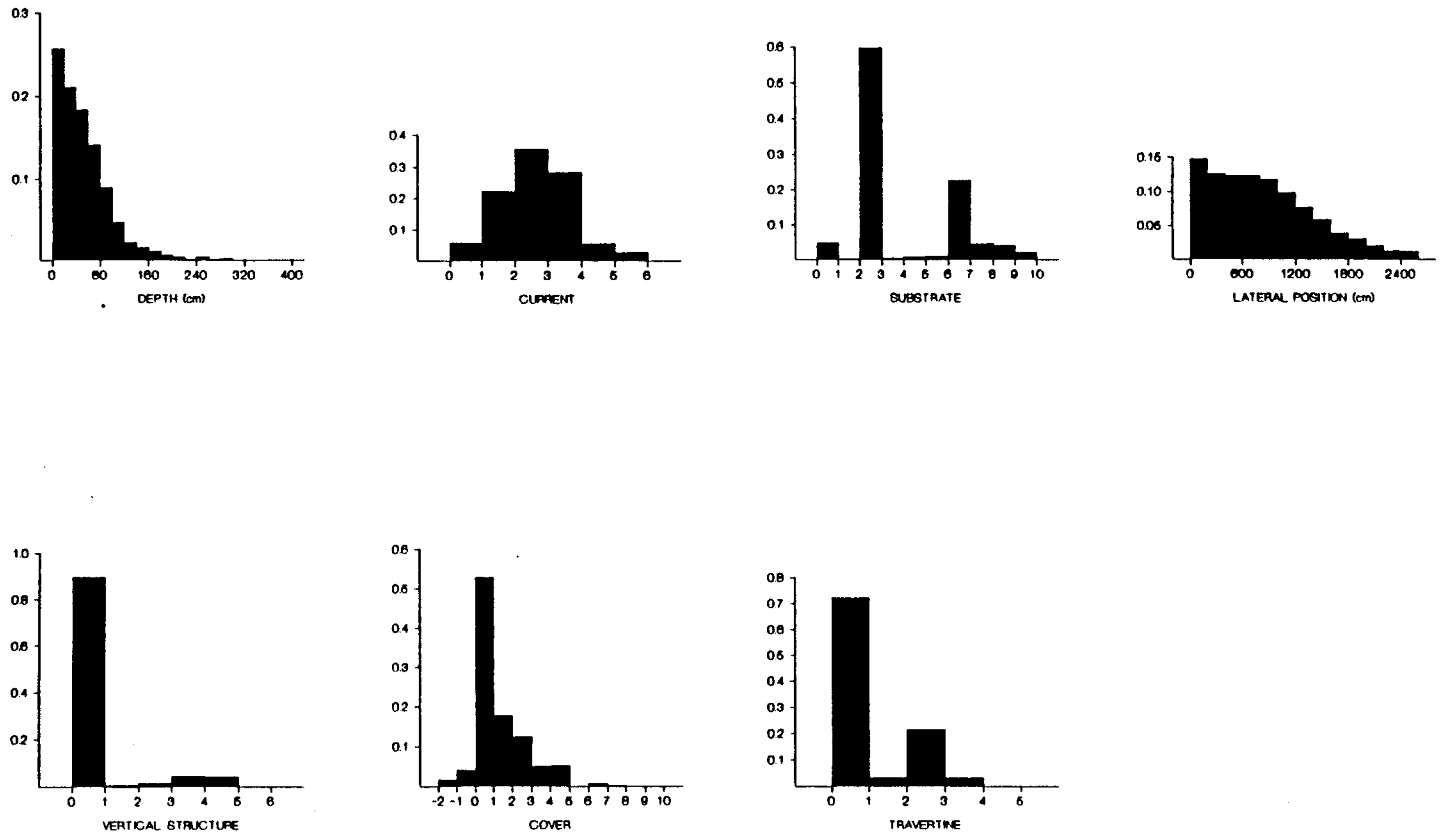
PANEL 5. km 15.0-21.0. The upper reach of the LCR is visibly very different at base flow. Above km 17 there are no consolidated travertine deposits and the water is usually very clear as there is no travertine precipitate (Mattes, 1993). Humpback chub are not known to occur above km 15 where dissolved CO_2 levels at base flow exceed 200 ppm, the lethal limit for most stream fish (Mattes, 1993). In the absence of travertine dams, the modal currents return to moderate (CUR=3; 0.30-0.70 m/s), substrates are dominated by sand (SUB=2) and there is a reduction in cobbles and boulder substrate (SUB>5), and areas of high vertical structure (VER>2) and cover (CVR>3) are reduced. There is a decrease in the amount of consolidated travertine present and these deposits only occur in the km 15-17 reach.



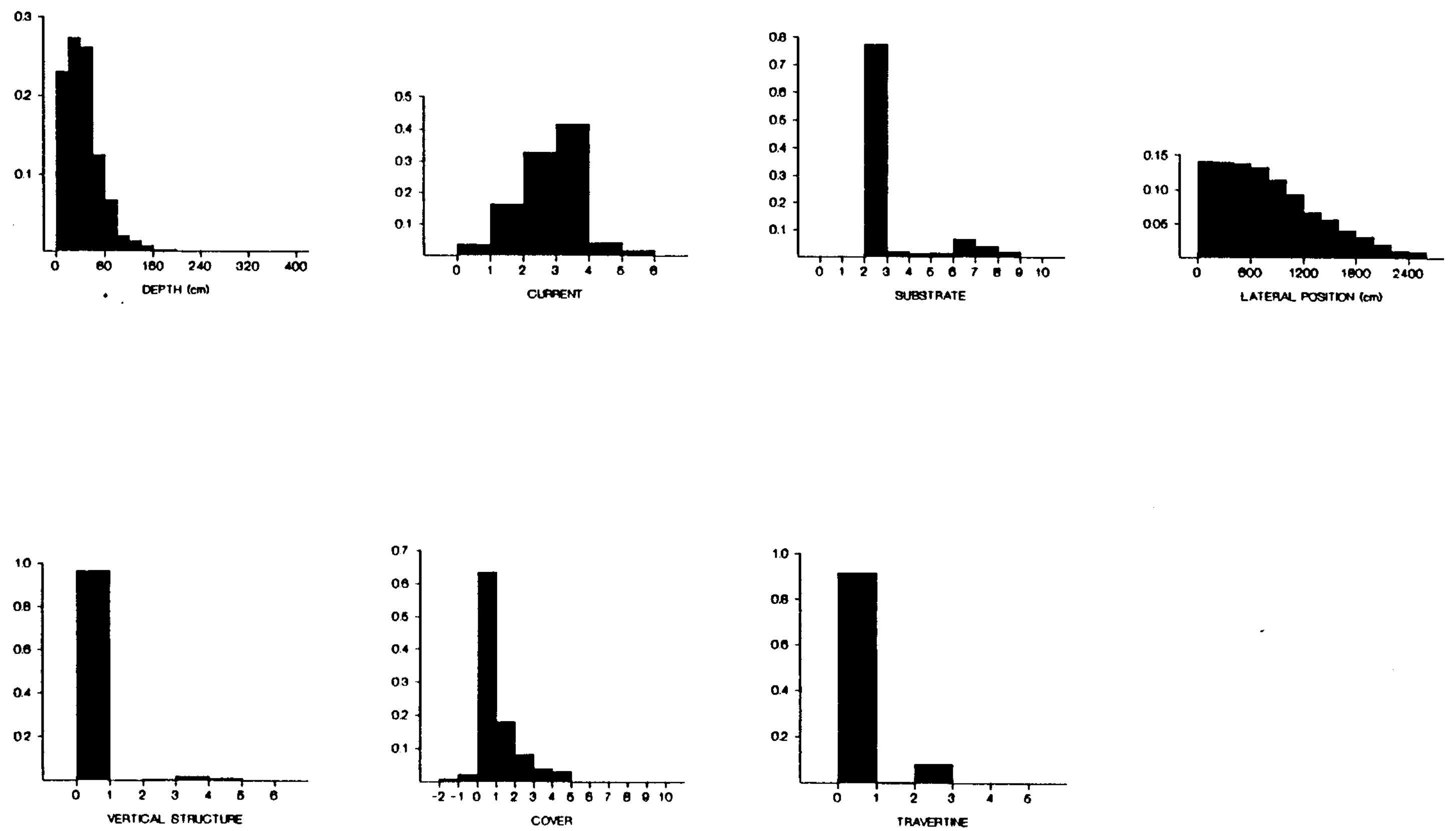
Little Colorado River 0.0-21.0 km
July-August 1991
Available Habitat N = 6802



Little Colorado River 0.00-4.99 km
7-8/91
Available Habitat N = 1539



Little Colorado River 10.0-14.99 km
Available Habitat N = 1727



Little Colorado River 15.0-21.0 km
Available Habitat N = 1909

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Habitat use by humpback chub, *Gila cypha*,
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GCES Phase II Final Report

APPENDIX IV

ANALYSIS OF HABITAT USE BY LCR FISHES, POWELL STUDY REACH, JUNE 1992

APPENDIX IV

ANALYSIS OF HABITAT USE BY LCR FISHES, POWELL STUDY REACH, JUNE 1992

June was the only sampling period in 1992 where the LCR remained at base flow for more than one month (see Append. II). This Powell Study Reach data set was the first opportunity to look at habitat use patterns under relatively stable conditions (lower Powell Study Area, Figs. 2-3). As with the analysis presented in Appendix V we first present available vs. habitat sampled for fish (sampled habitat), and then compare habitat use distributions with sampled habitat and habitat use among other fishes. Finally, we present a Principal Component Analysis of sampled habitat with projections of habitat use by LCR fishes onto PCA space.

Available habitat in 1992 was somewhat different than in 1993. The stream was shallower, had faster currents, and sand was the predominant substrate. Despite these differences, humpback chub showed very similar habitat use patterns in 1992 and 1993: they associated with areas containing large substrates and increased cover and vertical structure. During the day adult humpback chub showed greater association with deeper near-shore areas (vertical banks) containing high cover and vertical structure, but moved out to center channel areas with less cover and vertical structure at night. Because of a reproductive failure in 1992, essentially no YOY fish were present in the LCR. The size classes represented in the frequency distributions are juveniles (yearlings, >100 mm TL) to adult fish (>210 mm TL). For humpback chub, most of the individuals in our samples were juveniles (100-150 mm TL; 1991 year class).

Habitat sampled for fish

The transect data or available habitat data (Append. IV Fig. 1) is very similar to the transect habitat data for 1991 (Append III) and even more similar to the Powell Study Area subset for 1991 (Gorman et al., 1993). Noticeable differences in 1992 compared to 1991 include less marl (expected result of frequent flooding in 1992) and slower modal currents for this particular reach. The combined minihoopnet and minnow trap habitat data represented the "habitat sampled for fish" (Append. IV Fig. 2). The sampled habitat differs from the available habitat in that very shallow areas <10 cm deep are under-represented (cannot be effectively sampled with minnow traps) and modal currents are slightly higher than available (related to undersampling of relatively still shallow habitats). The higher amounts of travertine and larger substrate particle sizes in sampled habitats is also related to the same sampling bias. The LATP data show peculiar peaks at 4-5m intervals; this interval was the spacing distance for our systematic minihoopnet sampling grids. These deficiencies are viewed as relatively minor, and more importantly, were expected and can be defined or accounted for by comparison of data sets.

Habitat use patterns

Habitat use patterns by the fish follow two basic patterns: those that are more diurnally active vs. those that are more nocturnally active (Append. Table 3, Append. Fig. 3-4). Speckled dace (SPD) and humpback chub (HBC) show almost opposite patterns of habitat use: SPD are more diurnally active, use shallow edge areas with small substrate particles (<7) and low cover (<3). HBC use deeper water areas with larger substrate particles (>6), greater vertical structure (particularly >2) and greater cover (particularly > 4). In contrast to SPD, HBC show different patterns of habitat use in day vs. night periods. During the day HBC tend to use areas <400 cm from stream banks, use larger substrates (particularly 7, 8), slower currents, and increased use of category 4 cover. At night, HBC tend to move out from stream banks areas and use the entire stream channel (Append. Fig. 3). Although there is less use of areas of high cover HBC still shows an affinity for these habitats.

The PCA shows less diel change in habitat use by humpback chub than is evident in our analysis of 1993 data (Append. V). This is due in part because the variables and loadings are different between 1992 and 1993 and because the variables are not selected to maximize differences in habitat use by fish, but to reduce dimensionality of the habitat data set. Also, because most 1992 humpback chub were juveniles, their habitat use is expected to be intermediate between YOY and adults (see Append. V). YOY humpback chub are more diurnally active and use shallower habitats while adults are nocturnally active and use deeper habitats (Append. V.).

Although the amount of data for evaluation of bluehead sucker (BHS) and flannelmouth sucker (FMS) is much less than for the dominant species (SPD, HBC), the habitat use patterns are clear and consistent. Like the HBC, BHS and FMS daytime habitat use is largely restricted to nearshore habitats and use of midchannel habitats increases noticeably at night. Like the HBC, BHS and FMS show increased use of habitats with higher cover and vertical structure during the day; however this difference is more pronounced in the suckers. The suckers tend to show increased use of areas with faster currents, particularly at night. BHS stands out in their use of fast current (4) compared to the other species. FMS shows a greater difference in use of currents between day and night; during the day the use slow and slack water habitats with much cover and appear to shift to open channel habitat with moderate currents at night. BHS show an unusually affinity for large boulder areas with much cover during the day and shift to shallower, faster water habitat with smaller substrates at night.

TABLE 1. Habitat variables (full descriptions are contained in Appendix I)

Primary habitat variables:
DPH (depth, cm)
DPH2 (depth in 10cm intervals, depths= >210 are scored as 210 cm)
CUR (current velocity, 0-5 categories)
SUB (substrate particle size, 0-11 categories)
LATP (lateral distance from habitat pt to nearest stream edge in cm)
LATDS (lateral distance from set to nearest stream edge in cm)
VER (vertical structure at habitat point, 0-5 categories)
CVR (cover at habitat point, -2 to +7 categories)
CCV (current corrected cover at habitat pt, -5 to +7 categories)
TRA (type and amount of travertine at habitat pt, 0-3 categories)
MAR (type and amount of marl at habitat pt, 0-3 categories)
VEG (type and amount of vegetation at habitat pt, 0-3 categories)
SHA (type and amount of shade at habitat pt, 0-3 categories

Other habitat variables used in the analyses:
PT (depth at point of net)
MTH (depth at mouth of net)
GEAR (net gear type, mesh size, dimensions, # hoops)
DATE (date measurements were taken
EDG (distance to emergent edges within 100 cm)
CC (secondary current descriptors)
SS (secondary substrate and vegetation descriptors)
OVH (overhang and vertical structure descriptors)

TABLE 2. USFWS LCR fish habitat studies, Powell Study Reach 6/92: summary of sampling effort and diel catch rates.

A. Habitat sampling effort
(all nets and traps were set for a 24 hr period; "sets" are equivalent to trap/net days)

	N	# habitat pts
transects measured	36	999
minihoop net sets	90	1982
minnow trap sets	90	368

B. Fish captures

humpback chub	
adult (tagable, >150 mm TL)	31
juvenile	145
bluehead sucker	11
flannelmouth sucker	14
speckled dace	890

C. Overall fish capture statistics (sample period: 8 days; catch period per set: 24 hrs)

	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	176	122	65	395	0.92	3331
bluehead sucker	11	224	140	347	0.06	216
flannelmouth sucker	14	135	77	206	0.08	271
speckled dace	880	74	54	118	4.64	6357

D. Night fish capture statistics (sampling period 1800-800 hrs; 14 hrs)

	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	102	131	65	395	0.91	1932
bluehead sucker	5	207	140	258	0.04	100
flannelmouth sucker	9	131	77	206	0.08	176
speckled dace	282	73	56	115	2.51	2272

E. Day fish capture statistics (sampling period 800-1800 hrs; 10 hrs)

	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	74	109	76	354	0.80	1378
bluehead sucker	6	240	145	347	0.08	116
flannelmouth sucker	5	144	127	156	0.06	95
speckled dace	598	74	54	118	7.48	4085

TABLE 3. USFWS LCR fish habitat studies, Powell Study Reach, 6/92: summary of Principal Component Analysis.

Data set: USFWS-LCR/Powell-6/92, sampled habitat (minihoopnet and minnow trap)

Sample size: 2150 points

Variables entered: DPH (depth), CUR (current), SUB (substrate), LATP (lateral position)

Data transformation: $\log_e$ (variable +1)

FACTORS	1	2	3	4
LATENT ROOTS (Eigenvalues)				
	1.857	0.999	0.647	0.497
COMPONENT LOADINGS				
CUR	<u>0.806</u>	0.185	0.210	<u>0.522</u>
LATP	<u>0.755</u>	-0.288	<u>0.437</u>	<u>-0.396</u>
DPH	<u>0.645</u>	<u>-0.482</u>	<u>-0.593</u>	0.001
SUB	<u>0.470</u>	<u>0.806</u>	-0.247	-0.260
PERCENT of TOTAL VARIANCE EXPLAINED BY COMPONENTS				
	46.41	24.99	16.18	12.42

Figure 1. **USFWS LCR fish habitat studies, Powell Study Reach 6/92: available habitat sample along FWS transects.**

FWS transect habitat: Powell 6/92

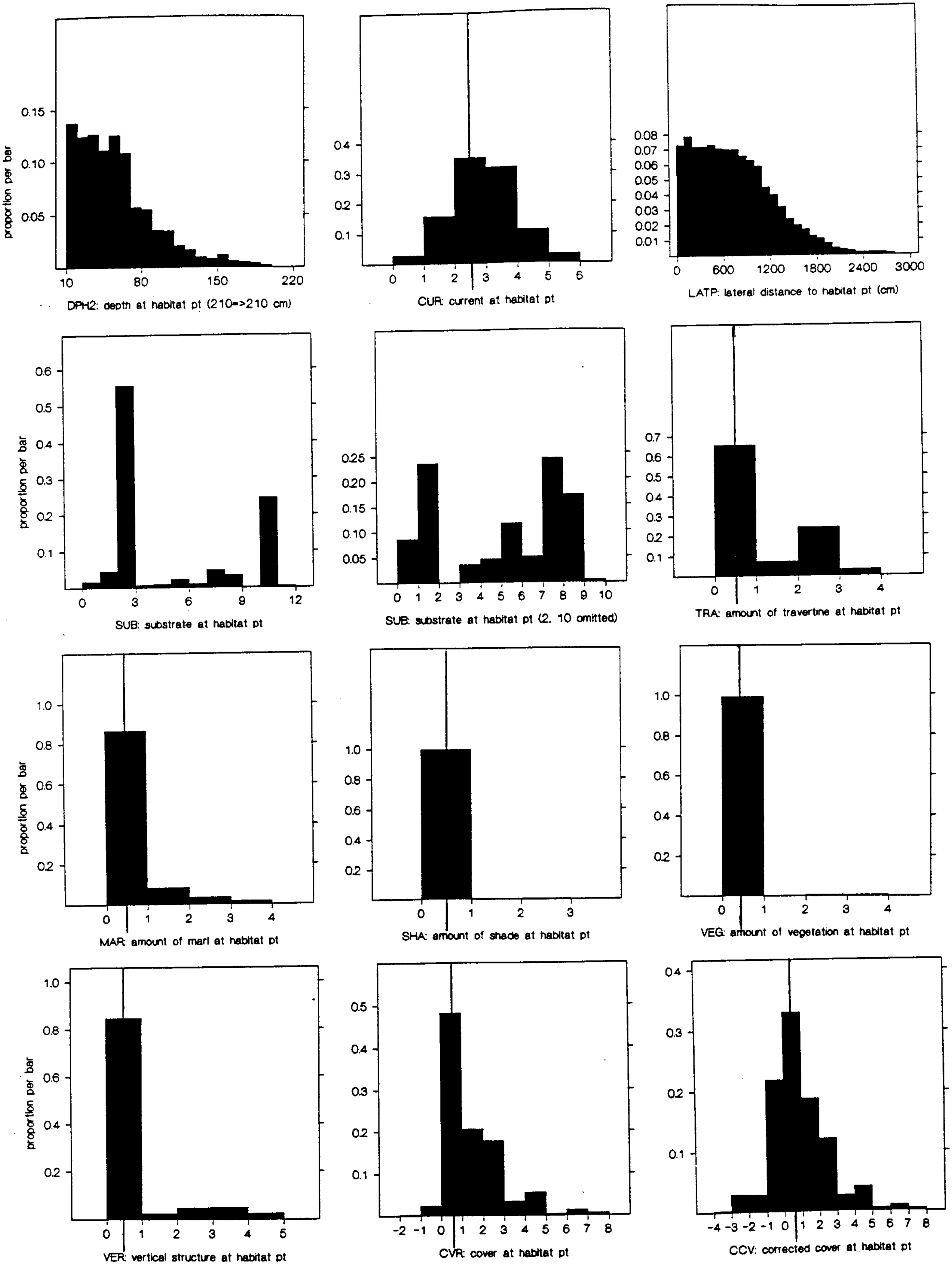


Figure 2. **USFWS LCR fish habitat studies, Powell Study Reach 6/92: minihoop/minnow trap habitat (sampled habitat).**

FWS minnoop/minnow trap habitat. Powell 07/92

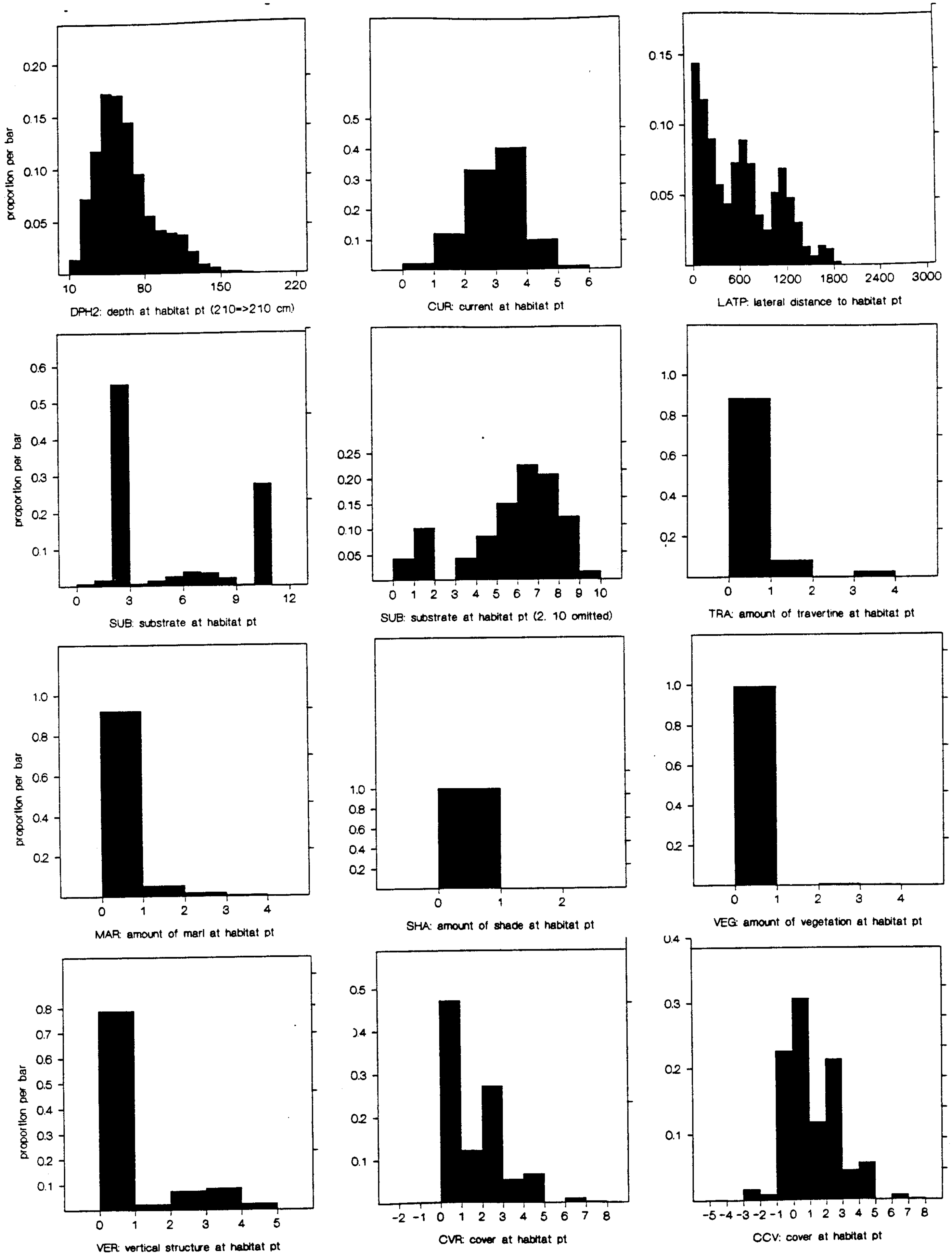


Figure 3. USFWS LCR fish habitat studies, Powell Study Reach 6/92: species habitat use.

Data shown represents weighted habitat use by species for day and night sampling periods in the USFWS Powell Study Reach, June 1992. Species habitat use shown are:

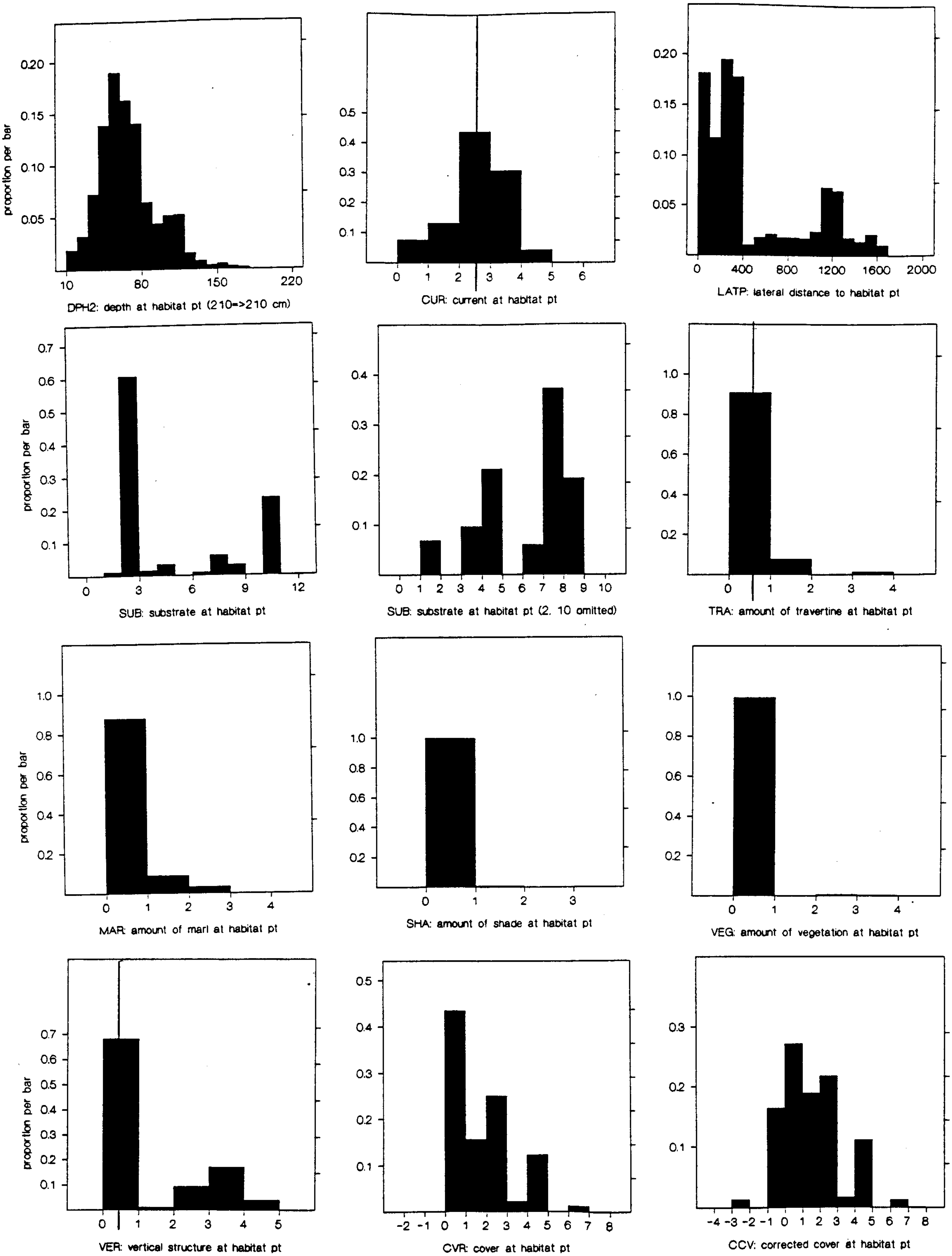
humpback chub (HBC)
- HBC habitat use (day): FWS/Powell 6/92
- HBC habitat use (night): FWS/Powell 6/92

speckled dace (SPD)
- SPD habitat use (day): FWS/Powell 6/92
- SPD habitat use (night): FWS/Powell 6/92

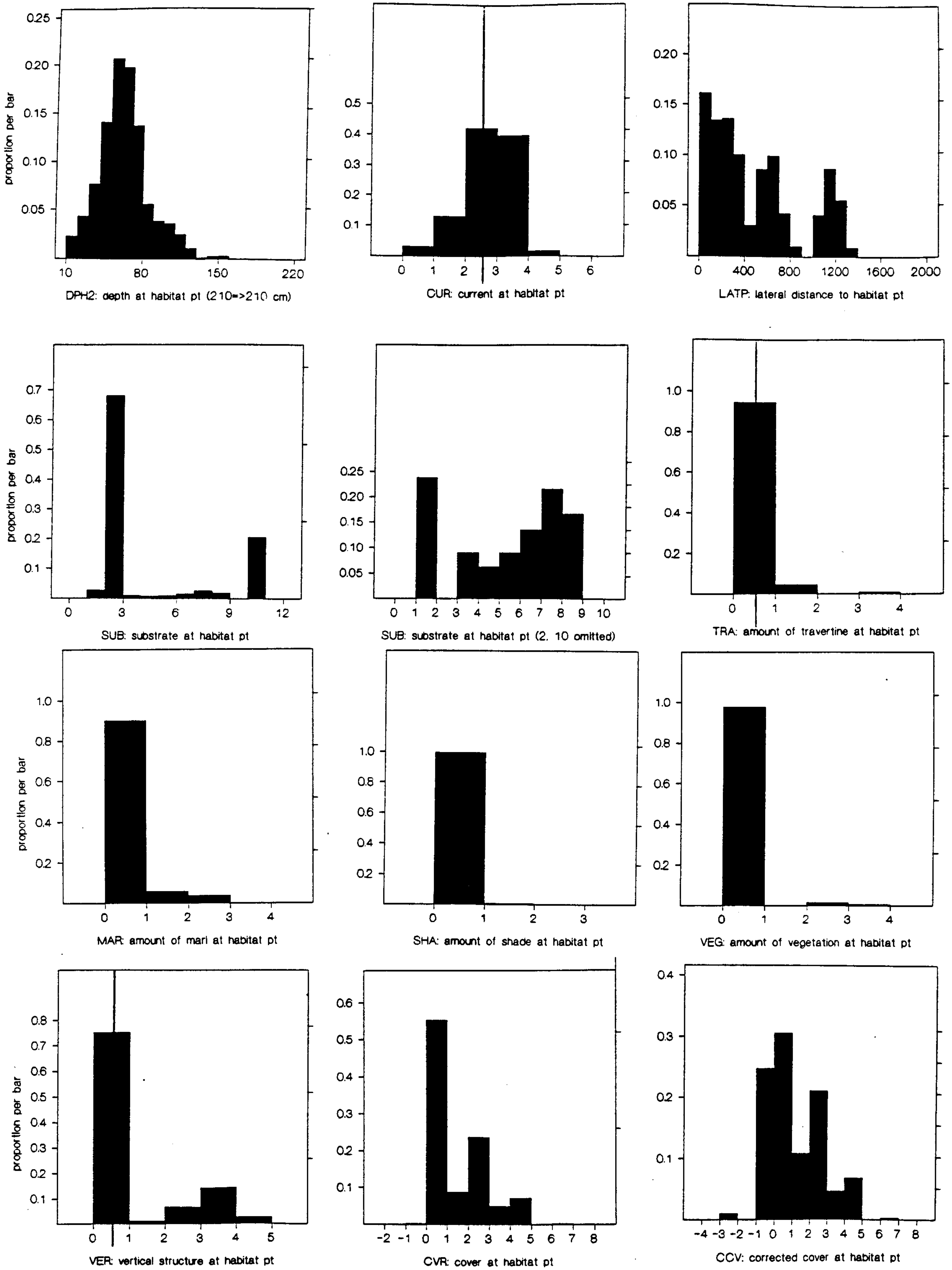
bluehead sucker (BHS)
- BHS habitat use (day): FWS/Powell 6/92
- BHS habitat use (night): FWS/Powell 6/92

flannelmouth sucker (FMS)
- FMS habitat use (day): FWS/Powell 6/92
- FMS habitat use (night): FWS/Powell 6/92

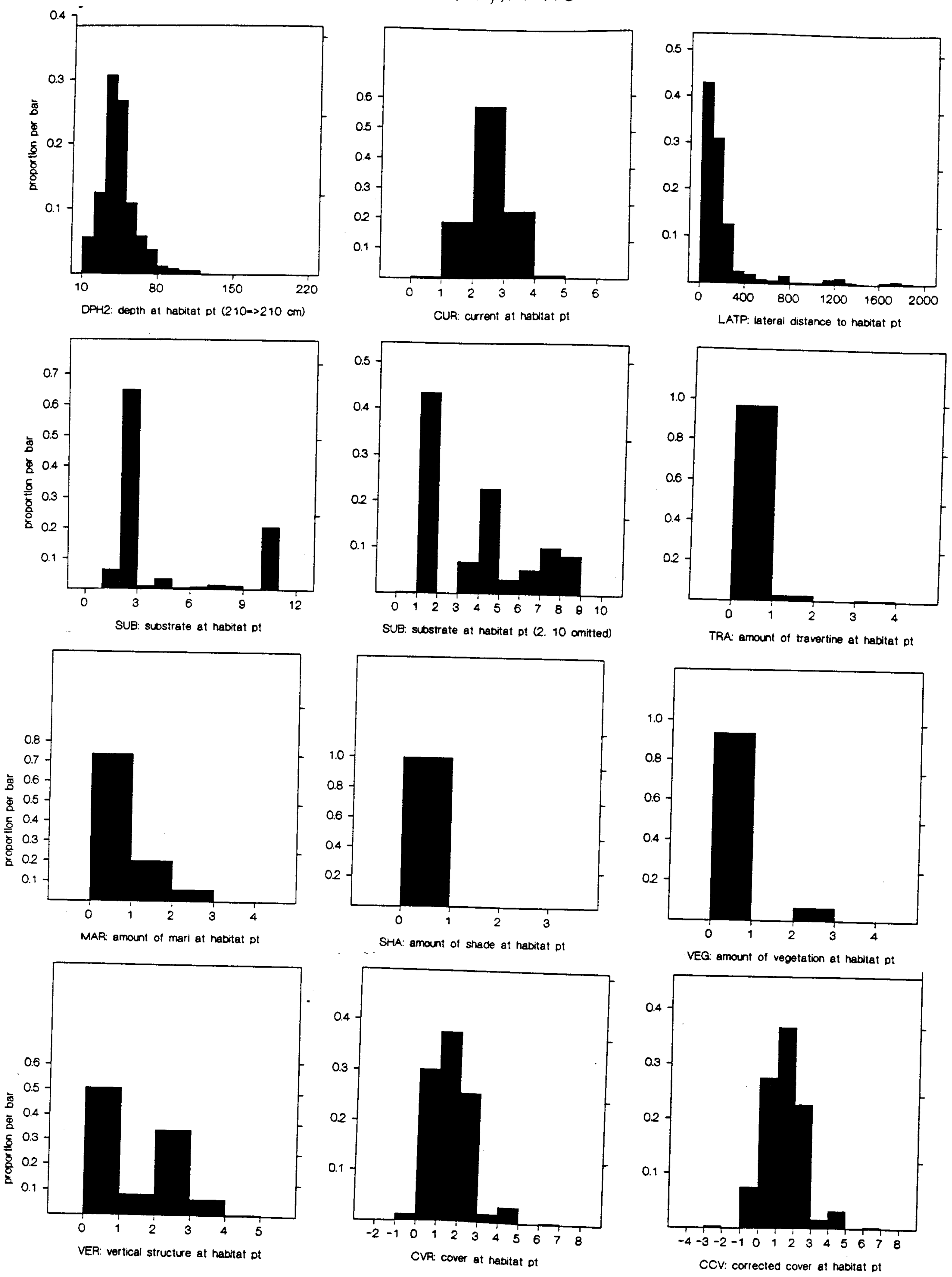
HBC habitat use (day). FWS/Powell 07/92



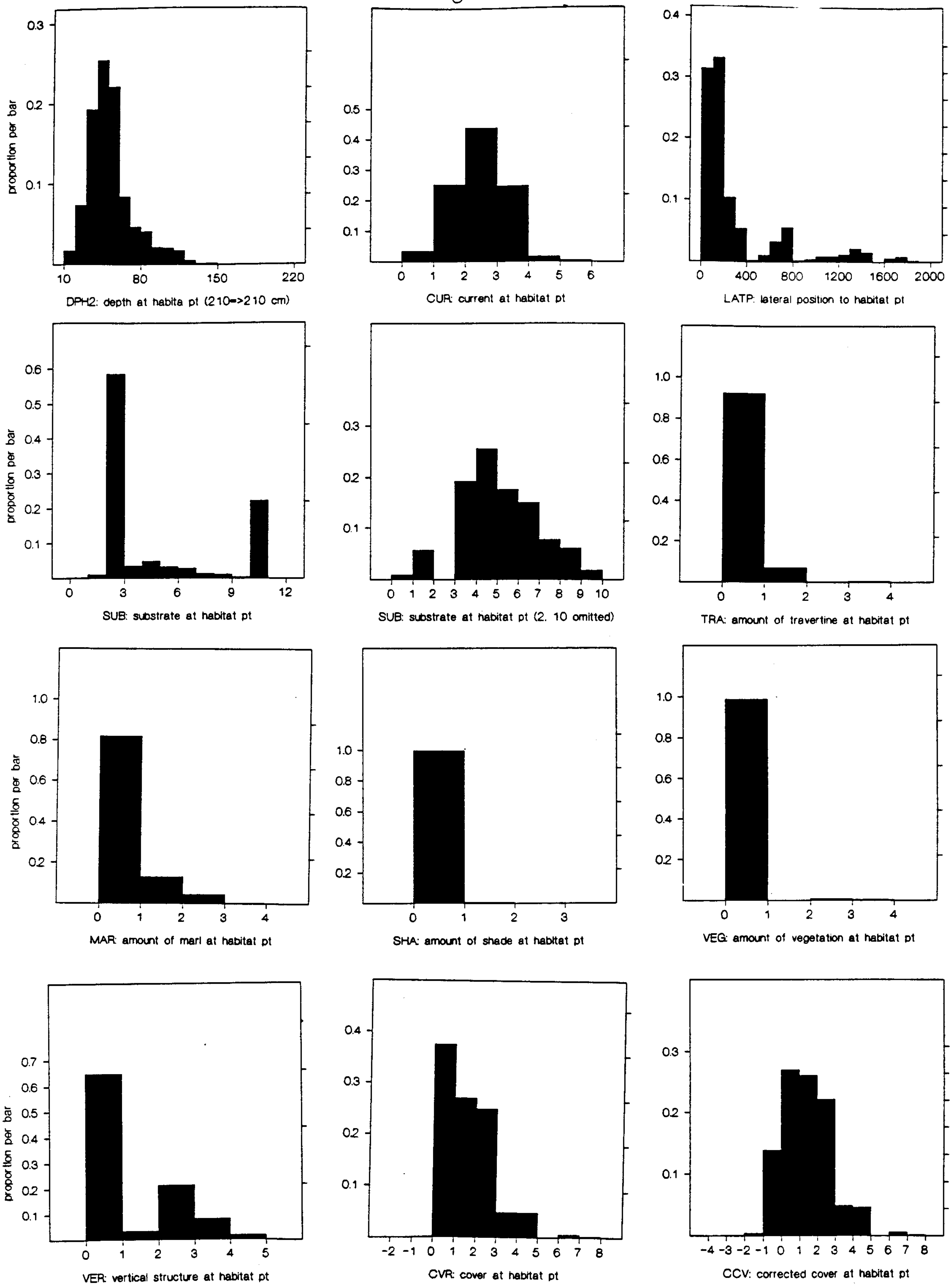
HBC habitat use (night). FWS/Powell



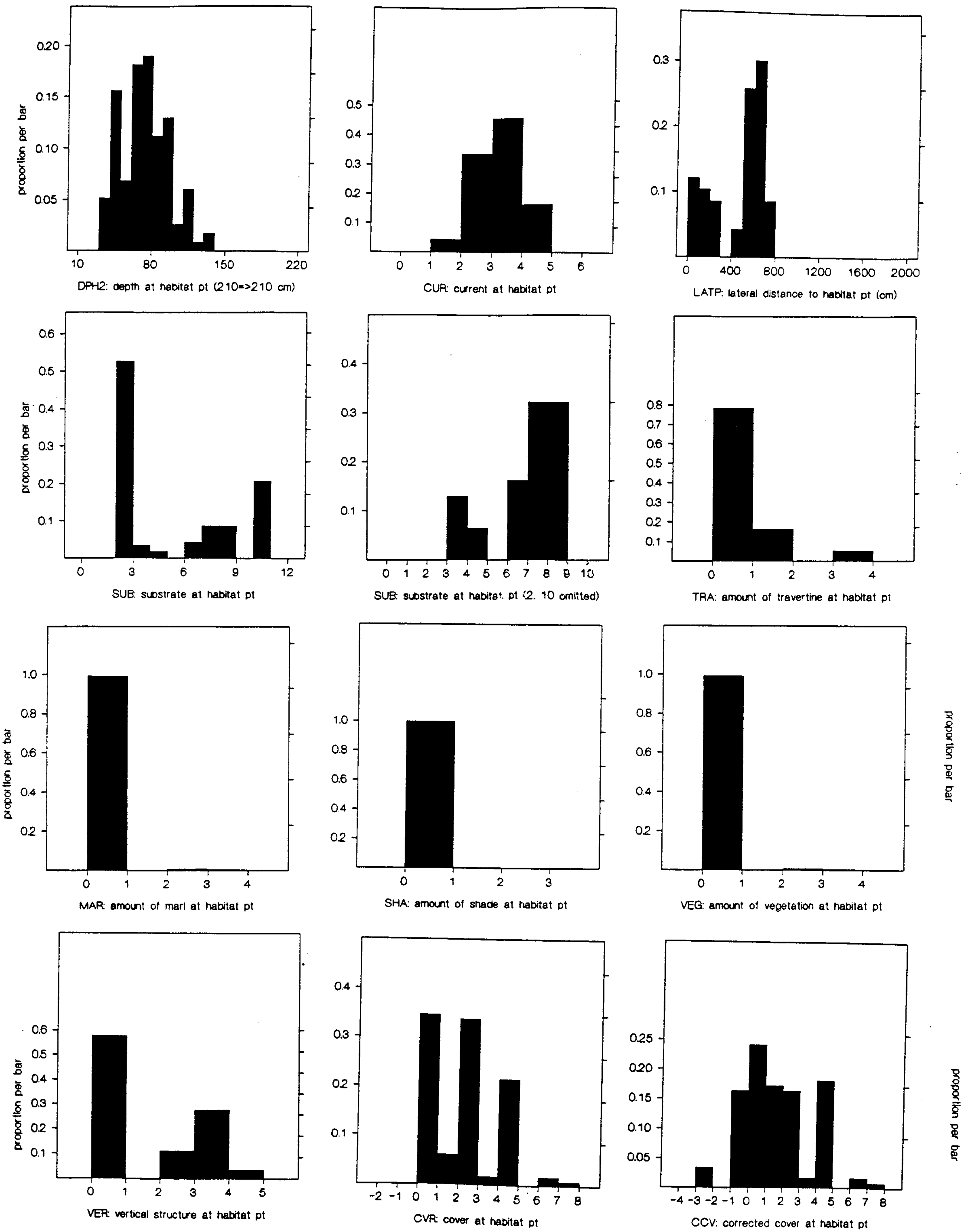
SPD habitat use (day): FWS/Powell 07/92



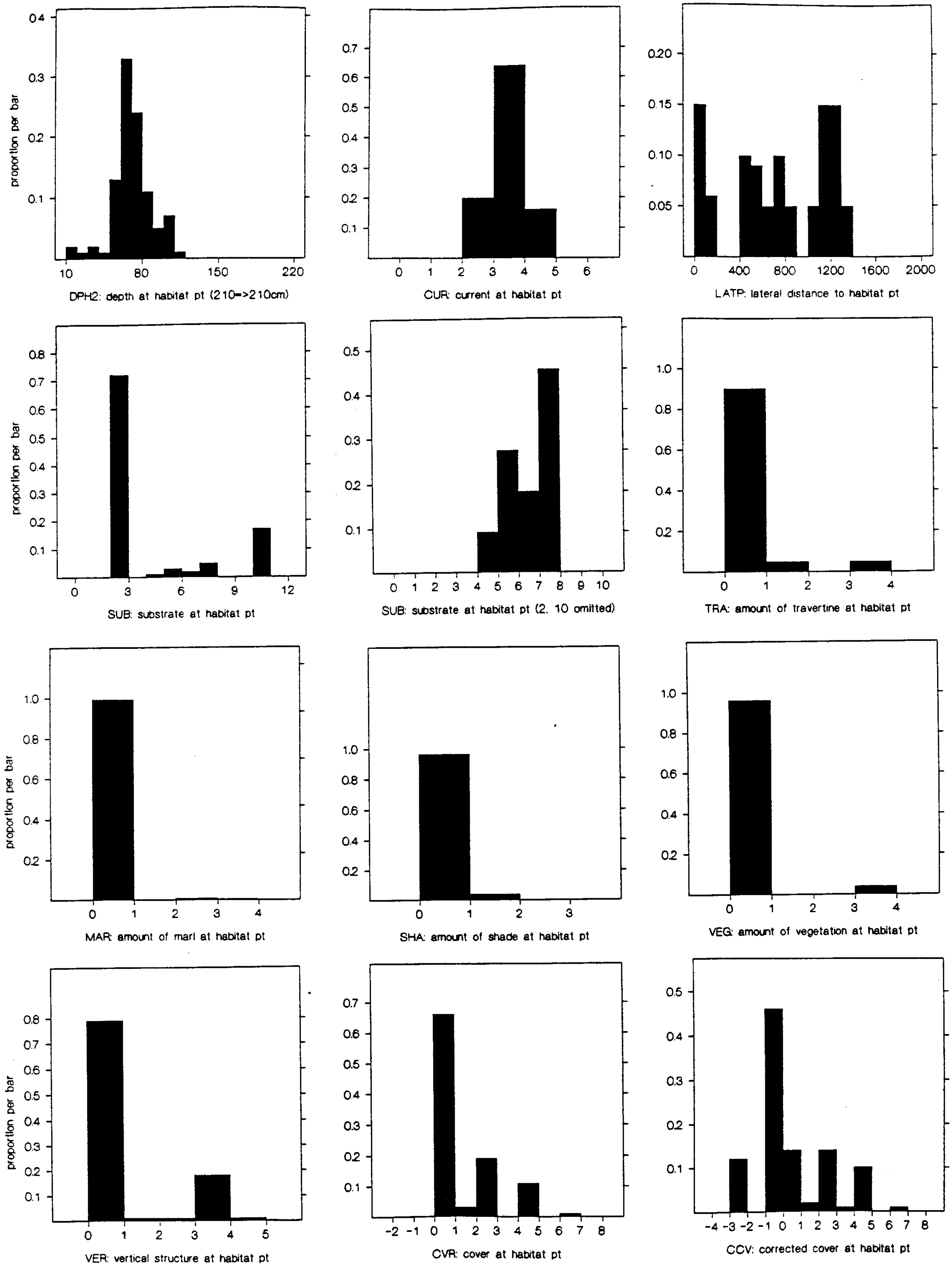
SFD habitat use (night). FWS/Powell 07/92



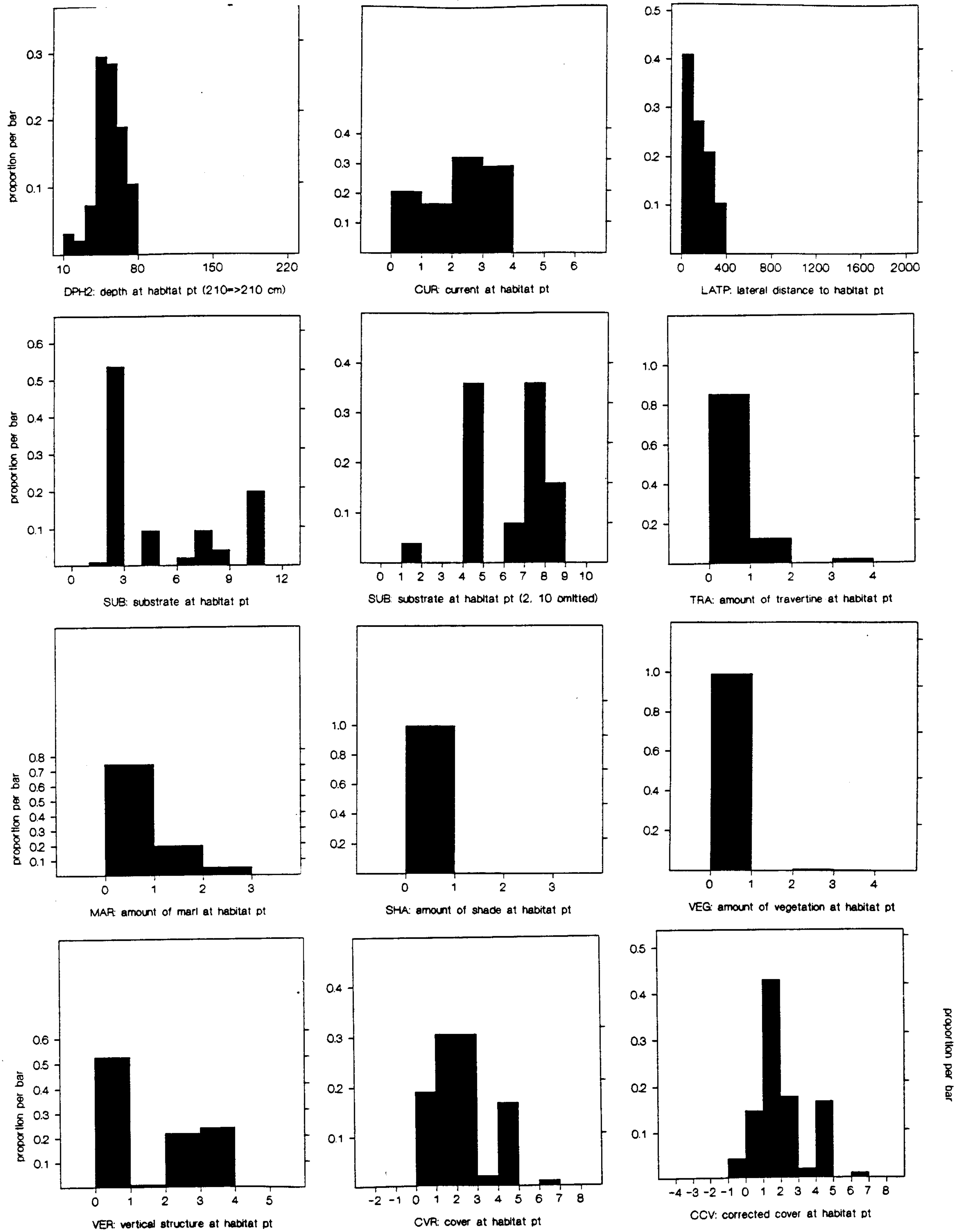
BHS habitat use (day): FWS/Powell 6/92



BHS habitat use (night): FWS/Powell 6/92



FMS habitat use (day): FWS/Powell 6/92



FMS habitat use (night): FWS/Powell 6/92

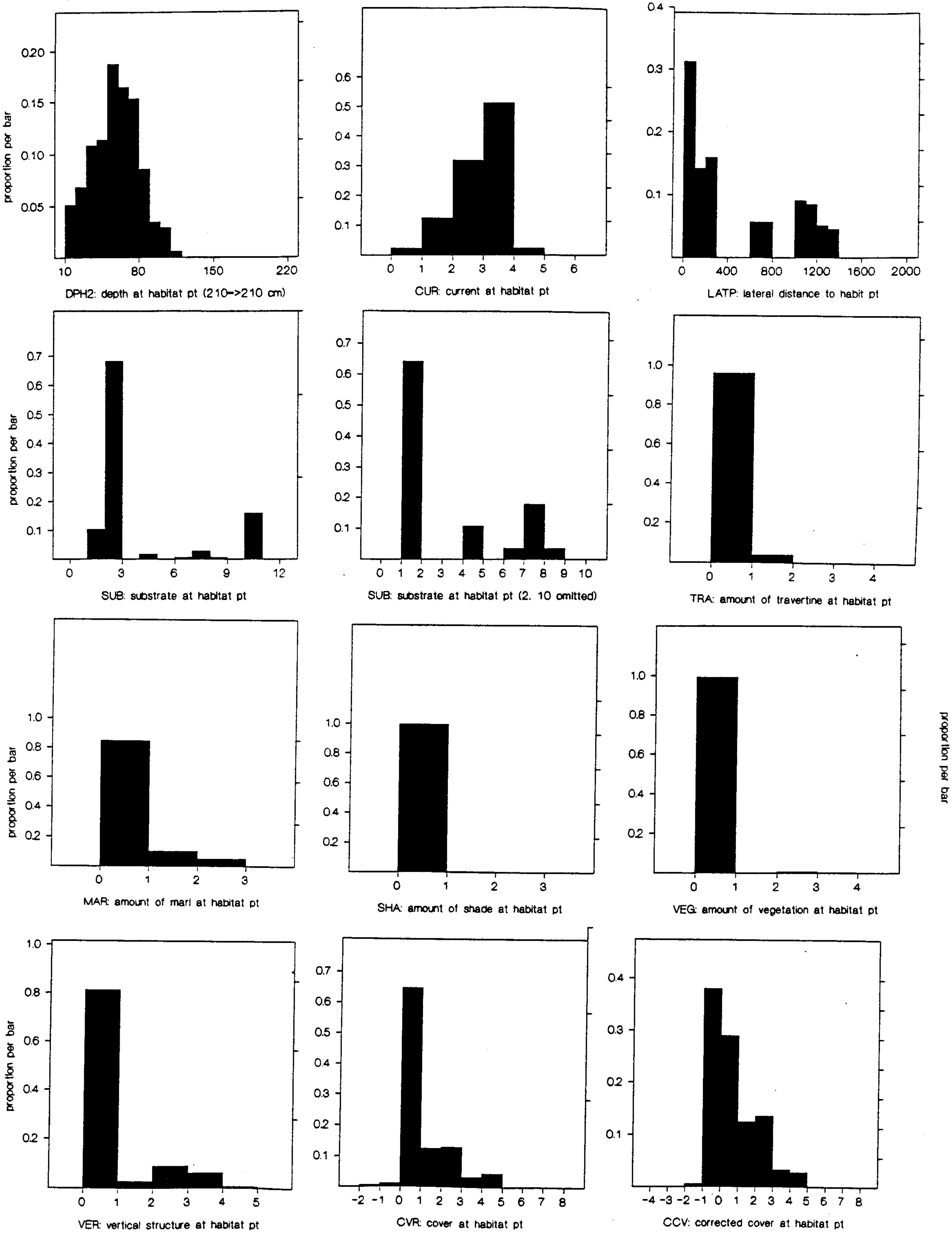


FIGURE 4. USFWS LCR fish habitat studies, Powell Study Reach 6/92: Habitat use by LCR fishes displayed in Principal Component Space for day and night periods.

Species shown:

humpback chub	HBC
speckled dace	SPD
bluehead sucker	BHS
flannelmouth sucker	FMS

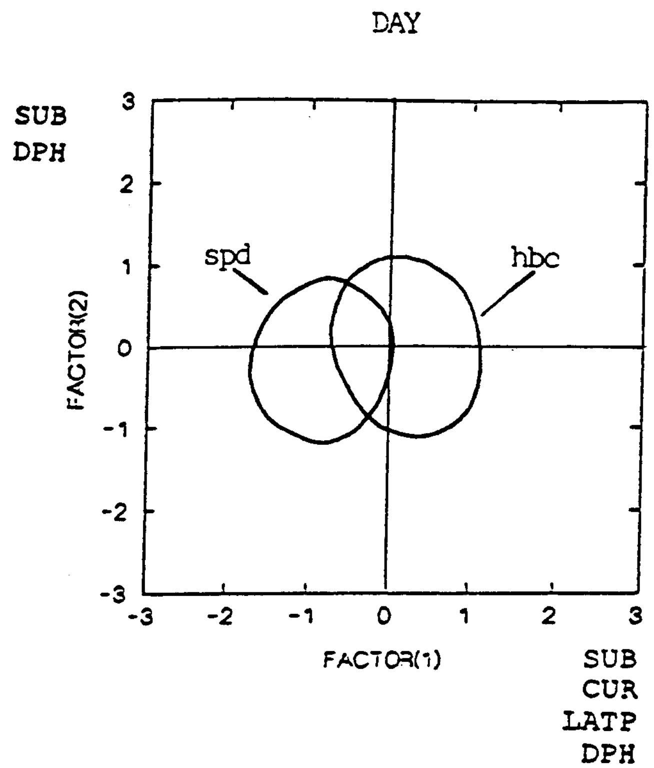
Ellipses represent area containing 50% of the habitat points for a particular species.

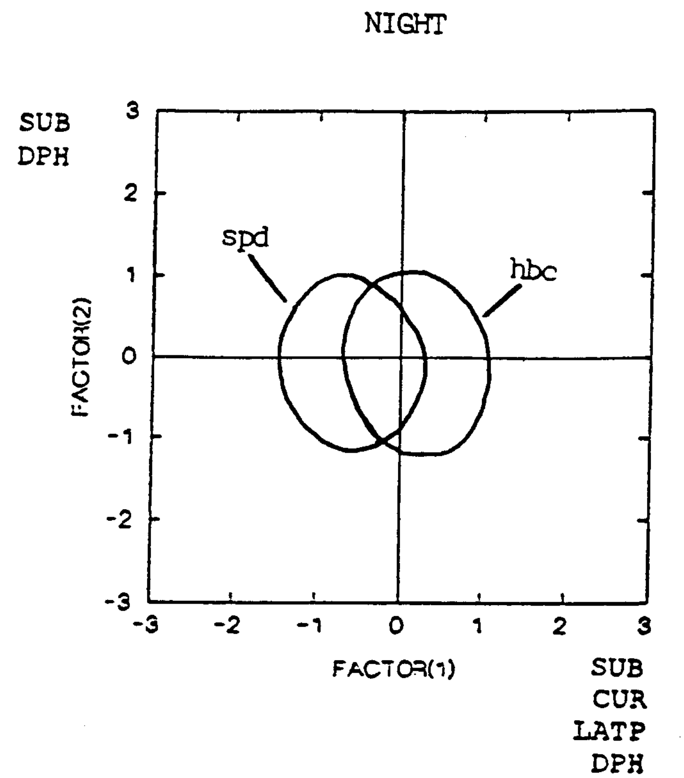
Interpretation of PCA axes:

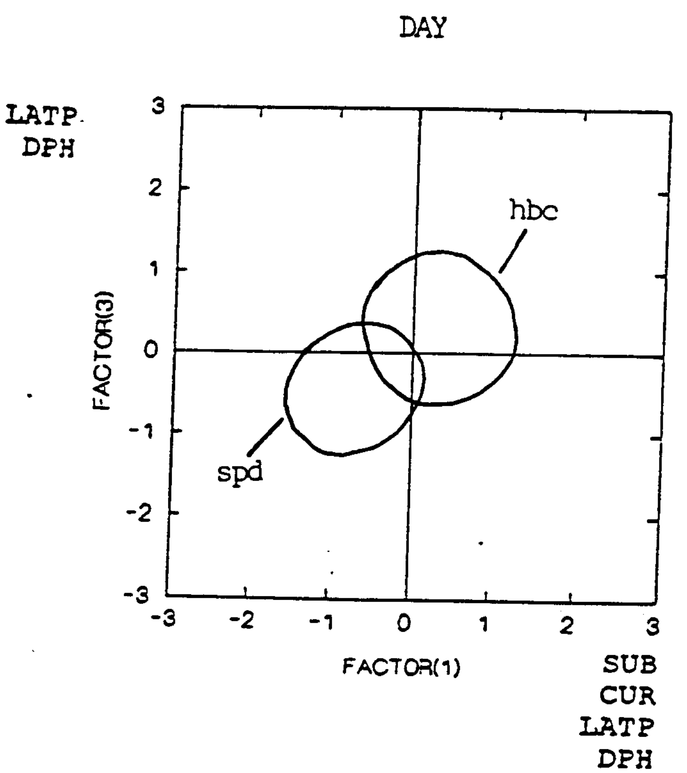
Factor 1 represents a lateral gradient of habitat from stream edge to center channel where currents, depth, and substrate size increase with increasing lateral position.

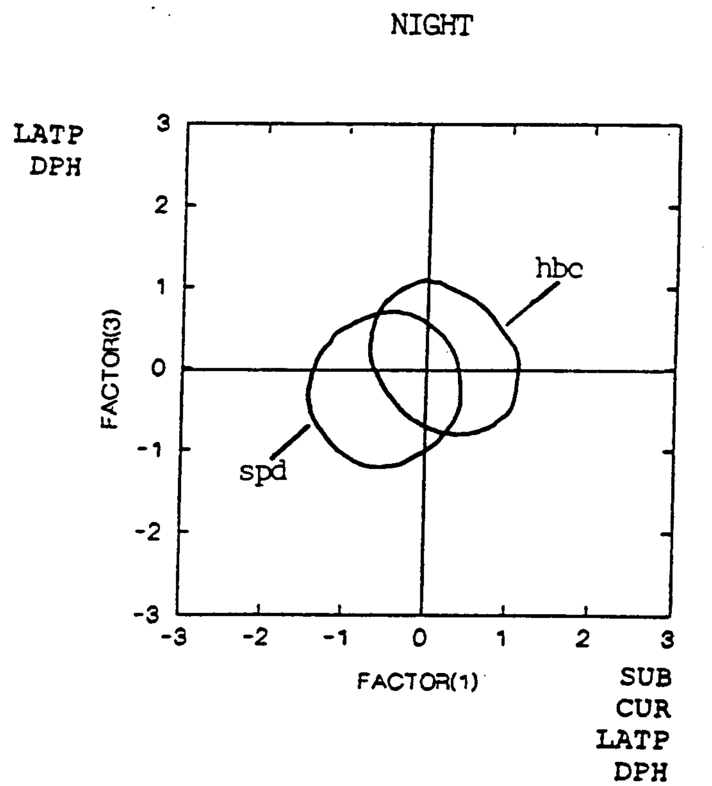
Factor 2 represents a gradient between deep areas with sand/fine substrate and shallow areas with larger substrate (travertine reefs)

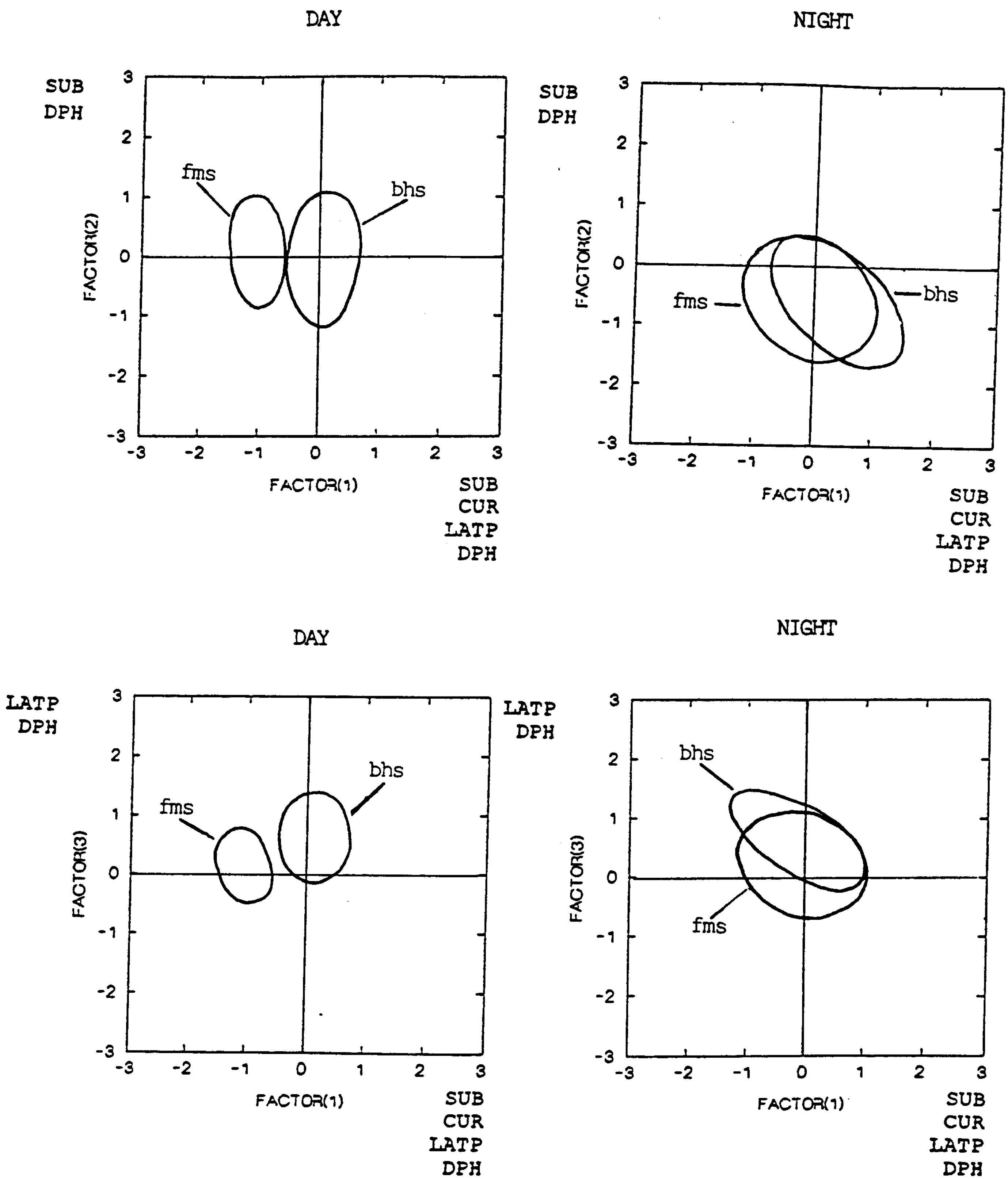
Factor 3 represents an anti-lateral gradient of shallow off-shore habitat to deep, near-shore habitat such as undercut banks.


DAY
SUB
DPH
FACTOR(2)
FACTOR(1)
spd
hbc
SUB
CUR
LATP
DPH


NIGHT
SUB
DPH
FACTOR(2)
FACTOR(1)
spd
hbc
SUB
CUR
LATP
DPH


DAY
LATP
DPH
FACTOR(3)
FACTOR(1)
hbc
spd
SUB
CUR
LATP
DPH


NIGHT
LATP
DPH
FACTOR(3)
FACTOR(1)
hbc
spd
SUB
CUR
LATP
DPH


DAY
NIGHT
SUB
DPH
FACTOR(2)
FACTOR(1)
SUB
CUR
LATP
DPH
fms
bhs
DAY
NIGHT
LATP
DPH
FACTOR(3)
FACTOR(1)
SUB
CUR
LATP
DPH
fms
bhs

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Arizona Fishery Resources Office

Habitat use by humpback chub, *Gila cypha,*
in the Little Colorado River and other tributaries of the
Colorado River

GCES Phase II Final Report

APPENDIX V

ANALYSIS OF HABITAT USE BY LCR FISHES, MAY-AUGUST 1993

PART 1: **Analysis of habitat use by LCR fishes: an overview**

PART 2: **Frequency histograms of available habitat and habitat use by LCR fishes, May-August 1993**

PART 3: **Principal Component Analysis of 6/93, 8/93 Powell Study Area habitat data**

APPENDIX V

ANALYSIS OF HABITAT USE BY LCR FISHES, MAY-AUGUST 1993

PART 1: Analysis of habitat use by LCR fishes: an overview

Introduction

The USFWS General Study Plan was first implemented in December 1991 (Gorman et al. 1992). Throughout most of 1992 the LCR was flooding or well above base flow. These conditions resulted in low capture rates of fish with passive sampling devices or precluded execution of the Study Plan. June was the only sampling period in 1992 when we were able to execute our Study Plan under base flow conditions. The LCR continued to flood regularly and flow well above base flow until May 1993. Throughout the summer of 1993 (May-August) the LCR was at base flow. We will provide example analyses of habitat data, with an emphasis on humpback chub, from the Powell and Salt study areas for May, June, July and August 1993. Previously, sample analyses were provided for June 1992 and 1993 Powell study area (Gorman, 1994; Append. IV). A comparative analysis of habitat use data from seine sampling from the Powell study area, September 1992, has also been previously analyzed (Gorman, 1994).

Length-frequency histograms (Fig. 4) provide a picture of the reproductive history of the LCR humpback chub population from 1991-1994. 1991 was a good reproductive year for humpback chub in the LCR. This year class has dominated the LCR humpback chub population until summer 1993. Prolonged and severe flooding in 1992 resulted in a complete reproductive failure for the LCR humpback chub population in 1992; virtually no YOY fish were caught in 1992 and sampling in 1993 did not yield any putative 1992 fish. Favorable reproductive conditions in 1993 resulted in an exceptionally strong year class of humpback chub in the LCR. Until summer 1993 our limited studies have provided partial descriptions of habitat use for large adult and juvenile humpback chub. The ideal base flow conditions of summer 1993 coupled with an abundant 1993 year class of humpback chub gave us an opportunity to gather extensive data on habitat use by adult, juvenile, and YOY humpback chub. The remaining gaps in our understanding of habitat use include: 1) YOY humpback chub from hatching to 50 mm TL, 2) spawning adult humpback chub, and 3) distribution of humpback chub life stages within the LCR relative to preferred habitats.

Available habitat and habitat sampled for fish

Transect data consists of habitat measurements taken along established USFWS transects within the Powell and Salt study areas (km 2.5-3.5, 10.5-11.5; Figs. 2-3). These data represent *available habitat* in the study area. Habitat measured around the FWS minihoopnets and minnow traps represents *habitat sampled for fish*. The fish habitat use data represents the weighted habitat data for fish captures by species separately for day and night sampling periods. Examination of available vs. sampled habitat data shows that the two data sets to be very similar. The sampled habitat differs from the available habitat in that very shallow areas < =10 cm deep are under-represented. This is because we cannot effectively sample habitats < 10 cm deep with minihoopnets and minnow traps. However, this minor bias in our sampling design did not affect our ability to discern habitat use patterns as habitat <20 cm deep is not used predominately by any of the species/size classes we were able to catch in our nets.

Habitat use patterns for LCR fishes

Catch per hour data reflects differences in diurnal activity among LCR fishes (Append. V Table 2). Higher catch rates for a period reflect greater activity and movement for a particular species/size class. YOY fishes in general showed increased diurnal activity (> =60% of captures were during daytime). Adult fish showed varying degrees of diel activity patterns. Both adults and YOY speckled dace were diurnally active (>61%). Adult bluehead and flannelmouth suckers showed 56% and 66% captures, respectively, during night sampling periods. Adult humpback chubs showed the greatest nocturnal activity with 81.8% of captures taken during the night sampling period. Subadult humpback chub showed 70.2% and juvenile humpback chub showed 60.3% of captures at night. There was a distinct shift in diel activity in humpback chub from YOY to adult. Append. V Figs. 3-5, 7-9 show distinct diel shifts in habitat use by adult humpback chub, bluehead sucker and flannelmouth sucker.

YOY humpback chub showed ontogenetic changes in habitat use with increasing size (Append Figs. 3-5, 8-9). In June 1993 YOY humpback chub were <50 mm TL and were associated with near-edge habitats with little current, and small substrate (Fig 4). These small fish used vertical positions in the water column (sensu Gorman, 1988) between mid pelagic to near benthic. As YOY fish increased in size, their habitat use patterns began to shift towards an adult-like ecology. In August 1993 YOY humpback chub were 65-75mm TL and had shifted habitat use to deeper areas at increasing distance from edges with slow currents and more complex arrays of substrate (Append V Fig. 5). Associated with this shift was increased use of areas with high vertical structure and cover and near-benthic vertical position (increased relative depth).

During the day, juvenile, sub-adult, and adult humpback chub showed an affinity for areas of relatively deep water, slow current, large substrates, high vertical structure and cover and near benthic vertical position (=>80% relative depth) (Append. Figs. 3-4). Lateral position varied with the location of deeper areas with high cover in the various study reaches. Apparently, some study reaches had large boulders and deep holes near mid-channel while other areas had deep water areas along vertical rocky or undercut banks. At night, the larger chub appeared to move out of these areas of high cover into shallower water with less cover, vertical structure, and sometimes fewer large substrates. Lateral position showed a shift that depended on the study reach and the location of daytime habitats (mid-channel vs. banks). Accompanying this nocturnal shift in habitat use was an increased use of vertical positions above near benthic zone.

A principal components analysis of sampled habitat data from the Powell lower study area for June and August 1993 is provided in Append V Table 3 and Append V Figs. 6-9. The principal axes may be interpreted as follows: Factor 1: substrate size (EPS-effective particle size) and cover; Factor 2: anti-lateral position (near shore) with decreasing currents and increasing vertical structure; Factor 3: depth and relative depth. Points that load positively on Factor 1 show association with increasing substrate size. Points that load positively on Factor 2 show association with near-shore areas with increasing vertical structure (e.g., vertical banks). Points that load positively on Factor 3 show association near benthic positions in deep water habitats.

A composite of all sampled habitat points for Factors 1-3 shows the general shape and volume of sampled habitat in PCA space (Append. Table 3, Append Fig. 6). A composite of adult fish habitat use shows that humpback chub, bluehead sucker, and flannelmouth sucker responded to the array of habitats in non-random and different ways. Speckled dace responded to the array of habitat in an apparently random manner; their use pattern is very similar to sampled habitat. Adult fish showed distinct patterns of habitat use between day and night; YOY fishes did not show such large differences. Speckled dace showed only small differences in habitat use patterns between day vs. night or YOY vs. adult. The PCA shows that all YOY fishes responded to habitat variables in similar ways and this predicts that they have large overlap in habitat use.

Our analysis identifies four distinct habitat ecologies for humpback chub that is tied to ontogeny:

1. post-larval, up to 50 mm TL

   Post-larval humpback chub use near shore areas (<300 cm lateral position) of shallow to moderate depth (<100 cm), zero to slow currents, small substrates, moderate cover and vertical structure, near-benthic to mid-pelagic vertical position, and strongly diurnally active.

2. YOY, 50-100 mm TL
   YOY humpback chub use near shore areas (<500 cm lateral position) of moderate depth (<200 cm, slow currents, small and large substrates, moderate to high cover and vertical structure, near benthic to lower pelagic vertical position, and diurnally active.

3. juvenile, 100-150 mm TL
   Juvenile humpback chub use near and offshore areas (<1200 cm lateral position) of moderate to deep water (<300 cm, day; <200 cm, night), slow currents, small and large substrates, moderate to high cover and vertical structure, near benthic vertical position (day) and lower-pelagic vertical position (night), and nocturnally active.

4. subadult, 150-210 mm TL and adult >210 mm TL
   Subadult and adult humpback chub use near and offshore areas (<1500 cm lateral position) of moderate to deep water (<300 cm day and night), slow currents, moderate to high cover and vertical structure, near benthic vertical position (day and night) and nocturnally active.

A schematic of habitat use by YOY, juvenile and adult humpback chub in late summer is represented in Append. V Figure 1. YOY and older chubs display a near-complementary pattern of habitat use between day and night periods. It is possible that predation pressure from adult fish during nocturnal periods may affect observed patterns of habitat use by YOY humpback chubs.

Habitat evaluation studies: active vs. passive sampling

Our analysis shows distinct patterns of habitat use and segregation for the native fishes of the LCR. Our results indicate that our sampling design and protocols with passive devices can detect habitat use in stream fishes; the expected result when these methods fail is inability to detect habitat use patterns.

All fish sampling methods have biases that have to be addressed in order to increase objectivity to a point where natural patterns are dominant in the data. We addressed the biases inherent to passive sampling gear (Gorman 1991; Gorman et al. 1992). Hoopnets and traps may present a structural modification of the local habitat and thereby attract fishes independent of the natural habitat structure. For example, if a fish responds to a minihoopnet in the same manner as an undercut bank or a small boulder, then the ability of minihoopnet sampling to distinguish use of areas with and without natural structure will be diminished. For this reason, passive devices have not been used to determine patterns of habitat use in stream fishes; for most fish ecologists they simply do not reveal patterns of habitat use (this report and Mendelson, 1975 are important exceptions). We recognize that sampling bias in passive devices is time-dependent (the longer a net fishes, the greater the bias) and proportional to the size of the device relative to the habitat sampled (Gorman, 1991). We further recognize that because of the novelty effect of a single capture device on a large sampling area (Gorman, 1991), capture devices must be distributed over a sampling area to minimize this effect (attempt to provide equal treatments to all habitat patches sampled). Our sampling design (Gorman 1991; Gorman et al. 1992) has addressed these problems by 1. minimizing the size of the nets/traps and use devices that are appropriately sized to the scale of sampled habitat, 2. nets are set for short periods of time (< =24 hrs) and then moved, and 3. nets and traps are set in grids.

Our data have been able to show differences in habitat use among an array of species and size classes on par with observational-based habitat studies (e.g., Gorman 1987, 1988a). That our sampling methods have successfully reduced that bias is indicated by our ability to discriminate habitat use between areas of high and low structure. We are not arguing that our methodology is superior to observational-based habitat studies; those studies provide data with less bias and variance. But those methods cannot be applied in all settings, and although our data may be more "fuzzy" than could be obtained by an observational study, we have nonetheless been able to detect distinct patterns of habitat use and segregation among LCR fishes.

The importance of sampling night and day periods is underscored by our work; most habitat studies of stream fishes describe only diurnal habitat use patterns. In the LCR, most fishes and size classes show very different diel habitat use patterns. If these periods were not sampled separately our data would not have shown distinct habitat use patterns among LCR fishes. Our approach and sampling methodology is unique in providing a balanced picture of day and night habitat use in stream fishes.

TABLE 1. Variables used in habitat analyses.
(full descriptions are contained in Appendix I)

Primary habitat variables:
DPH (depth, cm)
CUR (current velocity, 0-5 categories)
SUB (substrate particle size, 0-11 categories)
LATP (lateral distance from habitat pt to nearest stream edge in cm)
VER (vertical structure at habitat point, 0-5 categories)
CVR (cover at habitat point, -2 to +7 categories)
TRA (type and amount of travertine at habitat pt, 0-3 categories)
RDPH (relative depth of net, % of total depth of water column)

Secondary habitat variables
LATDS (lateral distance from set to nearest stream edge in cm)
CCV (current corrected cover (CVR) at habitat pt, -5 to +7 categories)
VRC (current corrected vertical structure (VER))
MAR (type and amount of marl at habitat pt, 0-3 categories)
VEG (type and amount of vegetation at habitat pt, 0-3 categories)
SHA (type and amount of shade at habitat pt, 0-3 categories
ADPH (absolute depth of net, surface to midpoint of mouth in cm)

Other habitat variables used in the analyses:
PT (depth at point of net)
MTH (depth at mouth of net)
GEAR (net gear type, mesh size, dimensions, # hoops)
DATE (date measurements were taken
EDG (distance to emergent edges within 100 cm)
CC (secondary current descriptors)
SS (secondary substrate and vegetation descriptors)
OVH (overhang and vertical structure descriptors)

Species in analyses:
HBC (humpback chub)
SPD (speckled dace)
BHS (bluehead sucker)
FMS (flannelmouth sucker)

TABLE 2. USFWS LCR fish habitat studies, Powell and Salt Study Reaches 5/93 through 8/93: Summary of sampling effort and capture statistics.

A. Habitat sampling effort, LCR May-August 1993
(all nets and traps were set for a 24 hr period; "sets" are equivalent to trap/net days)

	N	# habitat pts
minihoop net sets	883	17,660
minnow trap sets	547	2,188

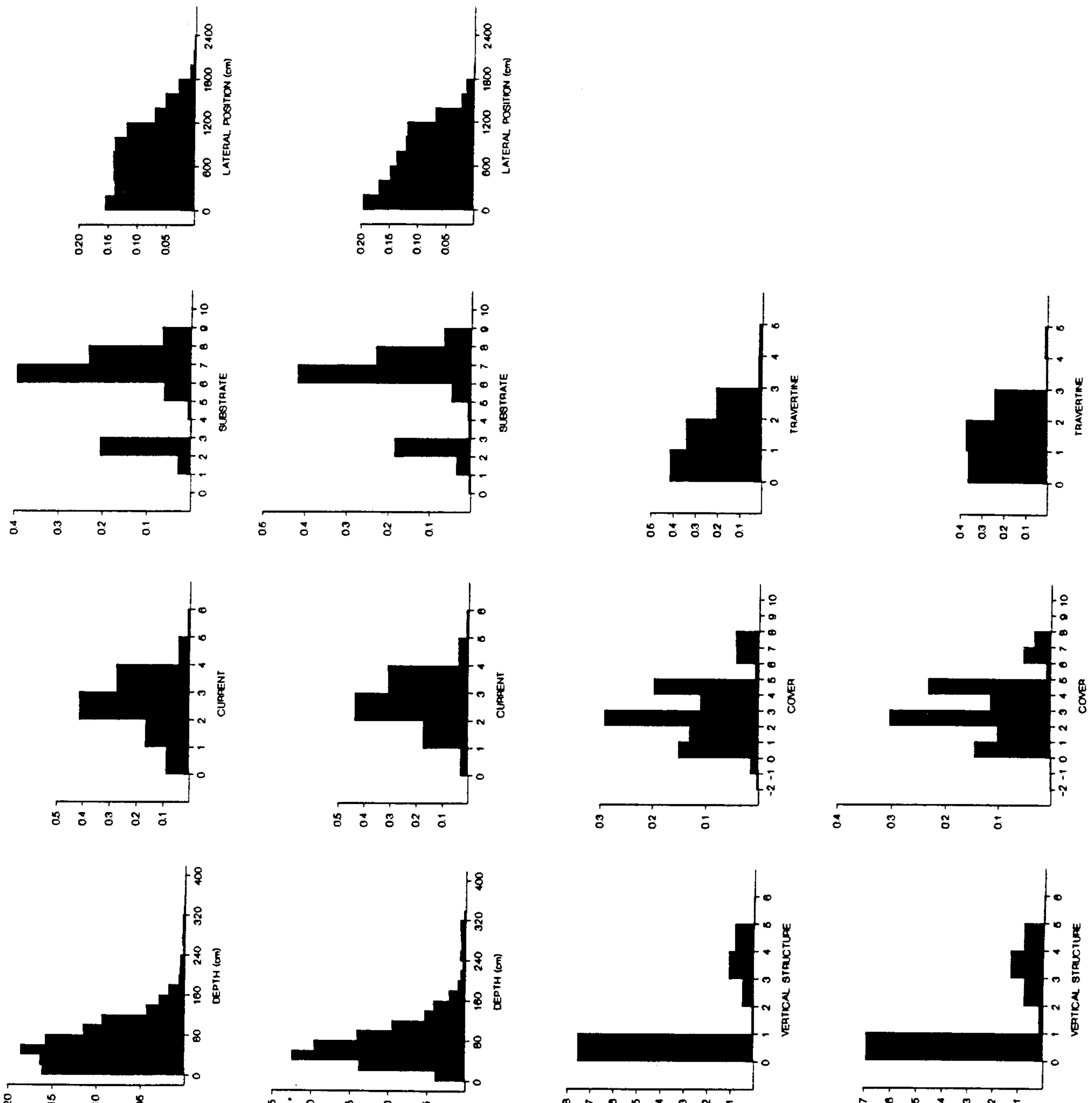
B. Fish captures, LCR May-August 1993. *Weighted captures* are captures divided by length of sampling period in hours. Daytime: 10 hrs; nighttime: 14 hrs. *% of captures* is percent of total weighted captures for a time period.

species / size class / period			captures	weighted captures	% of captures
humpback chub	YOY	day	4510	451.00	60.3
	(<=90 mm TL)	night	4158	297.00	29.7
	juvenile	day	43	4.30	43.6
	(>90 - 150 mm TL)	night	78	5.57	56.4
	subadult	day	66	6.60	29.8
	(>150 -210 mm TL)	night	218	15.57	70.2
	adult	day	36	3.60	18.2
	(>210 mm TL)	night	142	16.14	81.8
speckled dace	YOY	day	2655	265.5	65.9
	(<=70 mm TL)	night	1923	137.36	34.1
	adult	day	508	50.80	61.4
	(>70 mm TL)	night	457	31.93	38.6
bluehead sucker	YOY	day	506	50.60	69.8
	(<= 130 mm TL)	night	307	21.93	31.2
	adult	day	18	1.80	44.0
	(>130 mm TL)	night	32	2.29	56.0
flannelmouth sucker	YOY	day	75	7.50	59.7
	(<=130 mm TL)	night	71	5.07	40.3
	adult	day	8	0.80	34.0
	(>130 mm TL)	night	22	1.57	66.0

FIGURE 1. USFWS fish habitat studies. Schematic of habitat use by humpback chub, late summer 1993.

Shown are habitat use patterns by YOY, juvenile and adult humpback chub in late summer in a pool cross-section of the LCR. Smallest fish represent YOY, 65-85 mm TL. Intermediate fish represent juveniles ~150 mm TL. Largest fish represent adults ~250 mm TL. Most pool cross-sections will have either a vertical bank or large boulders in mid channel but rarely both as shown. Patterns of habitat use are inferred from habitat use frequency histograms (Append. V Figs. 2-5) and PCA projections (Append. V Figs. 7-9)

6/93, 8/93 Powell



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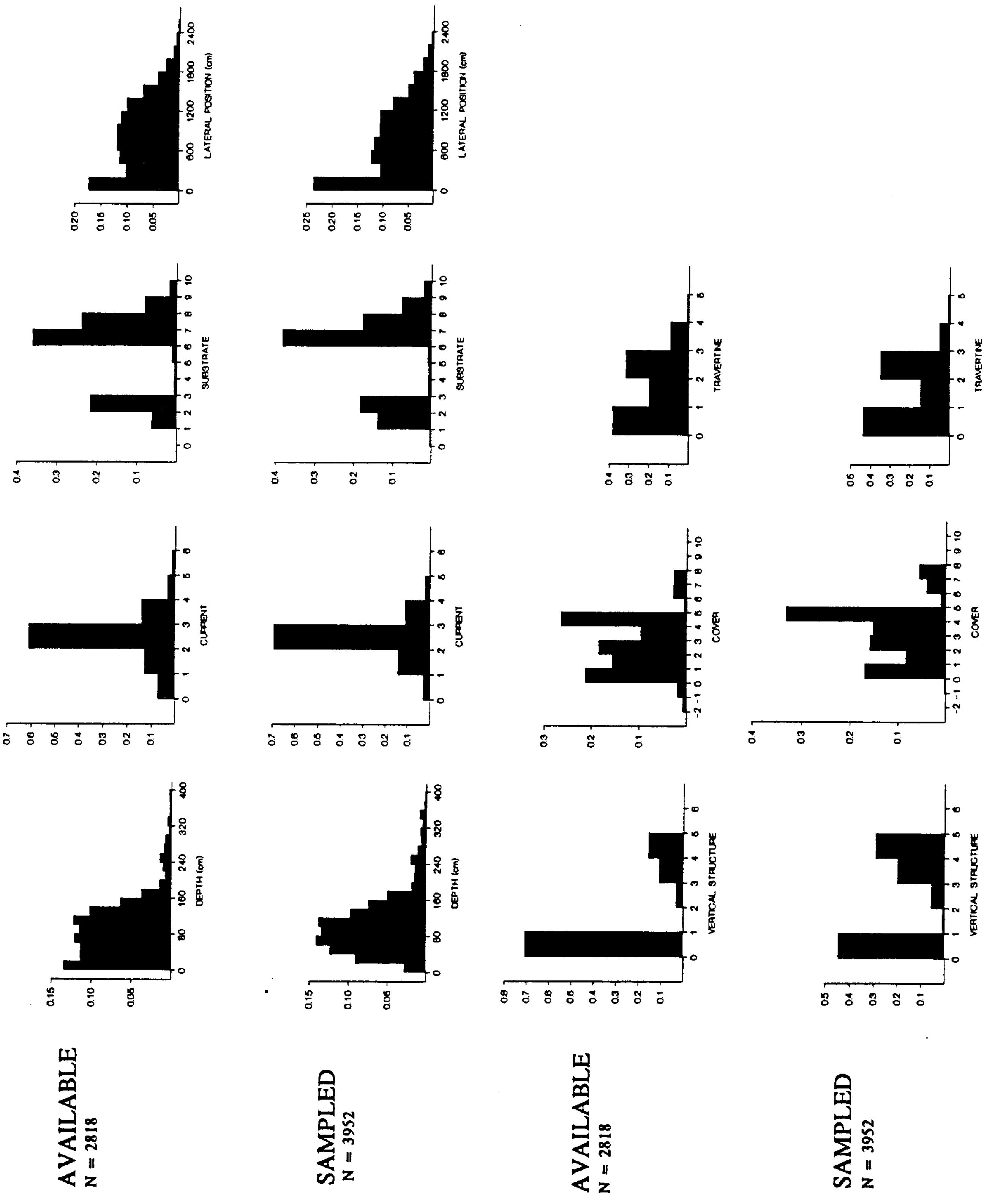
SAMPLED
N = 5651

AVAILABLE
N = 3642

SAMPLED
N = 5651

5/93, 7/93 Salt



AVAILABLE
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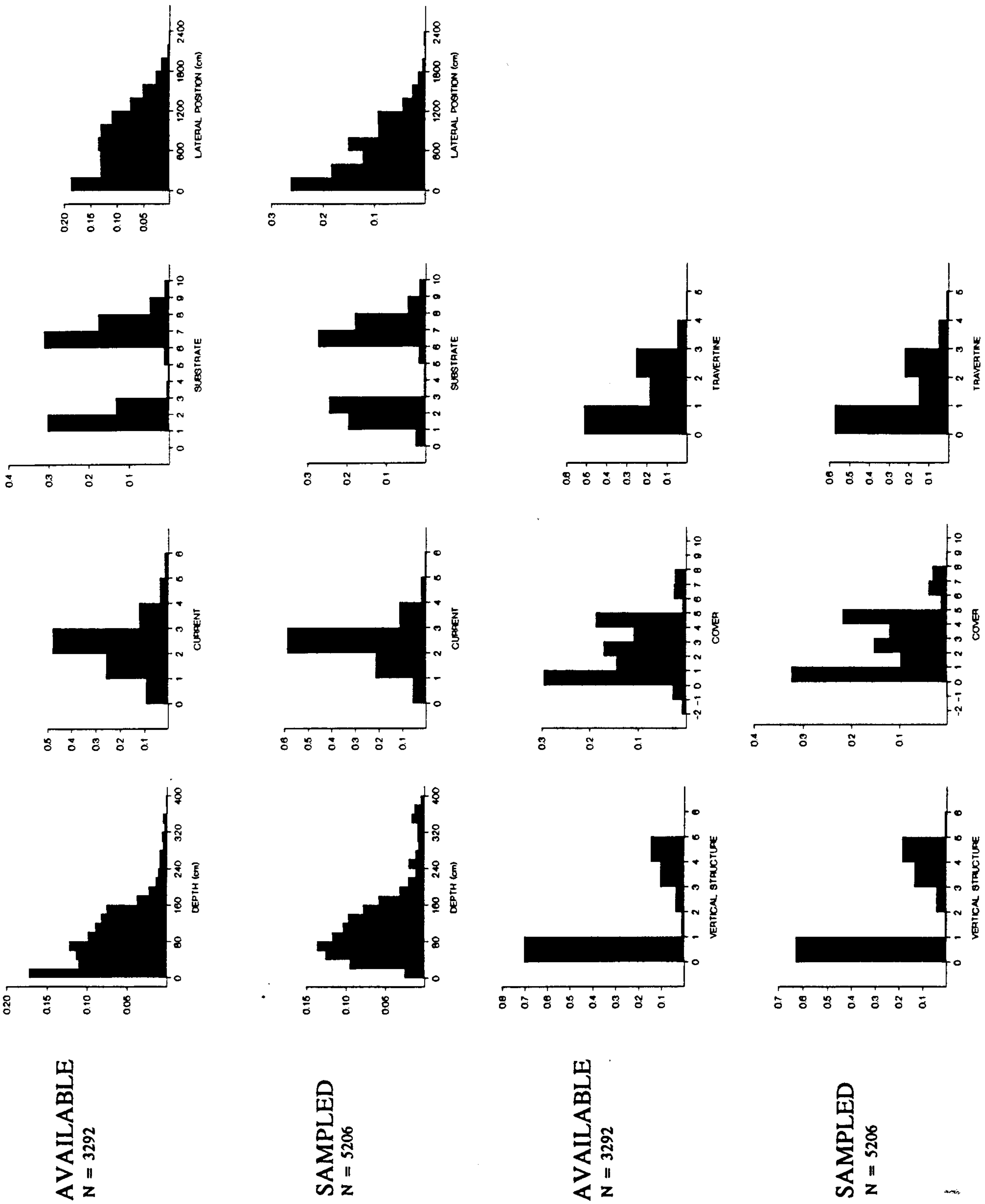
DEPTH (cm)
CURRENT
SUBSTRATE
LATERAL POSITION (cm)
SAMPLED
N = 3952
DEPTH (cm)
CURRENT
SUBSTRATE
LATERAL POSITION (cm)
AVAILABLE
N = 2818
VERTICAL STRUCTURE
COVER
TRAVERTINE
SAMPLED
N = 3952
VERTICAL STRUCTURE
COVER
TRAVERTINE

6/93, 8/93 Salt



AVAILABLE
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SAMPLED
N = 5206
AVAILABLE
N = 3292
SAMPLED
N = 5206
DEPTH (cm)
CURRENT
SUBSTRATE
LATERAL POSITION (cm)
VERTICAL STRUCTURE
COVER
TRAVERTINE

FIGURE 3. USFWS LCR fish habitat studies, Powell Study Area, 5/93-8/93: Sampled habitat and habitat use by native fishes.

Grouped in pairs by 500 m study reaches for each study area: 5/93, 7/93 and 6/93, 8/93.

Sampled distributions represent habitat sampled for fish. Data shown was measured from minihoopnets and minnow traps set in USFWS study grids.

Habitat use distributions are weighted and divided into day and night periods.

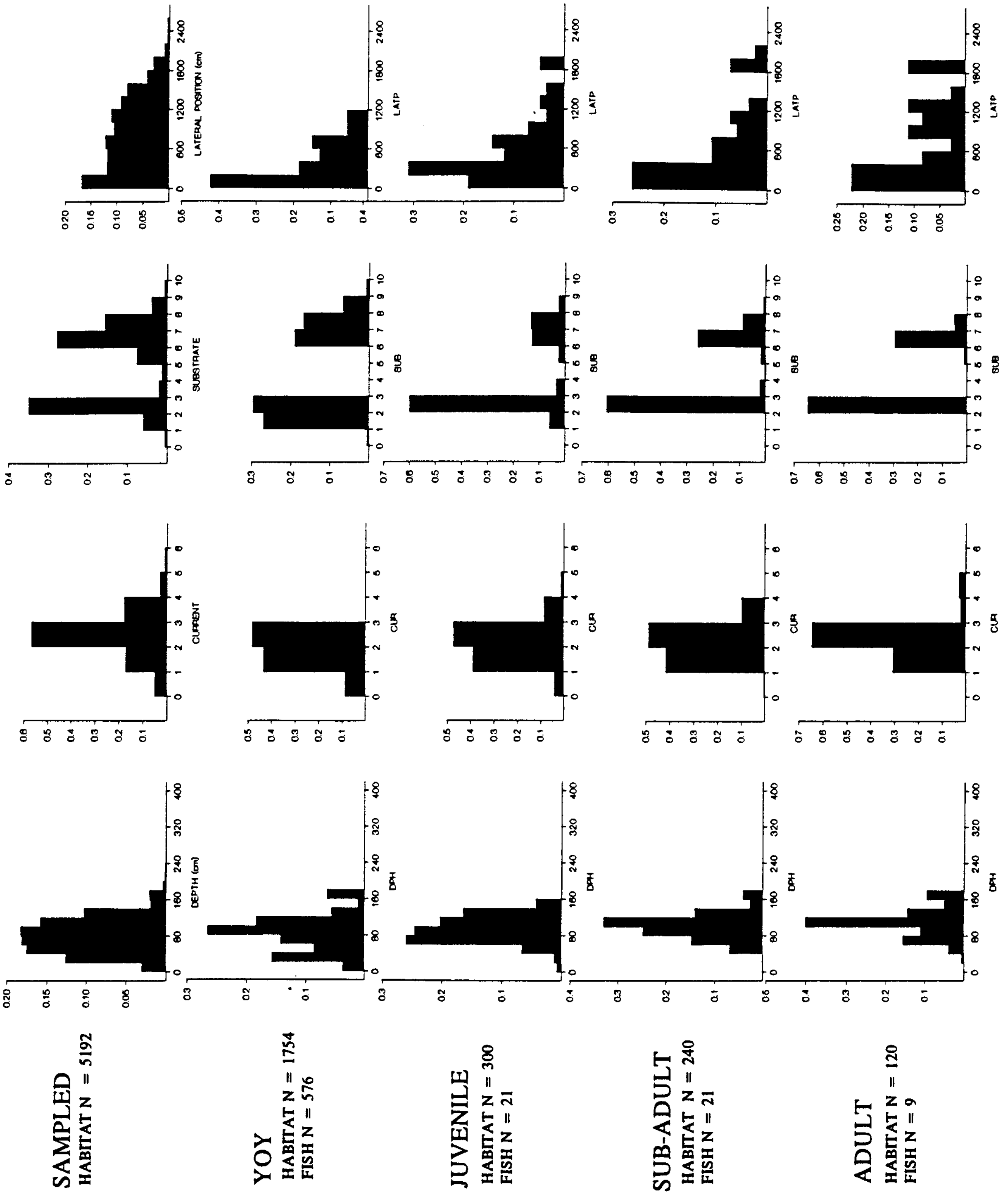
Habitat variables shown:
DPH, CUR, EPS (SUB), LATP, RDPH, VER, CVR, TRA

Species shown:

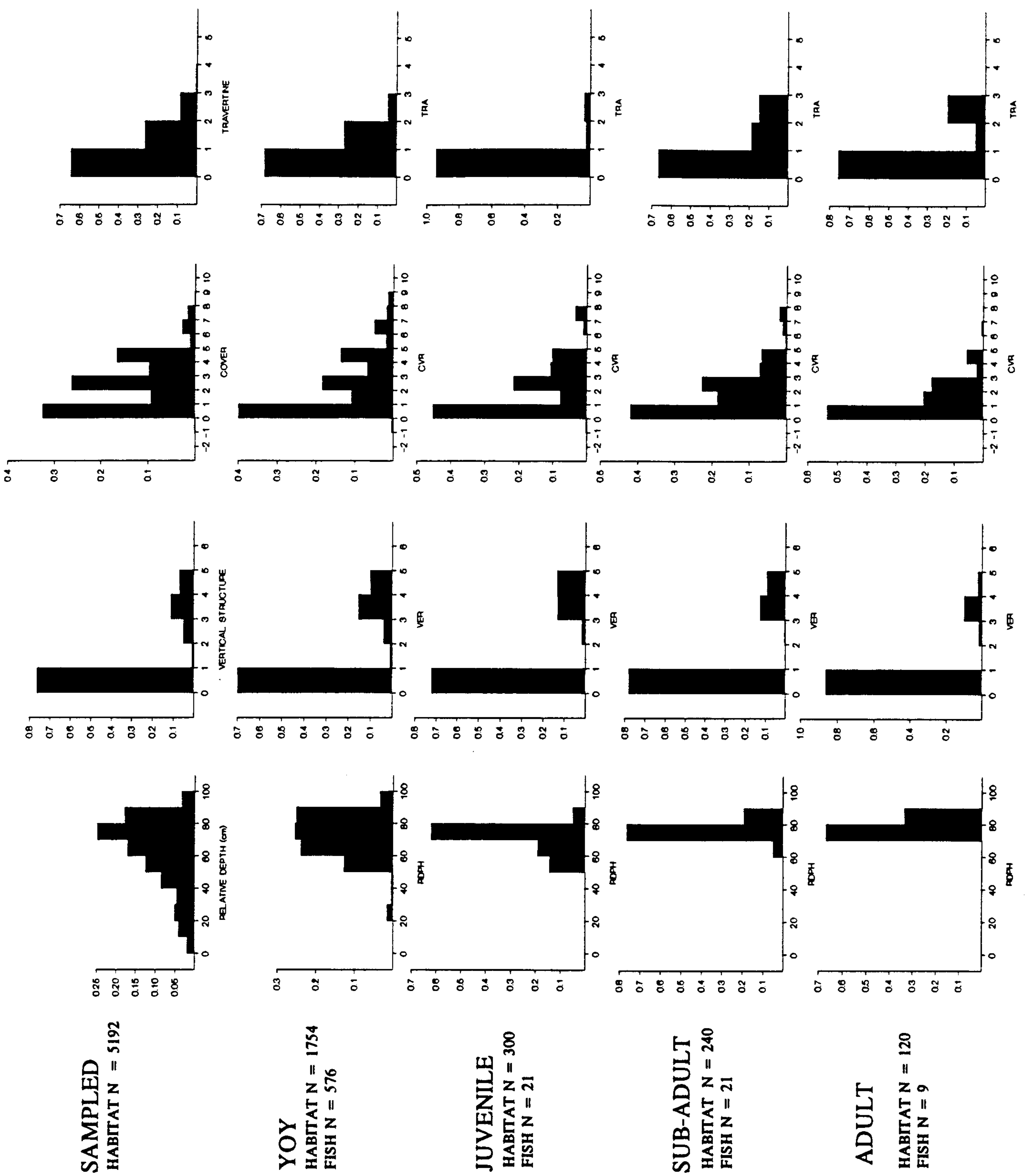
- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Table 1 for explanation of habitat variable codes.

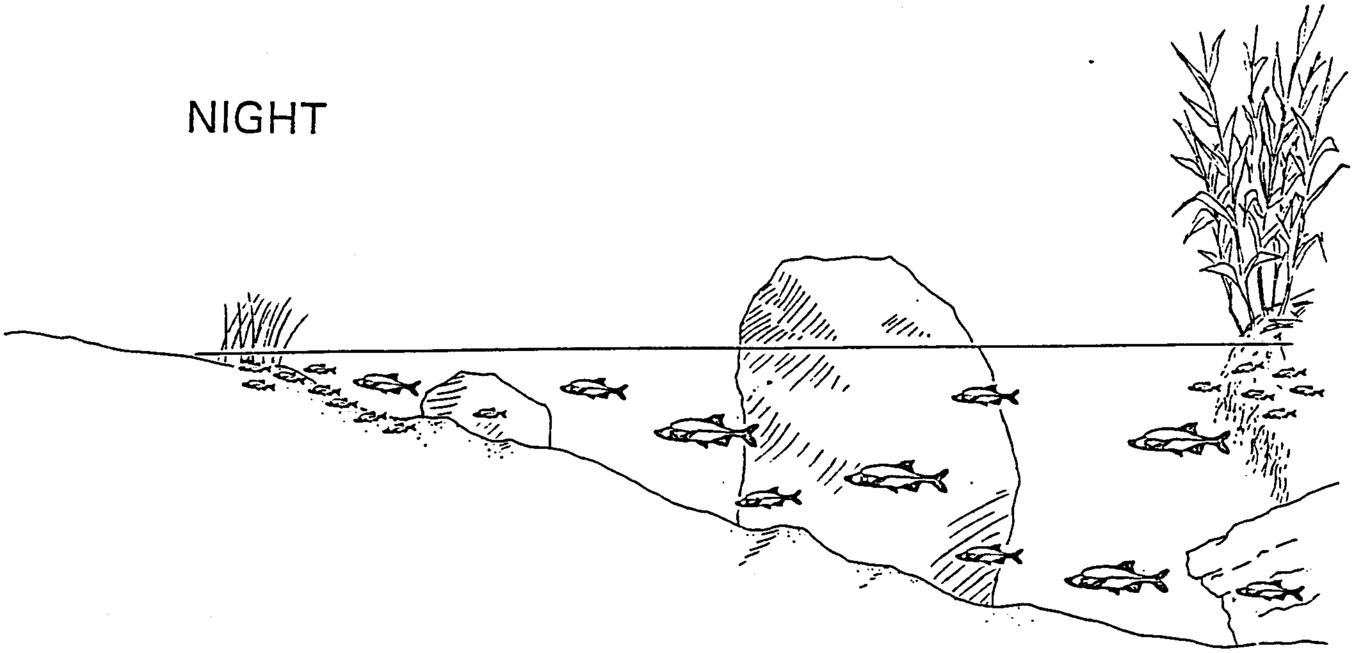
HBC 5/93, 7/93 Powell (DAY)



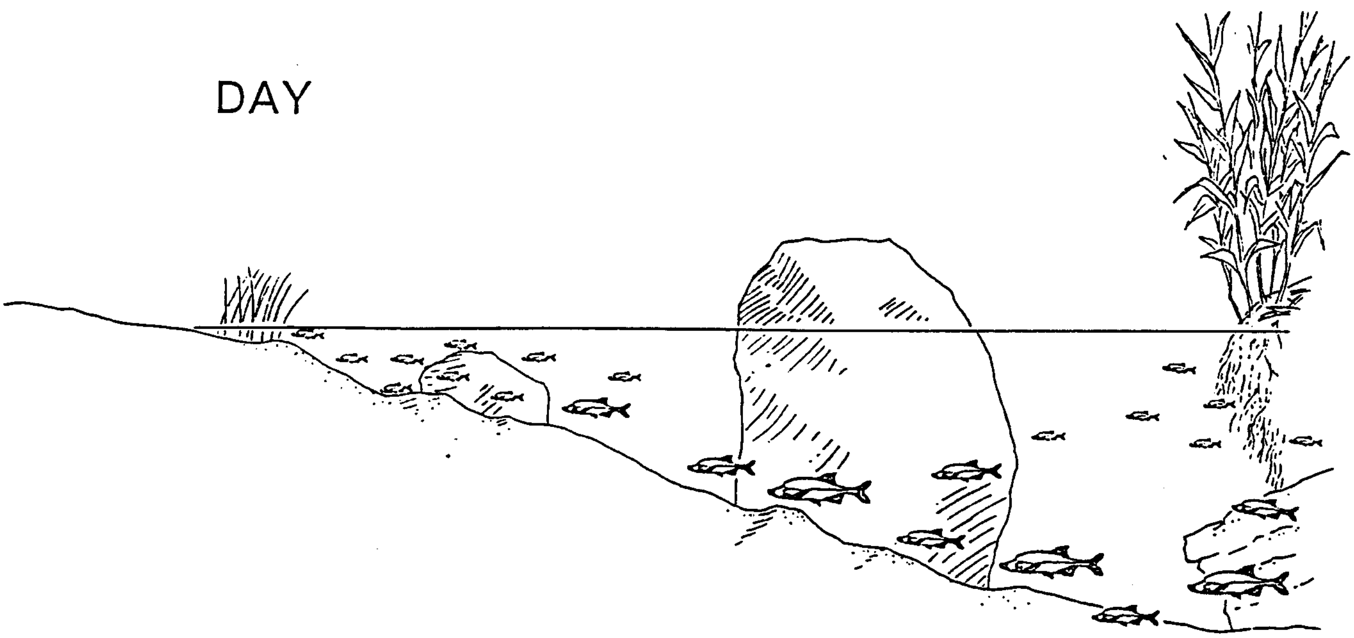
HBC 5/93, 7/93 Powell (DAY)



NIGHT



DAY



APPENDIX V

ANALYSIS OF HABITAT USE BY LCR FISHES, MAY-AUGUST 1993

PART 2: Frequency histograms of available habitat and habitat use by LCR fishes, May-August 1993

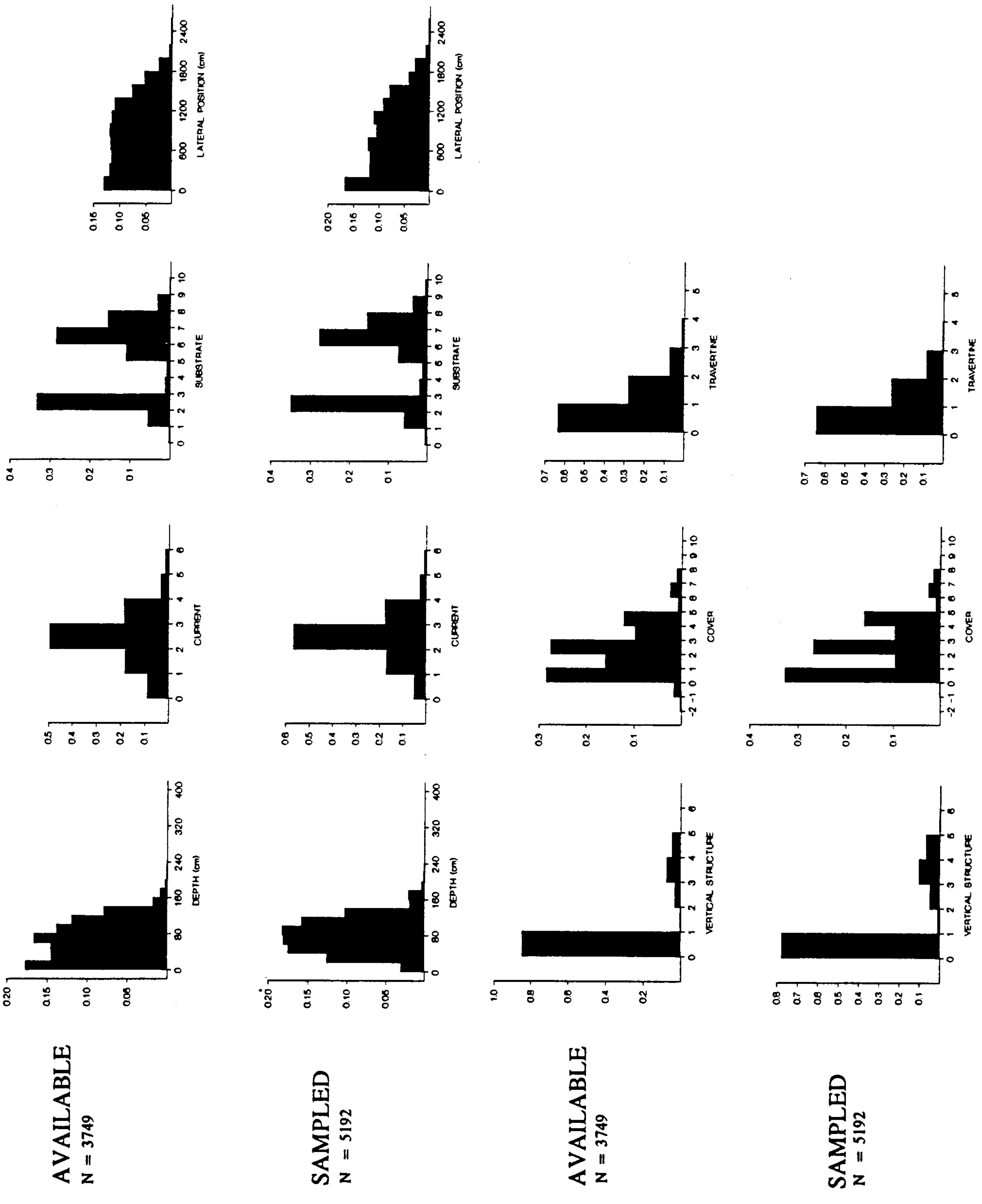
FIGURE 2. USFWS LCR fish habitat studies, Powell and Salt study areas, 5-8/93. Available habitat vs. sampled habitat data.

Grouped in pairs by 500 m study reaches for each study area: 5/93, 7/93 and 6/93, 8/93.
Available habitat was sampled from transects.
Sampled habitat represents habitat sampled in small grids around minihoopnets and minnow traps in study grids.

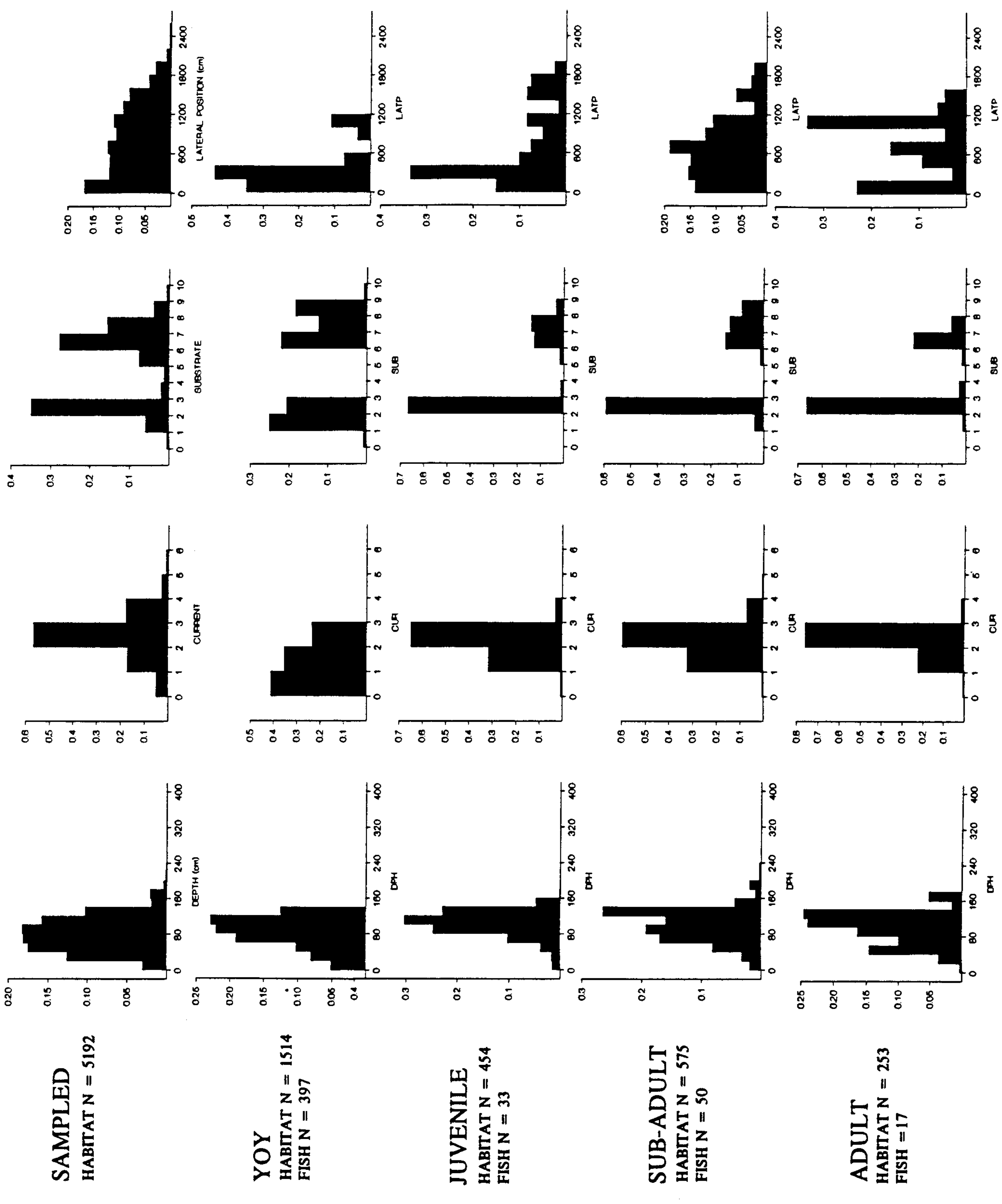
Habitat variables shown:
DPH, CUR, LATP, EPS (SUB), CVR, VER, TRA.

Consult Table 1 for explanation of habitat variable codes.

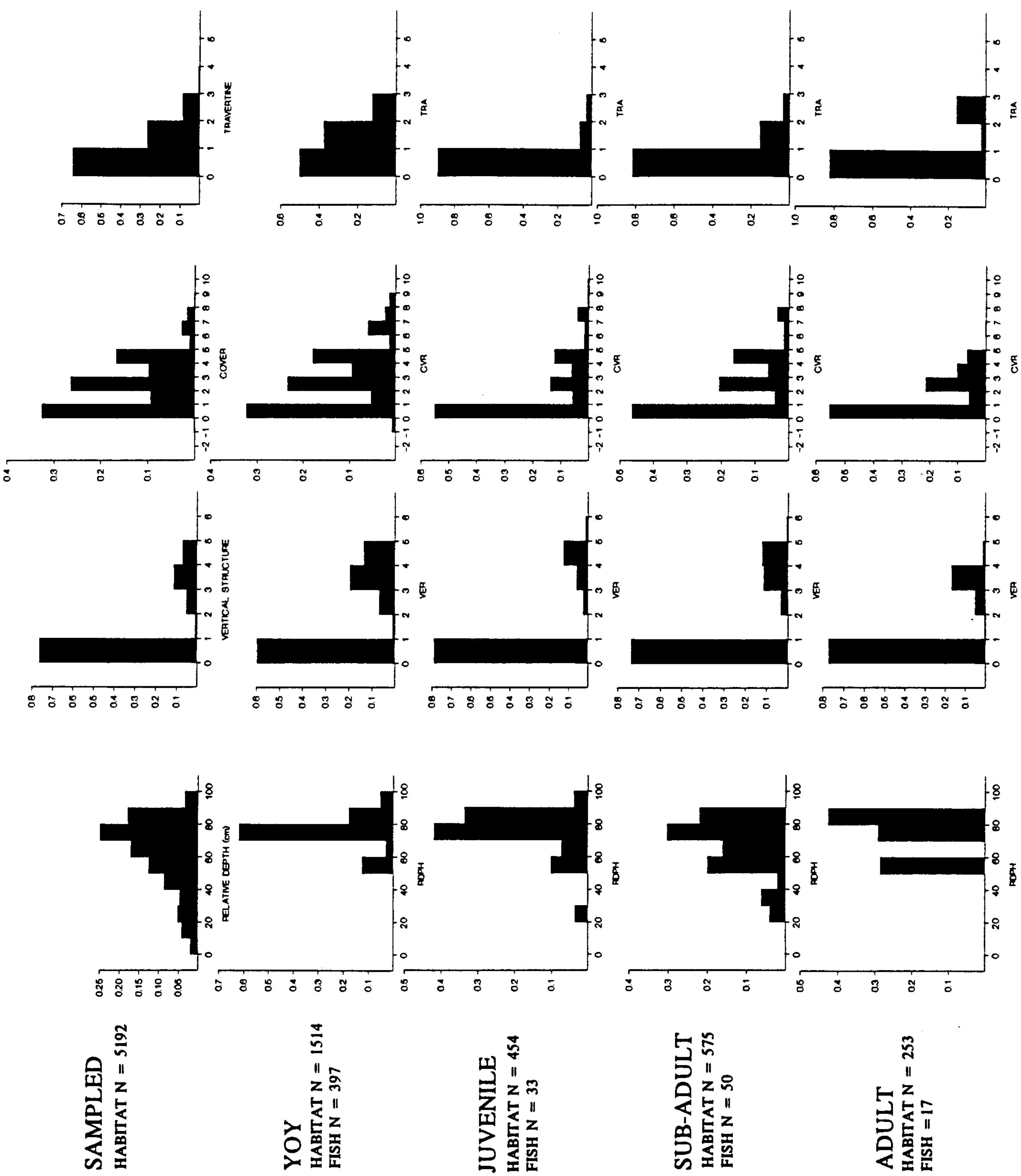
5/93, 7/93 Powell



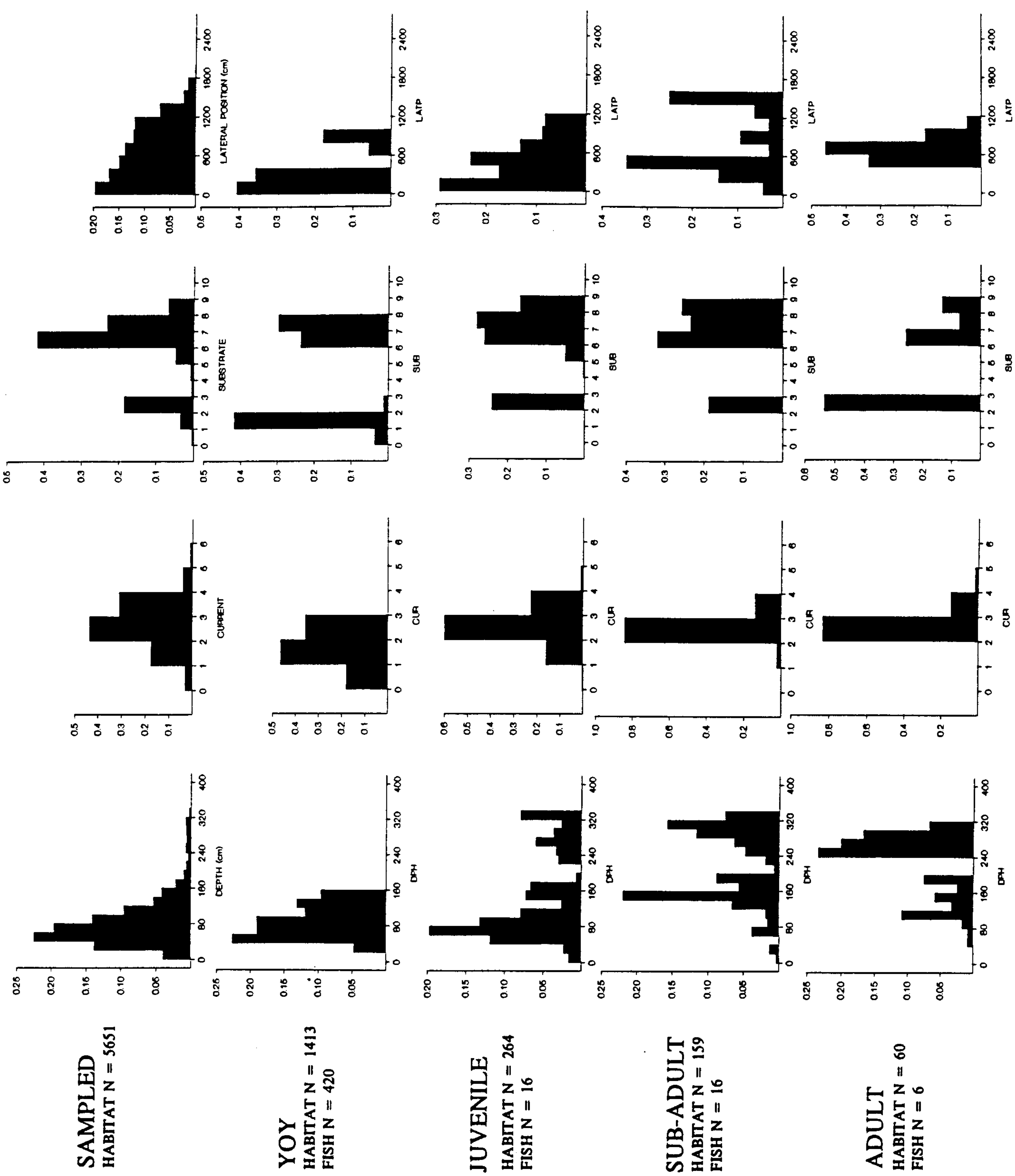
HBC 5/93, 7/93 Powell (NIGHT)



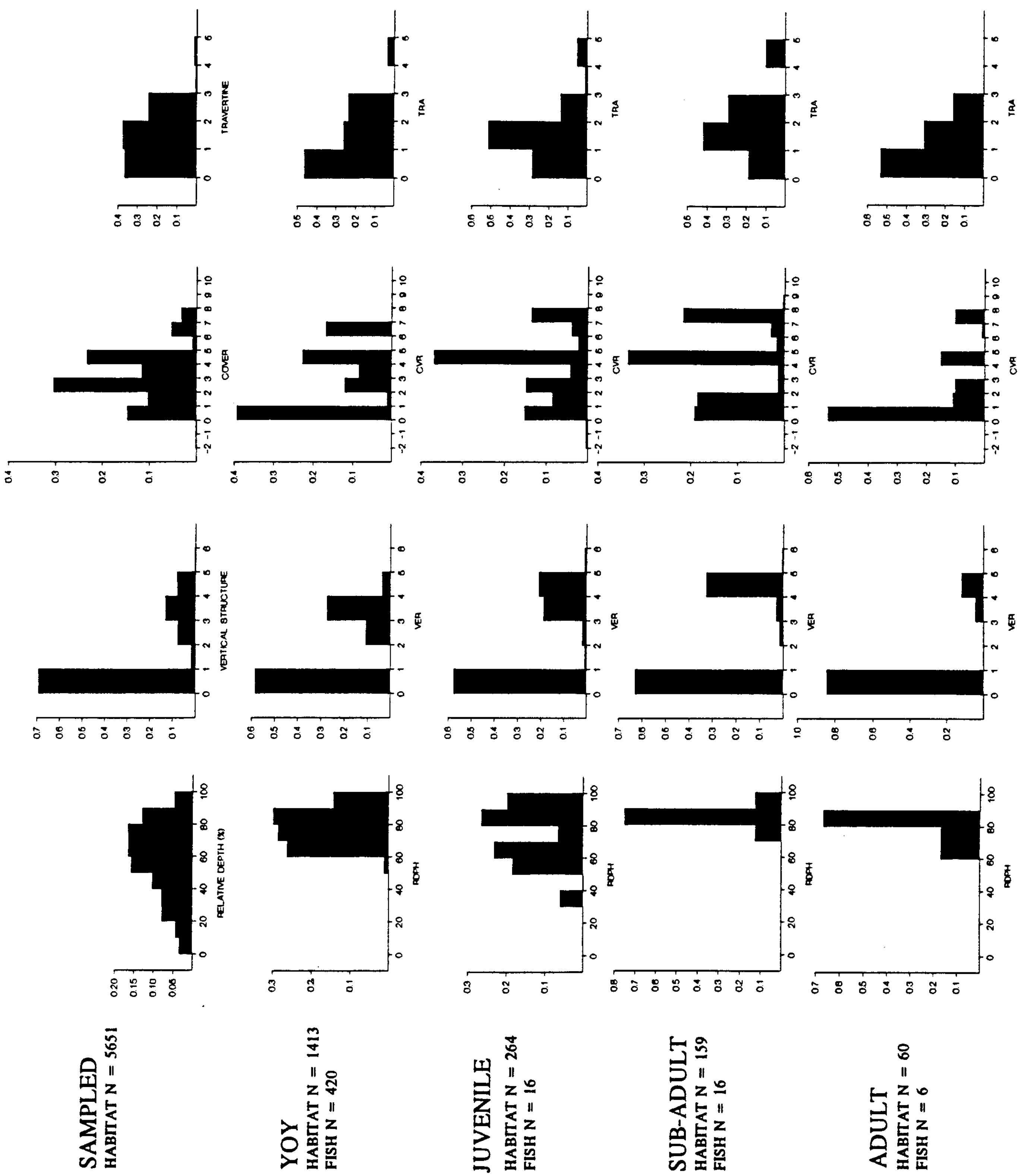
HBC 5/93, 7/93 Powell (NIGHT)



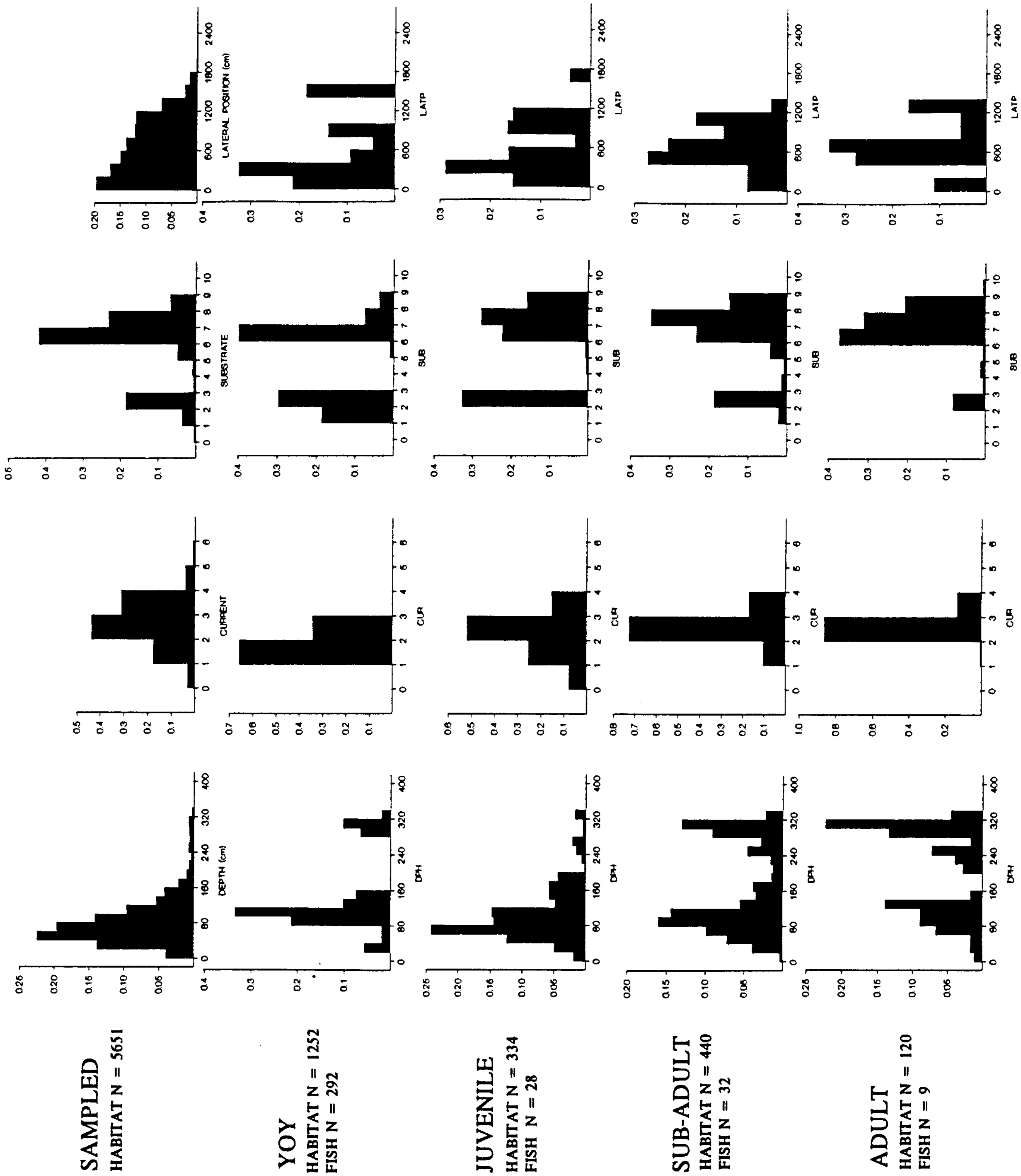
HBC 6/93, 8/93 Powell (DAY)



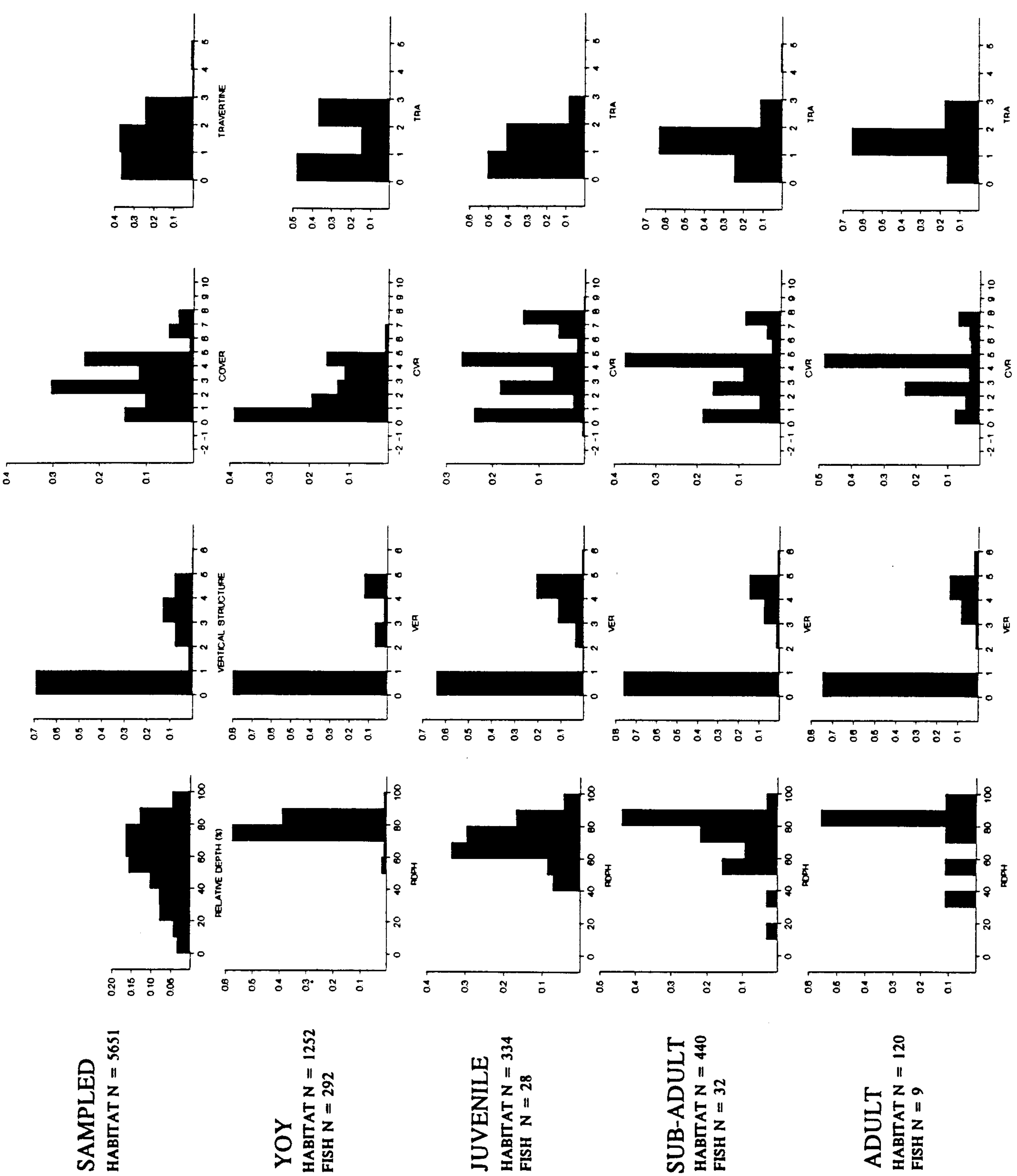
HBC 6/93, 8/93 Powell (DAY)



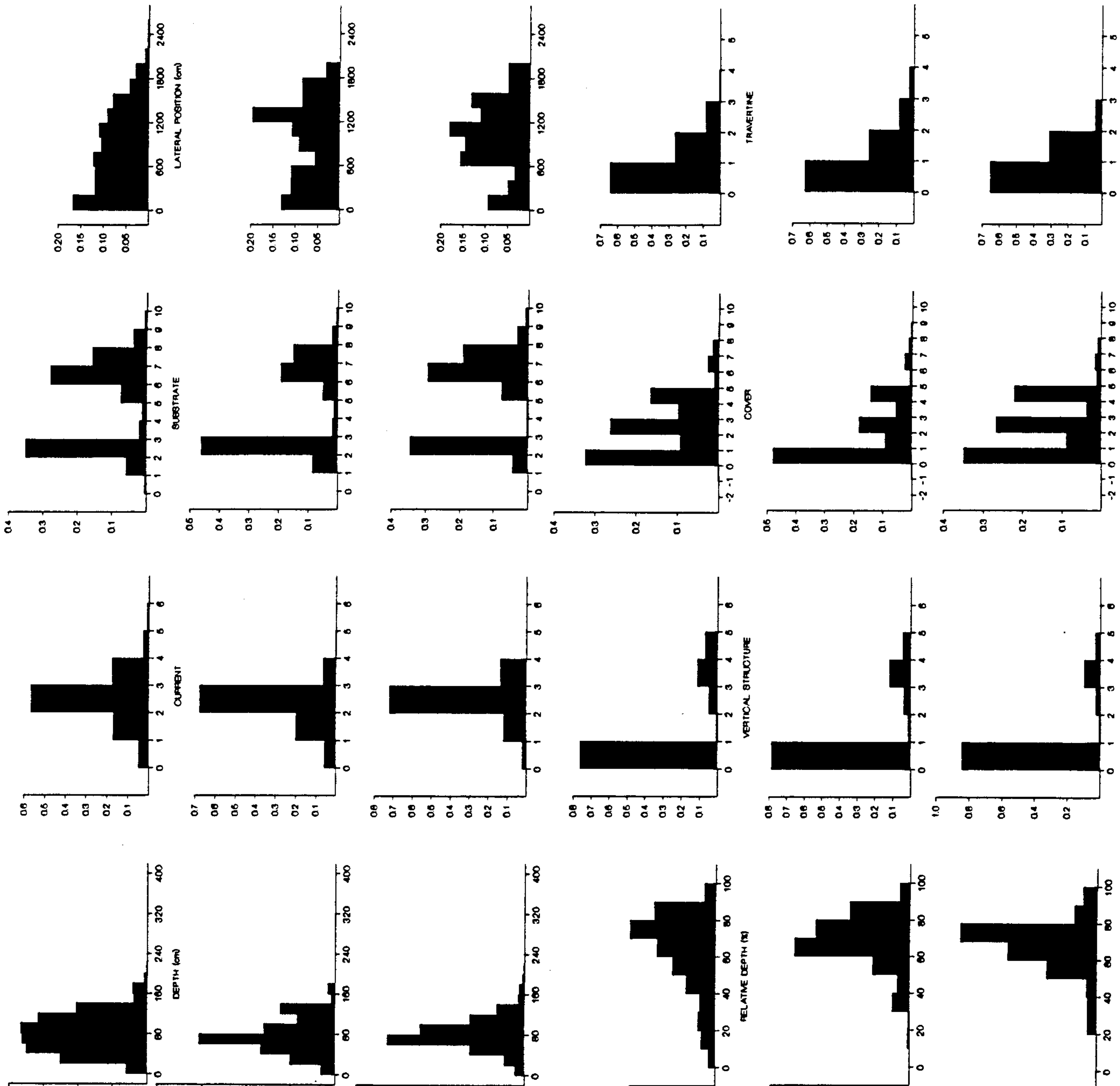
HBC 6/93, 8/93 Powell (NIGHT)



HBC 6/93, 8/93 Powell (NIGHT)



SPD 5/93, 7/93 Powell (DAY)



SAMPLED
HABITAT N = 5192

< = 70mm
HABITAT N = 1247
FISH N = 81

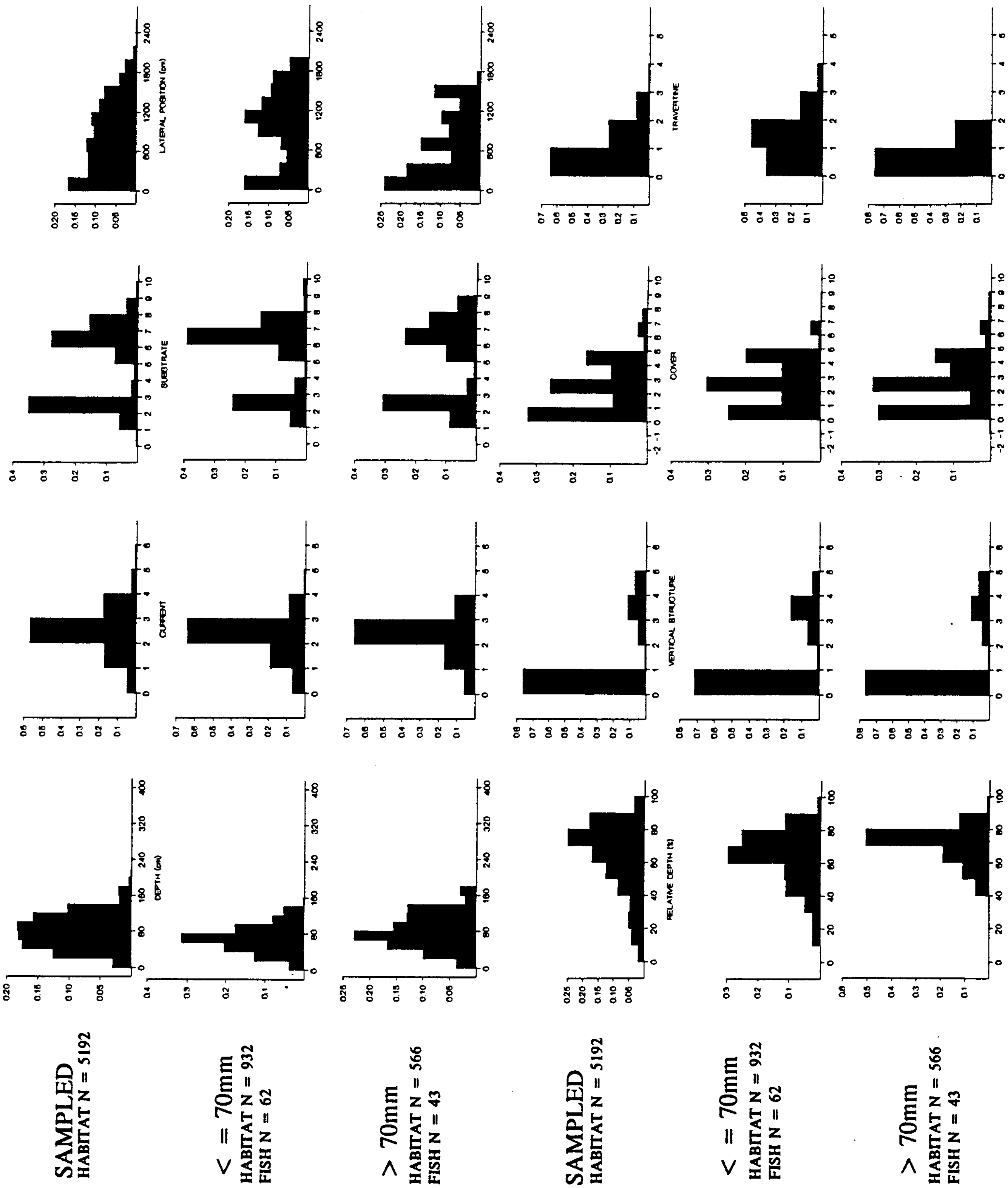
> 70mm
HABITAT N = 720
FISH N = 44

SAMPLED
HABITAT N = 5192

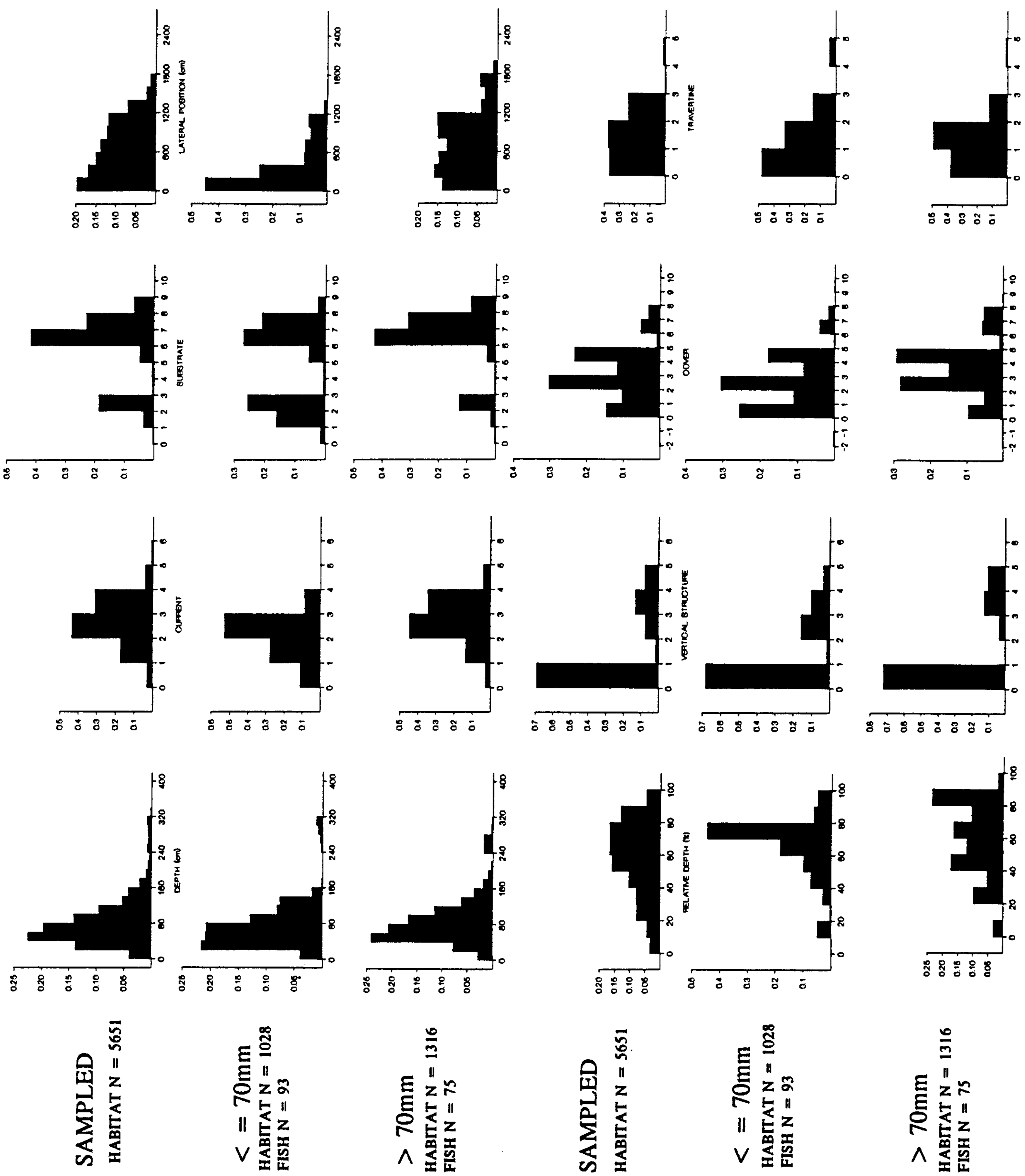
< = 70mm
HABITAT N = 1247
FISH N = 81

> 70mm
HABITAT N = 720
FISH N = 44

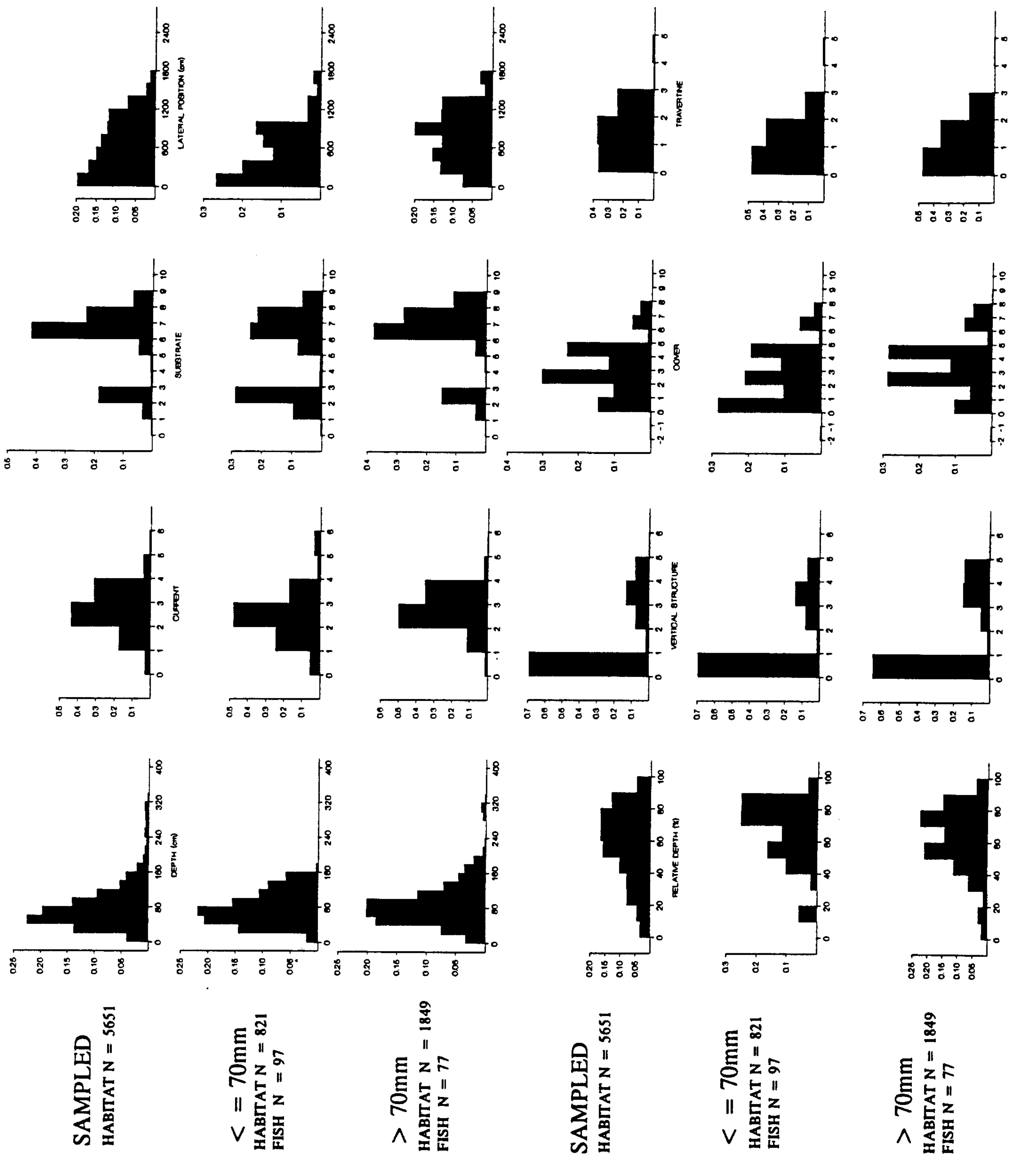
SPD 5/93, 7/93 Powell (NIGHT)



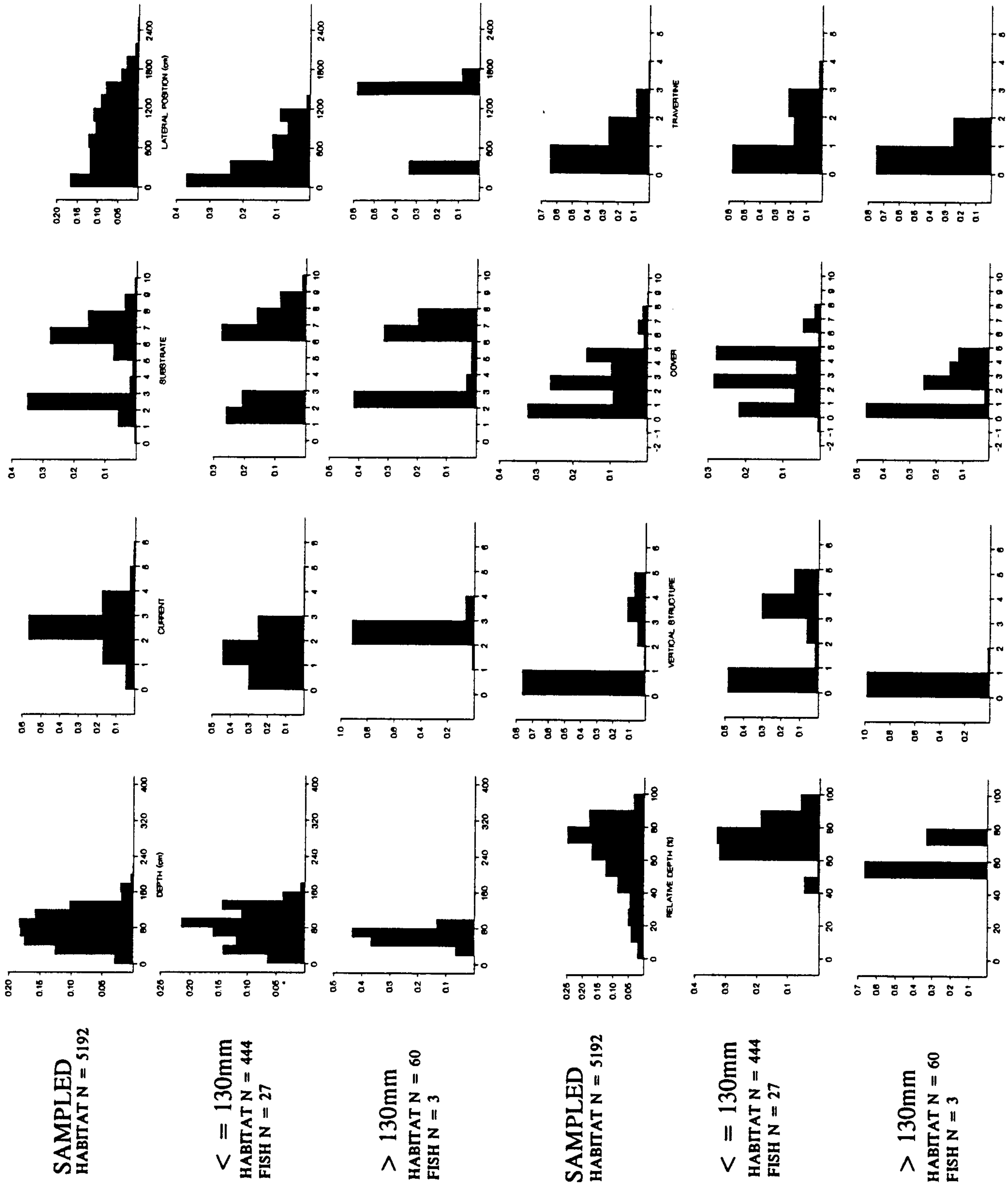
SPD 6/93, 8/93 Powell (DAY)



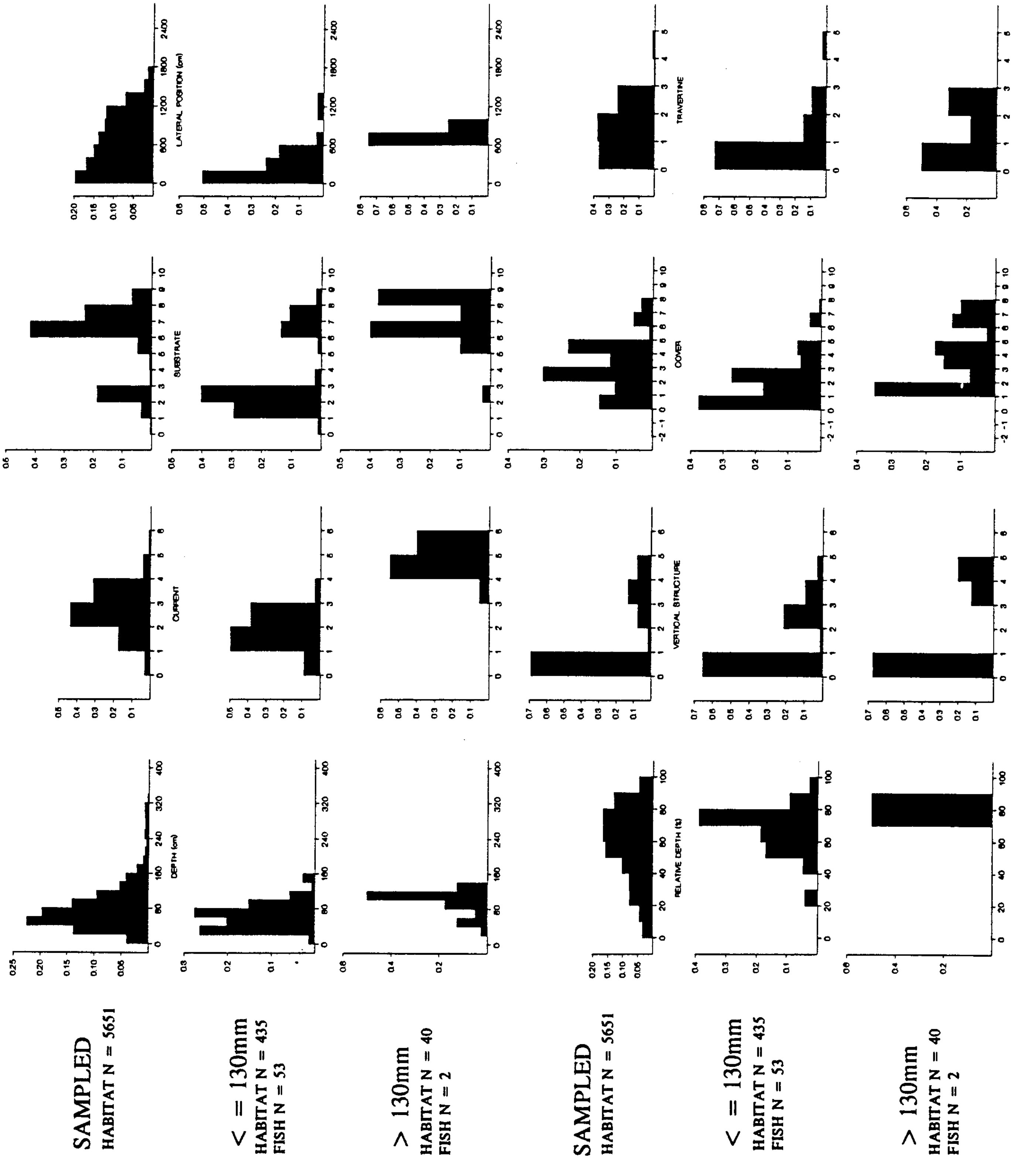
SPD 6/93, 8/93 Powell (NIGHT)



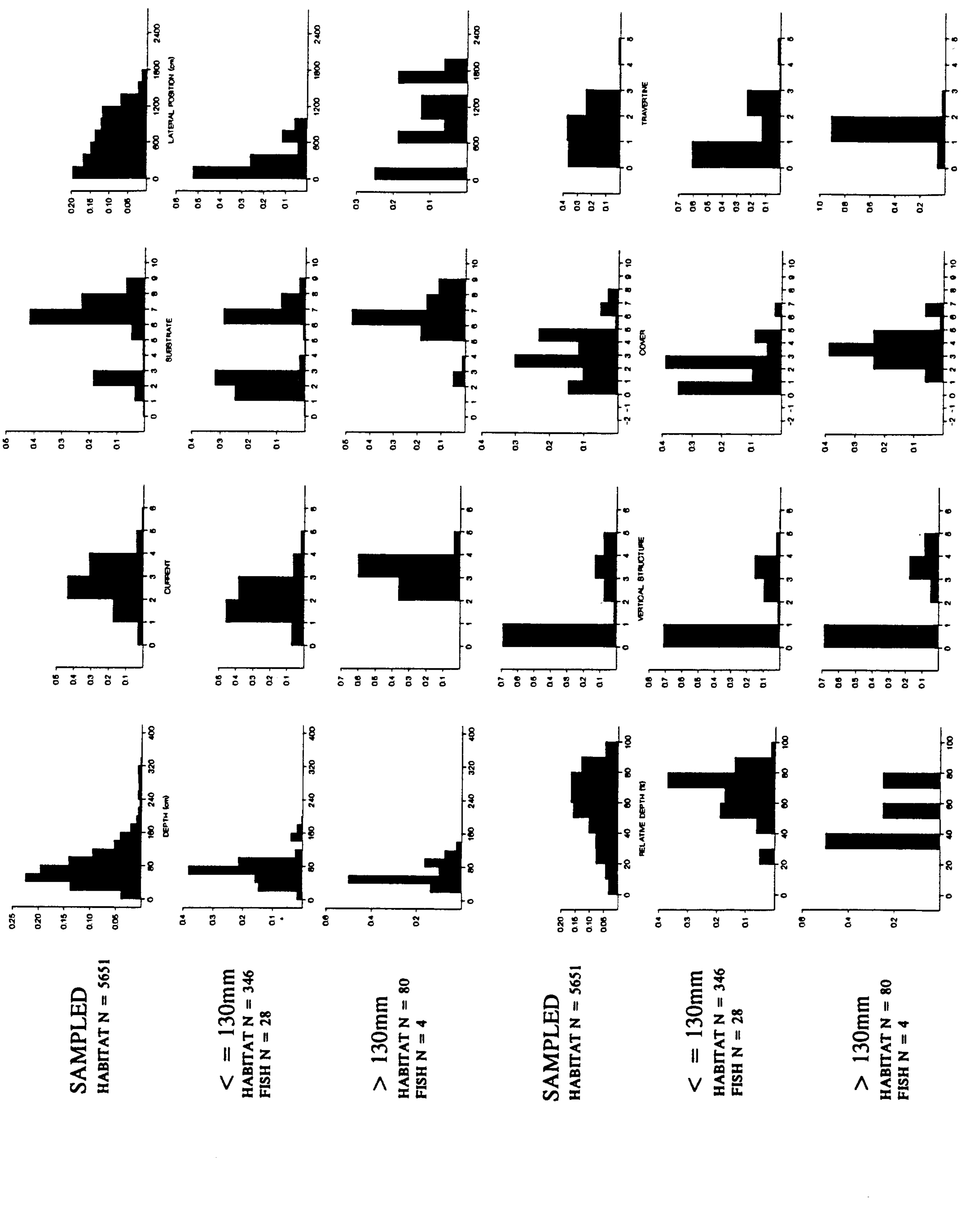
BHS 5/93, 7/93 Powell (NIGHT)



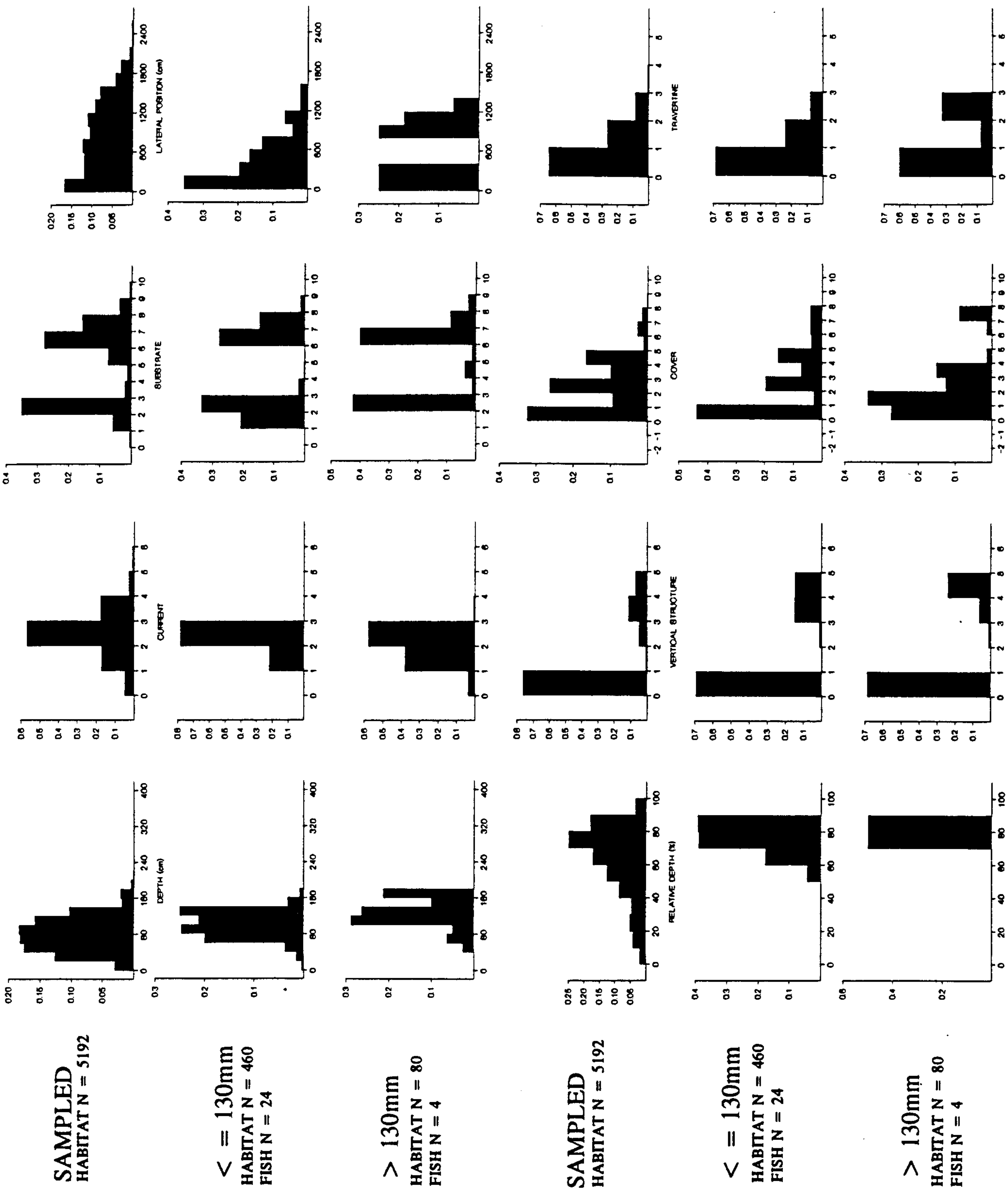
BHS 6/93, 8/93 Powell (DAY)



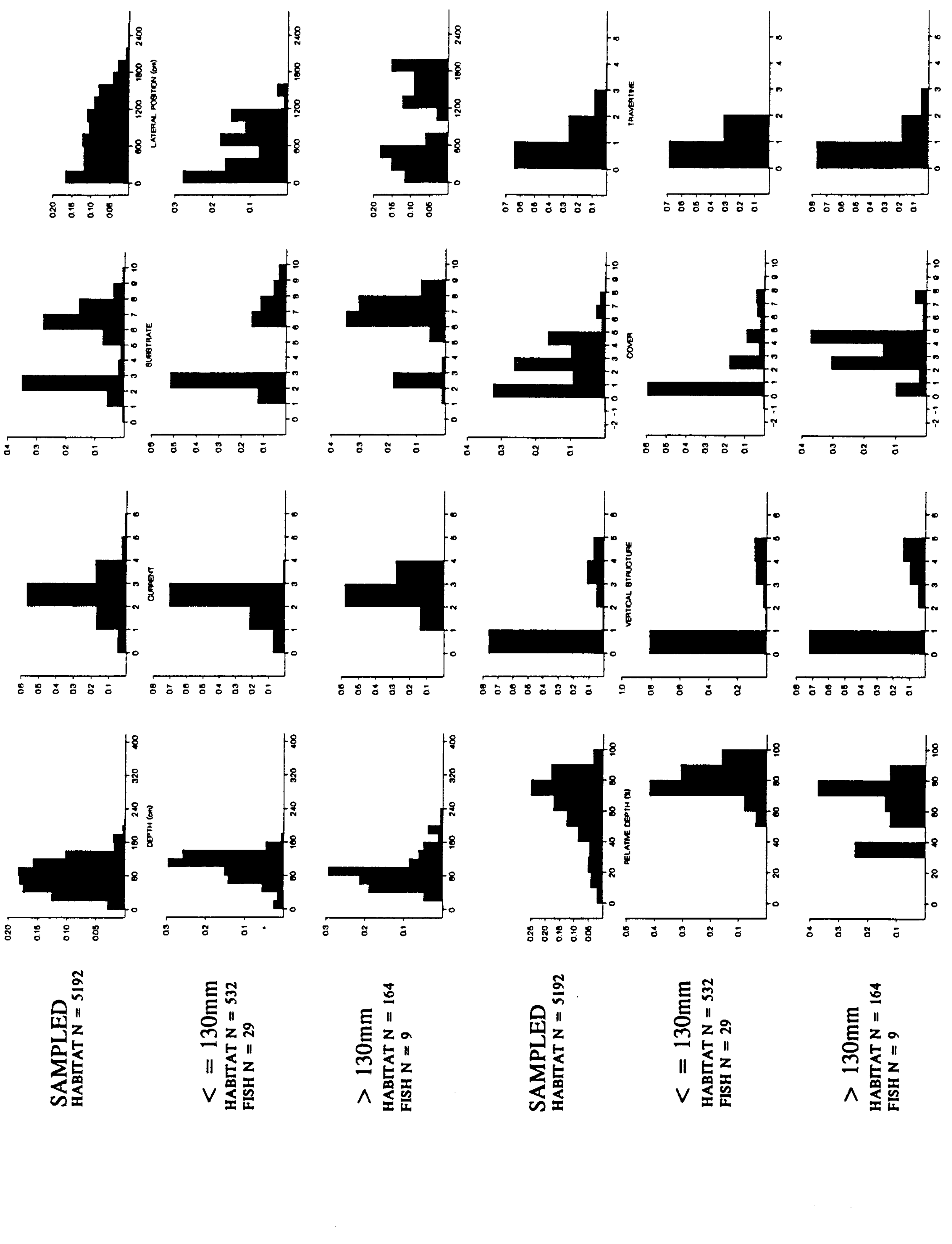
BHS 6/93, 8/93 Powell (NIGHT)



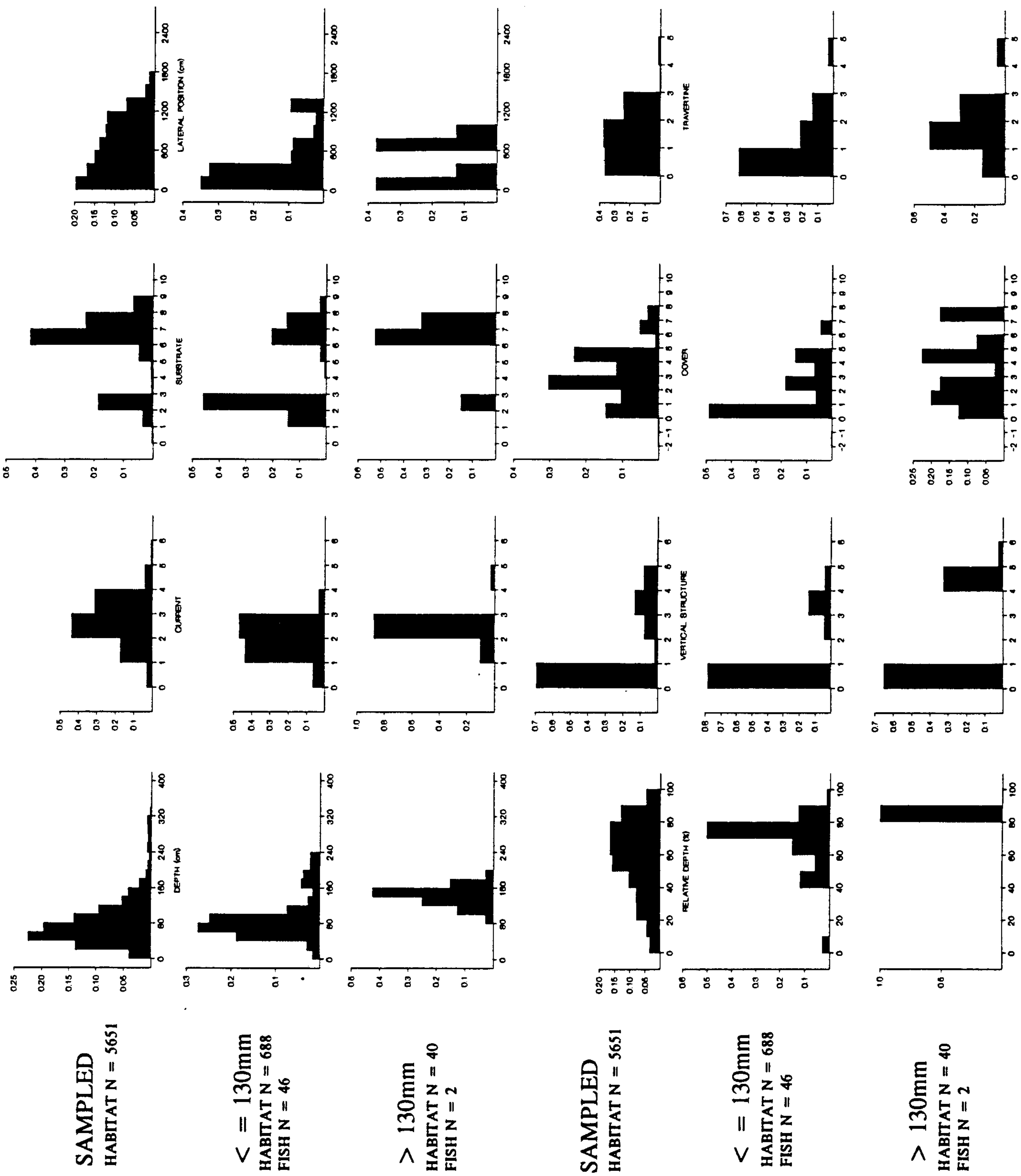
FMS 5/93, 7/93 Powell (DAY)



FMS 5/93, 7/93 Powell (NIGHT)



FMS 6/93, 8/93 Powell (DAY)



FMS 6/93, 8/93 Powell (NIGHT)

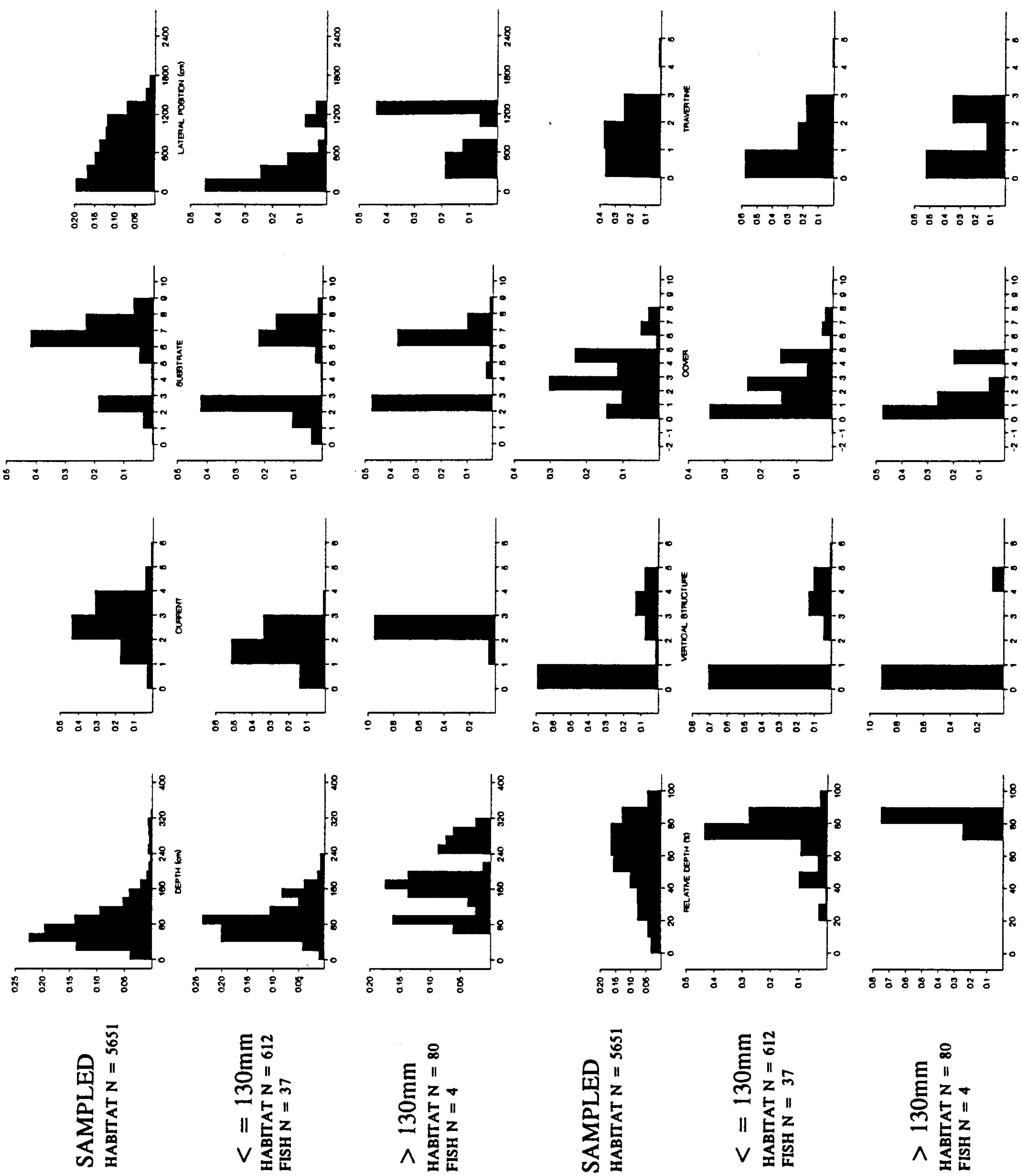


FIGURE 4. USFWS LCR fish habitat studies, Salt Study Area, 5/93-8/93: Sampled habitat and habitat use by native fishes.

Grouped in pairs by 500 m study reaches for each study area: 5/93, 7/93 and 6/93, 8/93.

Sampled distributions represent habitat sampled for fish. Data shown was measured from minihoopnets and minnow traps set in USFWS study grids.

Habitat use distributions are weighted and divided into day and night periods.

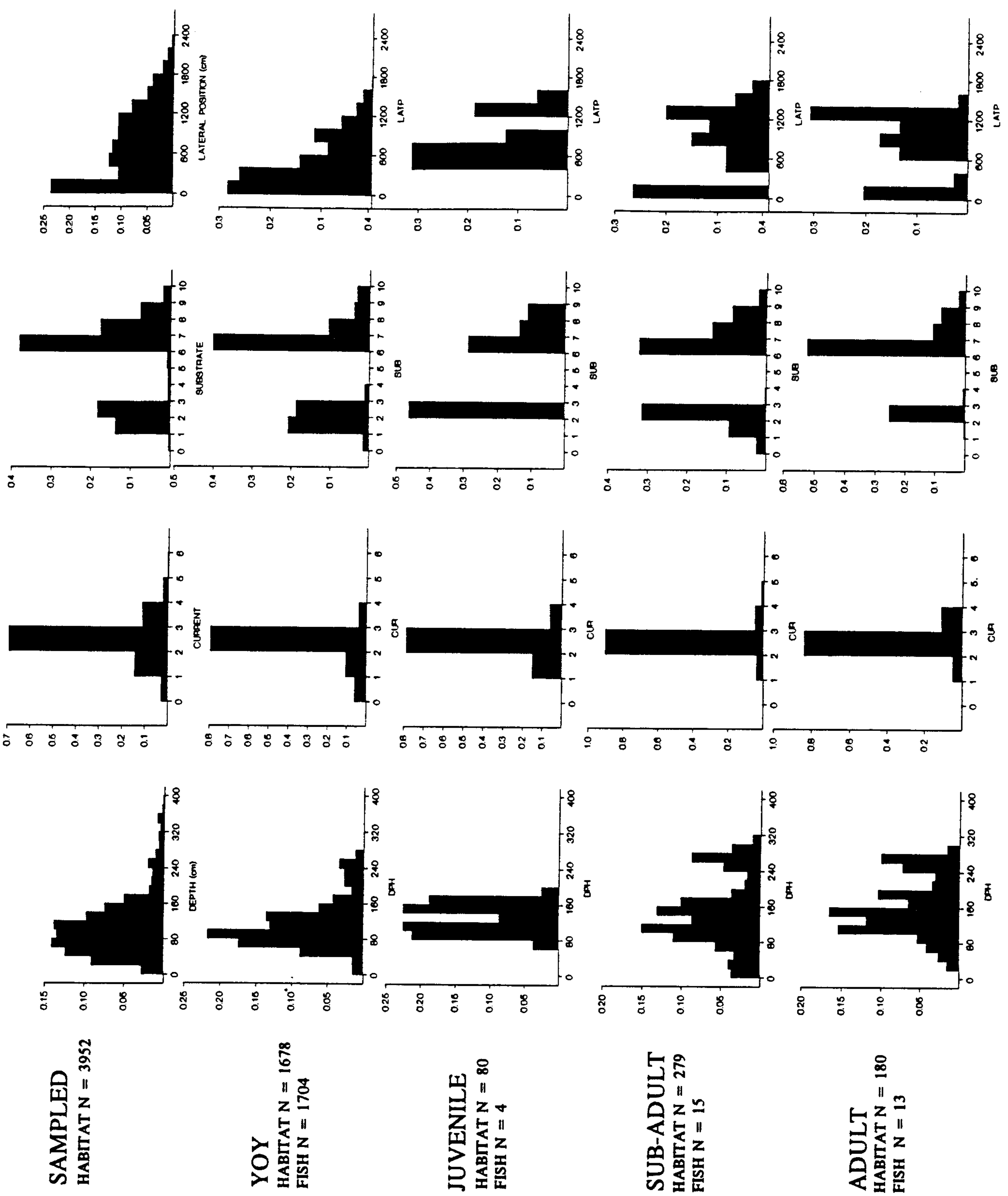
Habitat variables shown:
DPH, CUR, EPS (SUB), LATP, RDPH, VER, CVR, TRA

Species shown:

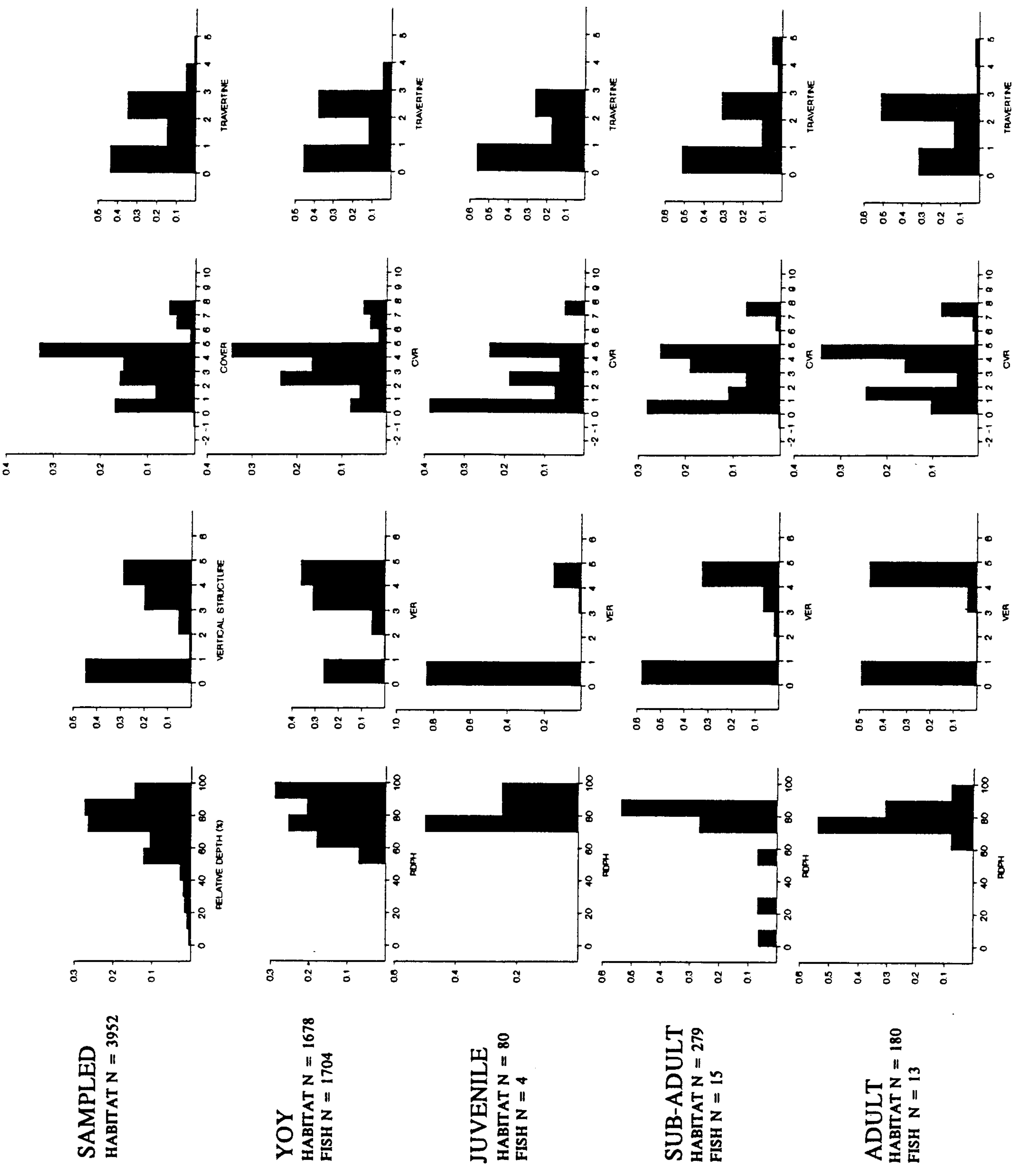
- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Table 1 for explanation of habitat variable codes.

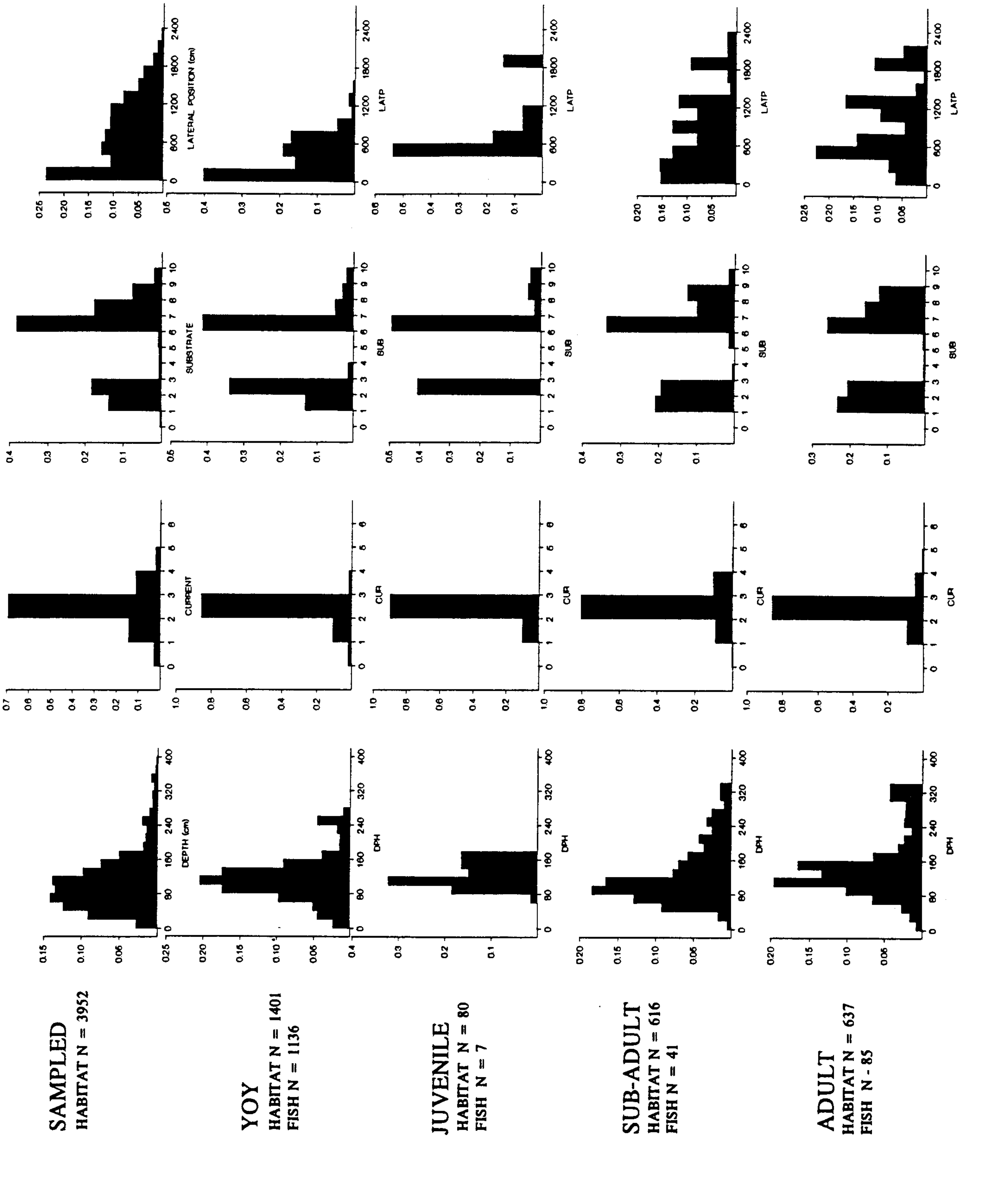
HBC 5/93, 7/93 Salt (DAY)



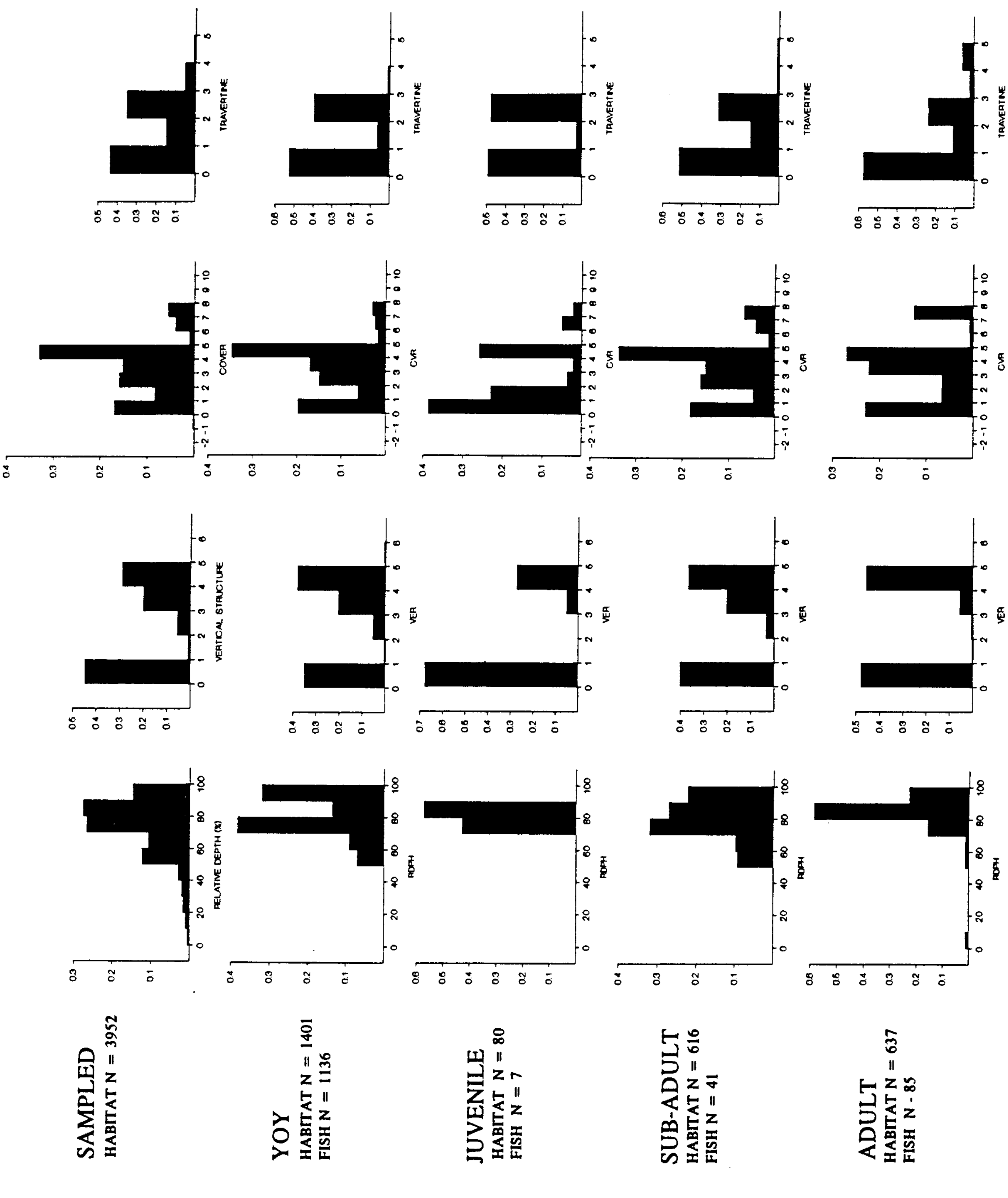
HBC 5/93, 7/93 Salt (DAY)



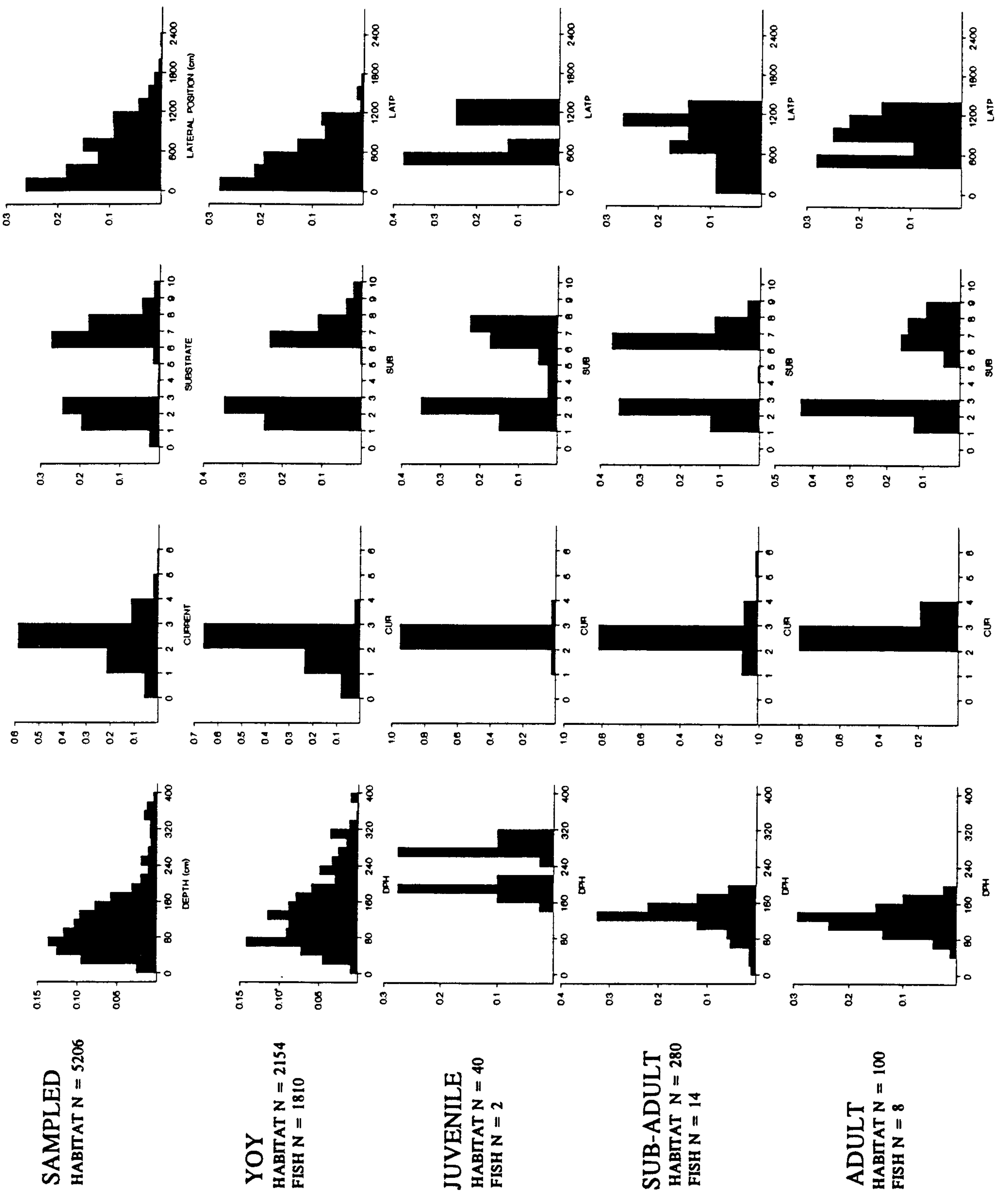
HBC 5/93, 7/93 Salt (NIGHT)



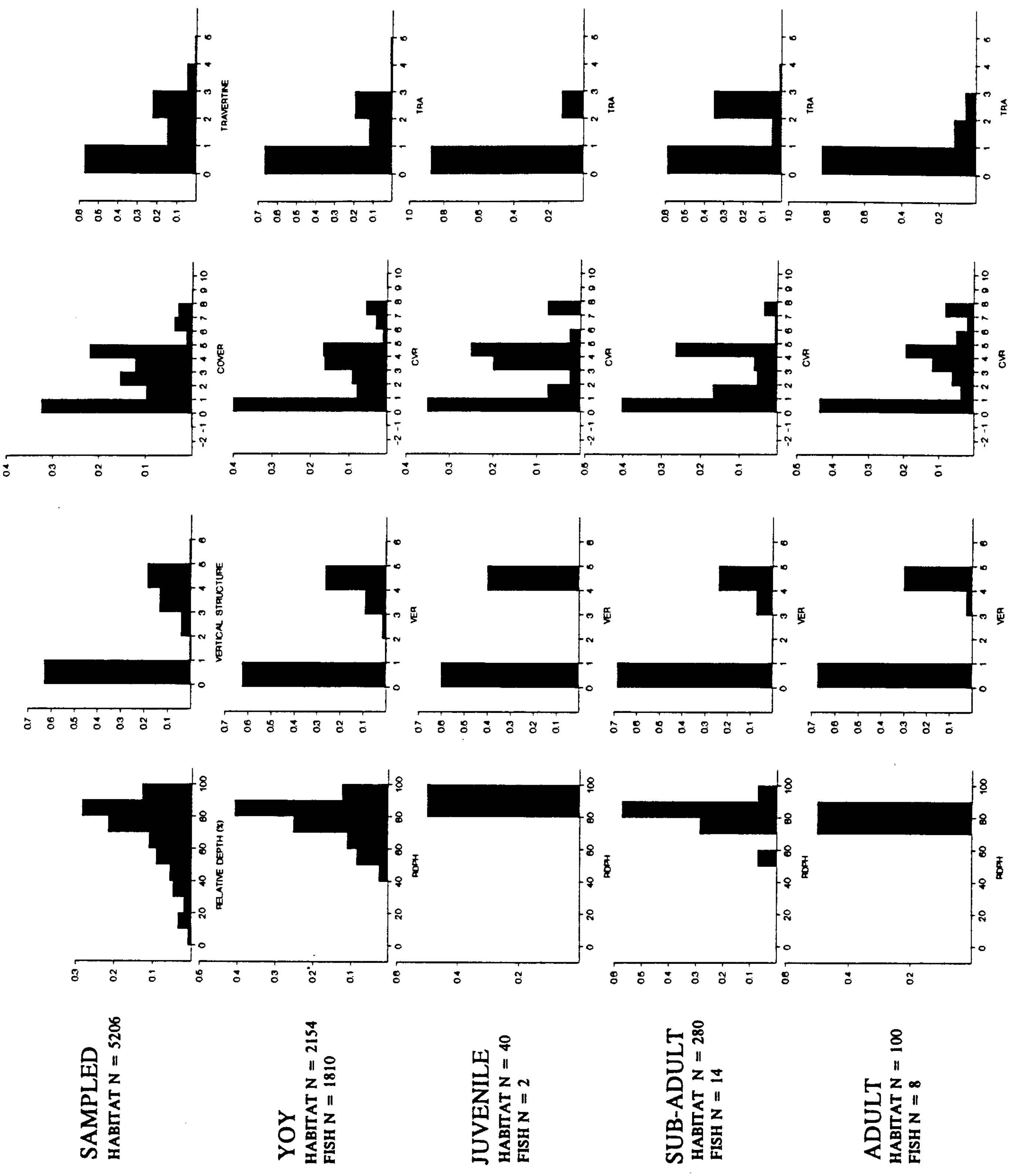
HBC 5/93, 7/93 Salt (NIGHT)



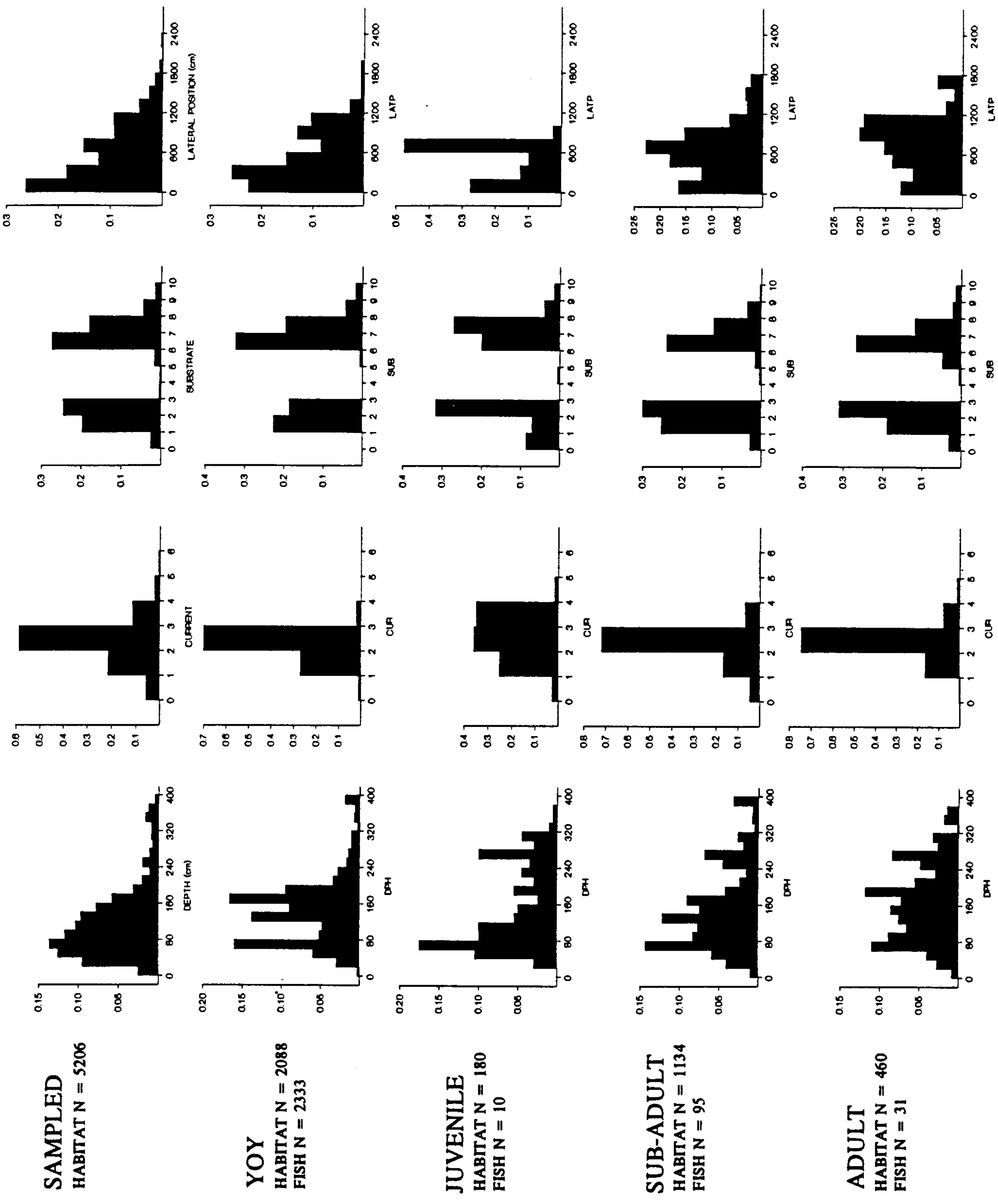
HBC 6/93, 8/93 Salt (DAY)



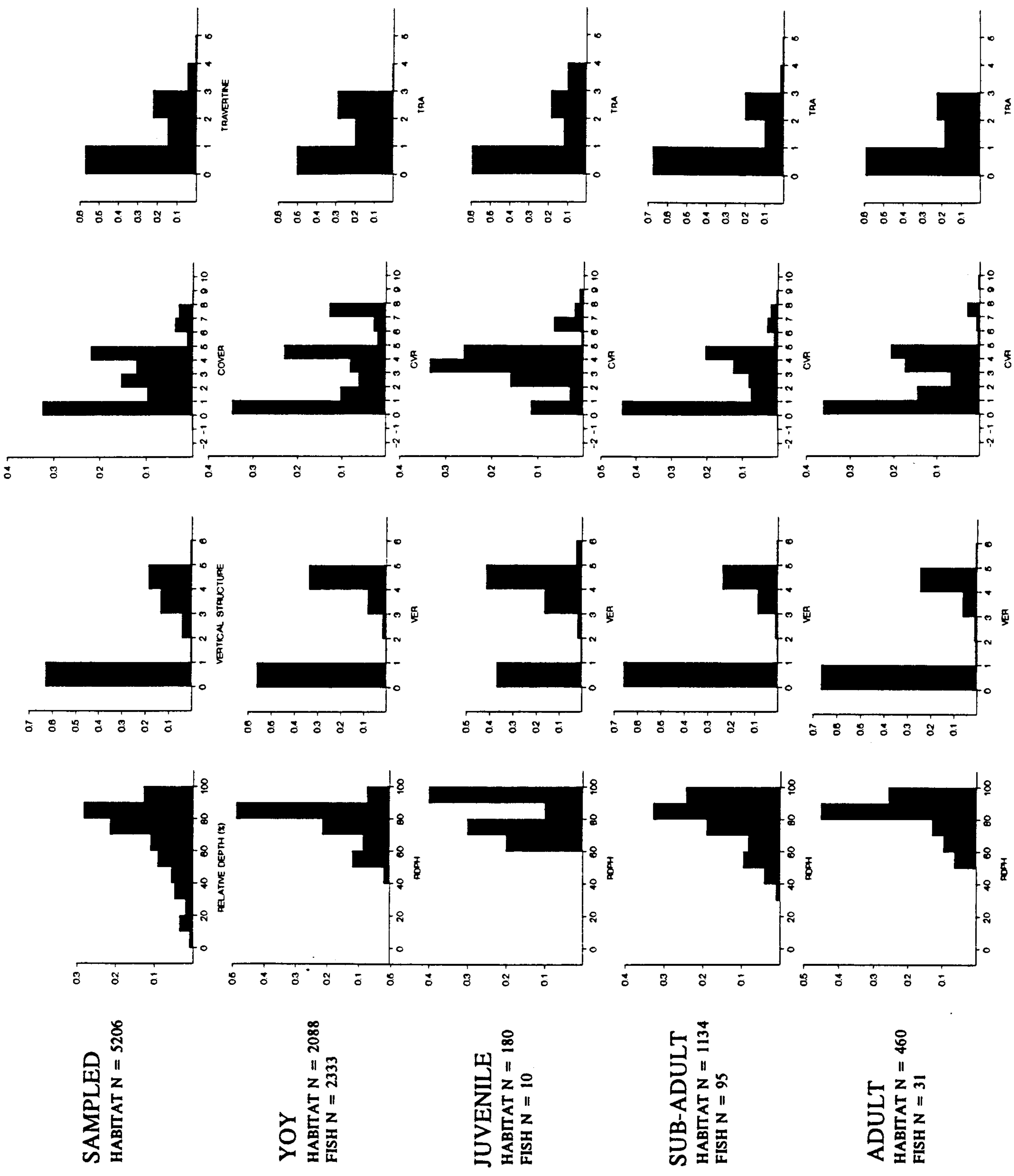
HBC 6/93, 8/93 Salt (DAY)



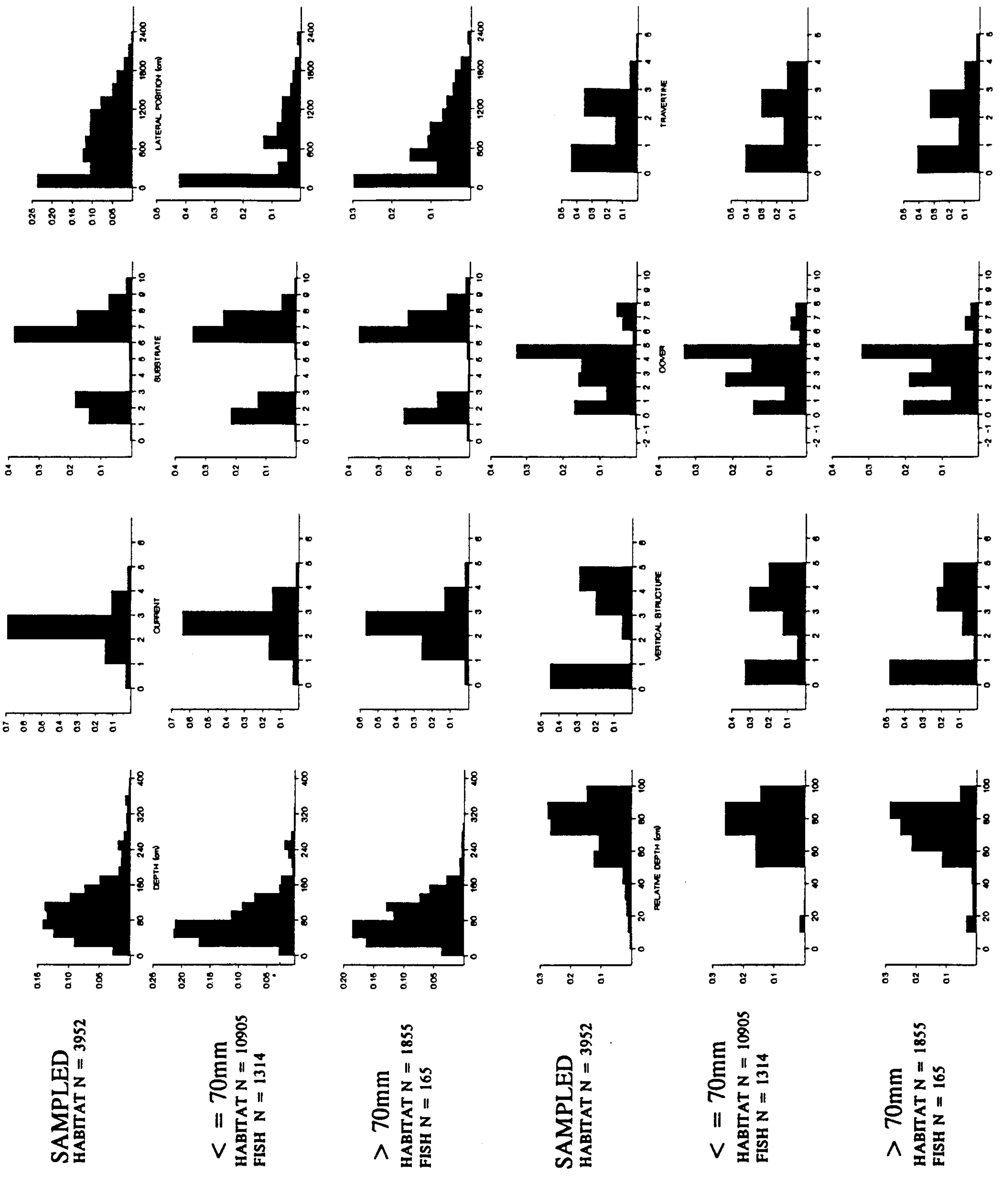
HBC 6/93, 8/93 Salt (NIGHT)



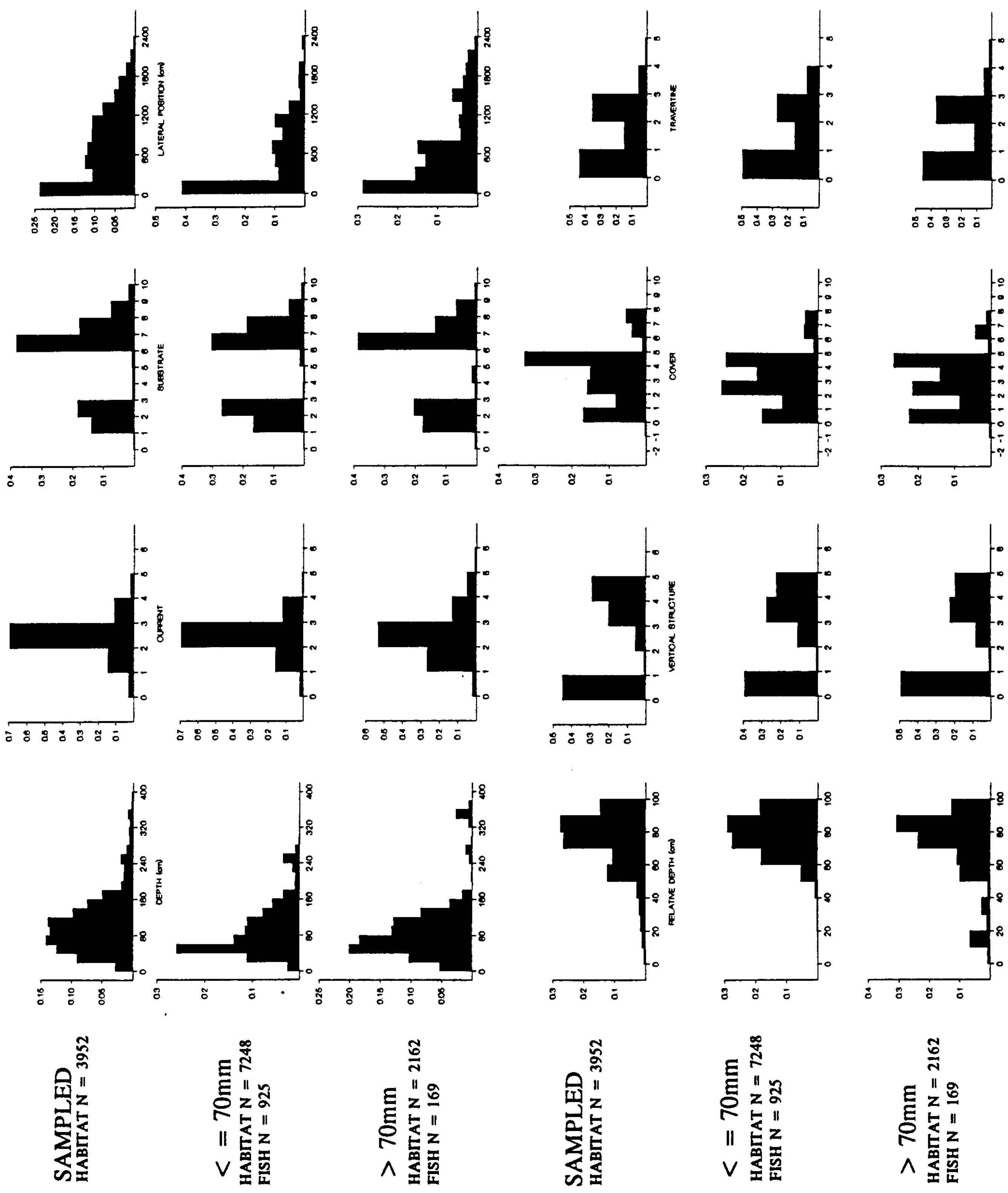
HBC 6/93, 8/93 Salt (NIGHT)



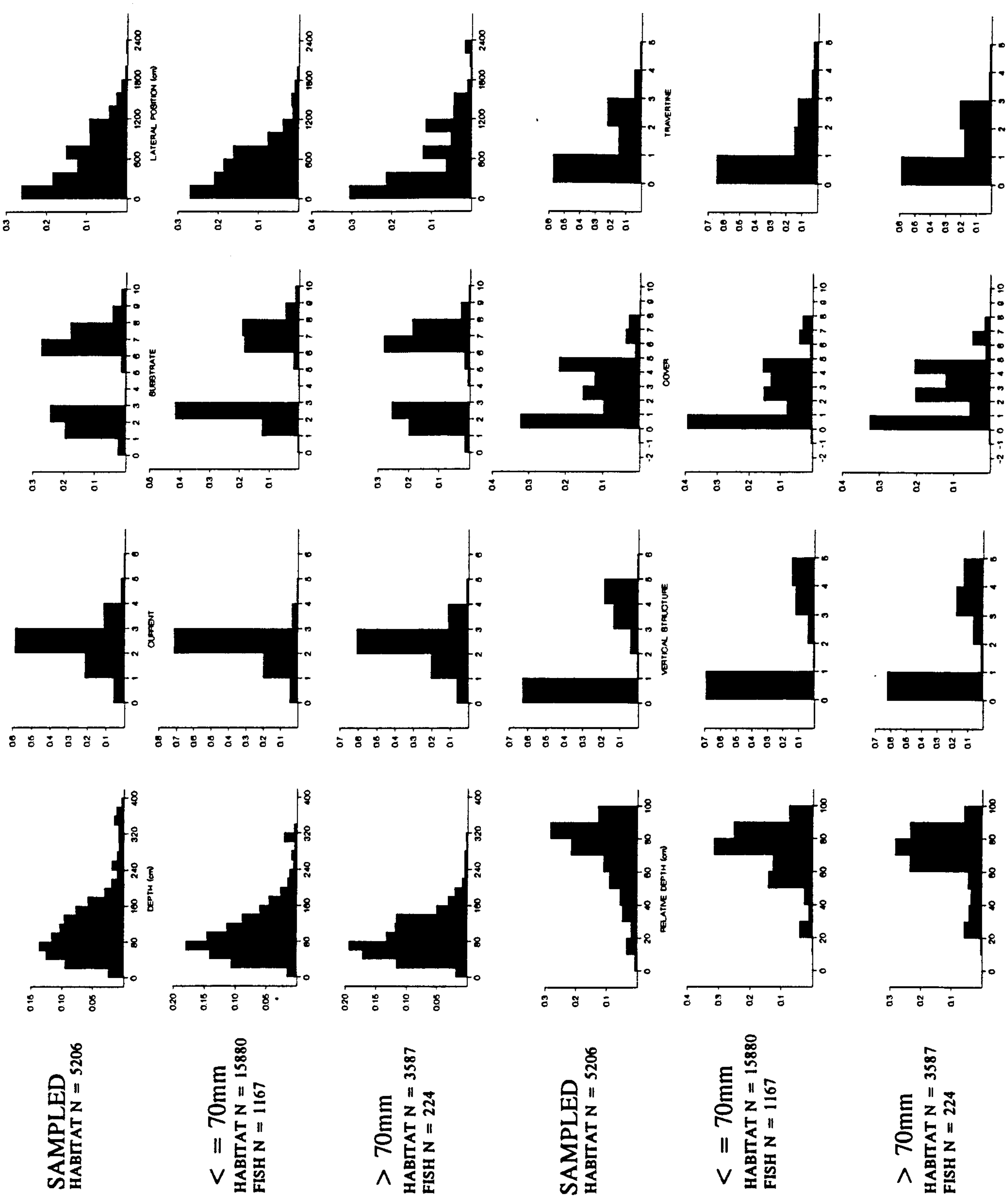
SPD 5/93, 7/93 Salt (DAY)



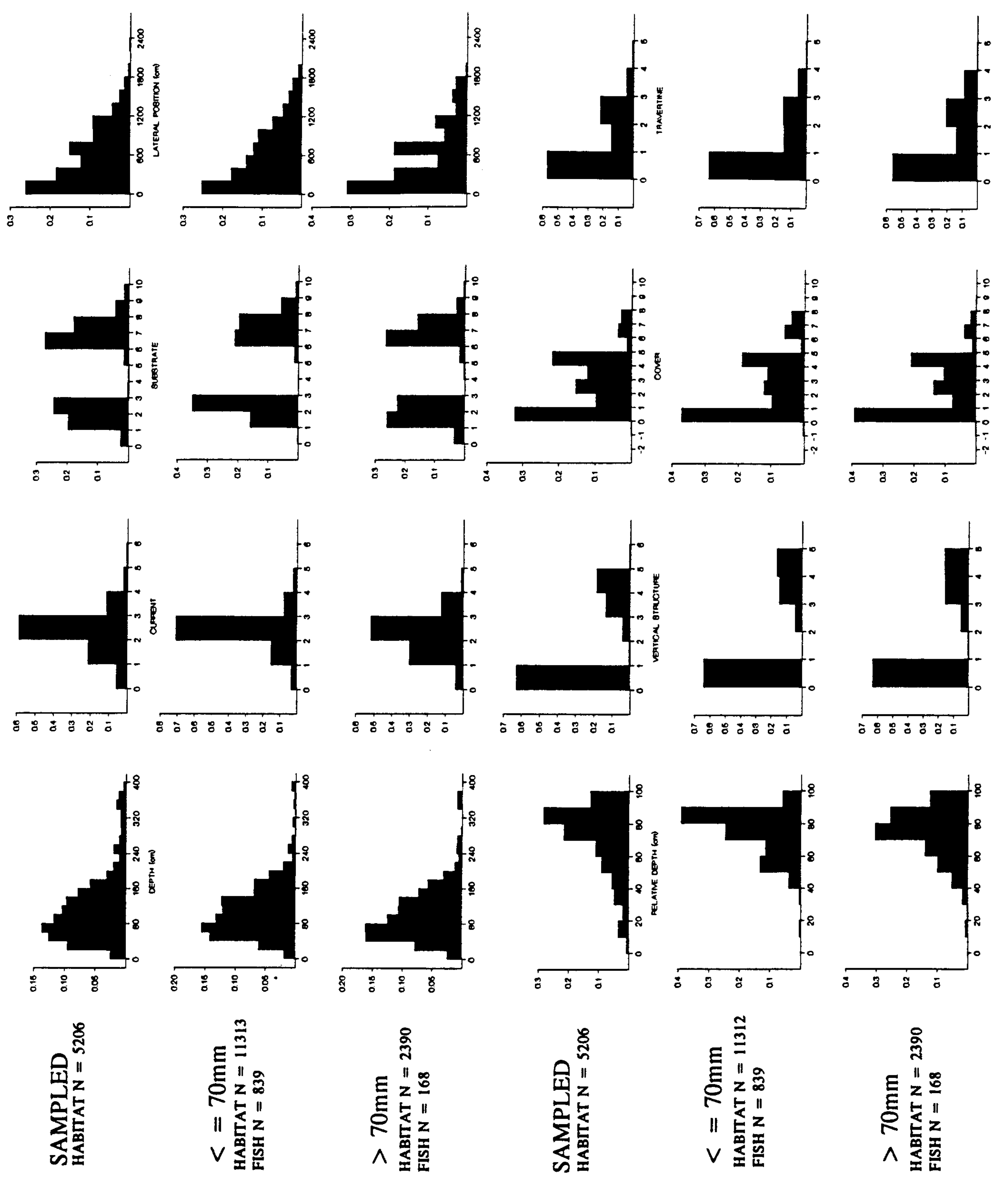
SPD 5/93, 7/93 Salt (NIGHT)



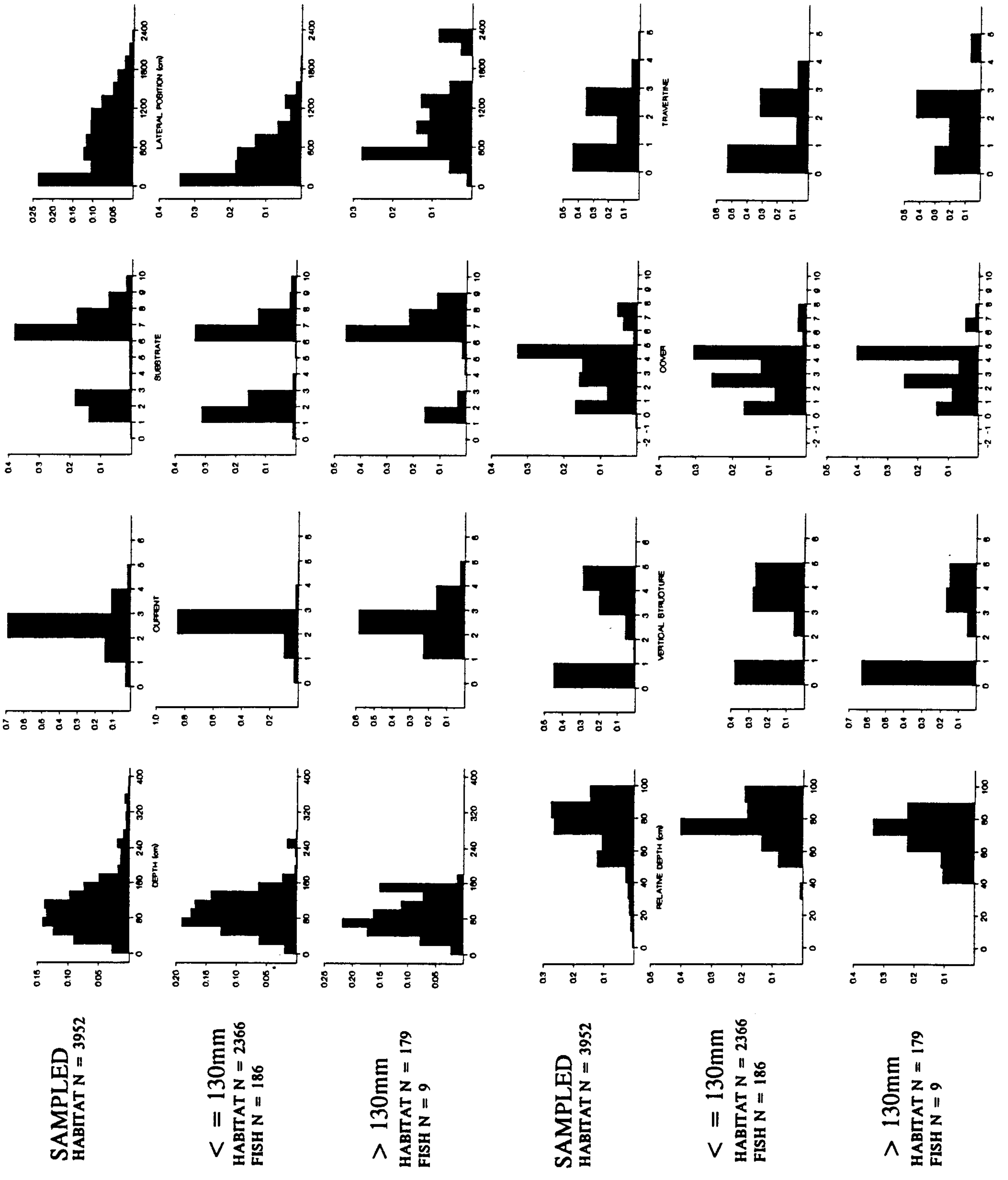
SPD 6/93, 8/93 Salt (DAY)



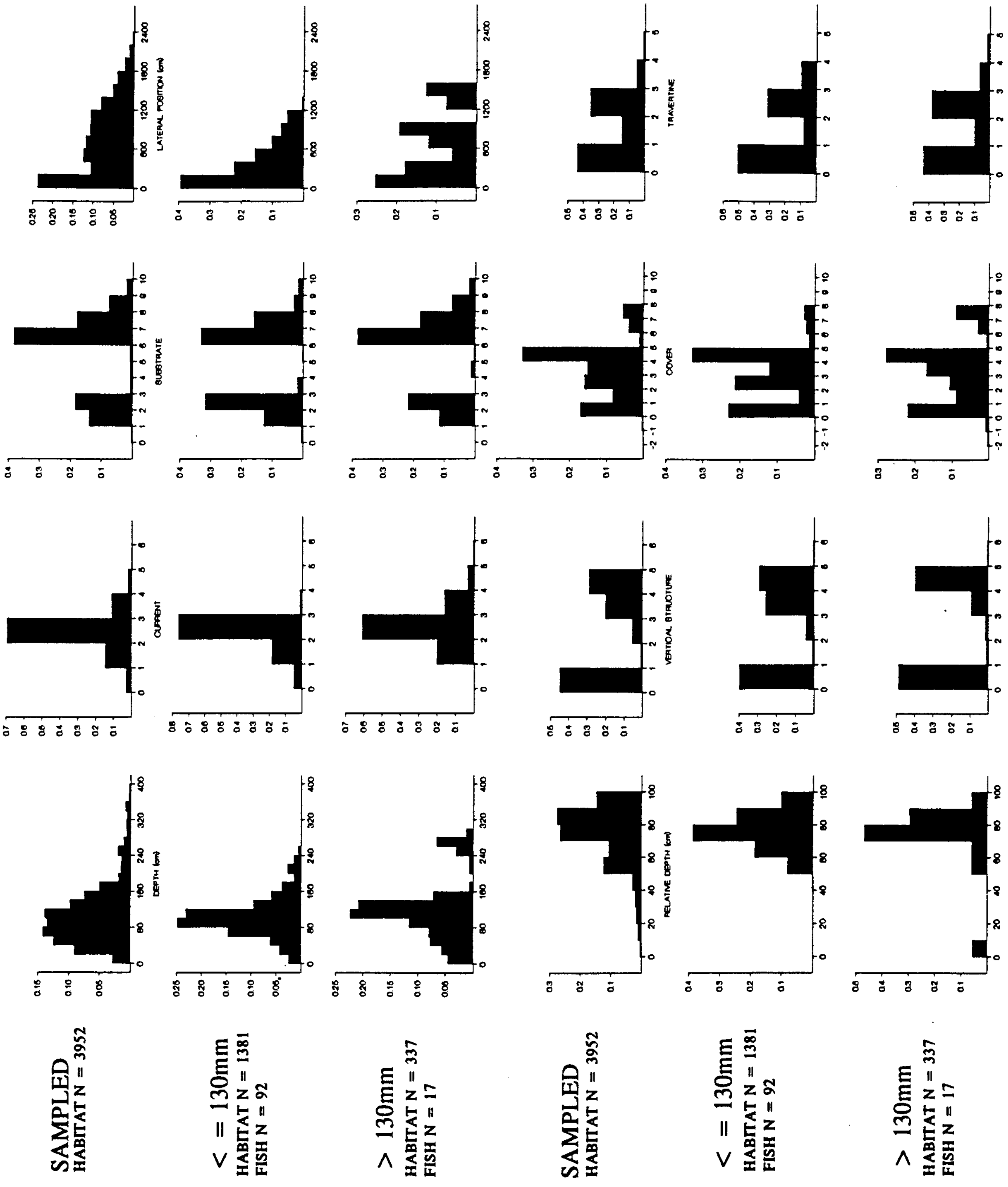
SPD 6/93, 8/93 Salt (NIGHT)



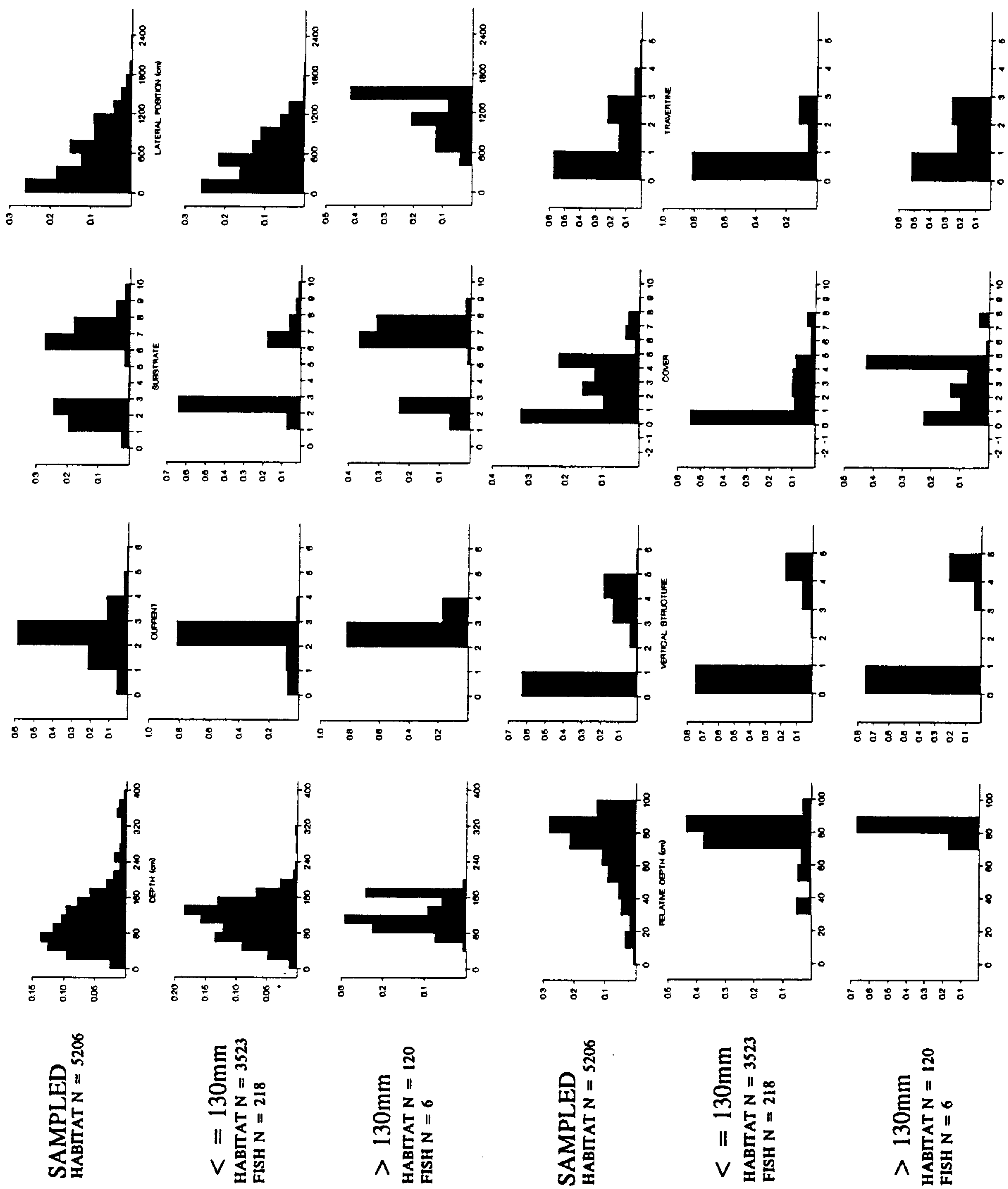
BHS 5/93, 7/93 Salt (DAY)



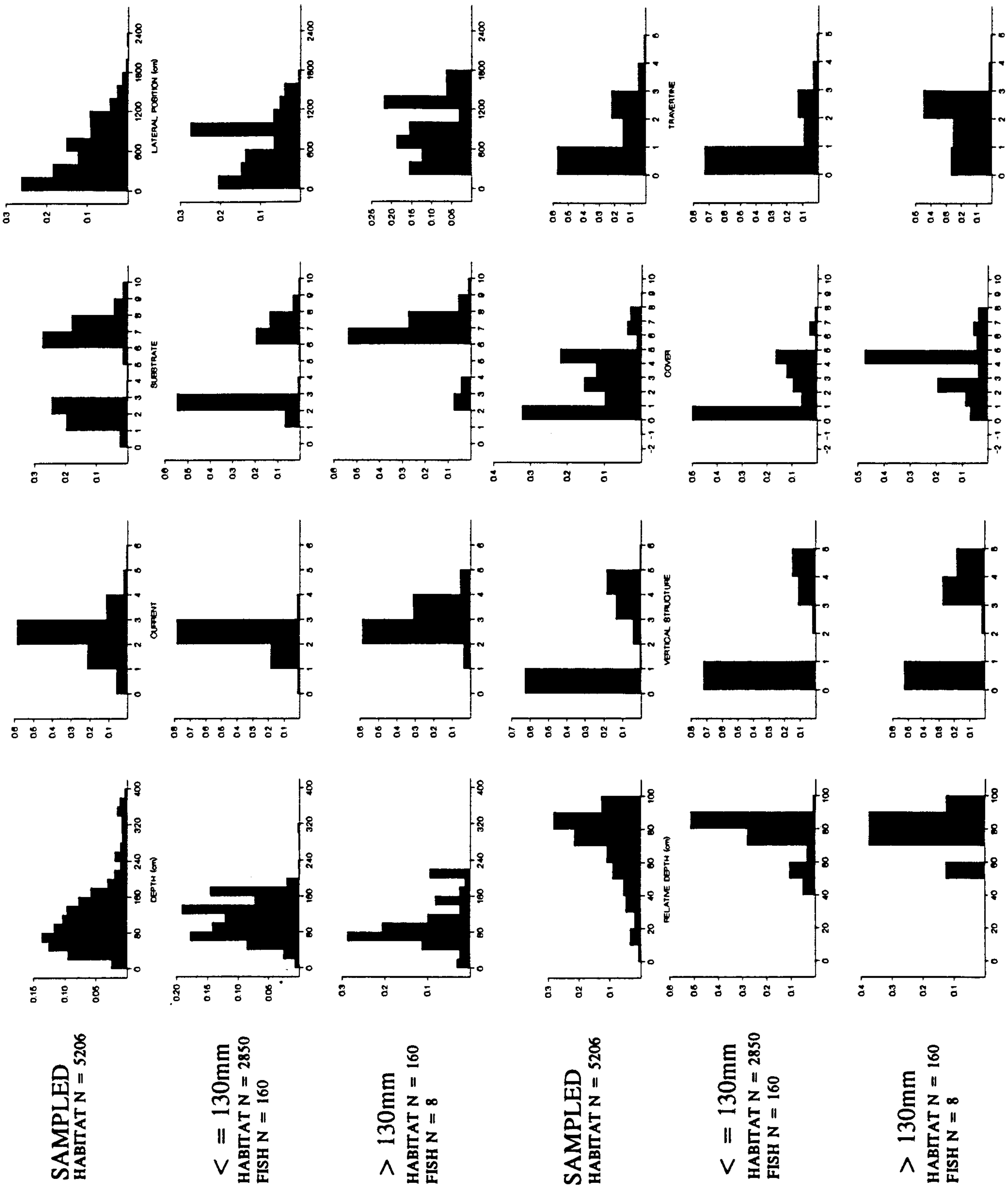
BHS 5/93, 7/93 Salt (NIGHT)



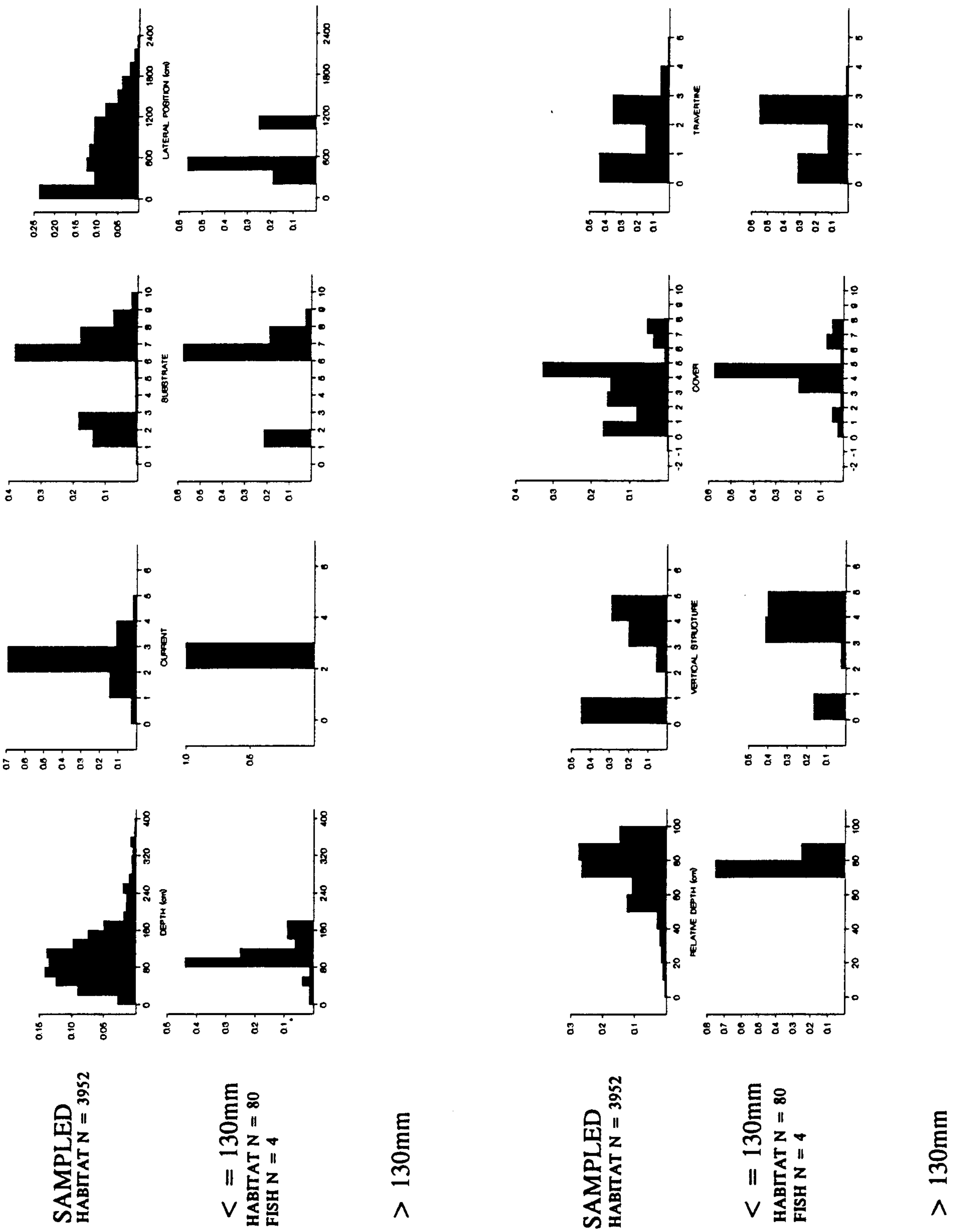
BHS 6/93, 8/93 Salt (DAY)



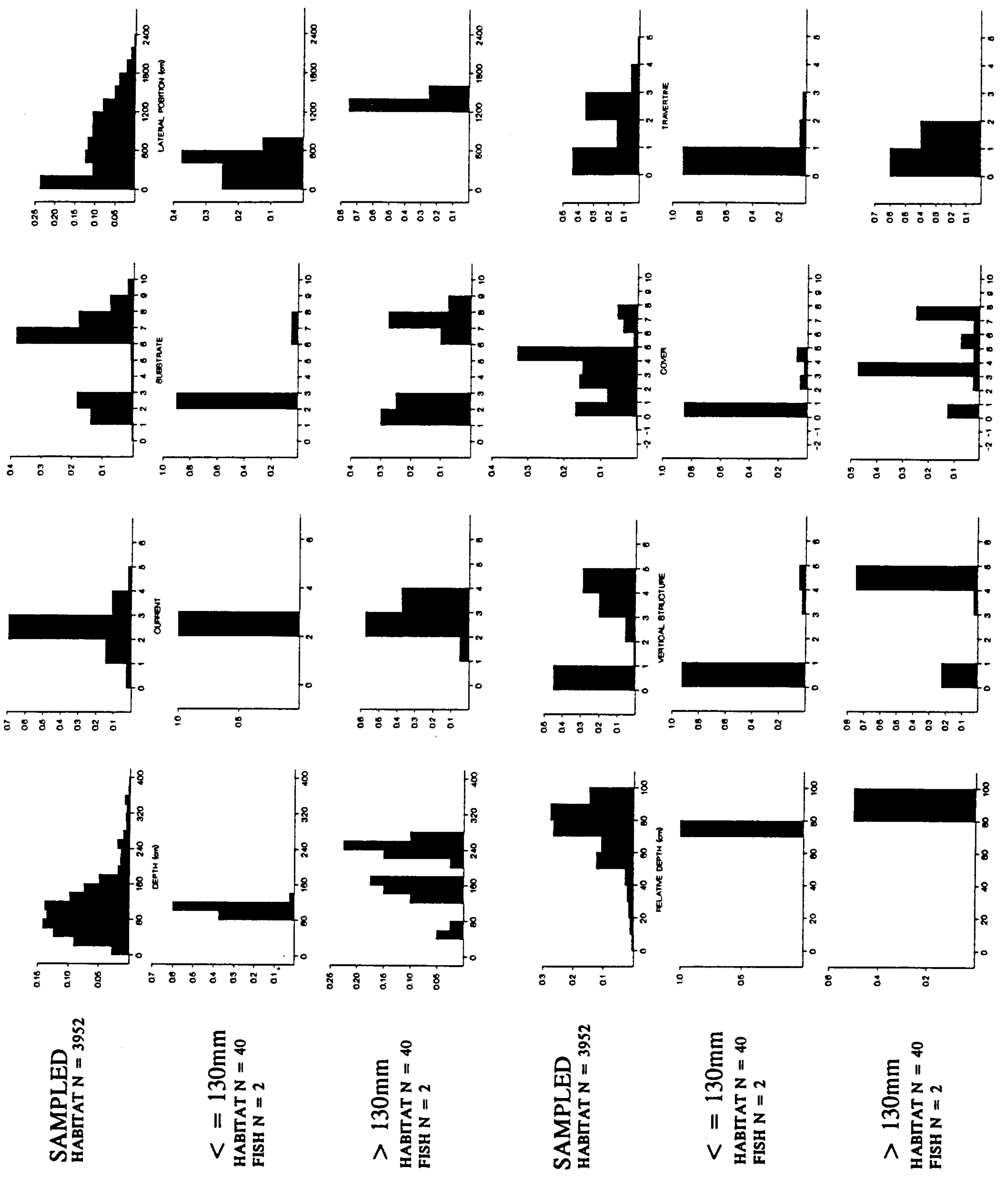
BHS 6/93, 8/93 Salt (NIGHT)



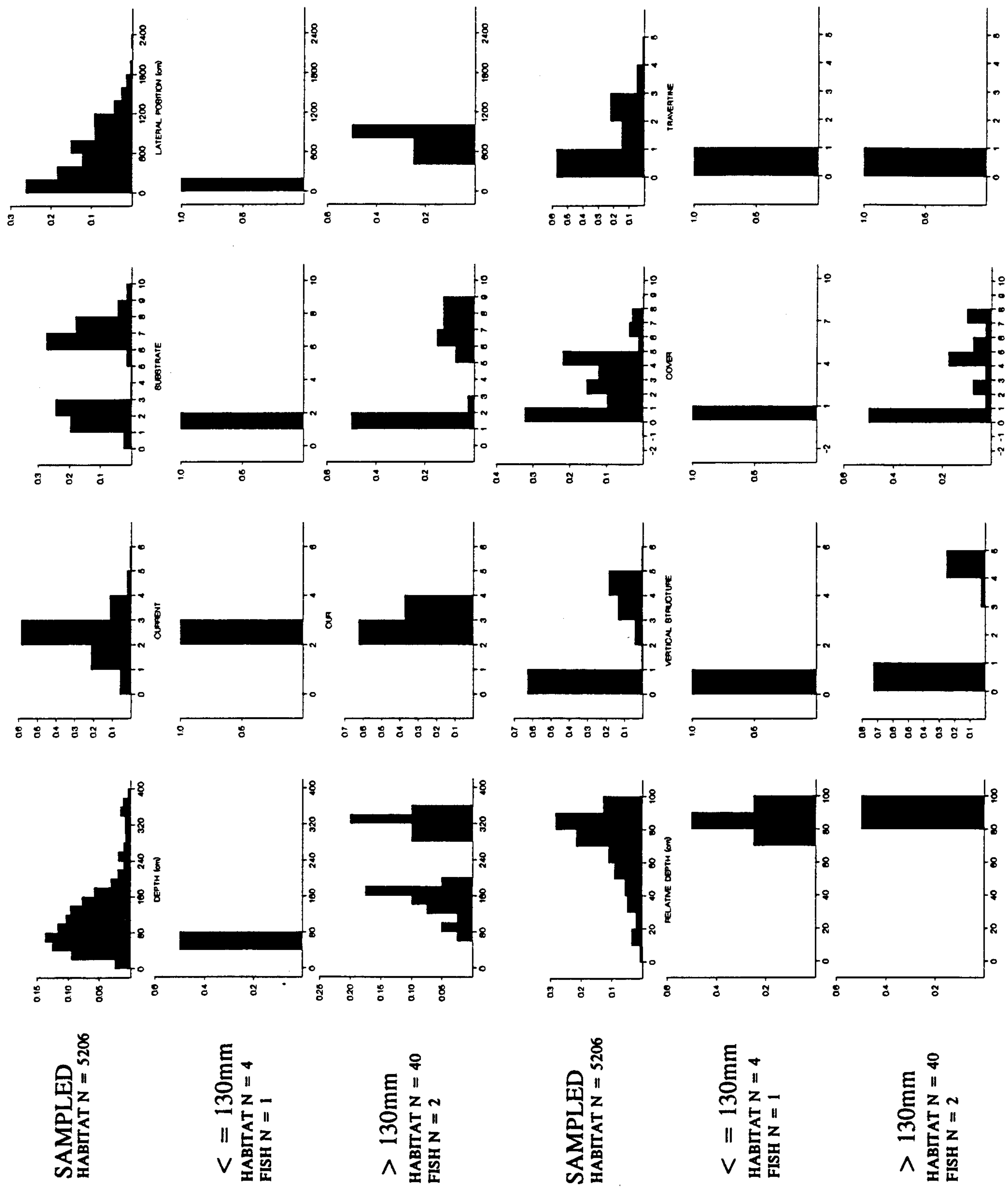
FMS 5/93, 7/93 Salt (DAY)



FMS 5/93, 7/93 Salt (NIGHT)



FMS 6/93, 8/93 Salt (DAY)



FMS 6/93, 8/93 Salt (NIGHT)

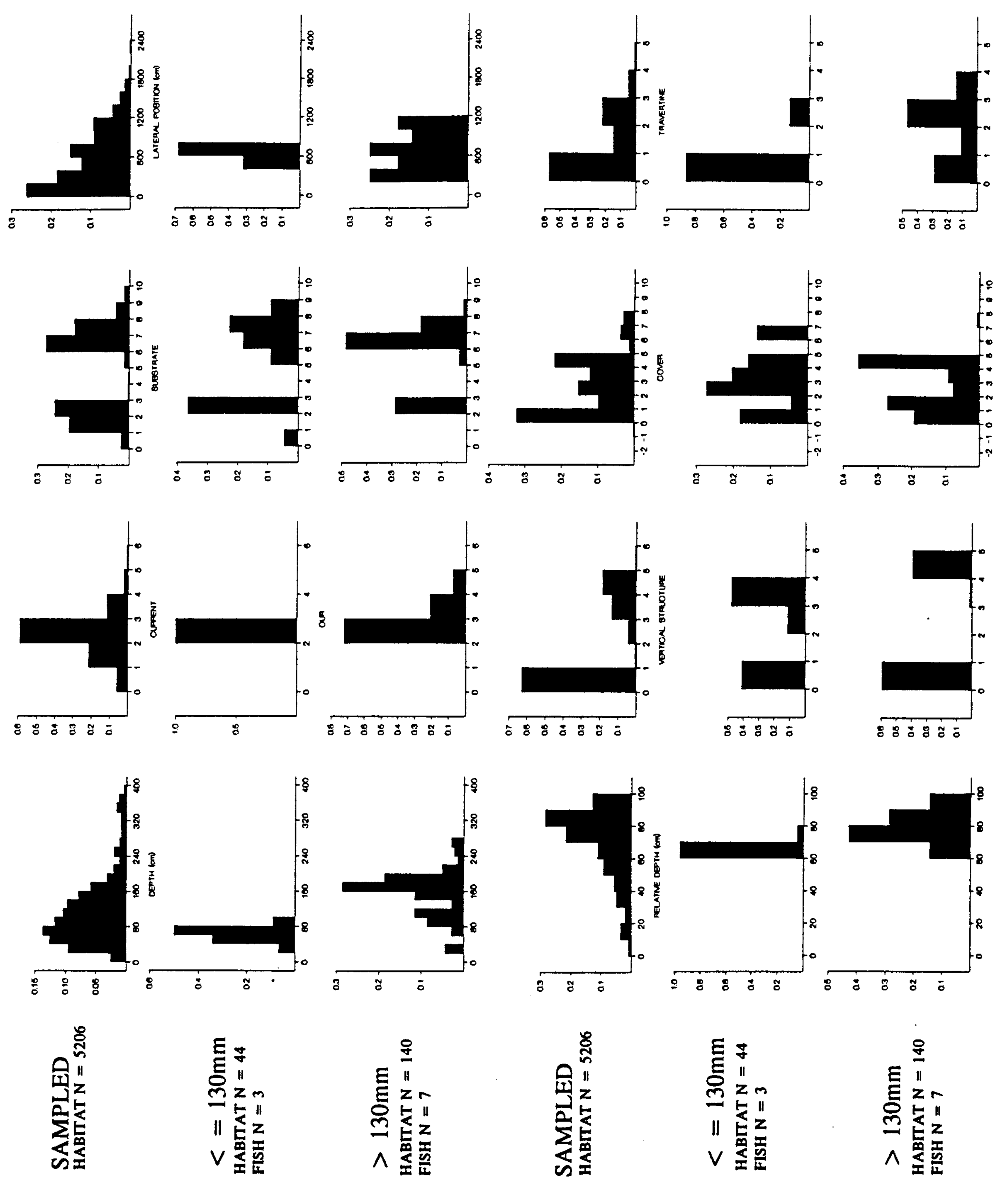


FIGURE 5. USFWS LCR fish habitat studies, Salt Study Area, 6/93-8/93: Sampled habitat and habitat use by YOY humpback chub.

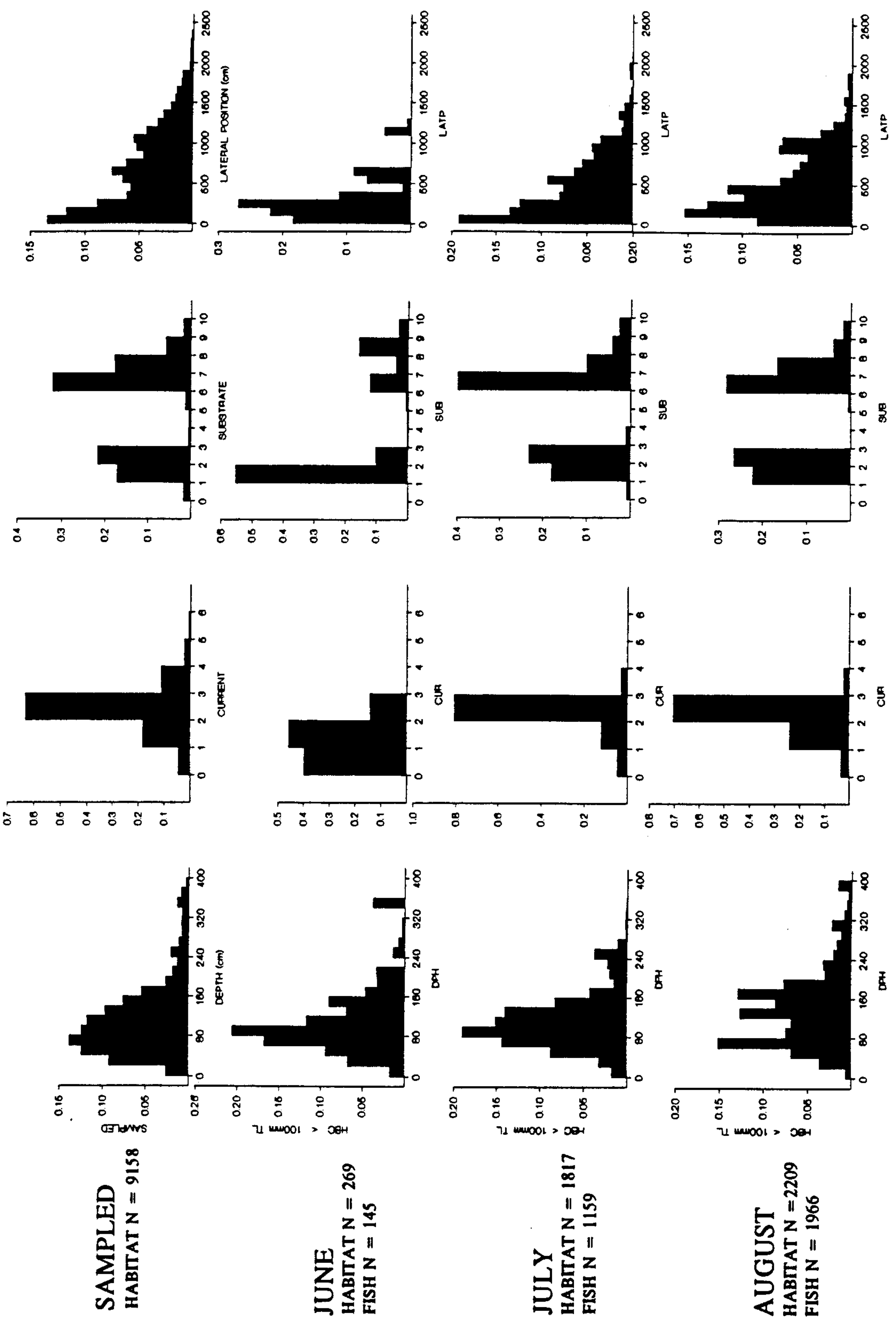
Sampled distributions represent habitat sampled for fish. Data shown was measured from minihoopnets and minnow traps set in USFWS study grids.

Habitat use distributions are weighted and divided into day and night periods.

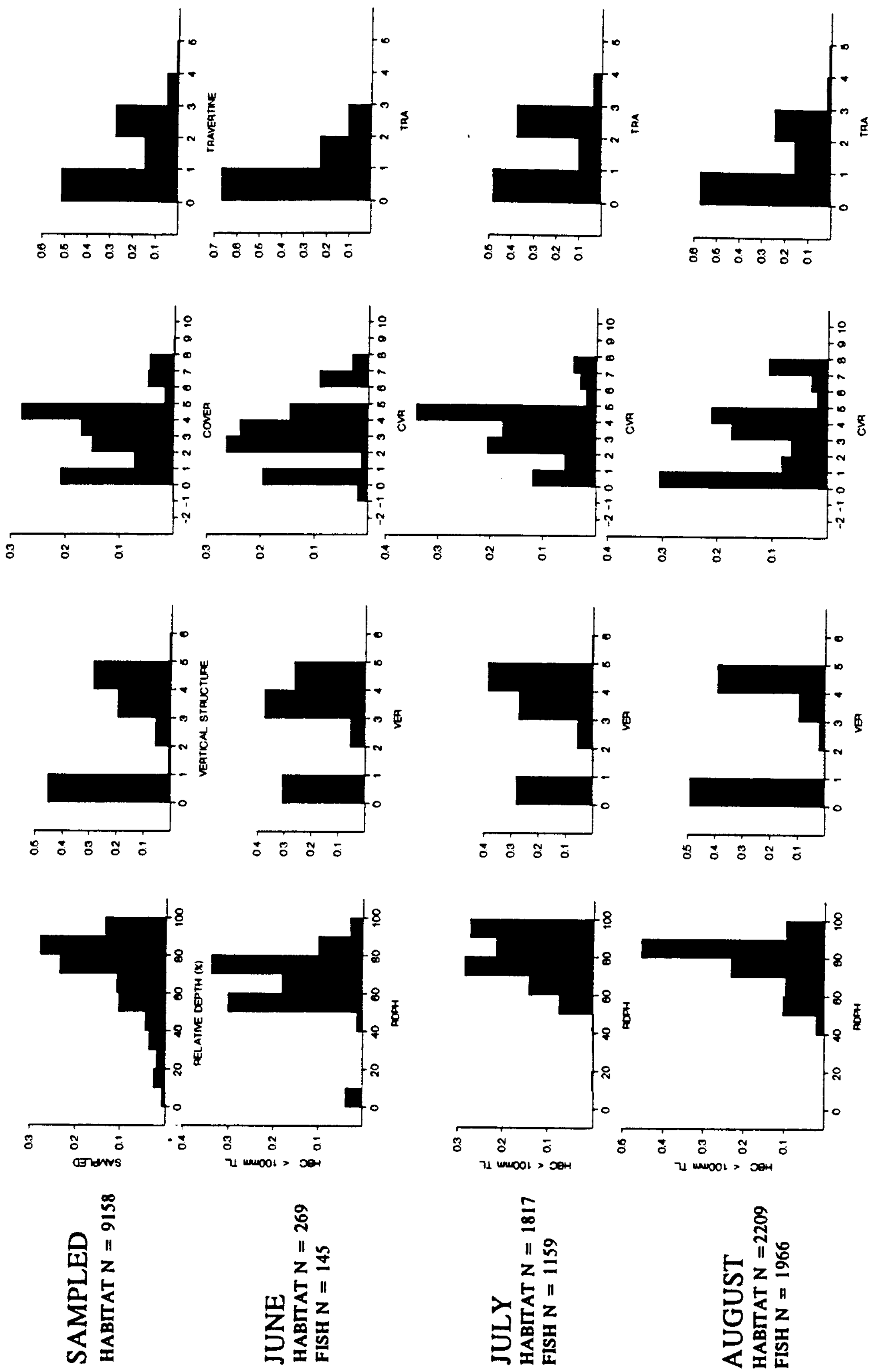
Habitat variables shown:
DPH, CUR, EPS (SUB), LATP, RDPH, VER, CVR, TRA

Consult Table 1 for explanation of habitat variable codes.

HBC 6/93 - 8/93 Salt YOY



HBC 6/93 - 8/93 Salt YOY



APPENDIX V

ANALYSIS OF HABITAT USE BY LCR FISHES, MAY-AUGUST 1993

PART 3: Principal Component Analysis of 6/93, 8/93 Powell Study Area habitat data

A principal component analysis (PCA) was performed on the combined Powell Study Reach 6/93 and 8/93 dataset. This data was collected from the lower Powell Study Area (km 2.5-3.0) and represents a homogeneous dataset for one 500 m section of stream. PCAs performed on other reaches are not identical because of changing habitat arrays and relative species densities.

Interpretation of Factors requires reviewing Appendix V Table 3. The power of these PCA projections is that they a provide multi-dimensional perspective of habitat use patterns not possible with one-dimensional habitat use distributions (Append. V Figs. 3-5). However, these PCA projections cannot be fully understood or interpreted outside the context of the habitat use distributions.

The principal axes may be interpreted as follows: Factor 1: substrate size (EPS-effective particle size) and cover; Factor 2: anti-lateral position (near shore) with decreasing currents and increasing vertical structure; Factor 3: depth and relative depth. Points that load positively on Factor 1 show association with increasing substrate size. Points that load positively on Factor 2 show association with near-shore areas with increasing vertical structure (e.g., vertical banks). Points that load positively on Factor 3 show association near benthic positions in deep water habitats.

For example, in Appendix V Figure 7, adult humpback chub show a positive association with Factor 1 both day and night, an increased positive association with Factor 2 at night, and positive association with Factor 3 during the day but some negative association at

night. This pattern suggests that adult humpback chub usually associate with areas of large substrate size and increased vertical structure (Factor 1), associate with near-shore areas at night (Factor 2), associate with deep-water near benthic positions during the day but shift to shallower water and use higher vertical positions in the water column at night (Factor 3). These same patterns may be deduced from the frequency histograms (Appendix V Figure 3).
Continuing with other species, adult bluehead sucker show positive association with Factor 1 day and night, negative association with Factor 2 during the day but showing both increased positive and negative association at night, positive association with Factor 3 during the day but expanding to positive and negative during the night. This pattern suggests that adult bluehead sucker associated with large substrates and increased vertical structure (Factor 1), used off-shore areas during the day, but shifted inshore and further offshore at night (Factor 2), and used deep water benthic areas during the day but also used shallower areas at night (Factor 3).

Adult flannelmouth sucker showed both positive and negative association with Factor 1 day and night and increasingly positive association with Factors 2 and 3 at night. This pattern suggests that adult flannelmouth sucker used areas of small and large substrate and low and high vertical structure. At night, adult flannelmouth sucker appeared to shift somewhat into deep near-shore areas and use near benthic positions.

Adult speckled dace did not show major diel shifts in habitat use as did the other species. The only noticeable shift was an increased negative association with Factor 2 at night, suggesting some individuals shifted closer to shore areas with vertical structure at night.

TABLE 3. USFWS LCR fish habitat studies, Powell Study Area, 6/93 and 8/93: Summary of PCA analyses of habitat data.

DATA SET: LCR/Powell-6/93 and 8/93, habitat data (minihoop + minnow trap)
SAMPLE SIZE: 5651 habitat points
VARIABLES ENTERED: DPH (depth), RDPH (relative depth), CUR (current), EPS (effective particle size- substrate), LATP (lateral position), CVR (cover), and VER (vertical structure).

	FACTORS		
	1	2	3
LATENT ROOTS (EIGENVALUES)	2.009	1.718	1.289
COMPONENT LOADINGS:			
LAPT	0.353	-0.654	0.393
DPH	0.194	0.069	0.830
RDPH	-0.105	0.379	0.620
CUR	0.529	-0.609	0.047
EPS	0.814	-0.133	-0.219
CVR	0.849	0.448	-0.102
VER	0.415	0.742	0.013
VARIANCE EXPLAINED BY COMPONENTS	2.009	1.718	1.289
PERCENT OF TOTAL VARIANCE EXPLAINED	28.697	24.543	18.407

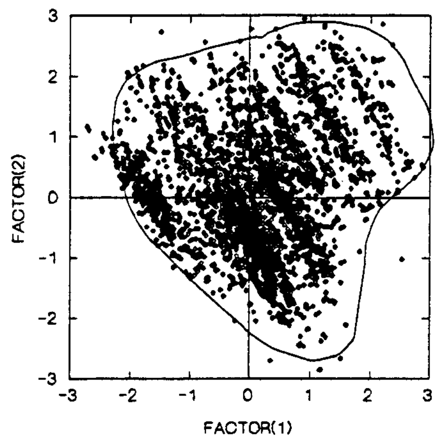
FIGURE 6. USFWS LCR fish habitat studies, Powell Study Area, lower study reach, 6/93 & 8/93, Principal Component Analysis. Projection of habitat sampled for fish (sampled habitat) on factors 1-3.

Species shown:

- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Table 3 for principal component loadings for habitat variables.

PRINCIPAL COMPONENT ANALYSIS
HABITAT COMPOSITE
Powell 6/93, 8/93



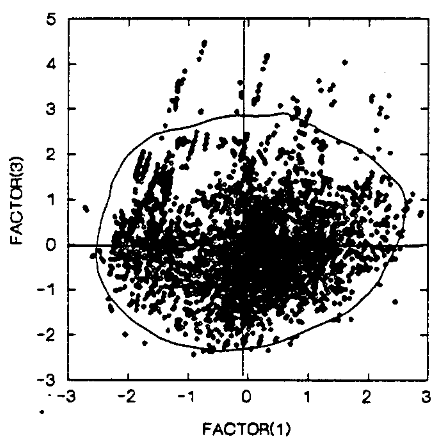


FIGURE 7. USFWS LCR fish habitat studies, Powell Study Area, lower study reach, 6/93 & 8/93, Principal Component Analysis. Composite projections of day and night habitat use by adult fish on factors 1-3.

Species shown:

- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Table 3 for principal component loadings for habitat variables.

PRINCIPAL COMPONENT ANALYSIS
COMPOSITE, HABITAT USE,
ADULT FISH, 6/93, 8/93 Powell

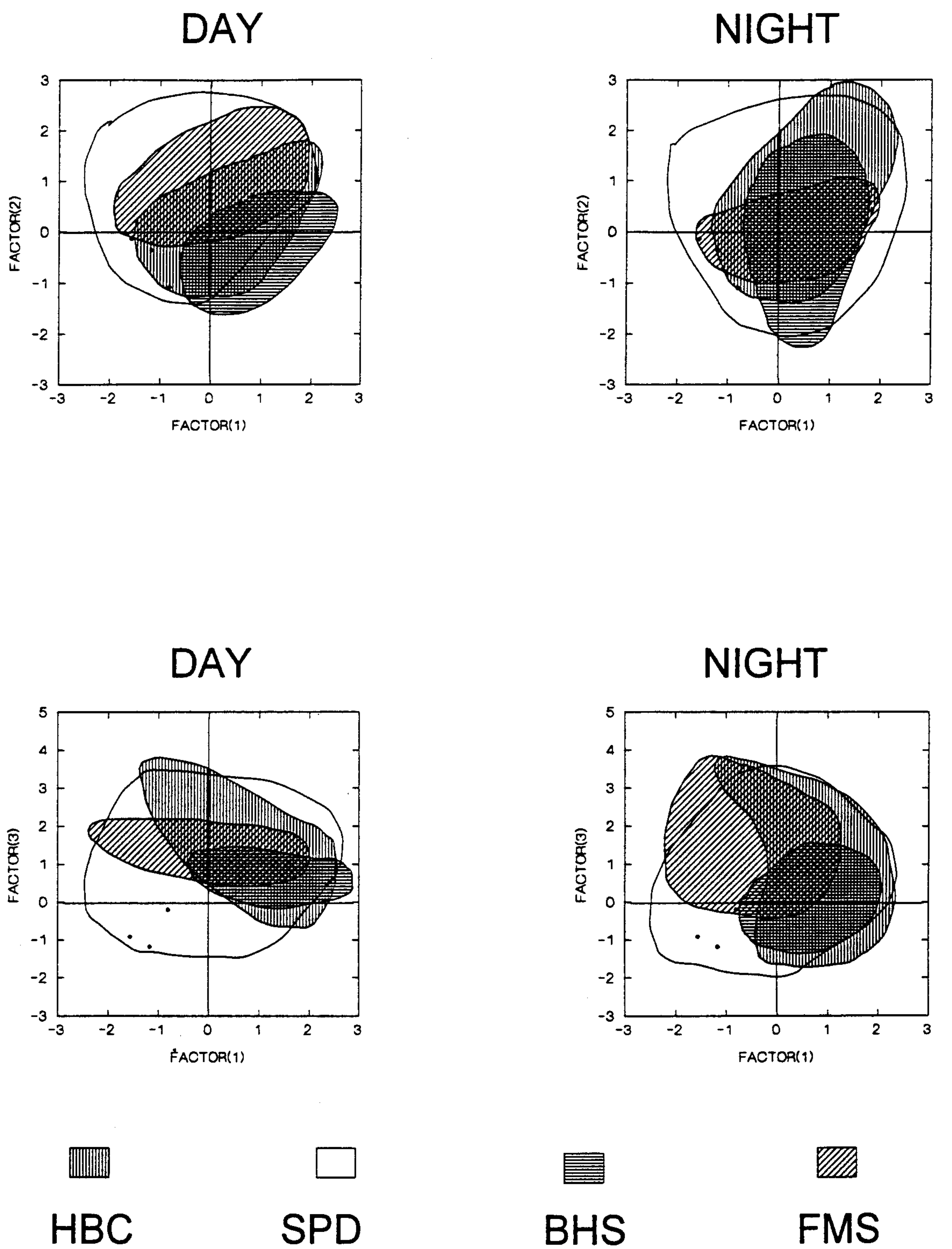


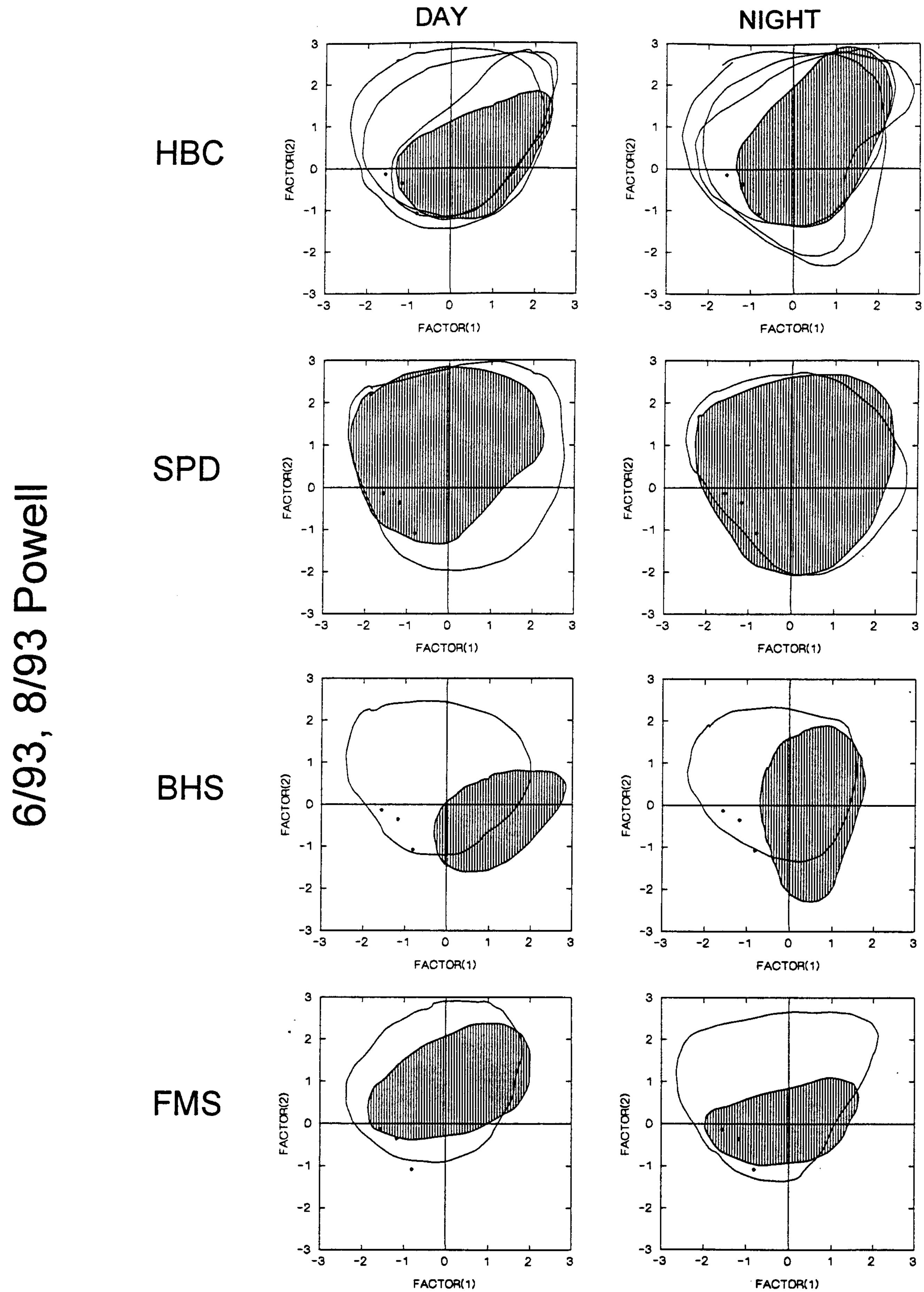
FIGURE 8. USFWS LCR fish habitat studies, Powell Study Area, lower study reach, 6/93 & 8/93, Principal Component Analysis. Composite projections of habitat use by adult fish (hatched) over smaller and YOY fish on factors 1-3.

Species shown:

- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Figure 8 for individual projections of habitat use by YOY and smaller fishes.

Consult Table 3 for principal component loadings for habitat variables.



6/93, 8/93 Powell
DAY
NIGHT
HBC
SPD
BHS
FMS
FACTOR(1)
FACTOR(2)

6/93, 8/93 Powell

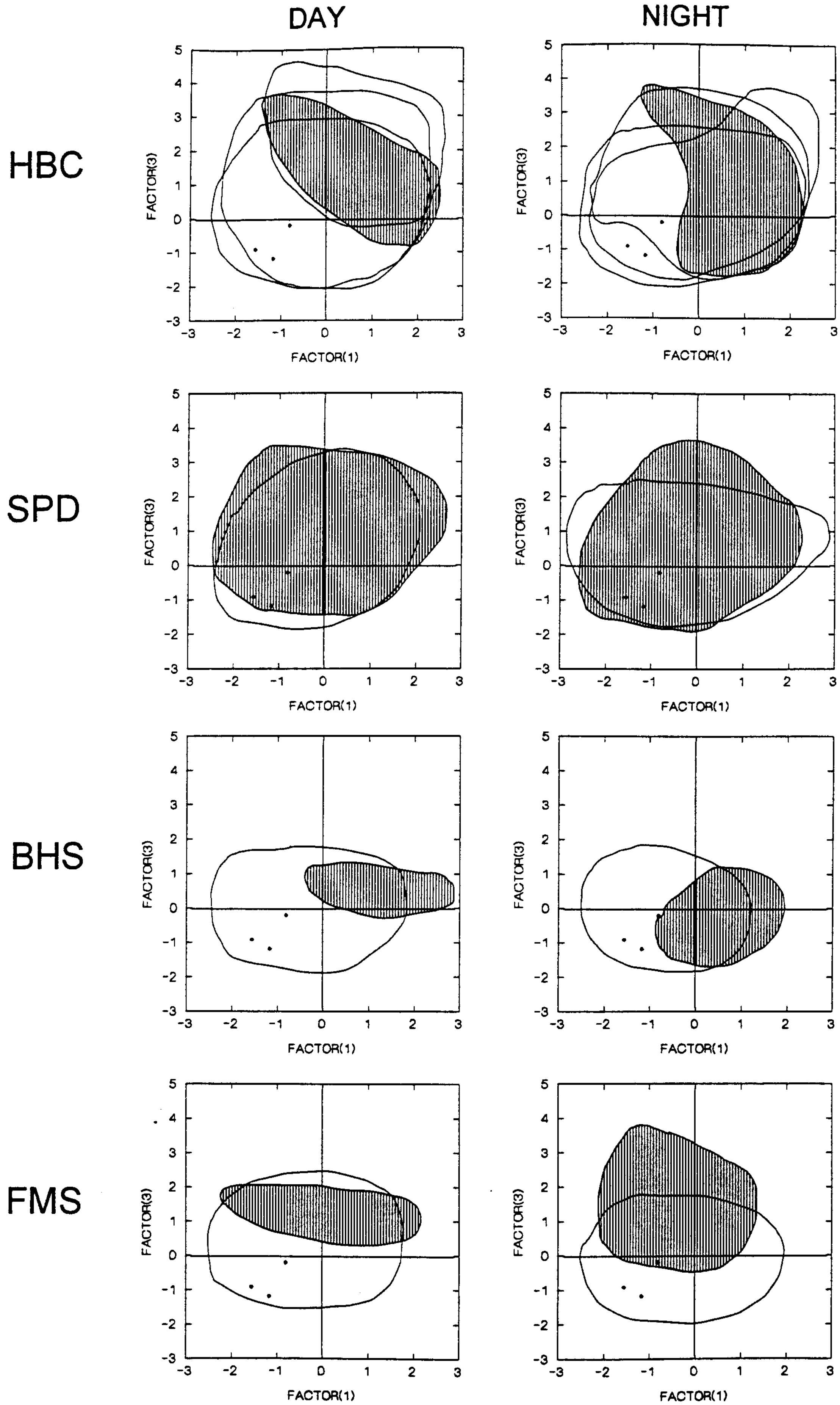


FIGURE 9. USFWS LCR fish habitat studies, Powell Study Area, lower study reach, 6/93, 8/93, Principal Component Analysis. Individual projections of habitat use by YOY through adult size classes of fishes on factors 1-3.

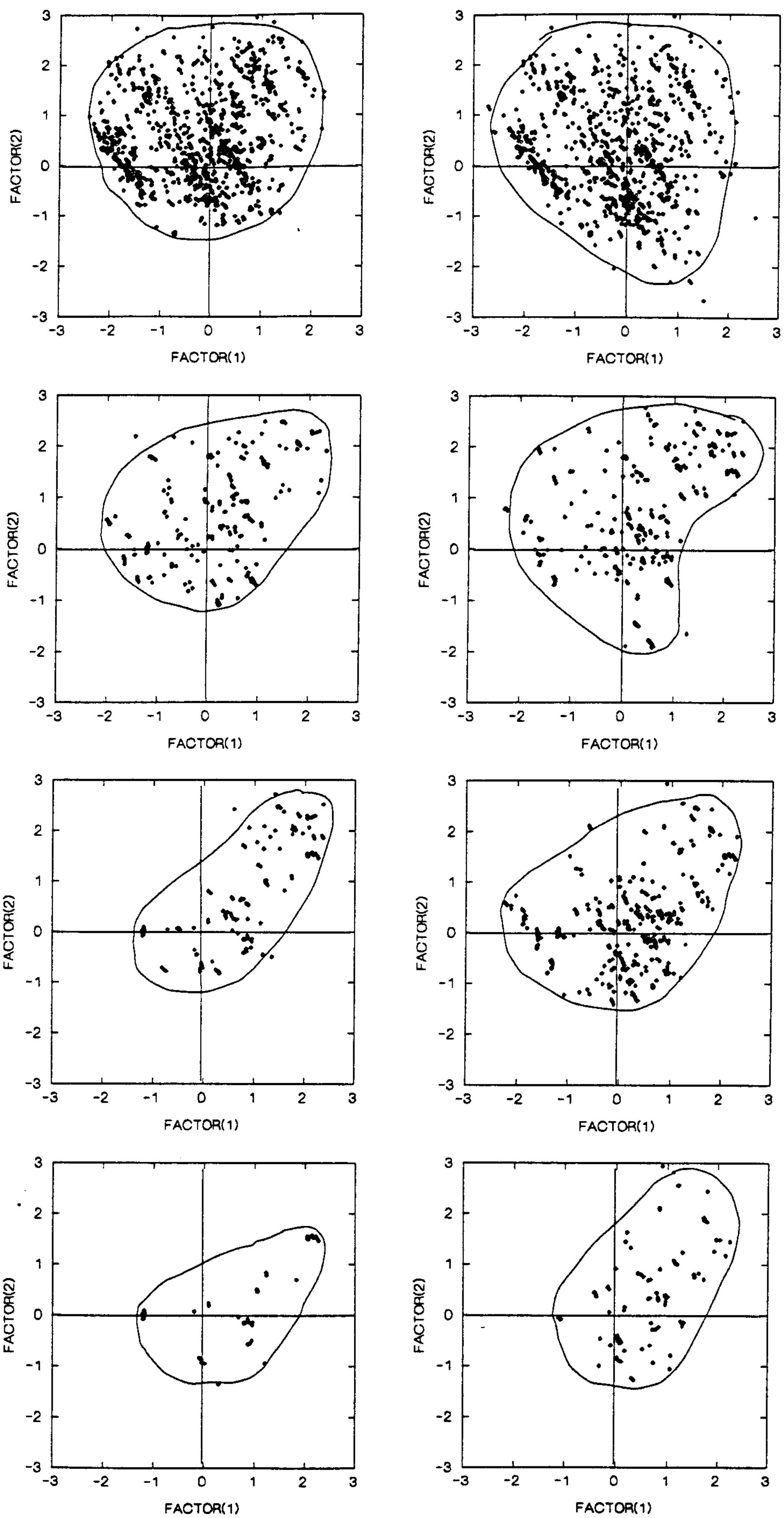
Species shown:

- HBC (humpback chub)
- SPD (speckled dace)
- BHS (bluehead sucker)
- FMS (flannelmouth sucker)

Consult Table 3 for principal component loadings for habitat variables.

HBC 6/93, 8/93 Powell

DAY NIGHT



YOY

HABITAT
DAY N = 1413
NIGHT N = 1252

FISH
DAY N = 420
NIGHT N = 292

JUVENILE

HABITAT
DAY N = 264
NIGHT N = 334

FISH
DAY N = 16
NIGHT N = 28

SUB-ADULT

HABITAT
DAY N = 159
NIGHT N = 440

FISH
DAY N = 16
NIGHT N = 32

ADULT

HABITAT
DAY N = 60
NIGHT N = 120

FISH
DAY N = 6
NIGHT N = 9

HBC 6/93, 8/93 Powell

DAY NIGHT

YOY

HABITAT
DAY N = 1413
NIGHT N = 1252

FISH
DAY N = 420
NIGHT N = 292

JUVENILE

HABITAT
DAY N = 264
NIGHT N = 334

FISH
DAY N = 16
NIGHT N = 28

SUB-ADULT

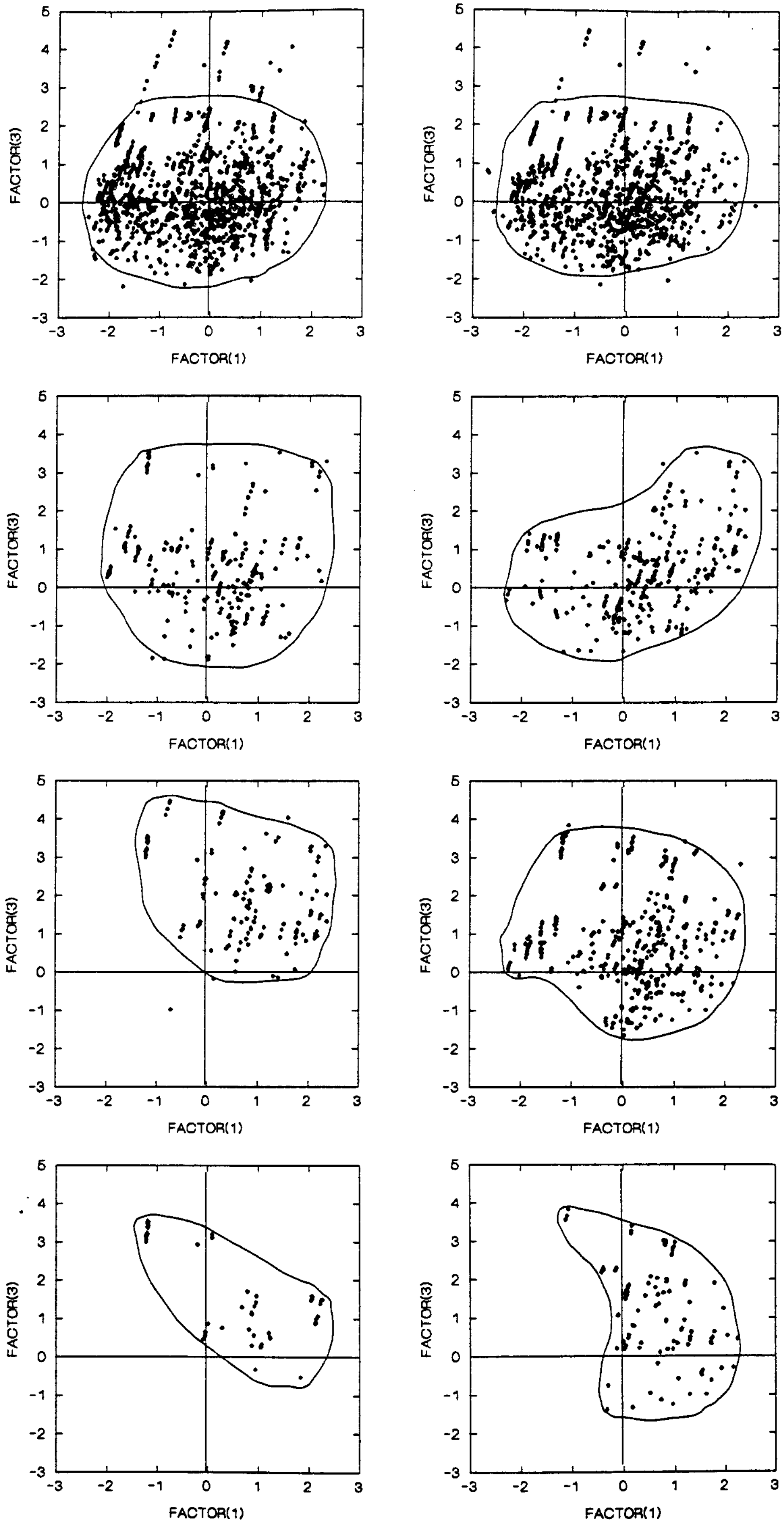
HABITAT
DAY N = 159
NIGHT N = 440

FISH
DAY N = 16
NIGHT N = 32

ADULT

HABITAT
DAY N = 60
NIGHT N = 120

FISH
DAY N = 6
NIGHT N = 9



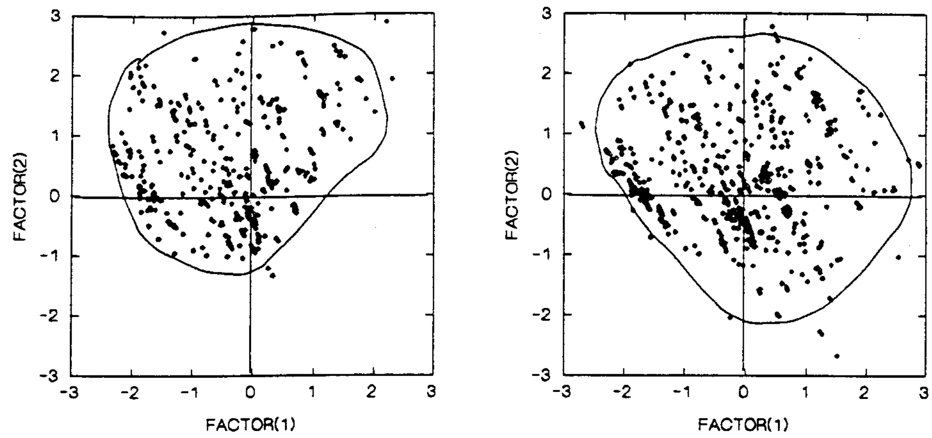
SPD 6/93, 8/93 Powell

DAY NIGHT

YOY

HABITAT
DAY N = 509
NIGHT N = 780

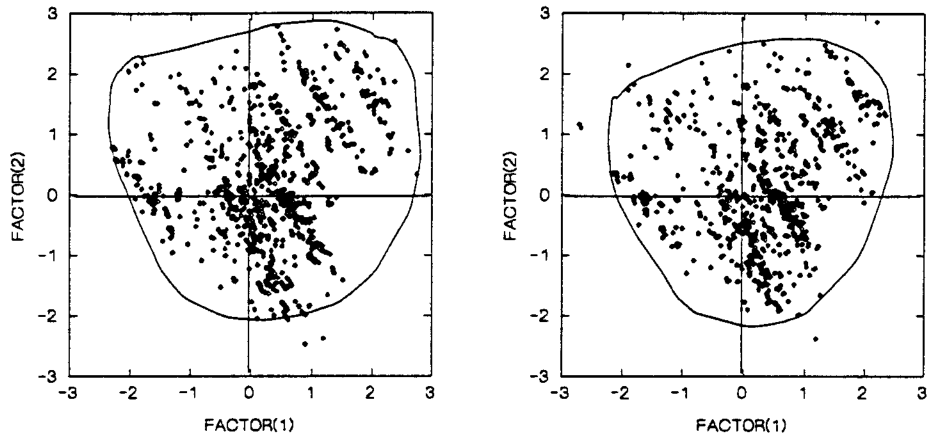
FISH
DAY N = 88
NIGHT N = 85



ADULT

HABITAT
DAY N = 1118
NIGHT N = 1052

FISH
DAY N = 107
NIGHT N = 82



YOY

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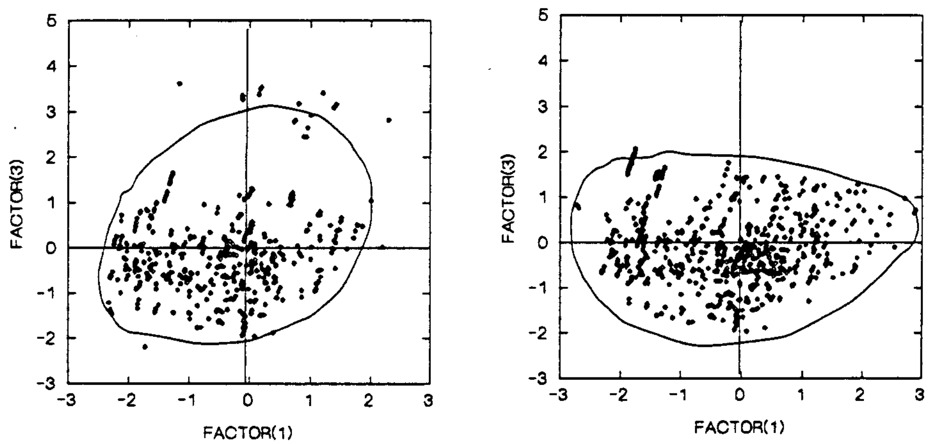
NIGHT N = 780

FISH
DAY N = 88
NIGHT N = 85



ADULT

HABITAT
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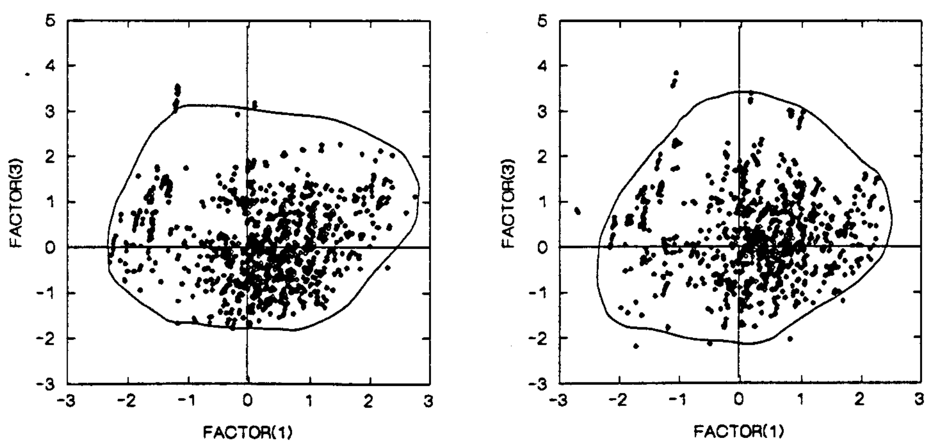
NIGHT N = 1052

FISH
DAY N = 107
NIGHT N = 82



BHS 6/93, 8/93 Powell

DAY NIGHT

YOY
HABITAT
DAY N = 311
NIGHT N = 254

FISH
DAY N = 46
NIGHT N = 27

ADULT
HABITAT
DAY N = 40
NIGHT N = 80

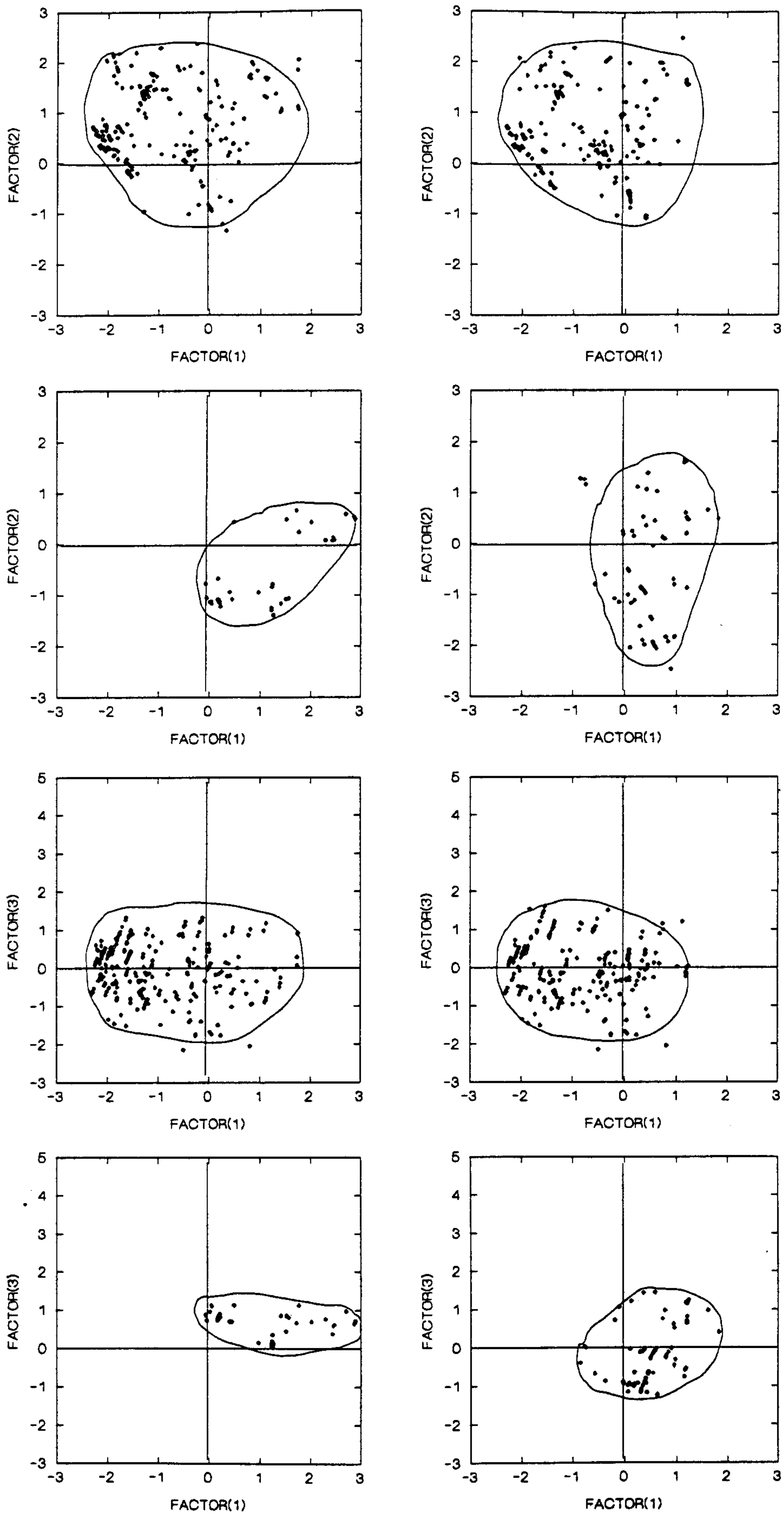
FISH
DAY N = 2
NIGHT N = 4

YOY
HABITAT
DAY N = 311
NIGHT N = 254

FISH
DAY N = 46
NIGHT N = 27

ADULT
HABITAT
DAY N = 40
NIGHT N = 80

FISH
DAY N = 2
NIGHT N = 4



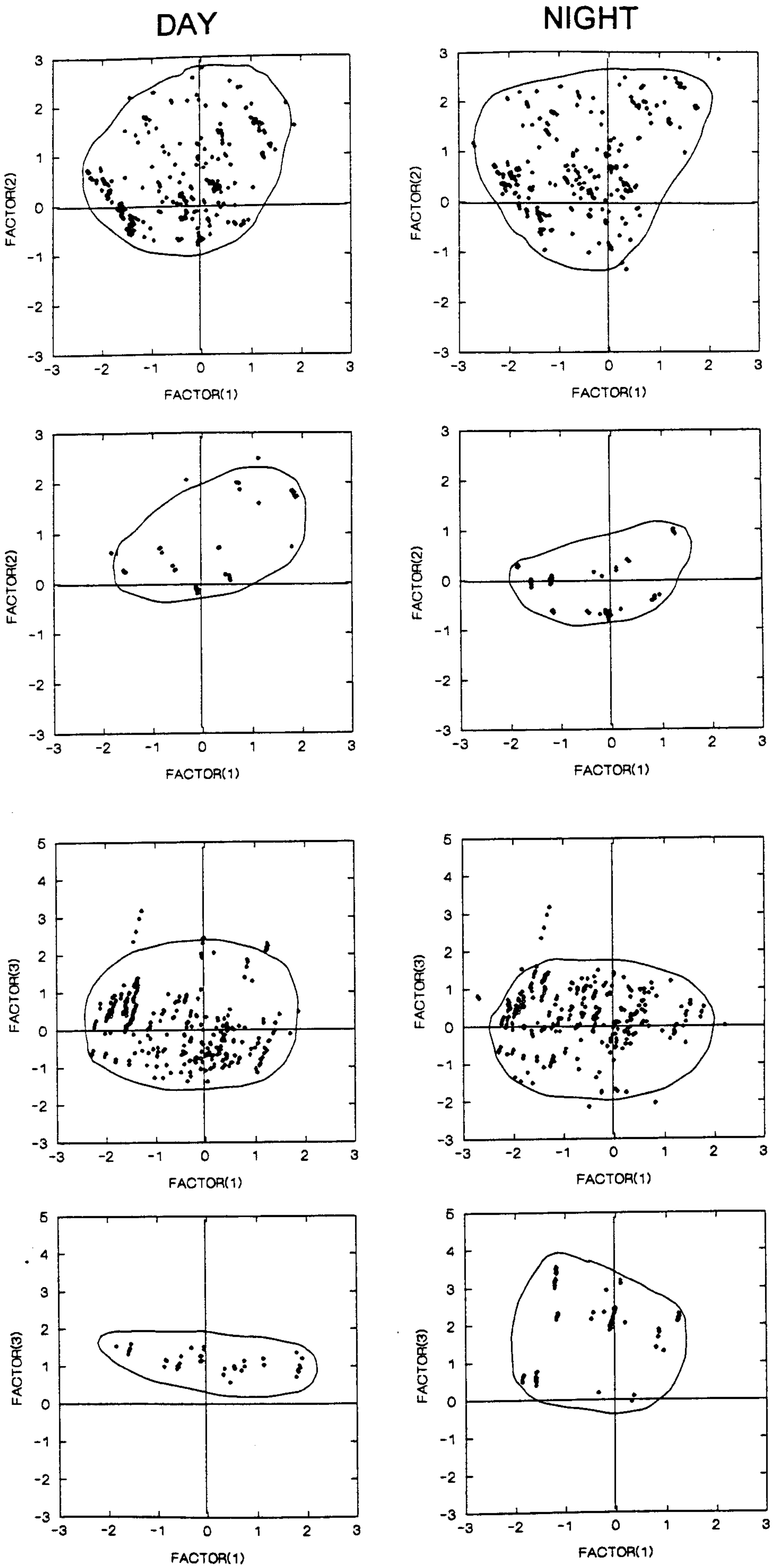
FMS 6/93, 8/93 Powell

YOY
HABITAT
DAY N = 384
NIGHT N = 360
FISH
DAY N = 40
NIGHT N = 42

ADULT
HABITAT
DAY N = 40
NIGHT N = 80
FISH
DAY N = 2
NIGHT N = 4

YOY
HABITAT
DAY N = 384
NIGHT N = 360
FISH
DAY N = 40
NIGHT N = 42

ADULT
HABITAT
DAY N = 40
NIGHT N = 80
FISH
DAY N = 2
NIGHT N = 4



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Habitat use by humpback chub, *Gila cypha,*
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APPENDIX VI

ANALYSIS OF HABITAT USE BY LCR FISHES, APRIL 1993 and 1994: IDENTIFICATION OF PUTATIVE HUMPBACK CHUB SPAWNING HABITAT

APPENDIX VI

ANALYSIS OF HABITAT USE BY LCR FISHES, APRIL 1993 and 1994: IDENTIFICATION OF PUTATIVE HUMPBACK CHUB SPAWNING HABITAT

This appendix is intended to provide a view of habitat use by humpback chub during elevated muddy spring flows. April is also a time when humpback chub and other native fishes spawn and habitat use patterns by adult fish might indicate habitat used by spawning fish. To detect unusual patterns of habitat use by spawning fish, habitat use distributions must be compared to distributions that show habitat use during the off spawning season, such as summer (Append. V).

Habitat use distributions by humpback chub (and other LCR fishes) in the spring are very similar to those observed in the summer months (compare with Append V). An inspection of habitat use by subadult and adult humpback chub for the Salt Study Reach, April 1993 and 1994 and for the Powell Study Reach, April 1993 provides the best perspective (Append. VI Figs. 1-3). Adult humpback chub (>210 mm TL) during the day use moderate to deep areas, remain close to the bottom, associate with moderate to large boulders, and include use of areas with increased cover and vertical structure. At night there is an increase in use of shallower near-shore areas and mid-water column vertical positions, and use of areas with fewer large boulders and less vertical structure and cover. This is the same pattern observed during the summer months under base flow, clear water conditions (Append. V).

This result shows that humpback chub have somewhat fixed patterns of habitat use under a broad range of seasonal (spring vs. summer) and flow (elevated muddy vs. clear stable) conditions. If humpback chub do have special spawning habitat, they are not detectable with our sampling approach. This may be because only a small fraction of the population participated in spawning or used spawning habitat at any one time, or that spawning is

a rare sporadic event that occupied a very small fraction of the daily activities of adult humpback chubs. In other words, spawning may have occurred within the normal range of habitat used by adult humpback chub or it was a rare event that is difficult to detect with most sampling approaches.

Bonytail chub, a very closely related species to humpback chub, has been observed spawning in ponds at the USFWS Dexter National Fish Hatchery (Roger Hammond, pers.

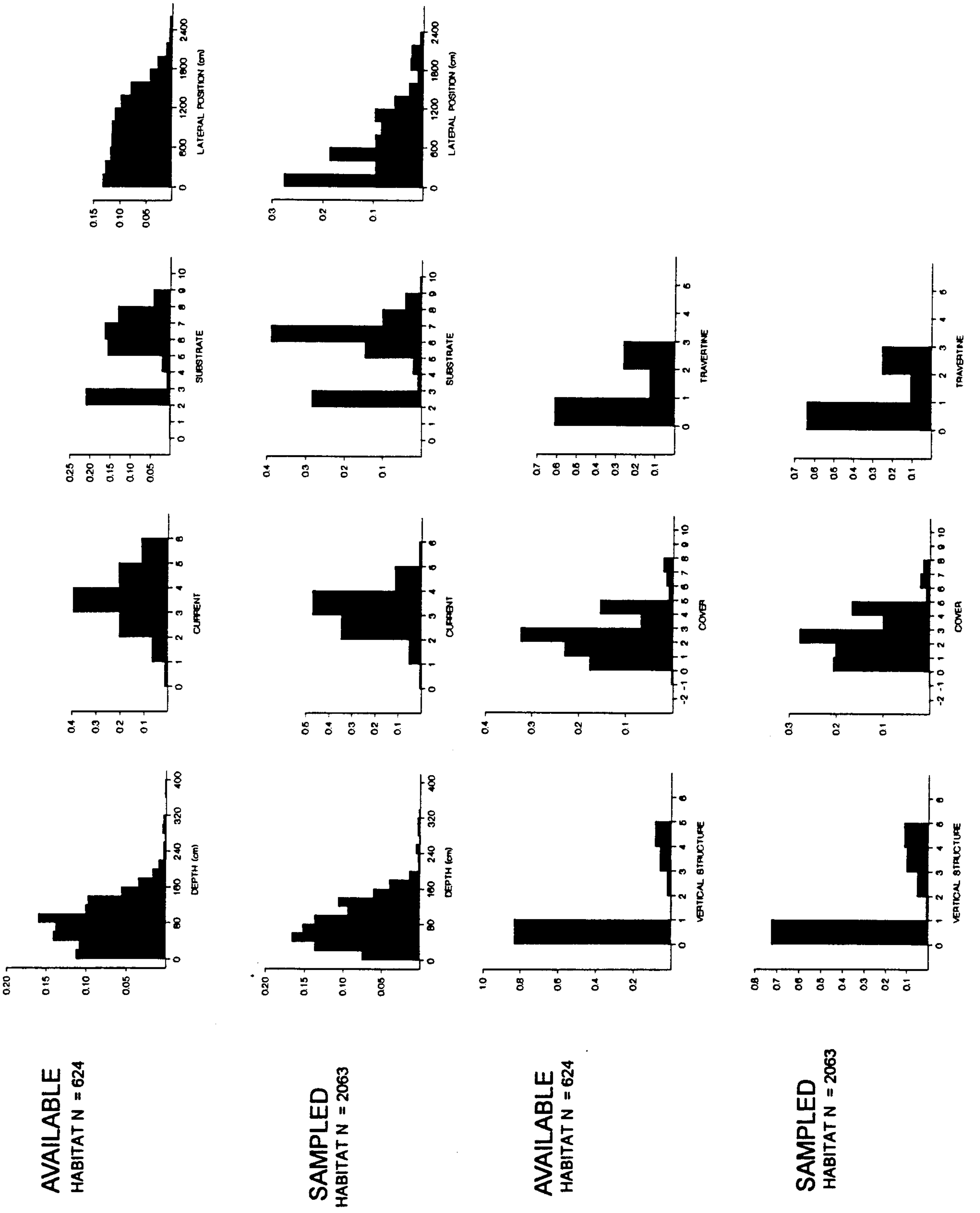
comm.). During the day, bonytail chub typically remain near the bottom of the deepest (center) of the ponds. Bonytail chub have been observed regularly using shallow margins of the ponds during crepuscular hours. During this time the fish congregate along overhanging grassy banks, around piles of submerged tumbleweeds and near the concrete steps of the kettle (drain). Spawning has been observed during April and May. During crepuscular hours, groups of 20-30 individuals have been observed spawning in shallower portions of the pond along overhanging grassy banks, over piles of submerged tumbleweeds, and on concrete steps around the drain of the pond. Since spawning involves many individuals it is not clear how many pairs are involved in the spawning act or the sex ratio of participants. The eggs are scatter-broadcast over the area of spawning behavior. Eggs were observed attached to submerged grass, tumbleweeds, and concrete ledges (steps). Some individuals have been observed with abrasions on their anal and lower caudal fins and it has been assumed that these individuals received the abrasions from spawning over the concrete steps. In another situation male and female bonytail were kept in separate raceways and when the fish were ripe, the groups were joined and spawning commenced immediately. Eggs were found attached along the bottom of the raceways.

This account shows many parallels with our data on humpback chub. In the ponds bonytail chub, like humpback chub in the LCR, associated with available vertical structure and showed a distinct diel pattern of habitat use. Spawning in bonytail chub occurred when environmental conditions (temperature, photoperiod, etc.) and physiological state (spawning readiness) were conducive. Spawning behavior was observed over a variety of structures and habitats. Characteristics of the fertilized eggs, hatching rates, and early life history stages are very similar in the two species (Lupher and Clarkson, 1993).

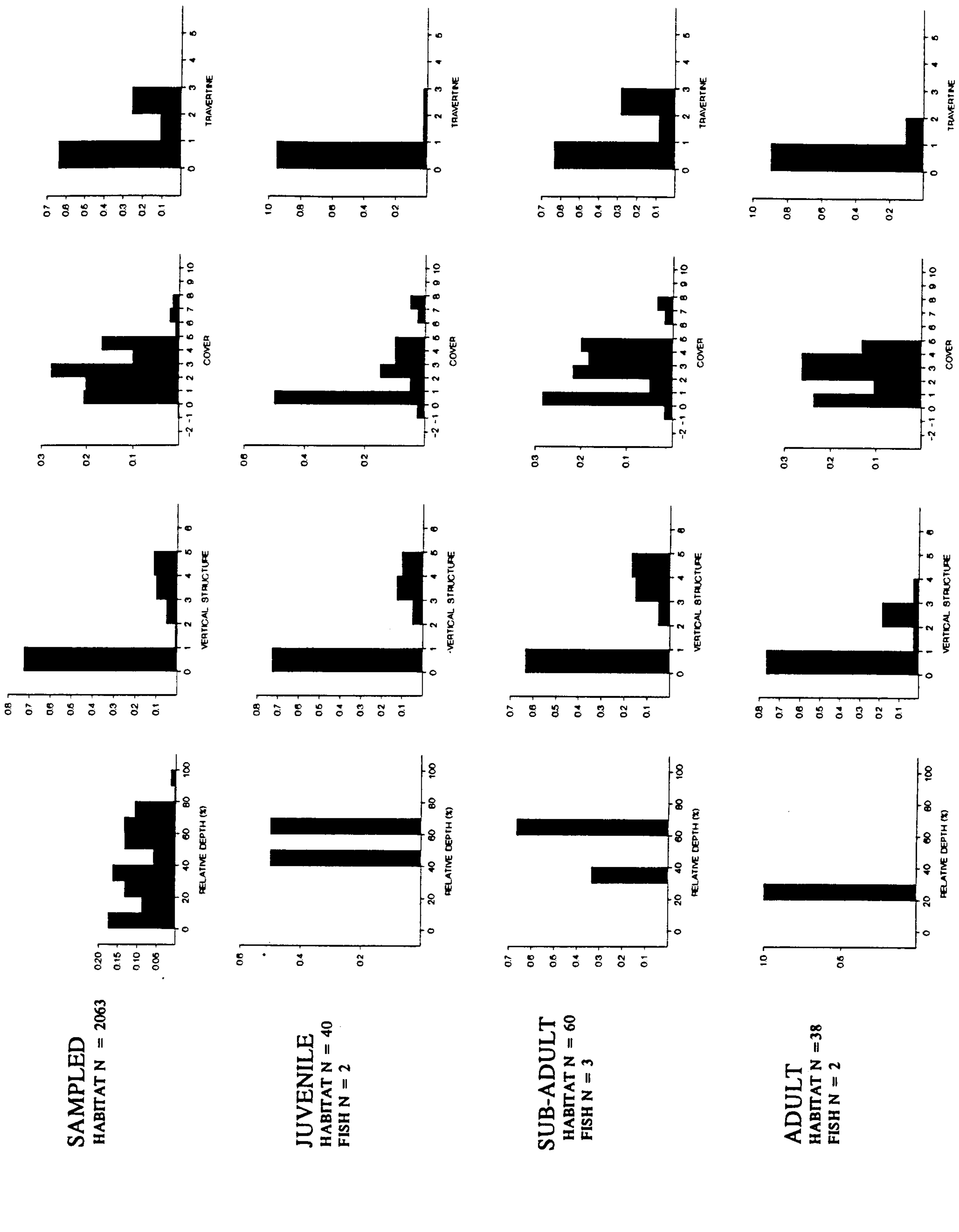
We expect that spawning behavior in humpback chub to be similar to that in bonytail chub. The opportunistic spawning behavior observed in bonytail chub suggests that humpback chub might also be opportunistic spawners, that is, they spawn within the range of habitat normally used by adults and when environmental cues and physiological conditions are conducive.

Figure 1. USFWS LCR fish habitat studies, Powell Study Reach 4/93: Available vs. sampled habitat and habitat use by humpback chub

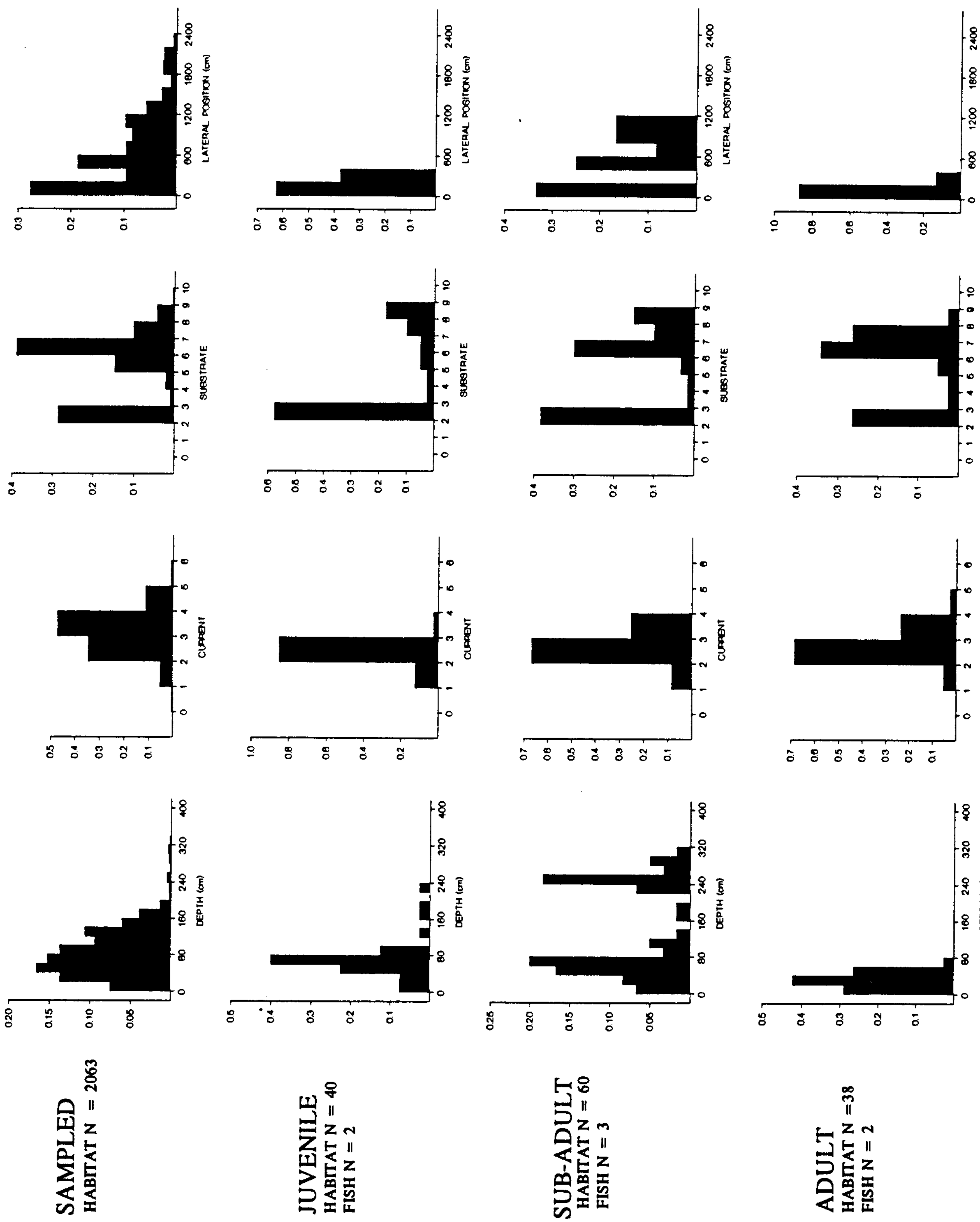
HBC April 1993 Powell



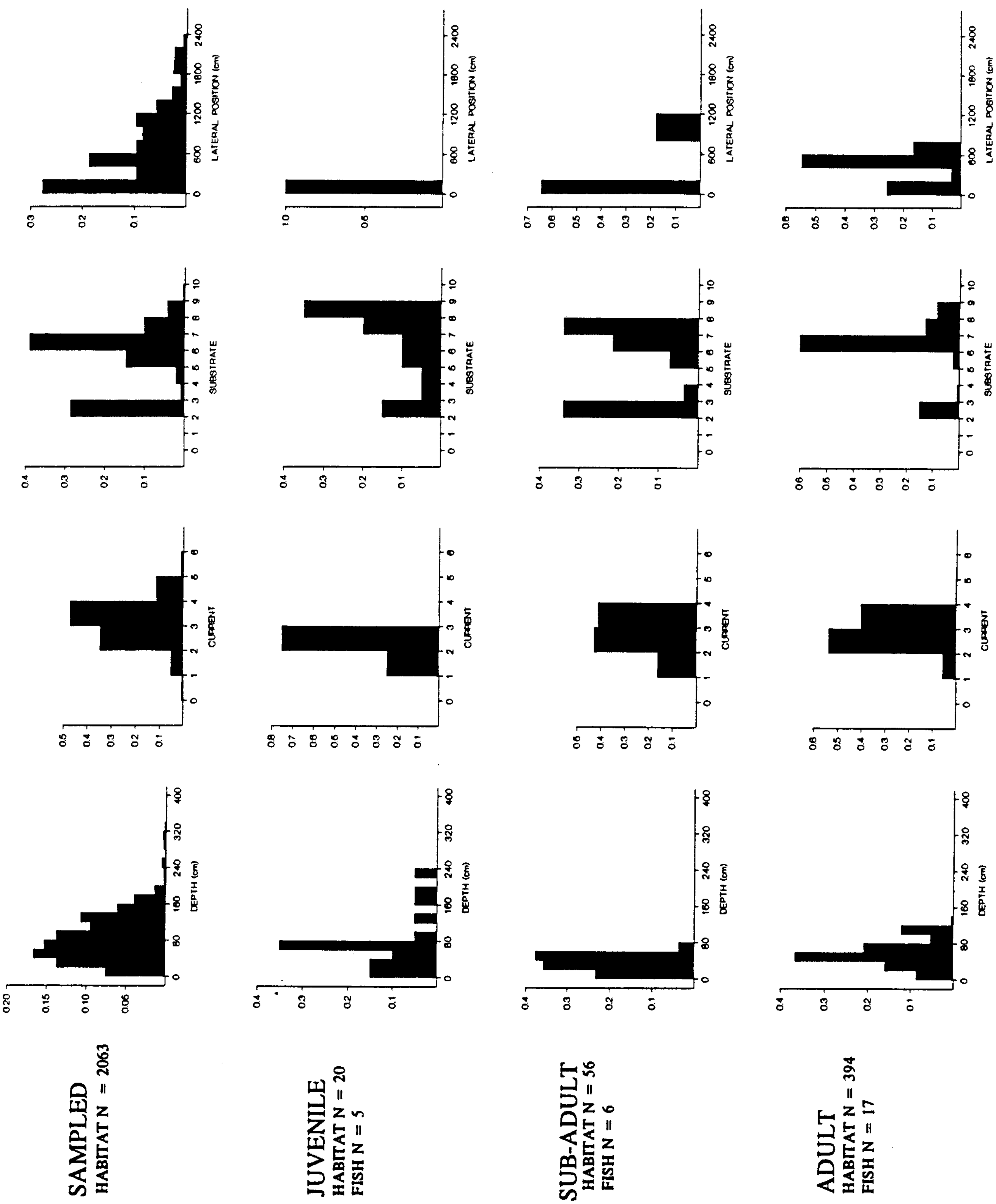
HBC April 1993 Powell (DAY)



HBC April 1993 Powell (DAY)



HBC April 1993 Powell (NIGHT)



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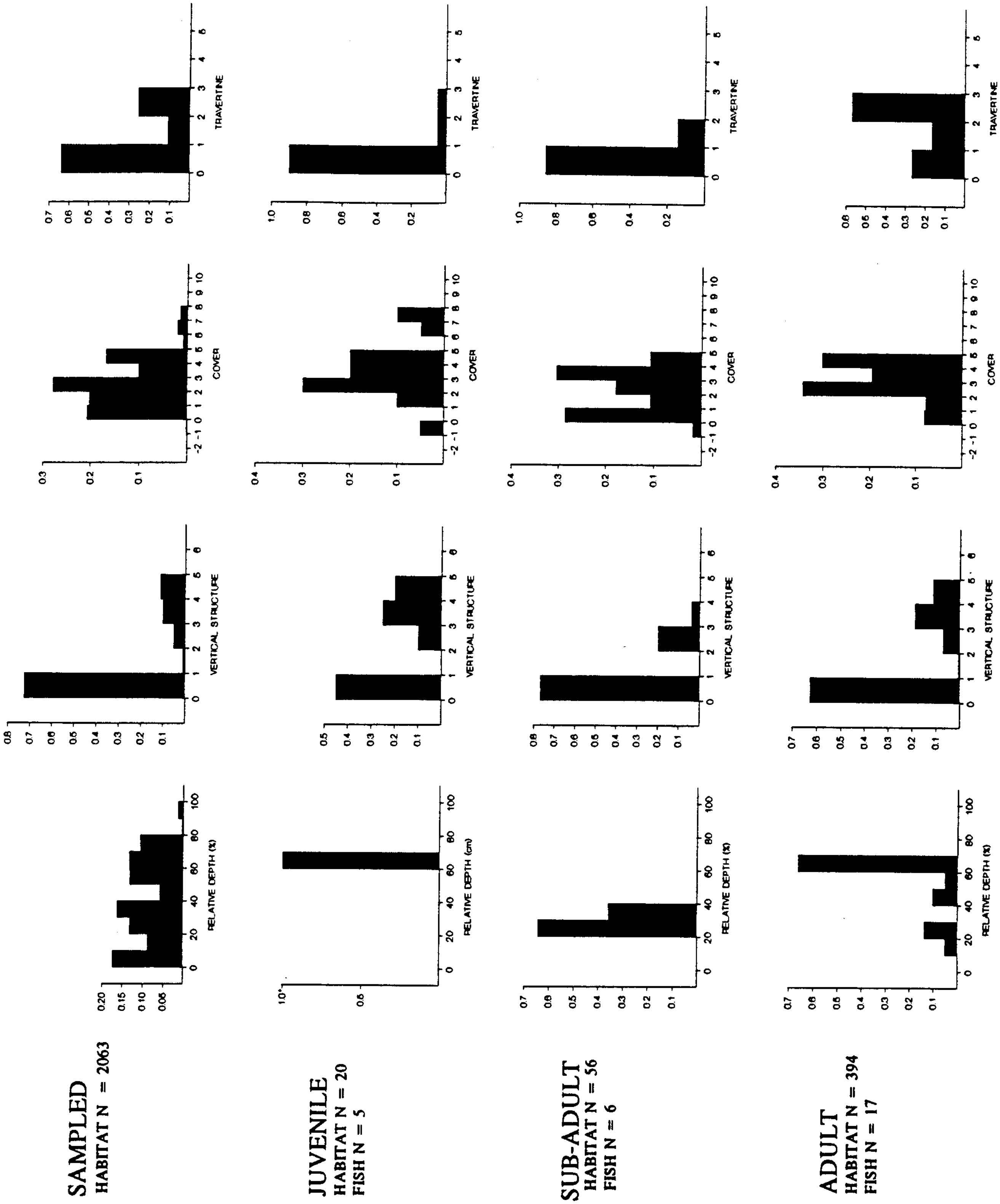
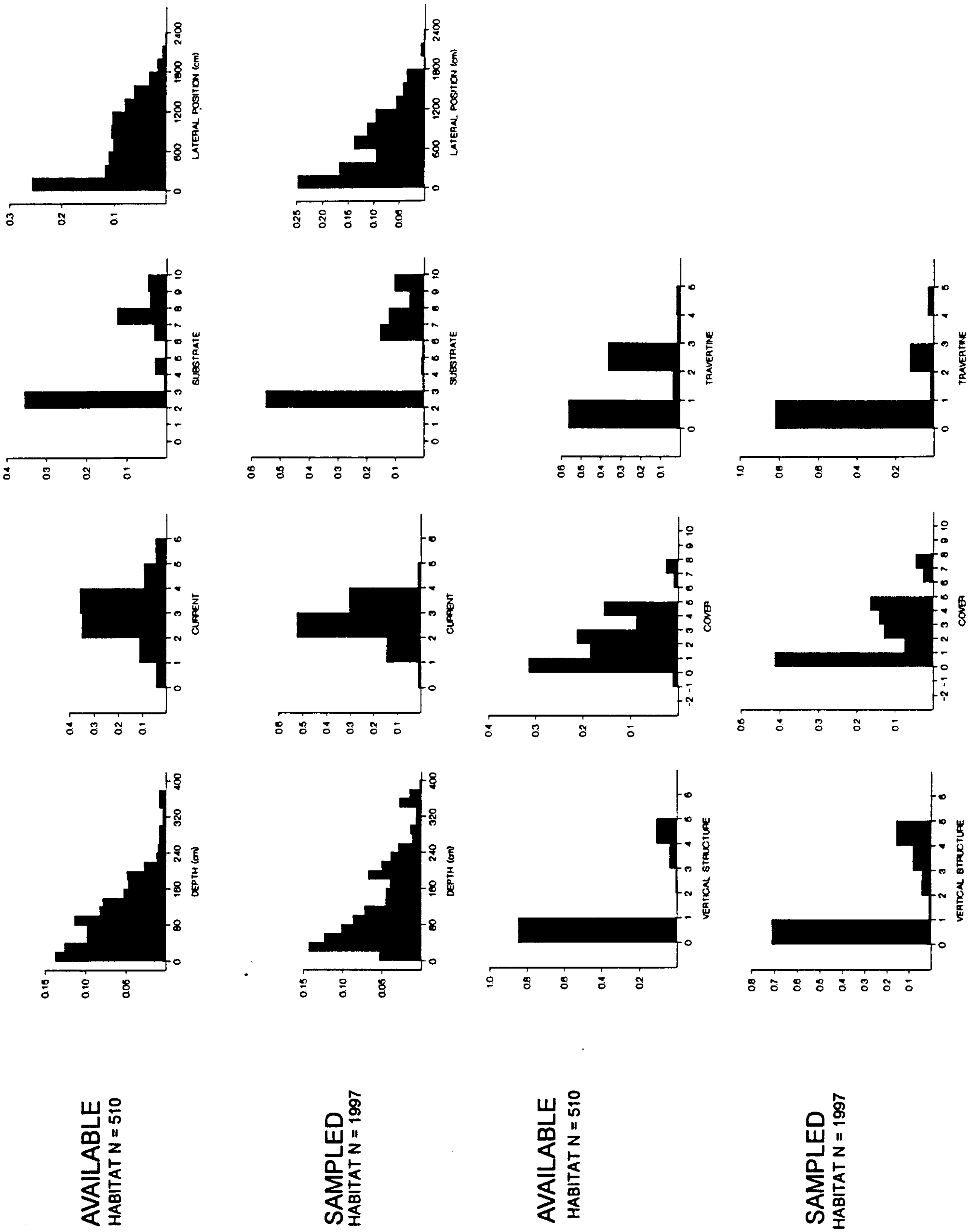
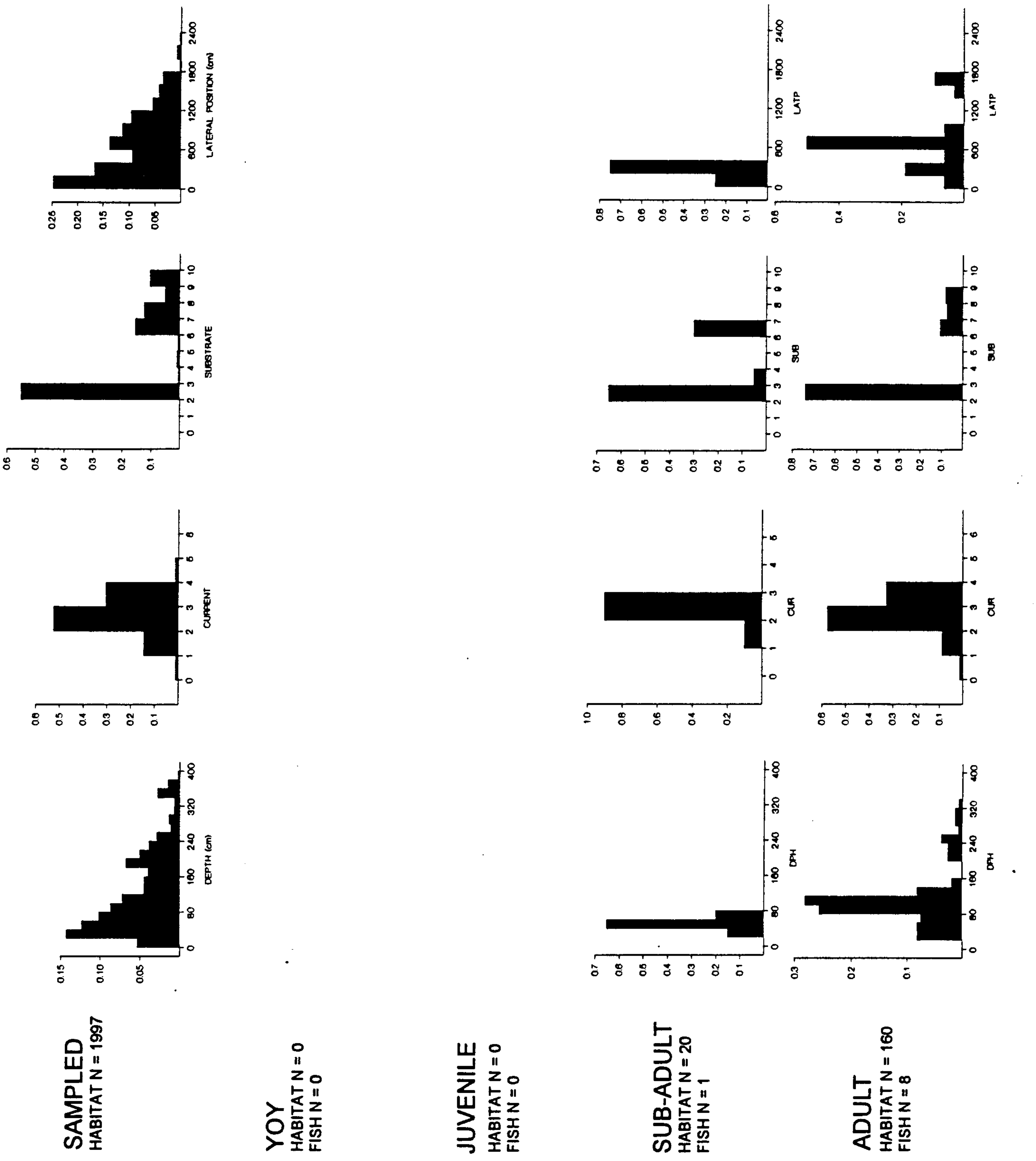


Figure 2. **USFWS LCR fish habitat studies, Salt Study Reach 4/93: Available vs. sampled habitat and habitat use by humpback chub**

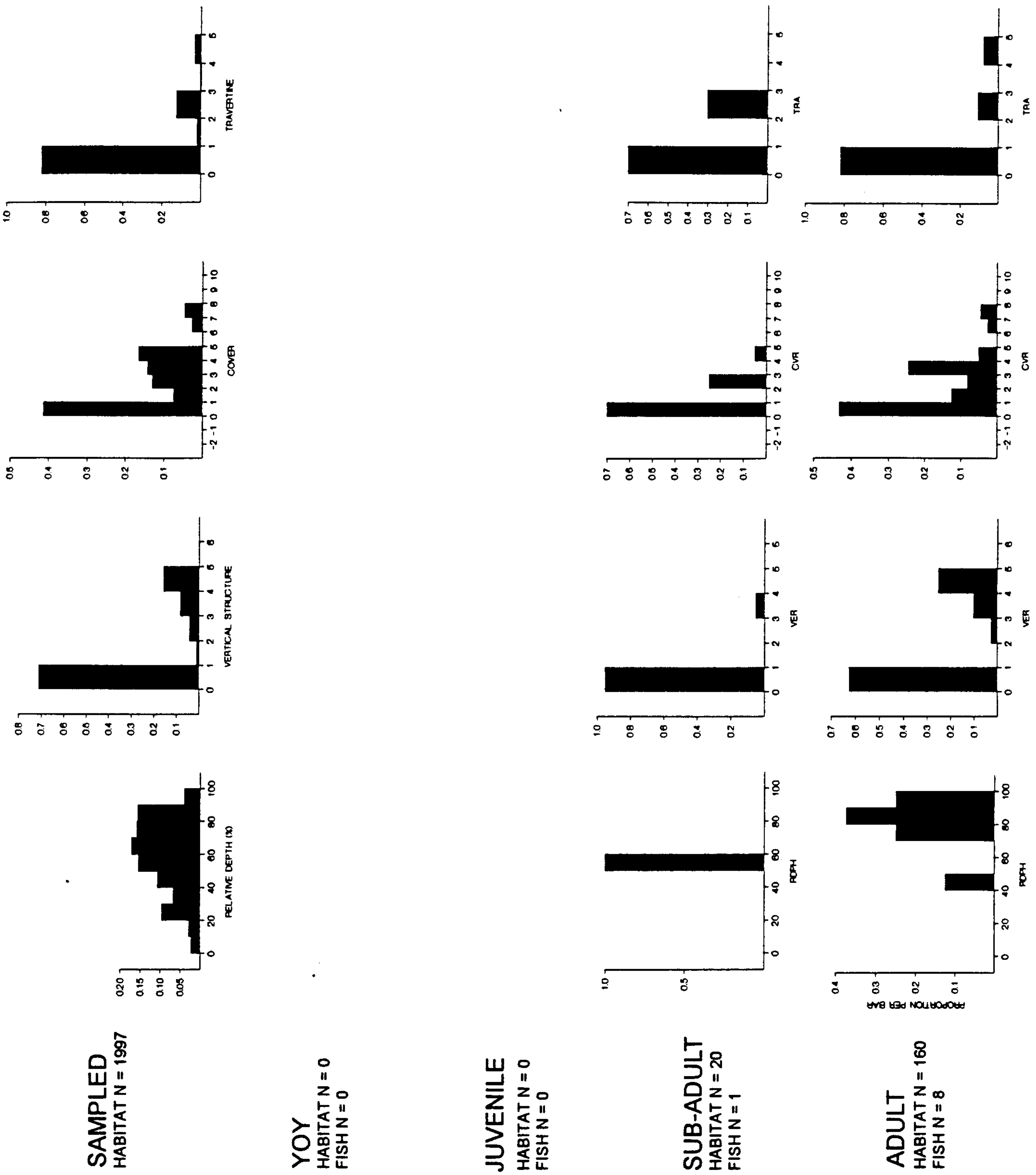
April 1993 Salt



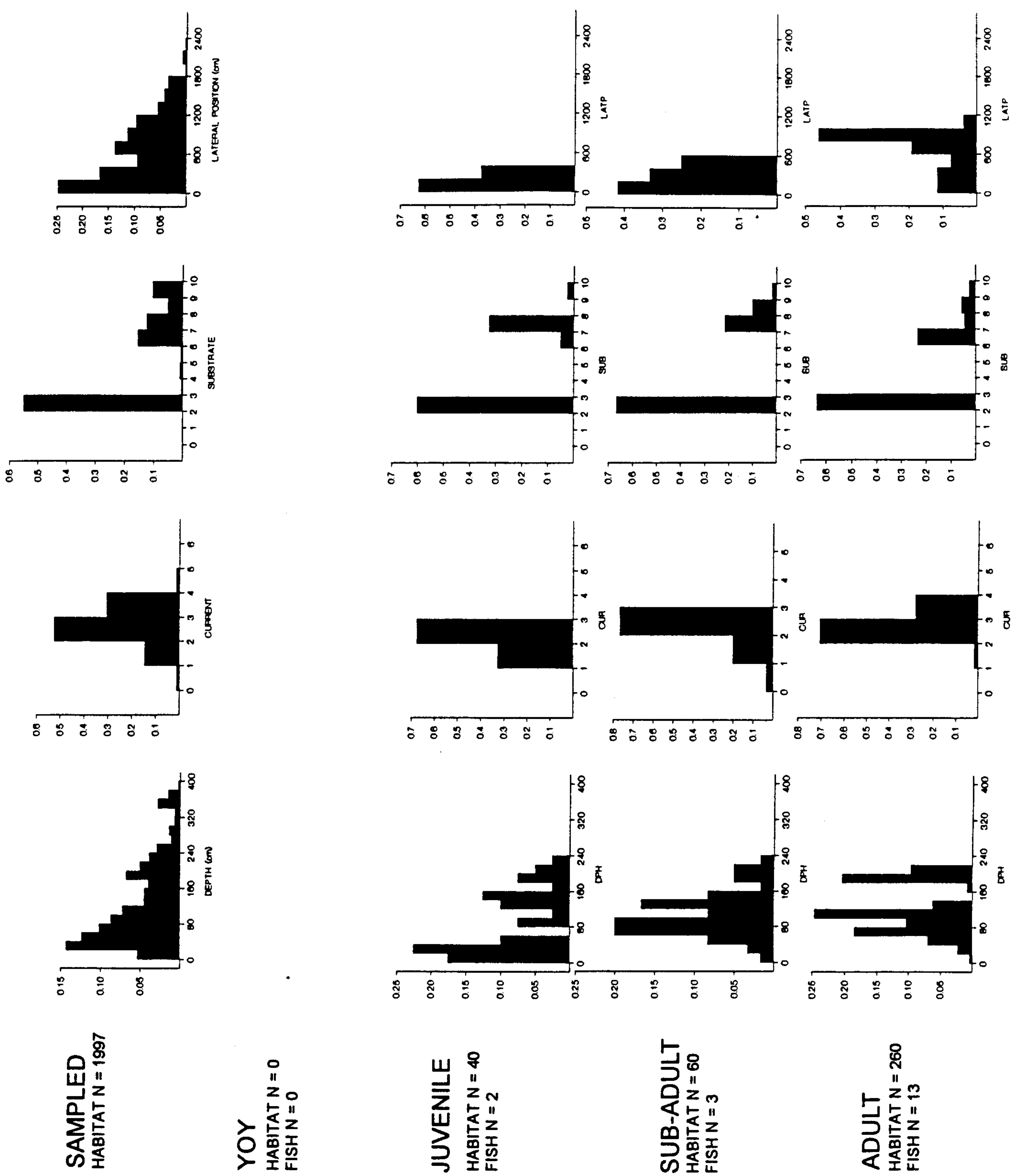
HBC April 1993 Salt (DAY)



HBC April 1993 Salt (DAY)



HBC April 1993 Salt (NIGHT)



HBC April 1993 Salt (NIGHT)

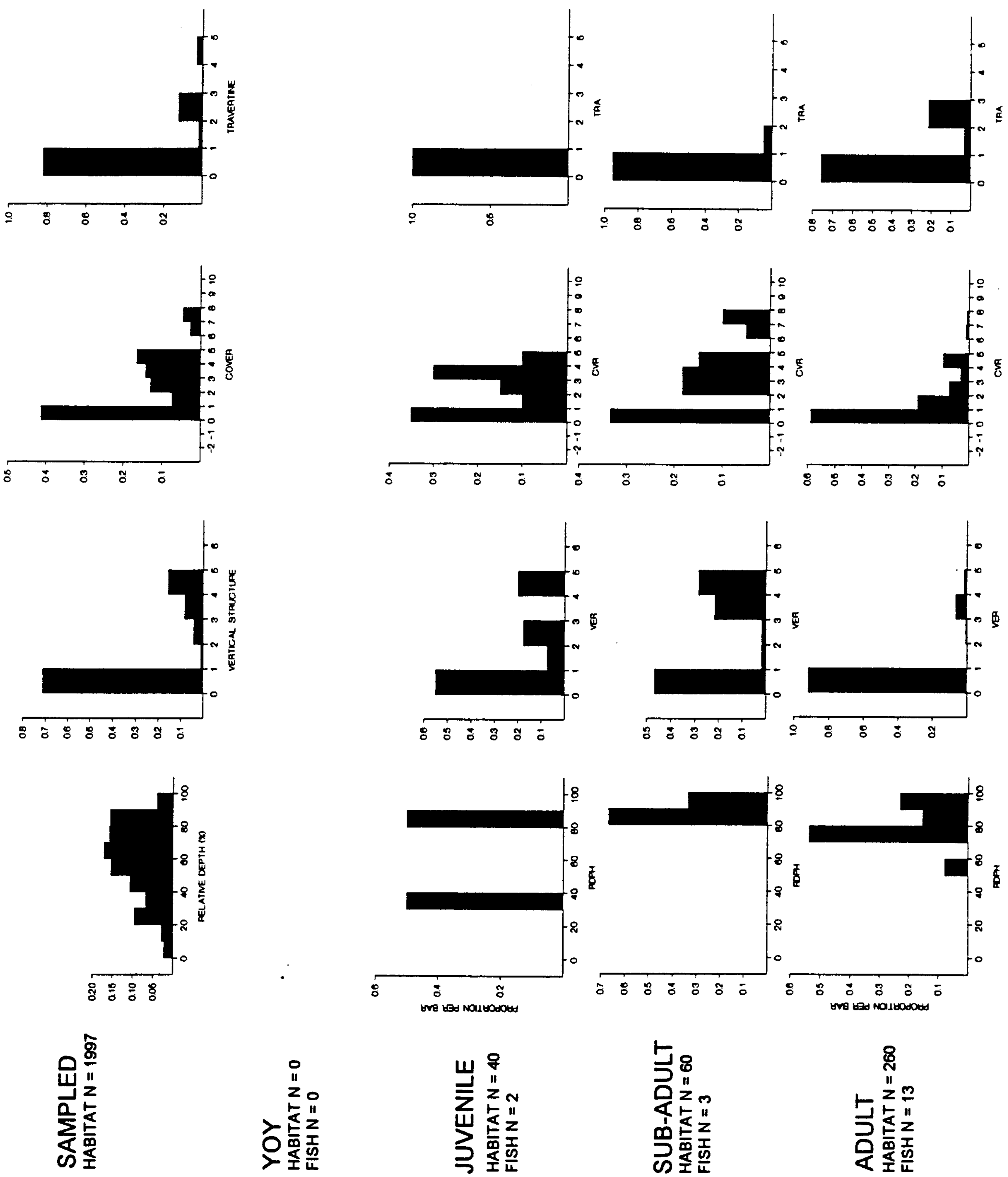
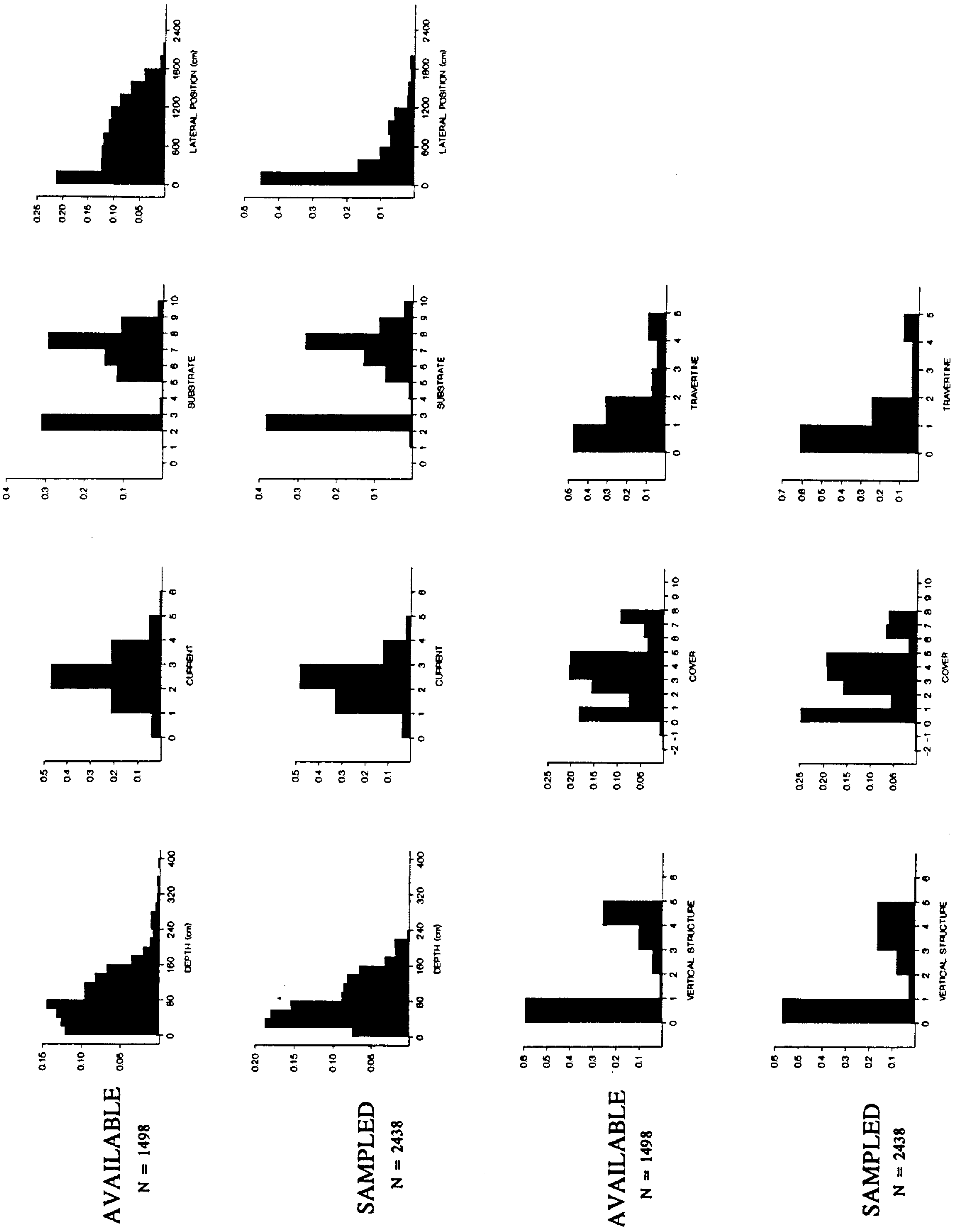


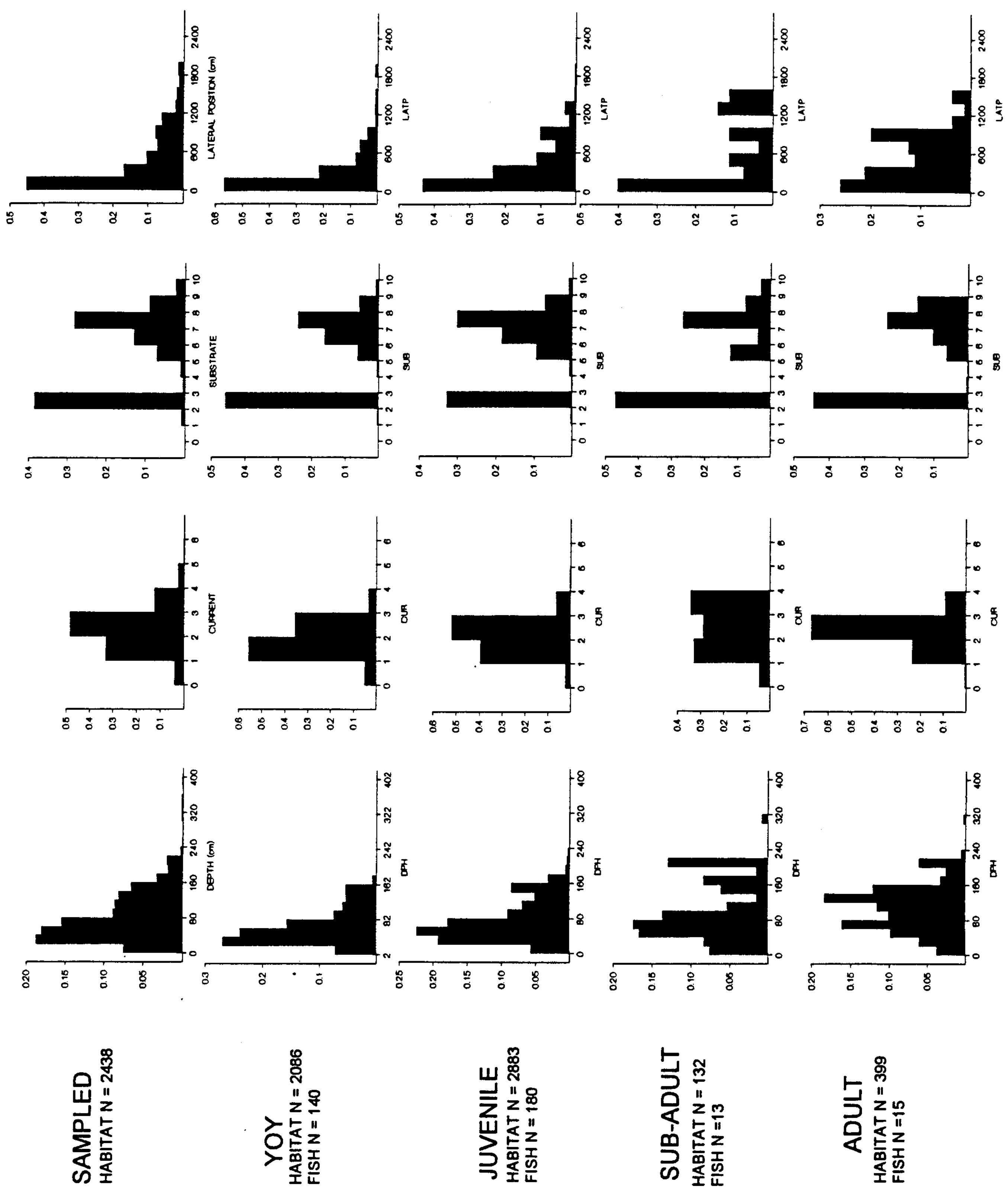
Figure 2. USFWS LCR fish habitat studies, Salt Study Reach 4/93: Available vs. sampled habitat and habitat use by humpback chub

Figure 3. USFWS LCR fish habitat studies, Salt Study Reach 4/94: Available vs. sampled habitat and habitat use by humpback chub

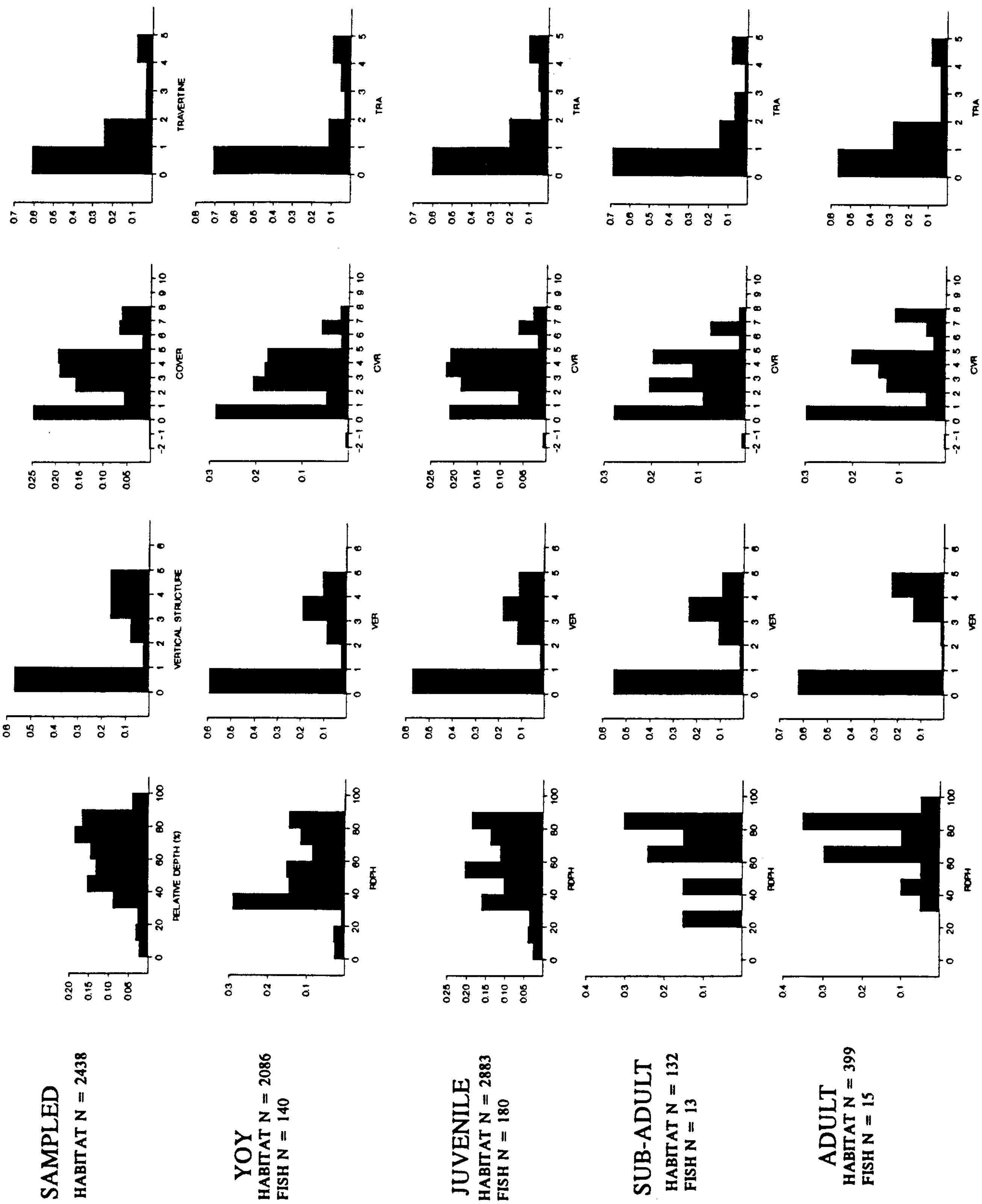
April 1994 Salt



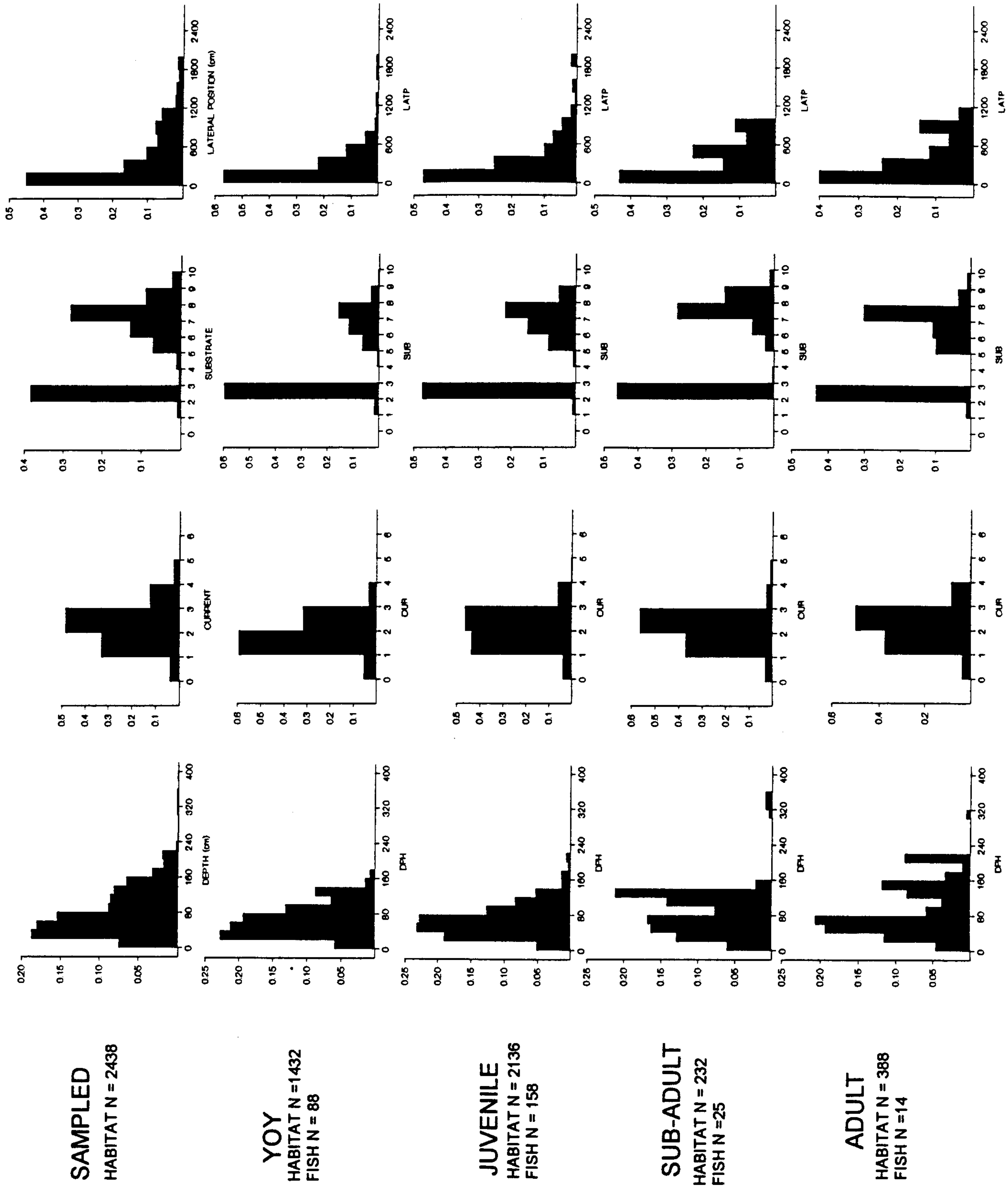
HBC April 1994 Salt (DAY)



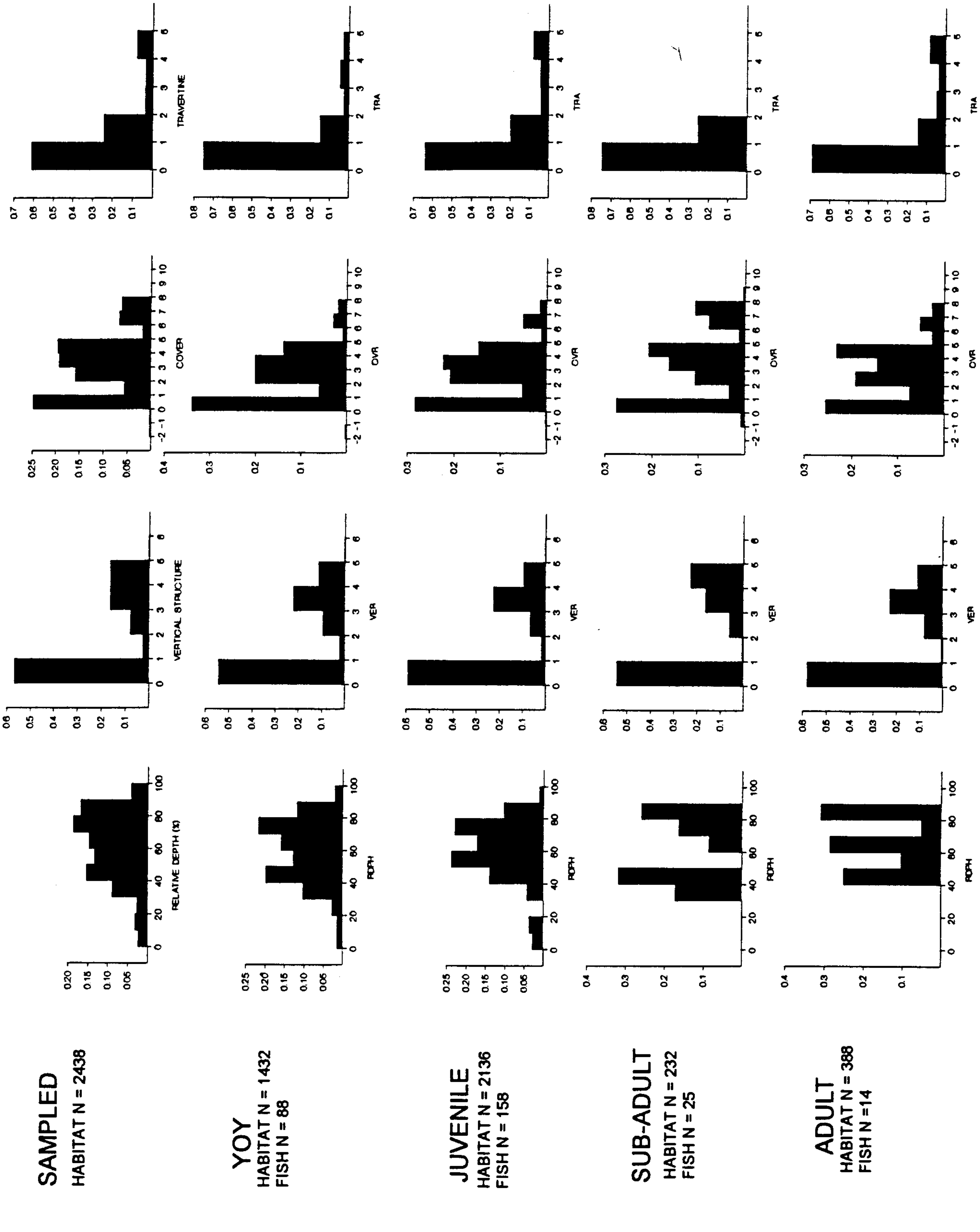
HBC April 1994 Salt (DAY)



HBC April 1994 Salt (NIGHT)



HBC April 1994 Salt (NIGHT)



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APPENDIX VII

COMPARISON OF HABITAT AMONG TRIBUTARY CONFLUENCES OF THE COLORADO RIVER IN THE GRAND CANYON

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Habitat was sampled in the confluences of smaller tributaries of the Colorado River in the Grand Canyon in June 1993 and July 1994. Habitat was sampled in the confluence of the Little Colorado River (LCR) in July 1991 and August 1993. In the smaller tributaries, habitat was measured along transects spaced at 10 m or 20 m intervals (1993 and 1994, respectively) from the mouth to 200 m upstream or to the first barrier falls (110 m in Shinumo, 100 m in Deer, and 130 m in Havasu). The length of the sample reach included only that area regularly impacted by fluctuating flows of the Colorado River. Habitat was measured as triple transects in 1994 (see Methods). Because the confluence of the LCR is used regularly by adult humpback chub it will serve as model for other tributaries.

Temporal changes

During the 1991 sampling, the LCR was measured at a time when the Colorado River was at a low experimental 5000 cfs flow. Also at that time sand was the predominant substrate in the LCR (see Append. III). As a result there was no backwatering and the channel at the confluence was relatively narrow, sandy, shallow to moderately deep, and modal currents were moderate (0.30-0.70 m/s) (Append. VII Fig 3). In 1993 the LCR confluence was measured at a time when the Colorado River was at an intermediate flow stage so that the confluence was partially backwatered. Also, floods in early 1993 had scoured much of the sand and deepened the channel. Compared to 1991, the LCR confluence was wider, deeper, less sandy, and modal currents were very slow to slow (< .30 m/s), and there was increased vertical structure and cover (Append. VII Fig. 3).

Havasu Creek was sampled in both 1993 and 1994. As with the LCR, Havasu Creek was impacted by flooding over the winter of 1993. The flooding scoured fine substrates and deposited a large bar of gravel- cobble substrate at the mouth. Compared to 1993 the confluence in 1994 had more deep areas, slower modal currents, more fine substrates, more vertical structure, but less cover (because of a predominance of sand and silt).

Kanab Creek was sampled in both 1993 and 1994. In 1993, silt was the primary substrate but in 1994 there were more exposed coarser substrates (sand to rocks). The slower currents and wider channel in 1993 is the result of sampling habitat when the mouth was partially backwatered by intermediate Colorado River flow stages.

Shinumo Creek was sampled both in 1993 and 1994. In 1994 summer spates had transported silt downstream to the confluence. This resulted in more fine sediment, fewer moderate depth areas and less cover than in 1993.

Deer, Tapeats, and Bright Angel creeks were sampled once in 1994.

Comparisons with the LCR

The most consistent difference between the LCR and the other tributaries is size; the LCR was deeper and much wider. Also, the LCR had no barriers to upstream movement as was the case for Shinumo, Deer, and Havasu creeks. Deer Creek was the shallowest of the tributaries. The only deep water was found in the plunge pool below the falls, but to reach this pool, fish would have to traverse stream channel with depths <20 cm. Bright Angel, Shinumo, Tapeats, and Kanab were larger streams but still much smaller than the LCR. Bright Angel had a cobble and small boulder substrate with slow to moderate currents; this provided considerable cover but not much deep vertical structure. Other than at the inflow area, there were no deep holes in the lower 200 m. Shinumo had slower currents and more accessible deep water areas and juvenile and adult humpback chub have been captured in the confluence over the past three years (Gorman et al, 1993; Gorman 1994). Unfortunately, the amount of habitat in Shinumo is very small. Tapeats Creek was the coldest of the tributaries (Table 10) and had a higher gradient and faster currents than Shinumo or Bright Angel. Like the other small tributaries, Tapeats Creek offered very little deep water habitat. Kanab Creek had a broad and open confluence but discharge was very low, summer water temperatures exceeded 30°C, and frequent summer spates tended to fill the confluence with silt and sand so that deep water areas were relatively rare. Havasu creek was the largest of the smaller tributaries and its confluence was closest in habitat structure to the LCR. Havasu offered more deep water habitat than the other tributaries, was consistently wider, and had more similar arrays of substrate and vertical structure to the LCR.

Comparison of Lower Reaches of LCR, Havasu, Kanab, and Shinumo creeks with Discriminant Analysis

1993 transect data from the lower 1 km of Kanab and Havasu creeks, the lower 130 m of Shinumo Creek, and the lower 600 m of the LCR were compared using discriminant analysis. The extent of stream channel included in this analysis was greater than the previous univariate overview of the confluences. Our objective in using discriminant analysis was to perform a preliminary multivariate analysis that would delimit differences among the lower reaches and identify habitat variables that were responsible. Because individual datasets based on the original sample points were so large, we used mean and standard deviation statistics calculated for each habitat transect. Habitat variables used in the analysis included lateral position (LATP, distance from nearest bank), water depth (DPH), current velocity (CURV), effective particle size (EPS=SUB), cover (CCV, corrected for current velocity), vertical structure (VRC, corrected for current velocity), and travertine (TRA).

The analysis correctly classified 89 of 100 (89 %) transects within Havasu Creek, 95 of 102 (93 %) transects within Kanab Creek, 33 of 33 (100 %) transects within the LCR, and 12 of 14 (86 %) transects within Shinumo Creek. Stream width and water depth were highly correlated to dependent canonical factor 1, current velocity and effective particle size were correlated to dependent canonical factor 2, and depth and vertical structure were correlated to canonical factor 3. Classification functions for each of the streams are presented in Append. VII Table 1. The relationships among stream transects on dependent canonical factors are graphically represented in Append. VII Figs. 1 and 2.

The classification demonstrates the relative dissimilarity among the four tributary segments included in the discriminant analysis. Of the four tributaries, transects of the LCR are the most distinctive. As was observed in the univariate analysis of confluences, the stream channel within the lower 600 m of the LCR is wider with greater depths than the channels of Havasu, Kanab, and Shinumo; stream width and depth are highly correlated to canonical factor 1. Of the remaining stream segments included in the analysis, physical features within Havasu Creek appear to be the most closely associated with the LCR (as was noted in the univariate analysis). Transects within Kanab appear to be relatively homogeneous as represented by the tight clustering on canonical factors 1 and 2. Further analysis of these data is needed to determine influence of stream channel dissimilarities on potential habitat use by humpback chub in tributaries.

Table 1. USFWS LCR fish habitat studies: Group classification function coefficients for tributary confluence reaches.
Data was acquired from field measurements during June 1993. Standard deviation data denoted with *.

	Havasu	Kanab	LCR	Shimumo
LATP*	0.028	0.025	-0.006	0.031
DPH*	0.004	-0.082	0.139	-0.089
CURV*	-8.812	0.129	7.238	6.456
EPS*	5.267	5.198	5.238	4.933
CCV*	-0.118	-0.057	-0.014	-0.188
VRC*	3.948	1.138	3.223	2.160
TRA*	1.100	-8.402	-5.736	-8.695
MLATP	-0.010	-0.013	0.053	-0.016
MDPH	0.250	0.147	0.353	0.239
MCURV	17.575	-3.034	-3.921	-9.502
MEPS	4.394	4.469	2.293	6.735
MCCV	0.170	-0.029	0.201	0.028
MVRC	-8.383	-5.010	-10.585	-6.609
MTRA	-9.991	-8.214	4.294	-11.738
CONSTANTS	-27.460	-15.366	-50.157	-27.945

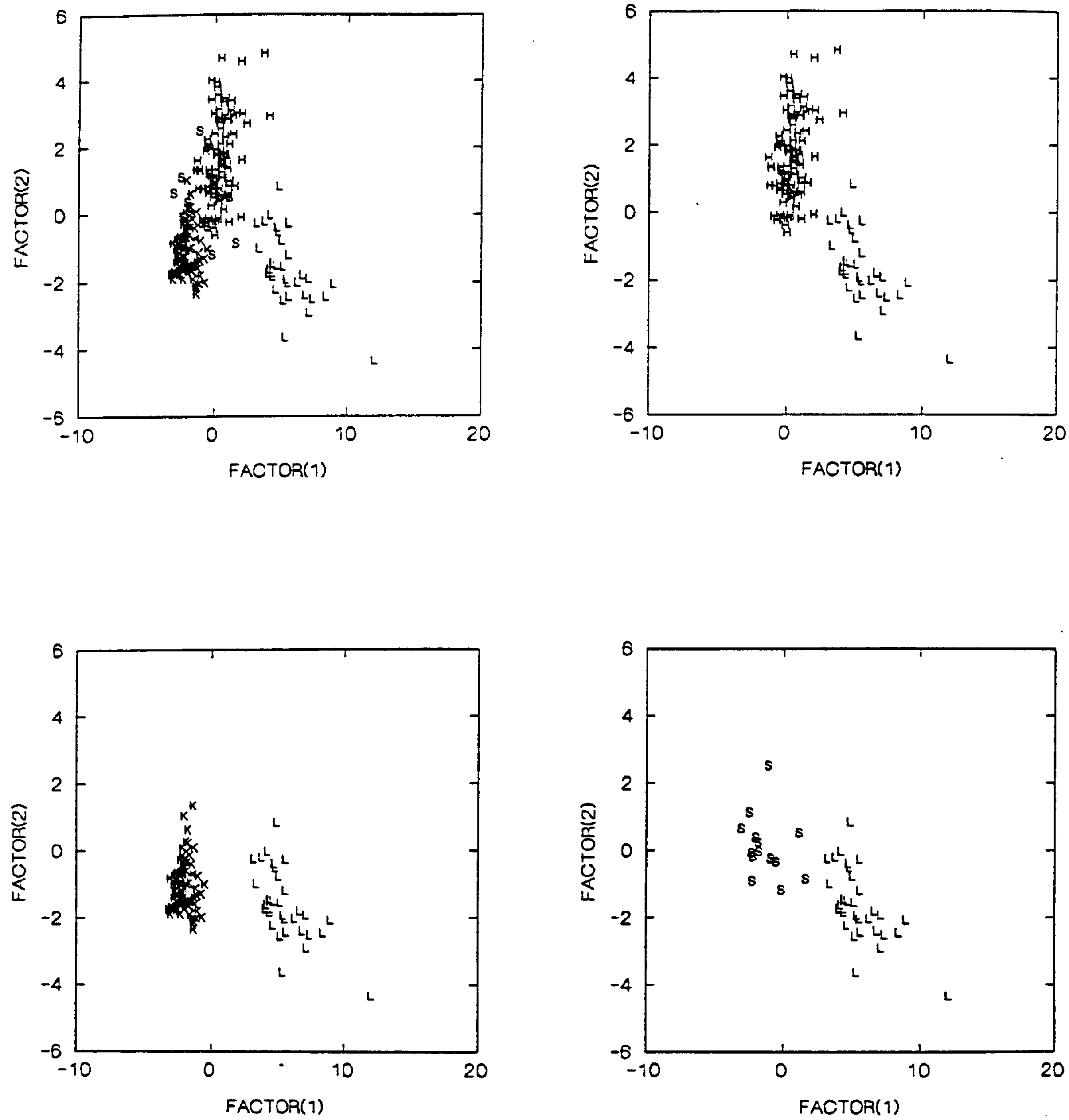


Figure 1. LCR, Havasu, Kanab, and Shinumo transect habitat loadings of dependent variables on canonical factors.

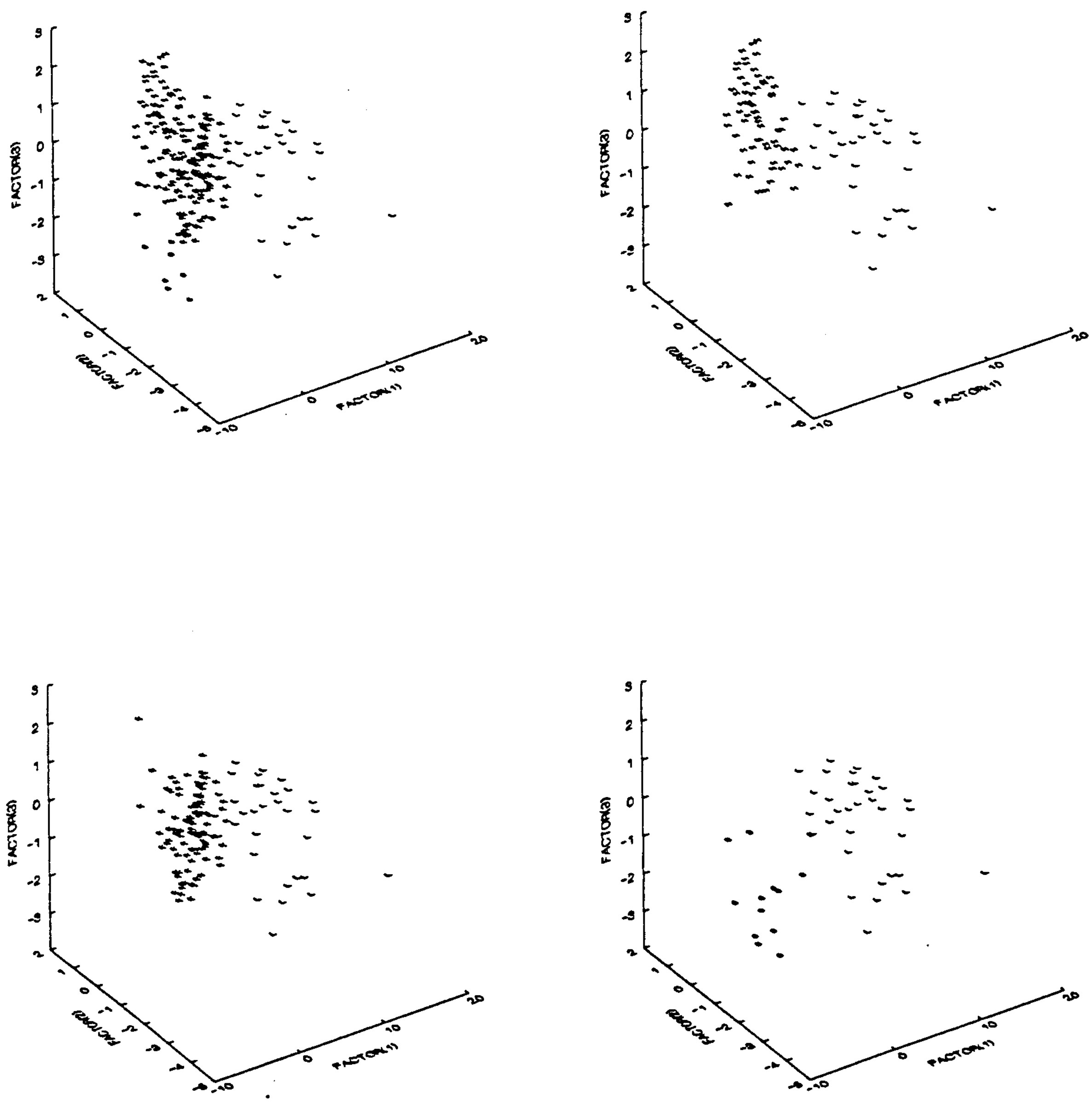
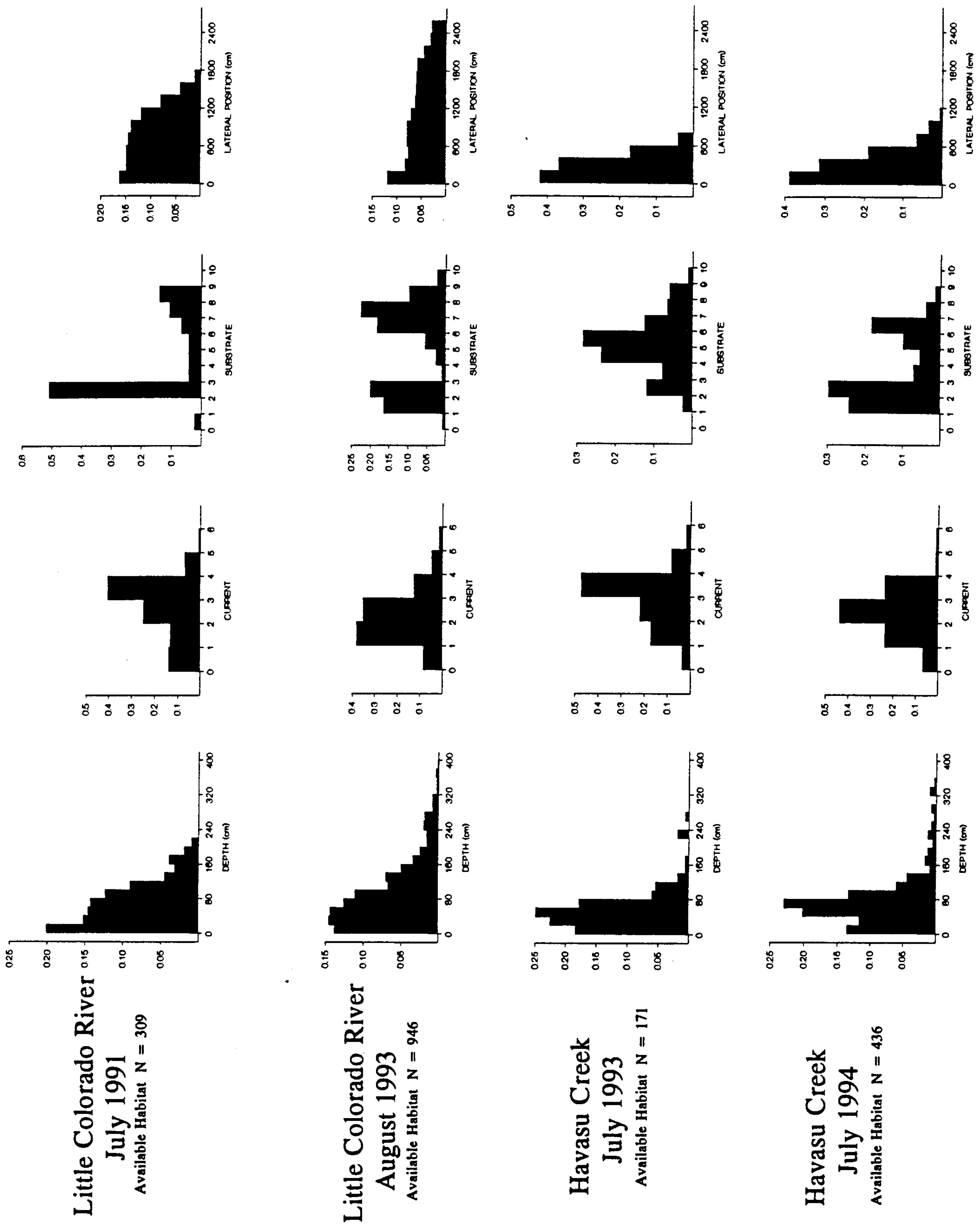


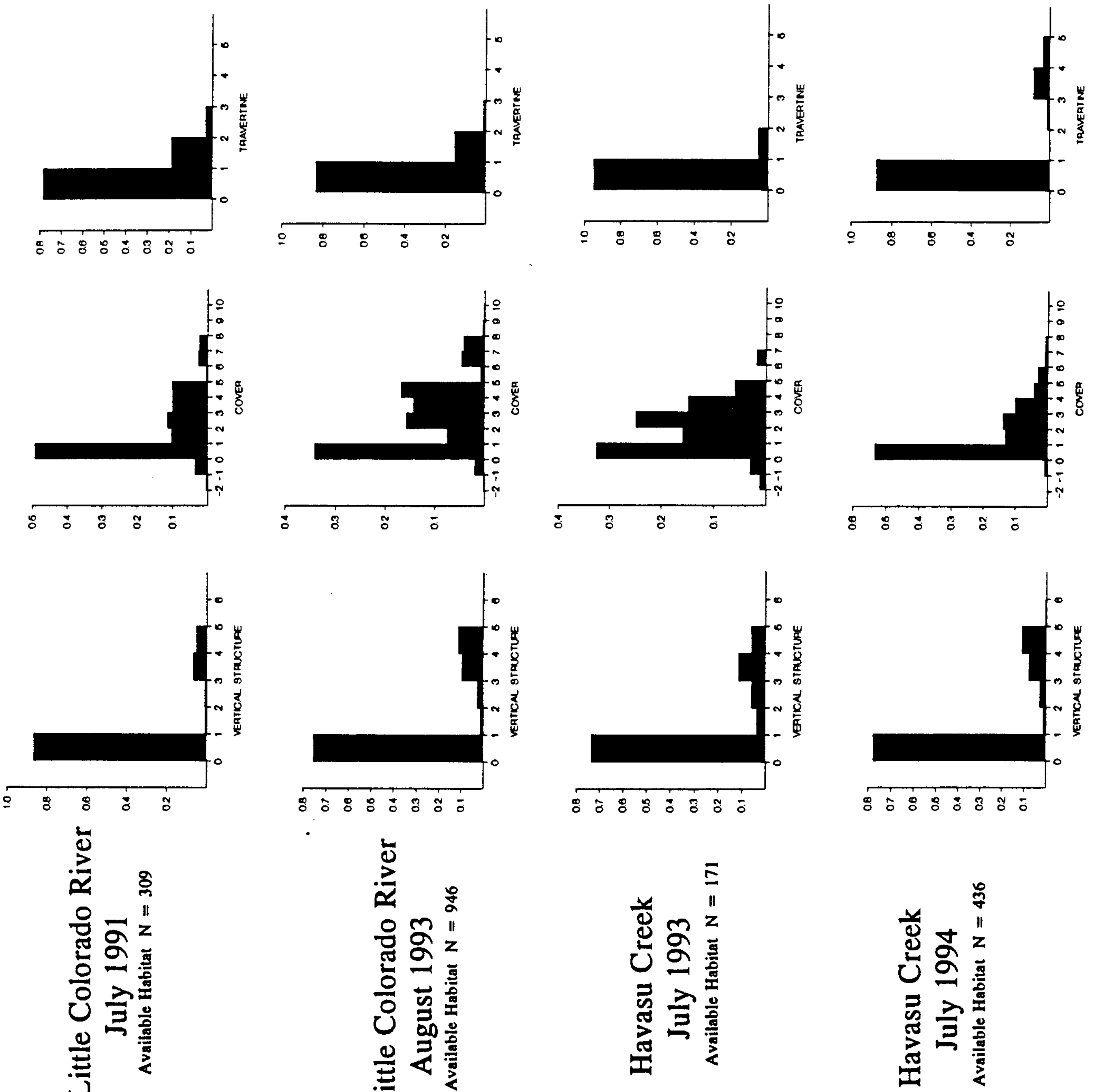
Figure 2. LCR, Havasu, Kanab, and Shinumo transect habitat loadings of dependent variables on canonical factors.

FIGURE 3. **USFWS LCR fish habitat studies: comparison of available habitat in Grand Canyon tributary confluences.**

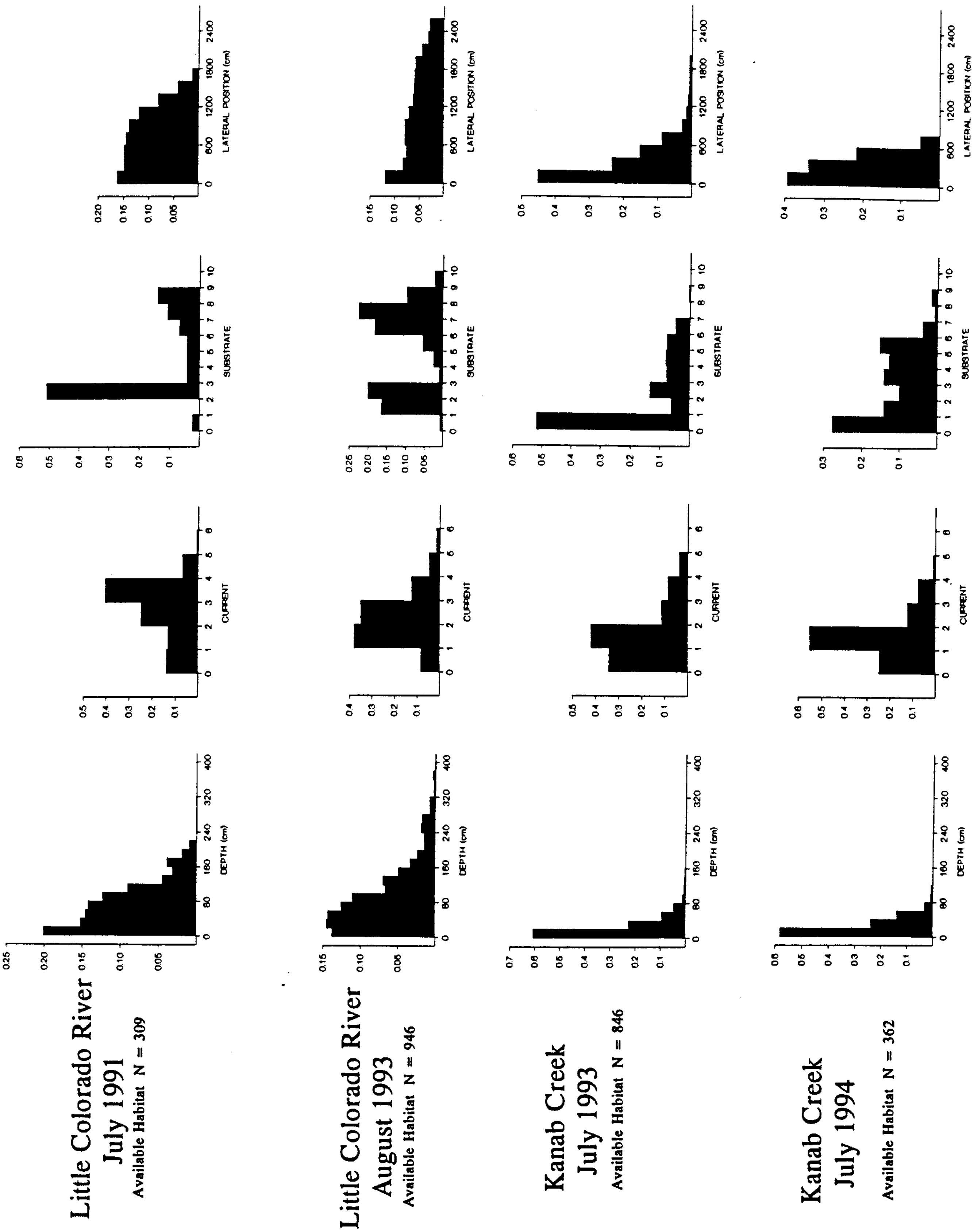
Comparison of Grand Canyon Tributary confluences



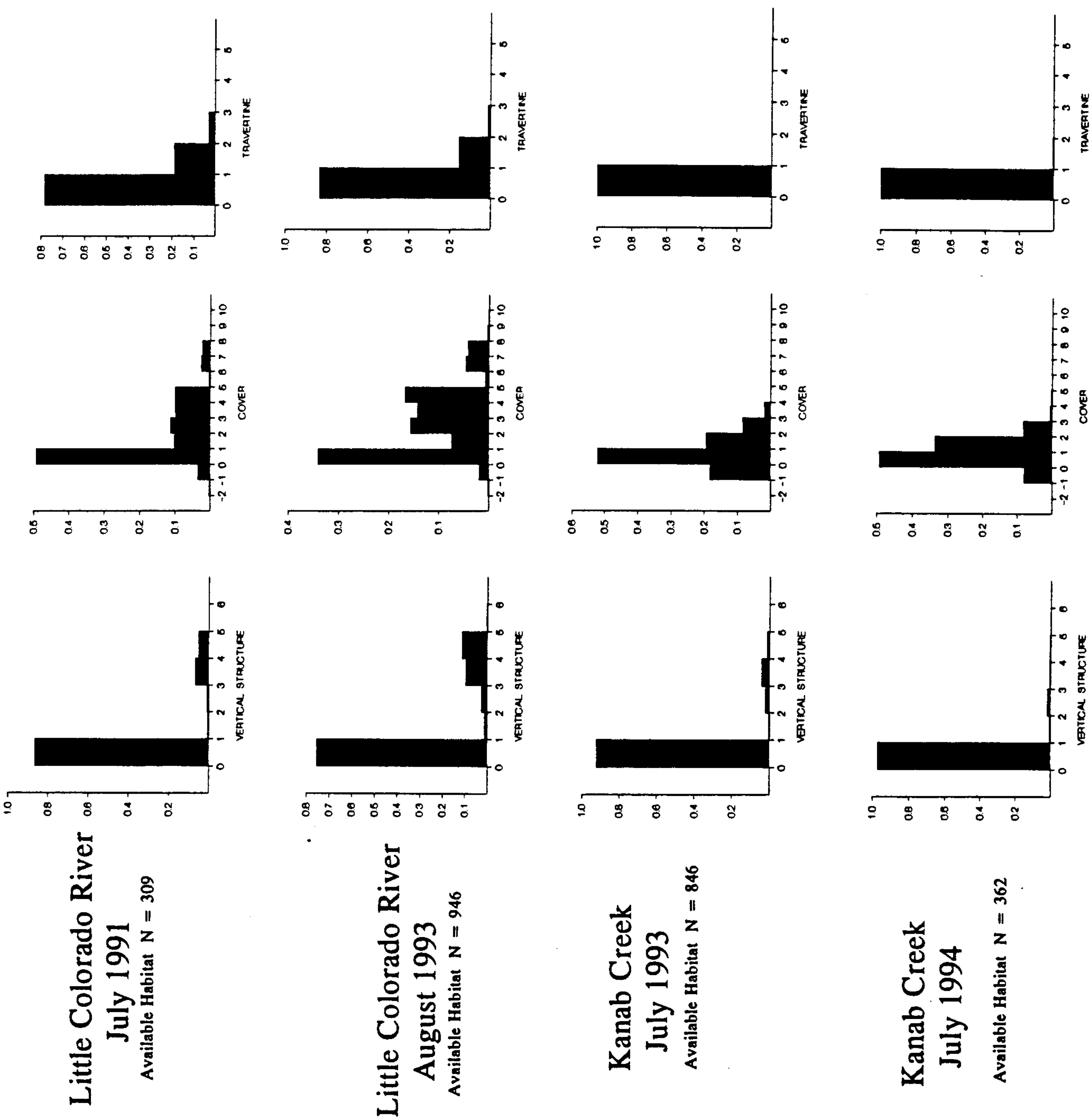
Comparison of Grand Canyon Tributary confluences



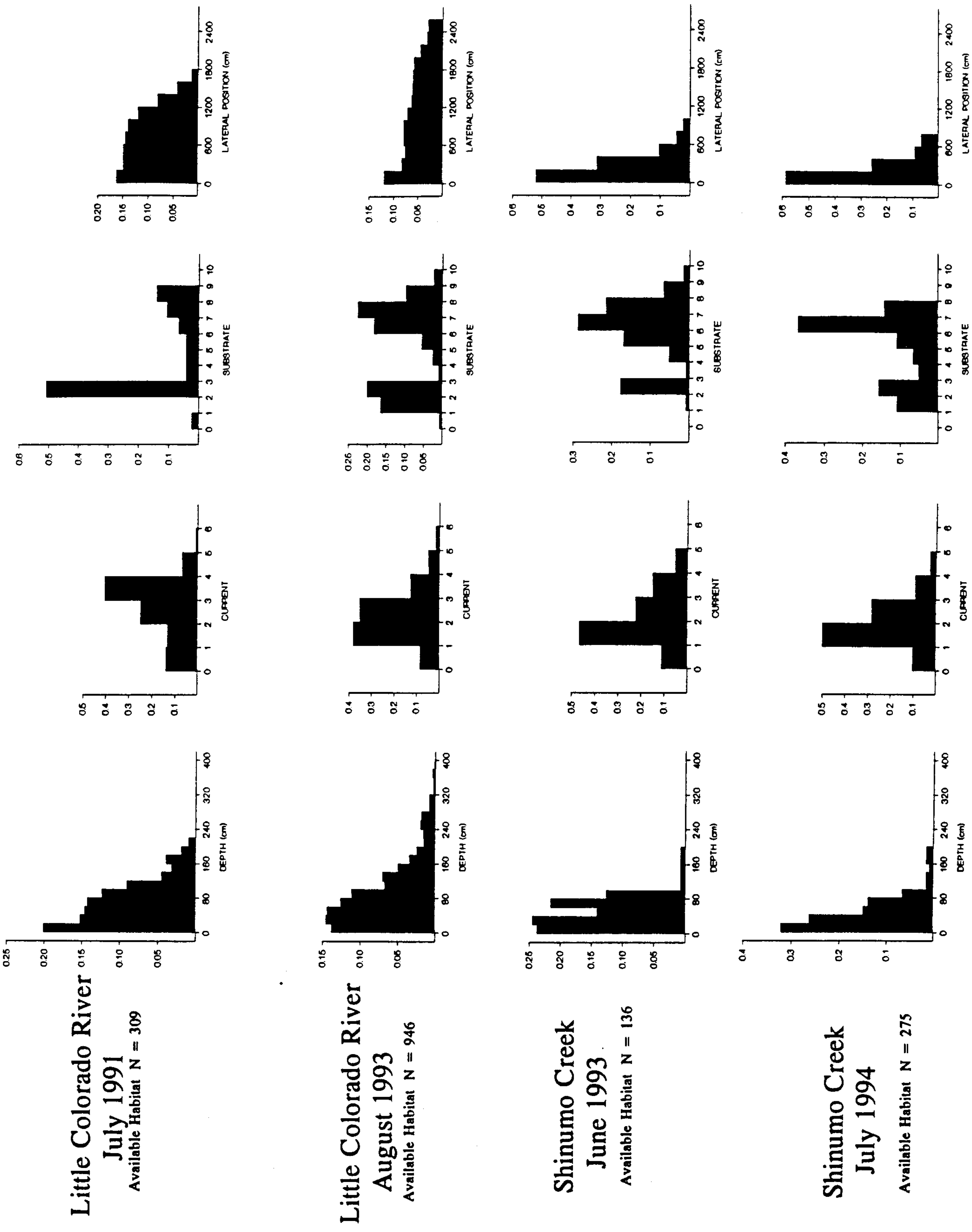
Comparison of Grand Canyon Tributary confluences



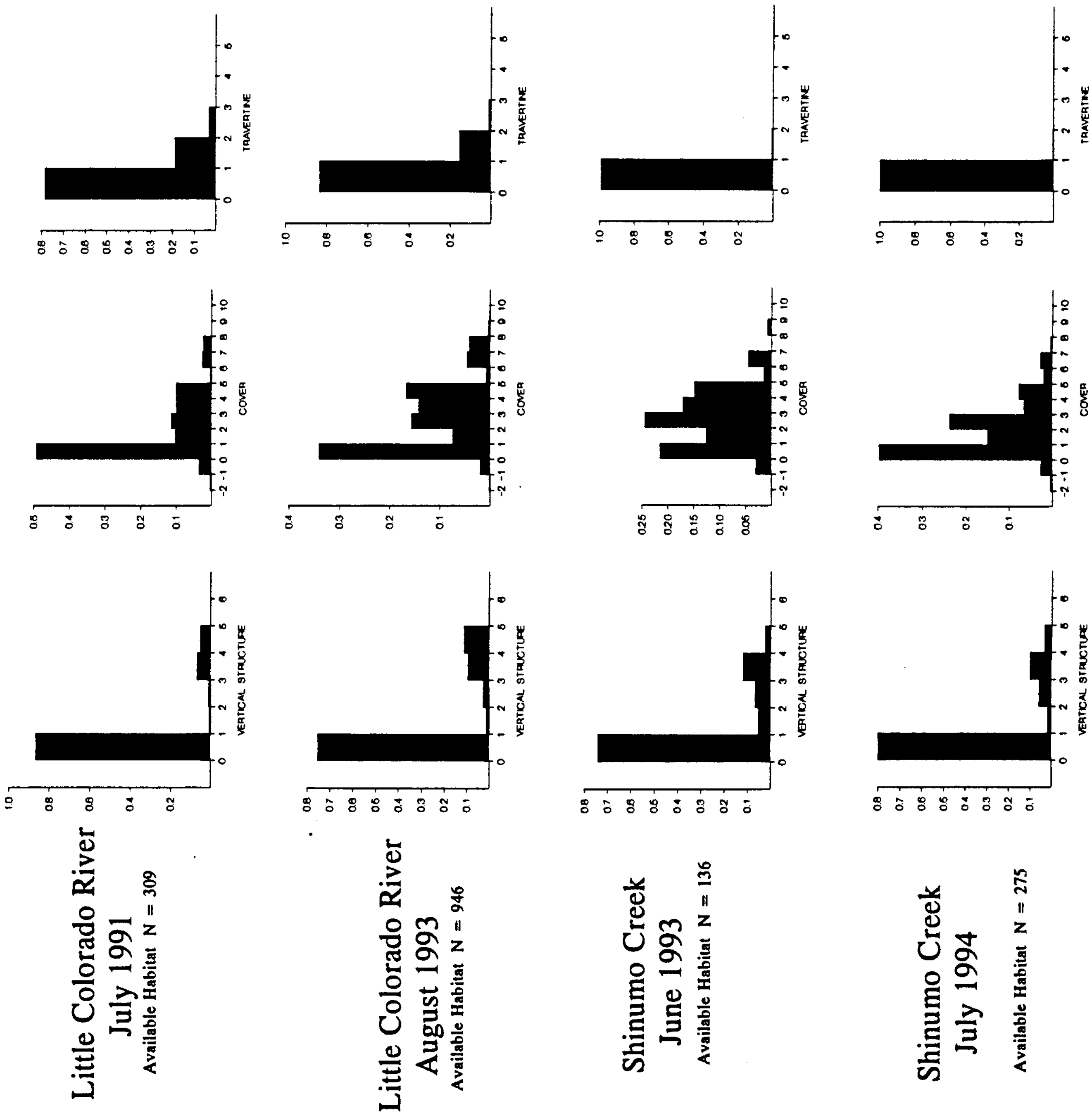
Comparison of Grand Canyon Tributary confluences



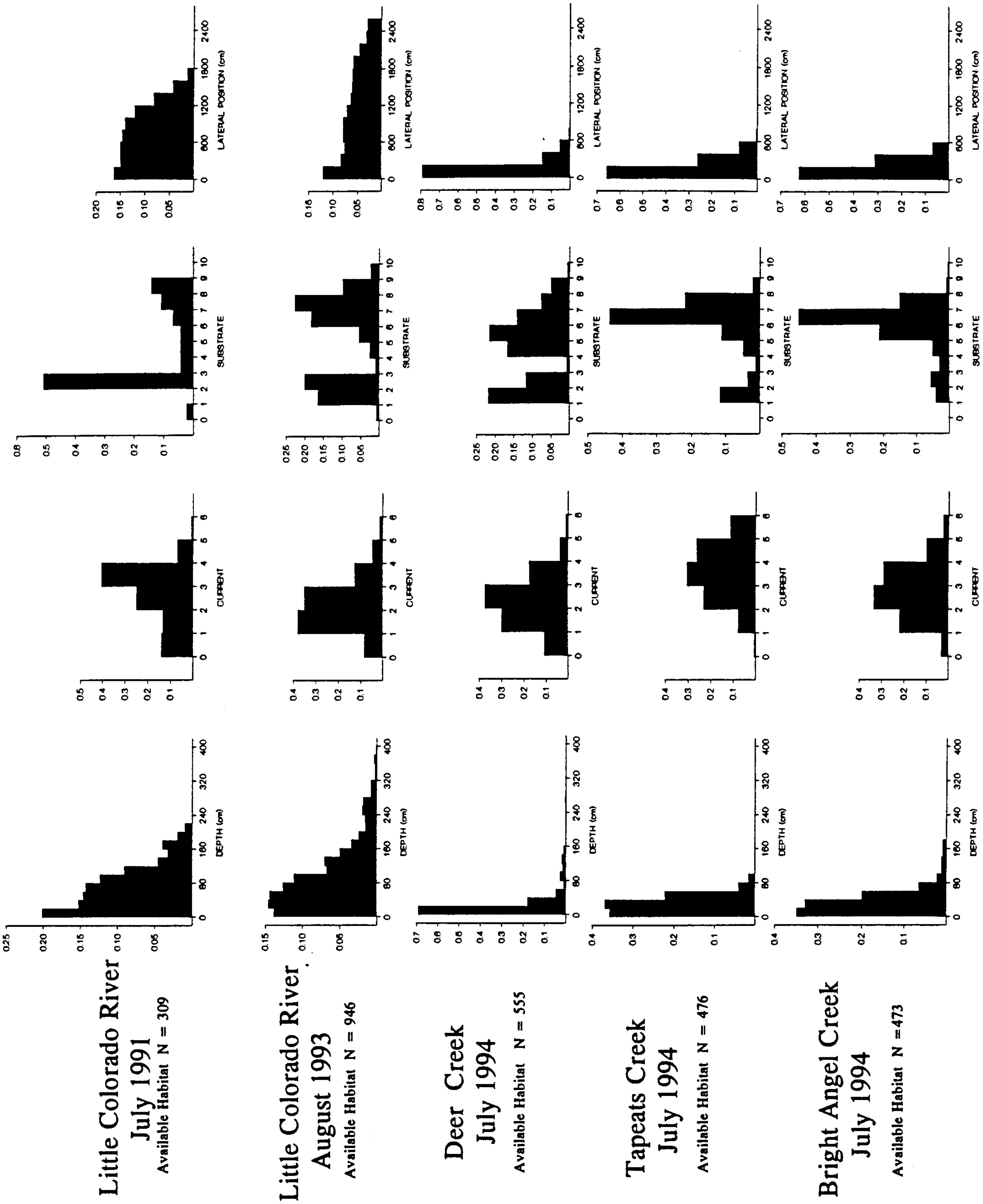
Comparison of Grand Canyon Tributary confluences



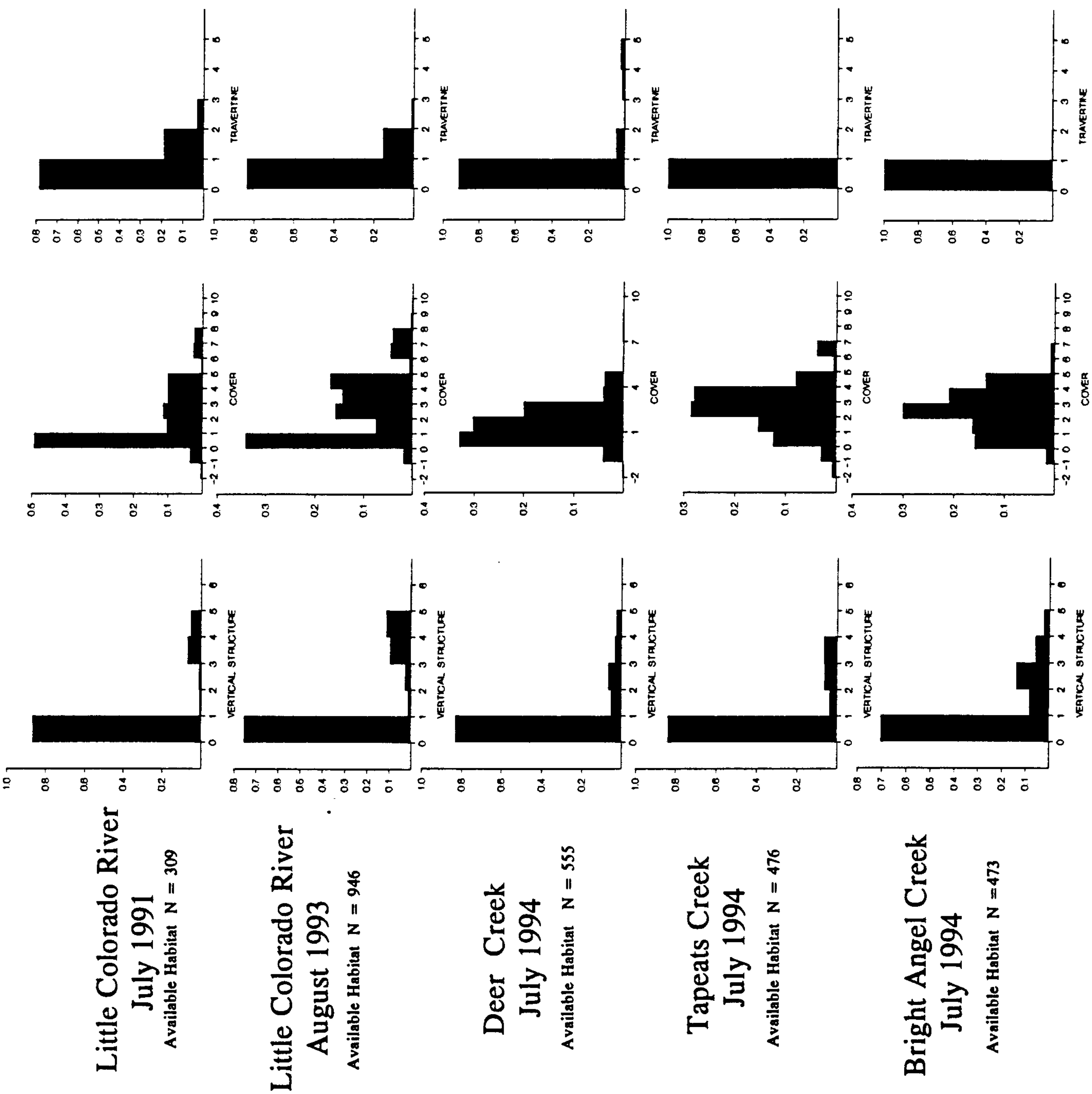
Comparison of Grand Canyon Tributary confluences



Comparison of Grand Canyon Tributary confluences



Comparison of Grand Canyon Tributary confluences



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APPENDIX VIII

COMPARISON OF AVAILABLE HABITAT AMONG UPSTREAM REACHES OF TRIBUTARIES OF THE COLORADO RIVER IN THE GRAND CANYON

WITH

EVALUATION OF AVAILABLE HABITAT FOR HUMPBACK CHUB

APPENDIX VIII

COMPARISON OF AVAILABLE HABITAT AMONG UPSTREAM REACHES OF TRIBUTARIES OF THE COLORADO RIVER IN THE GRAND CANYON

WITH

EVALUATION OF AVAILABLE HABITAT FOR HUMPBACK CHUB

The intent of the analysis presented in this appendix is to "identify potential humpback chub habitats within the various tributaries of the Colorado River and evaluate the suitability of these habitats to recovery efforts" (USFWS GCES contract objective #4). As humpback chub maintain a relatively large reproducing population in the Little Colorado River (LCR), we will use the habitat relationships of the humpback chub in the LCR as model for comparison with other tributaries in the Grand Canyon.

Habitat was sampled in the upstream reaches of smaller tributaries of the Colorado River in the Grand Canyon in June 1993 and July 1994. Habitat was sampled in the Little Colorado River (LCR) from 1991-1994. In the smaller tributaries, habitat was measured along transects spaced at 100 m intervals from 100-200 m above the mouth to a distance of 4 to 10 km upstream (see METHODS). Habitat in the LCR was measured in July-August 1991 at 100 m intervals from the confluence to Blue Springs (21 km); the subset from 0-15 km (known range of humpback chub distribution in the LCR) is used in this analysis. Habitat for 1993 is represented by measurements taken along FWS transects spaced at 20 m intervals at the two study reaches Powell and Salt (km 2.5-3.5, km 10.5-11.5, respectively) during June and July, 1993. These two LCR datasets were chosen for this analysis because the LCR was at base flow throughout the summers of 1991 and 1993 and humpback chub reproduced successfully in the LCR those years, thus providing an array of habitat use patterns from YOY to adult fish.

<u>Temporal changes</u>

The general habitat conditions in the LCR are discussed in Appendix III. 1991 and 1993 represent two ends of the spectrum of available habitat in the LCR under base flow conditions (Append VIII Fig. 1). In 1991 the LCR channel was filled with sand substrates which reduced the amount of deep water habitat and increased current velocities. In the winter of 1993 large floods scoured most of the sand and fine sediments from the LCR which greatly increased the amount of deep water habitat and was accompanied by decreased current velocities.

Havasu Creek was sampled in both 1993 and 1994 (Append. VIII Fig. 1). As with the LCR, Havasu Creek was impacted by flooding over the winter of 1993. The flooding scoured fine substrates and eroded travertine deposits. By 1994 sand became co-dominant with cobble substrate and travertine deposition and areas with slower currents increased. Distributions of depth, lateral position (provides an indication of channel width), vertical structure and cover remained relatively unchanged.

Kanab Creek was sampled in both 1993 and 1994 (Append. VIII Fig. 2). Habitat configuration was similar in both years. In both 1993 and 1994, rocks (SUB=5) were the primary substrate but in 1993 sand was more common as a substrate. Depths, lateral position, and vertical structure were relatively unchanged. Slight changes in low cover (<2) between years is a reflection of small changes in relative proportions of substrates <6. The slight changes in substrate and current suggest that flood events between 1993 and 1994 samples had reworked the stream bed and removed some of the finer material.

Shinumo Creek was sampled both in 1993 and 1994 (Append. VIII Fig. 3). Changes in habitat were more subtle between years than was the case for Havasu and Kanab creeks. Shinumo was subjected to severe flooding in the winter of 1993 but not 1994 and this may be the underlying cause of differences. In 1994, modal currents were slower, stream width was reduced slightly, stream depth increased slightly, and silty substrates all but disappeared. Distributions of vertical structure and cover remained relatively unchanged.

Tapeats Creek and Bright Angel creeks were sampled only in 1994 (Append. VIII Fig. 4).

Comparisons with the LCR

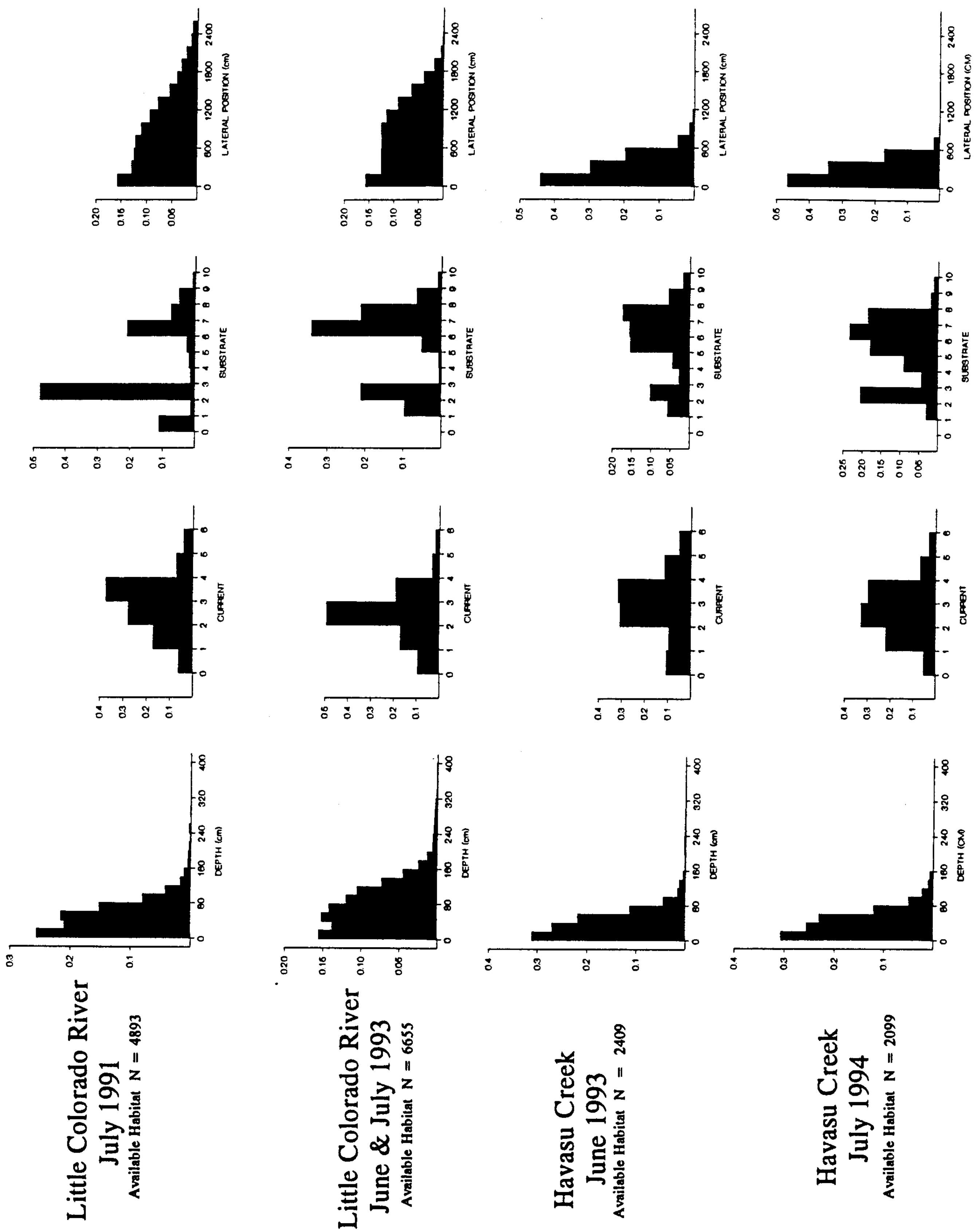
As with comparisons among tributary confluences, the most consistent difference between upstream reaches of the LCR and other tributaries is size; the LCR had more deep water (>100 cm) habitat and was much wider (Append. VIII Figs 1-4). The tributaries least like the LCR included Bright Angel, Tapeats, and Shimumo, mostly because of their small size and shallowness. However these streams offer considerable amount of vertical structure and cover. Tapeats is more unlike the LCR in that it is a cold (~15°C; Table 10) high gradient stream with swift currents. Kanab Creek drains a very large watershed (>6000 km^2) but is a relatively small stream at base flow (<10 cfs) and is subject to severe floods (>4000 cfs) that can alter the bed material and transport large quantities of sediment. Kanab Creek appears to be a harsh environment for stream fish; we measured low dissolved O_2 levels (<3 ppm; Table 10), water temperatures exceeding 30°C (Table 10), and observed many dead, diseased, or dying fish in upstream areas in both years of sampling.

Among the smaller tributaries, upstream reaches of Havasu Creek were most like those in the LCR (Append. VIII Fig. 1). Havasu Creek is the largest of the smaller tributaries and has 1/4 to 1/3 the base flow discharge of the LCR. Although its width is rarely greater than 12 m (LATP <600 cm), it is considerable wider than any of the smaller tributaries. It has more deep habitat (>100 cm) than the other tributaries and its depth distribution is similar to that in the LCR for 1991. It has comparable distributions of substrate and current to the LCR (but so do Bright Angel and Shinumo creeks). Perhaps most unique shared characteristic between Havasu and the LCR is travertine; Havasu has comparable distributions of travertine to that found in the LCR. The travertine structure of Havasu also enhances the amount of high vertical structure (>2) and cover (>3) present. No other tributary offers as much cover and vertical structure (except for Tapeats, but it is not comparable to the LCR in other ways).

To address whether Havasu Creek contains ranges of habitat used by humpback chub in the LCR we compared habitat use distributions of humpback chub from the LCR from a combined dataset of Powell and Salt study reaches for June-July 1993 (Append. VIII Fig. 6) with available habitat in Havasu Creek for 1993 and 1994 (Append. VIII Fig. 5). For YOY humpback chub there is considerable overlap between habitat used in the LCR and that available in Havasu Creek. For juvenile, subadult, and adult humpback chub there is still large overlap on most habitat variables except for depth and lateral position. Larger humpback chub showed a disproportionate use of areas >200 cm deep in the LCR but although these areas appear to be very rare in Havasu Creek they are also relatively rare in the LCR, even in 1993 (compare with Append. VIII Fig. 6). The use of large lateral positions in the LCR is probably a function of the distribution of deep holes sought out by adult humpback chubs; they also use these habitats when they are much closer to shore. Perhaps the most important concordance between the distributions is the amount of habitat with high vertical structure and cover present in Havasu Creek; these areas appear to be selected by juvenile, subadult and adult humpback chub. Overall, except for its smaller size, Havasu Creek contains comparable ranges of available habitat like that used by YOY to adult size classes of humpback chub in the LCR. This observation suggests that if humpback chub were placed in Havasu Creek they would find suitable arrays of habitat for reproduction and recruitment.

FIGURE 1. **USFWS LCR fish habitat studies: comparison of available habitat in upstream reaches of Havasu Creek and the LCR**

Comparison of Grand Canyon Tributaries



Comparison of Grand Canyon Tributaries

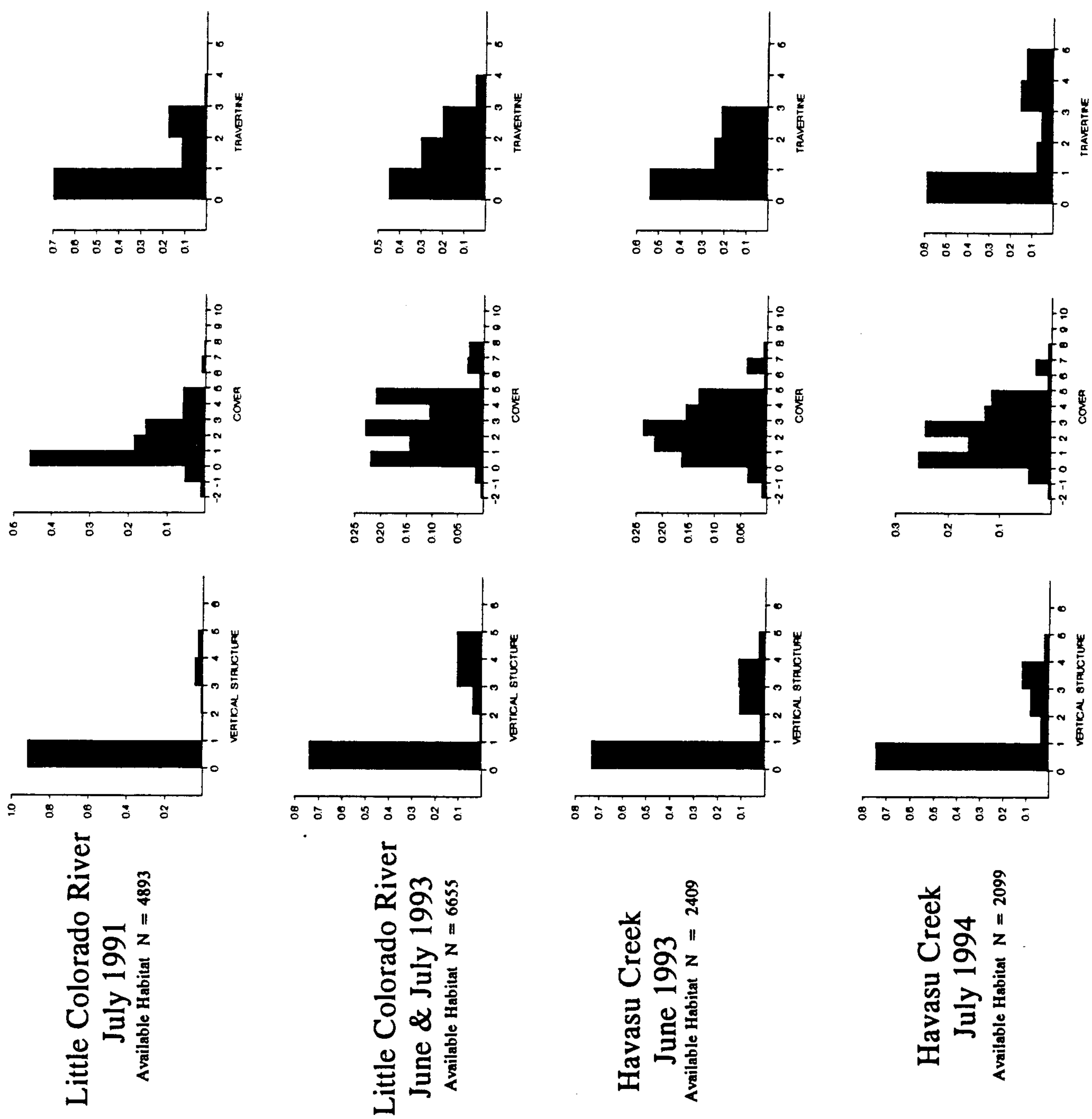
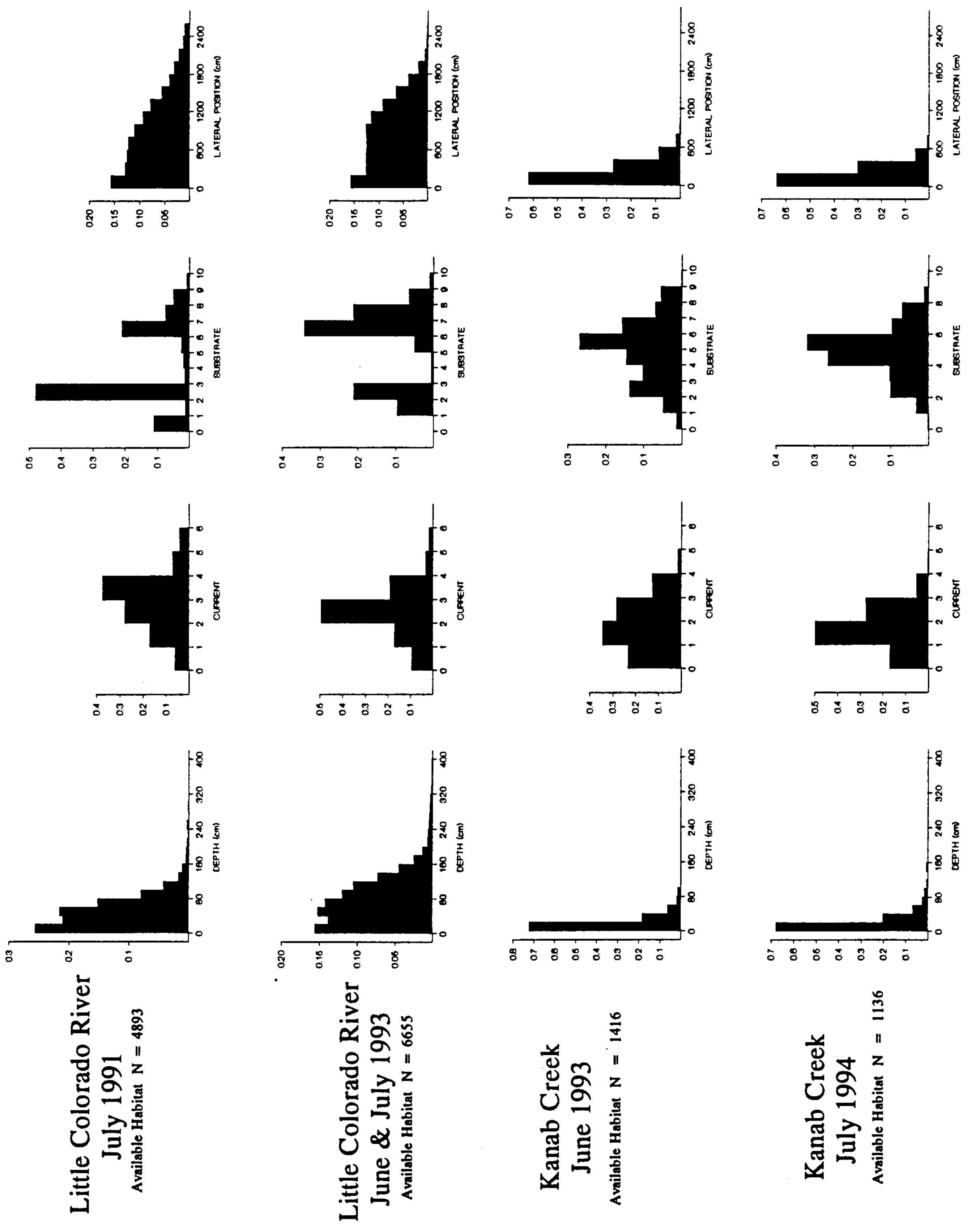


FIGURE 2. **USFWS LCR fish habitat studies: comparison of available habitat in upstream reaches of Kanab Creek and the LCR**

Comparison of Grand Canyon Tributaries



Comparison of Grand Canyon Tributaries

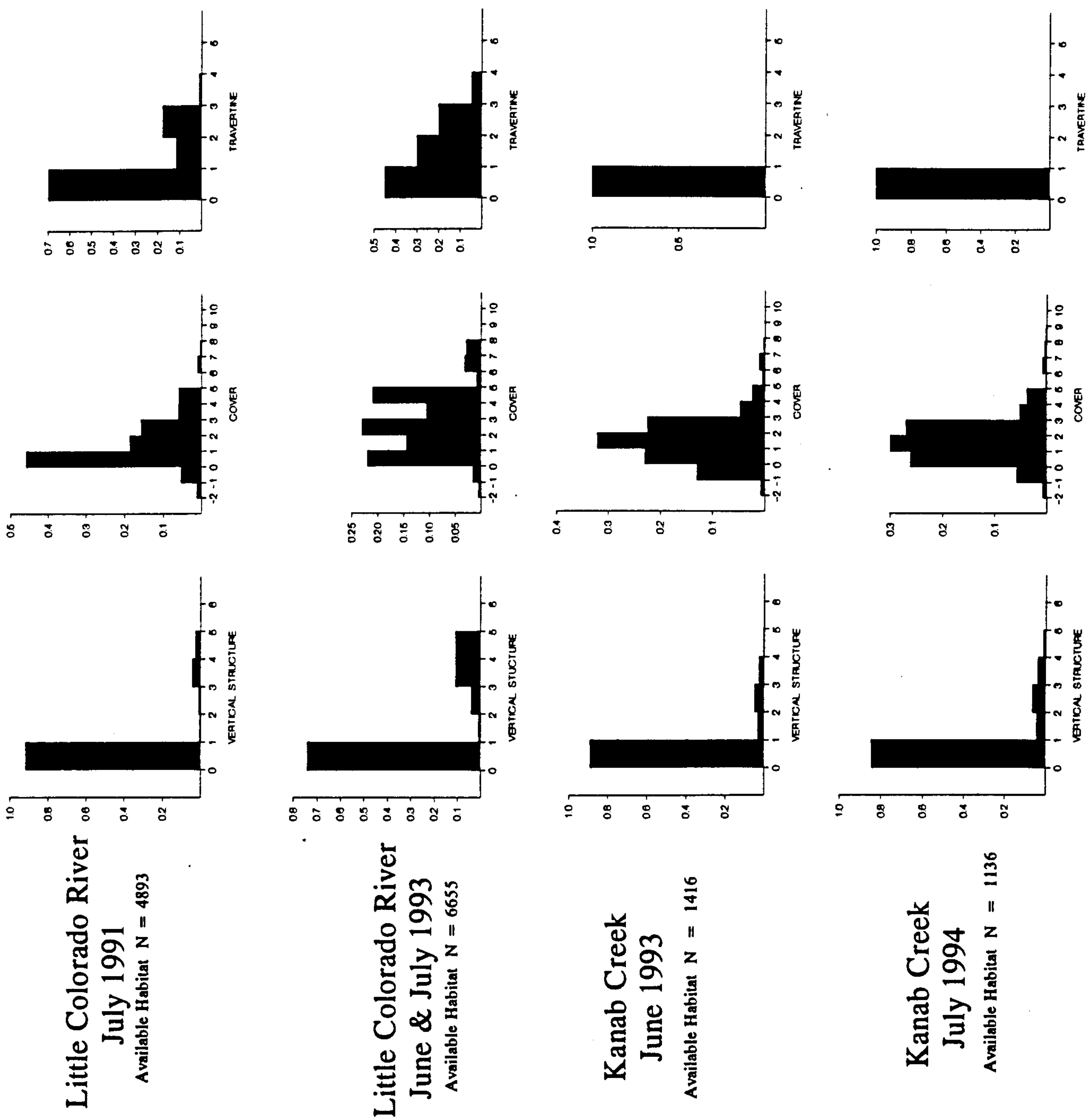
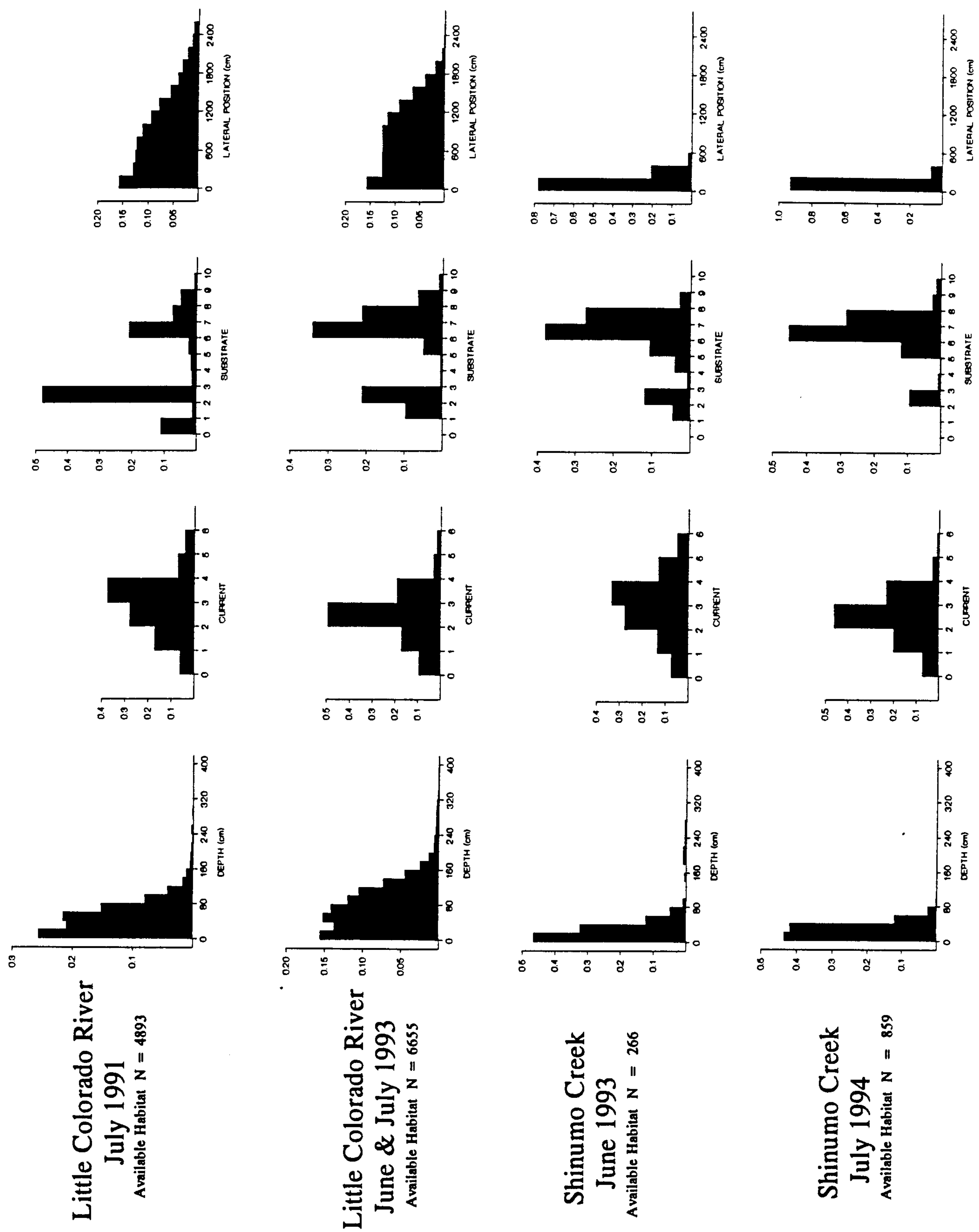


FIGURE 3. **USFWS LCR fish habitat studies: comparison of available habitat in upstream reaches of Shimumo Creek and the LCR**

Comparison of Grand Canyon Tributaries



Comparison of Grand Canyon Tributaries

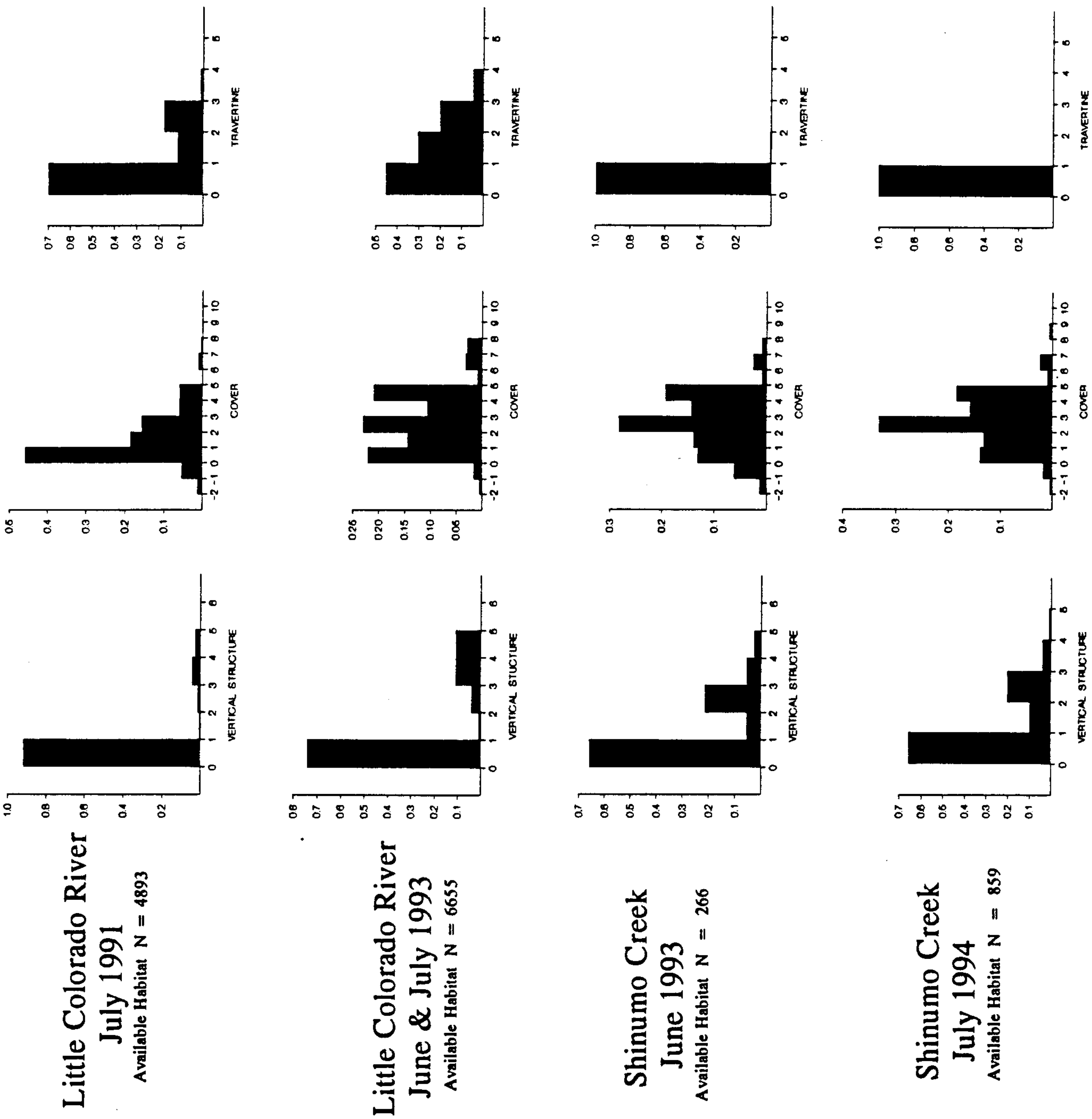
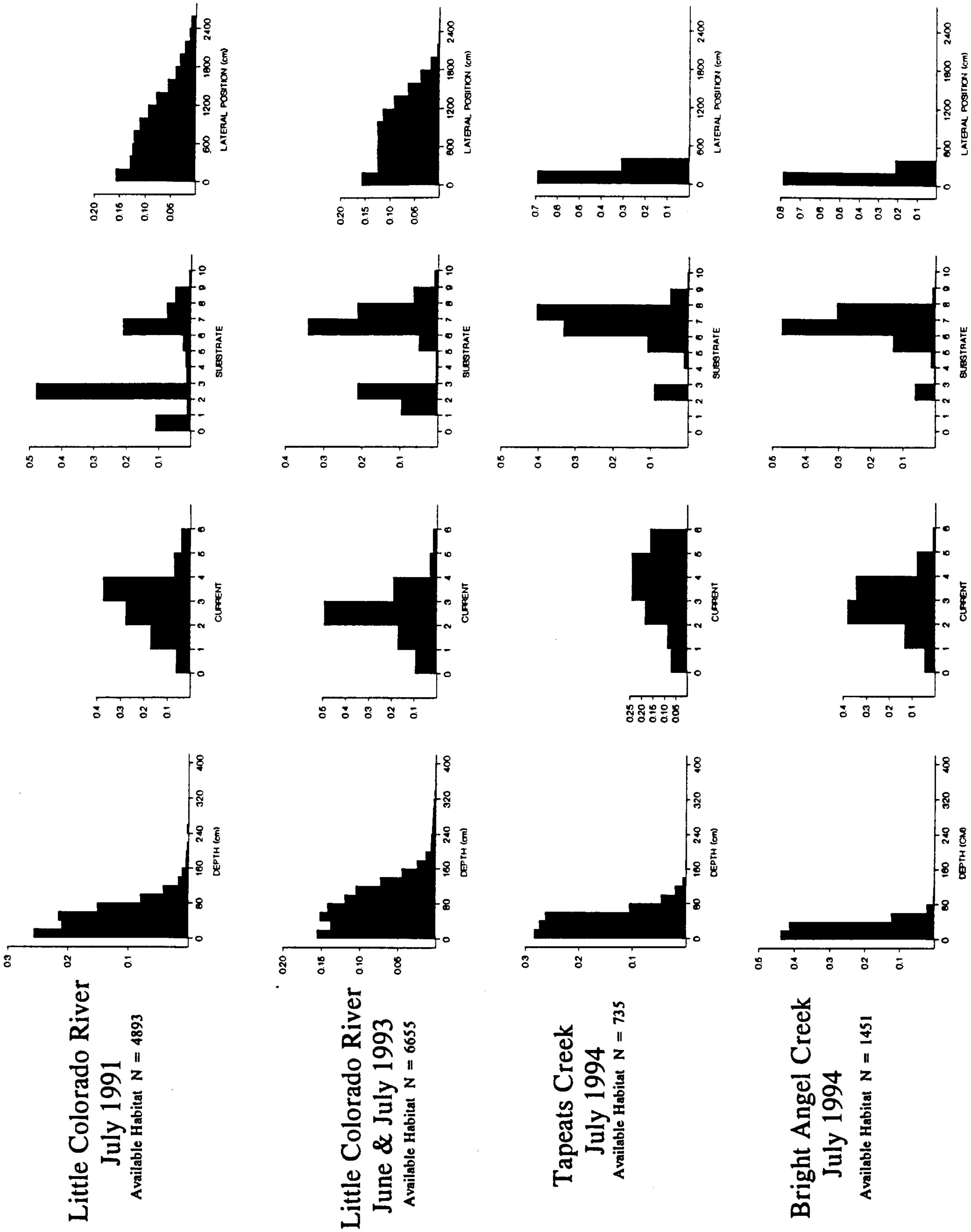


FIGURE 4. **USFWS LCR fish habitat studies: comparison of available habitat in upstream reaches of Tapeats and Bright Angel creeks and the LCR**

Comparison of Grand Canyon Tributaries



Comparison of Grand Canyon Tributaries

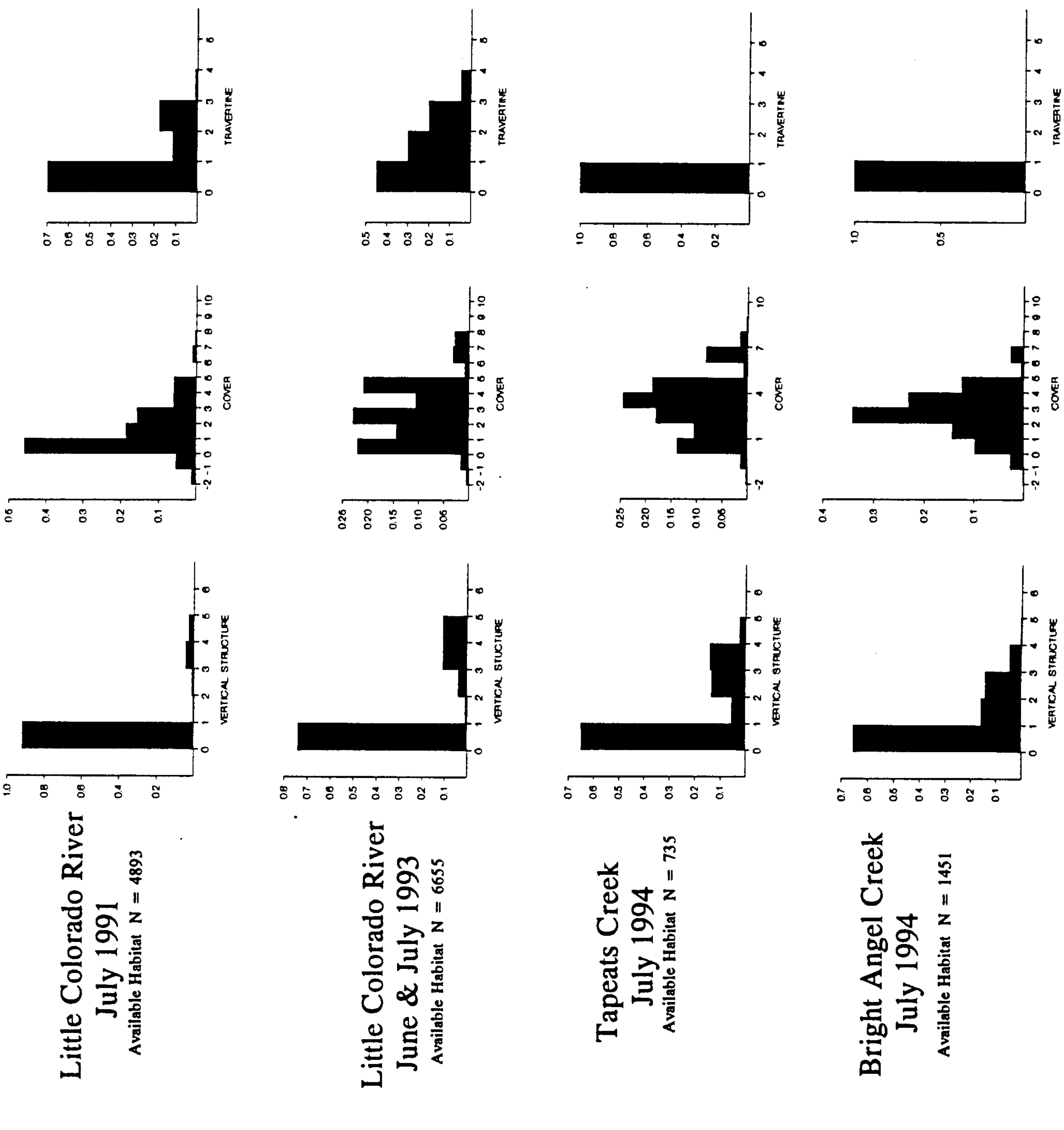
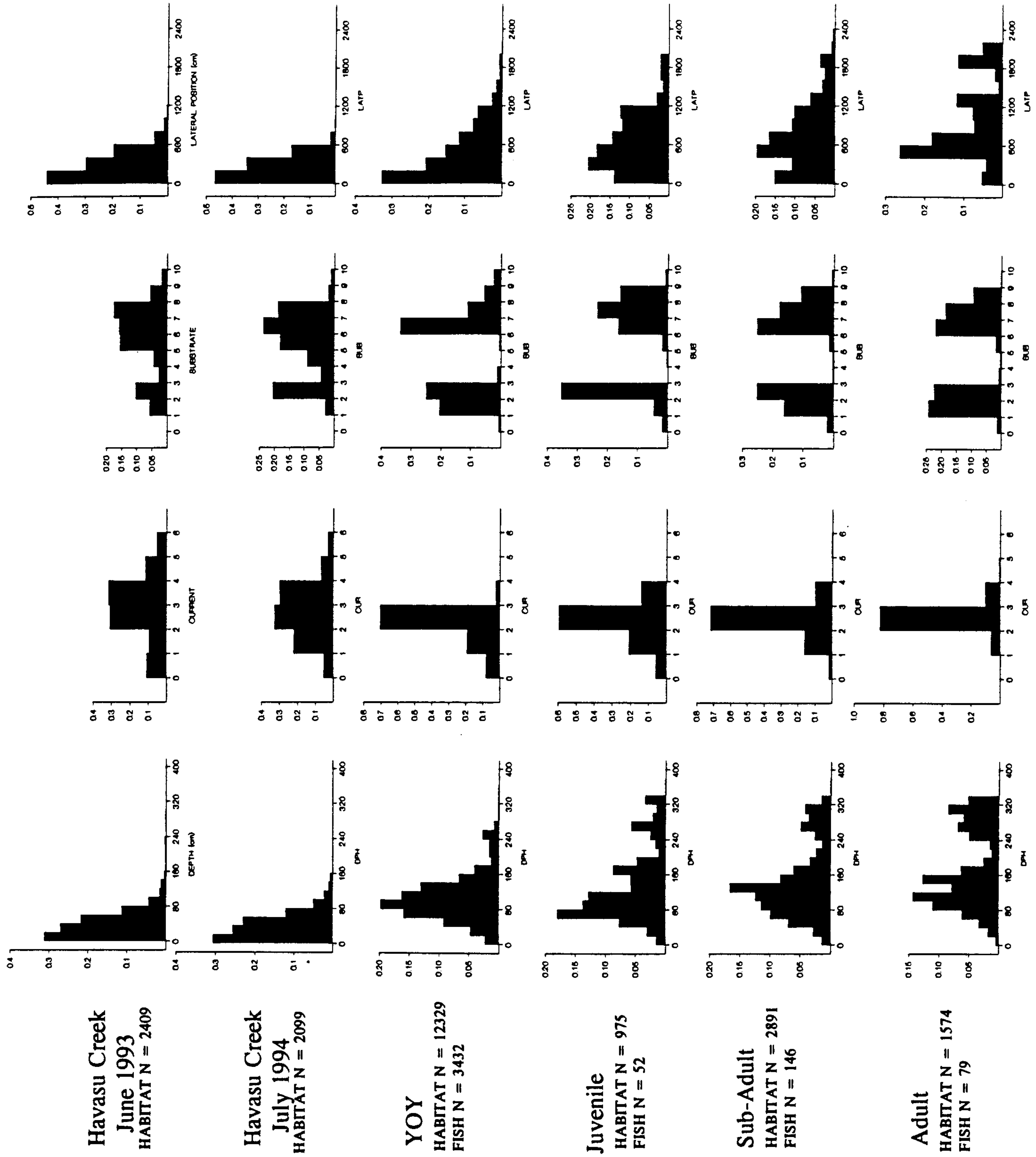


FIGURE 5. **USFWS LCR fish habitat studies: comparison of available habitat in upstream reaches of Havasu Creek and habitat use by humpback chub in the LCR**

See Figure 6 for comparison of habitat use by humpback chub with available habitat in the LCR.

Havasu Creek Available habitat vs Little Colorado River HBC use June-July 1993



Havasu Creek Available habitat vs Little Colorado River HBC use June-July 1993

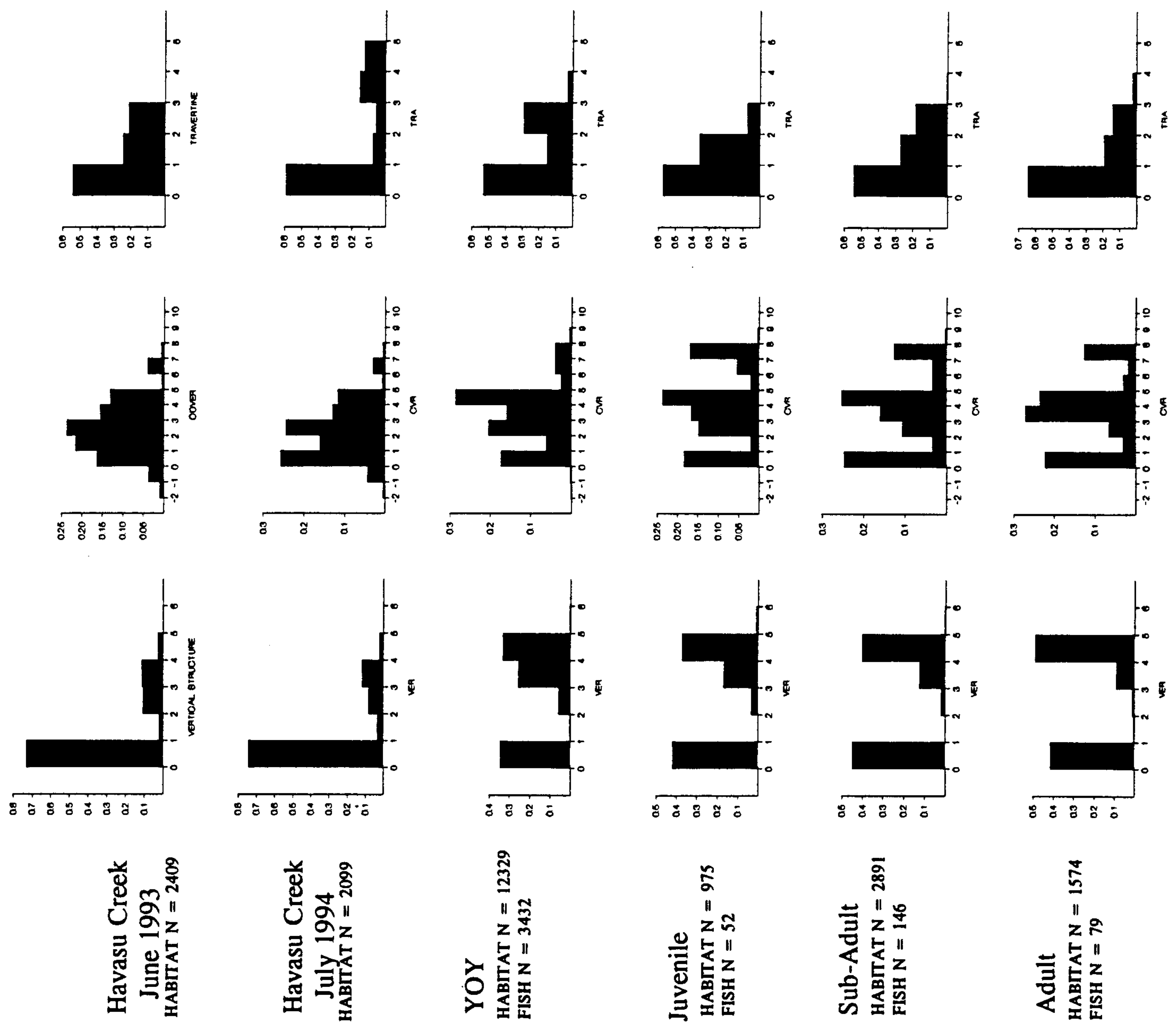
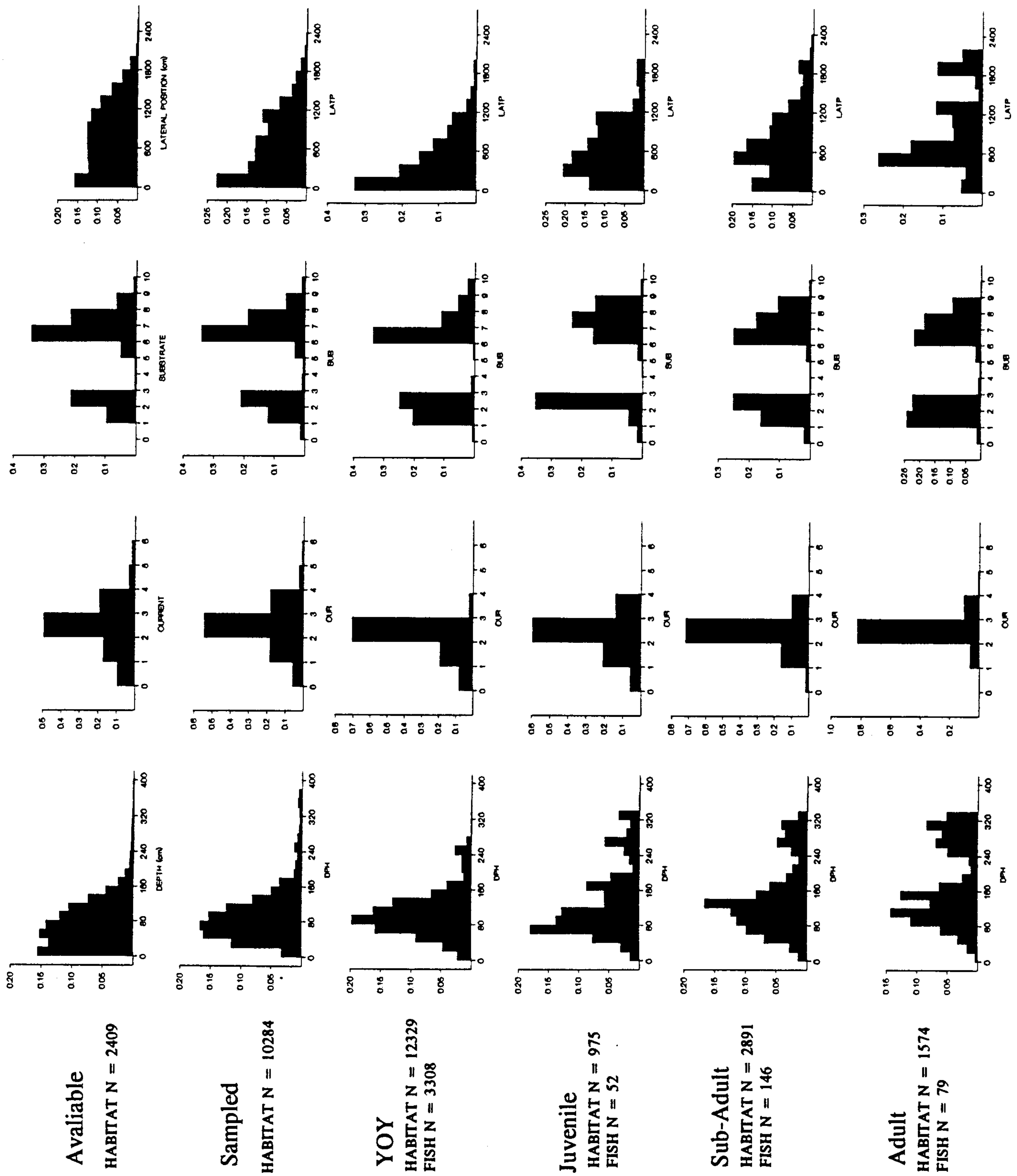


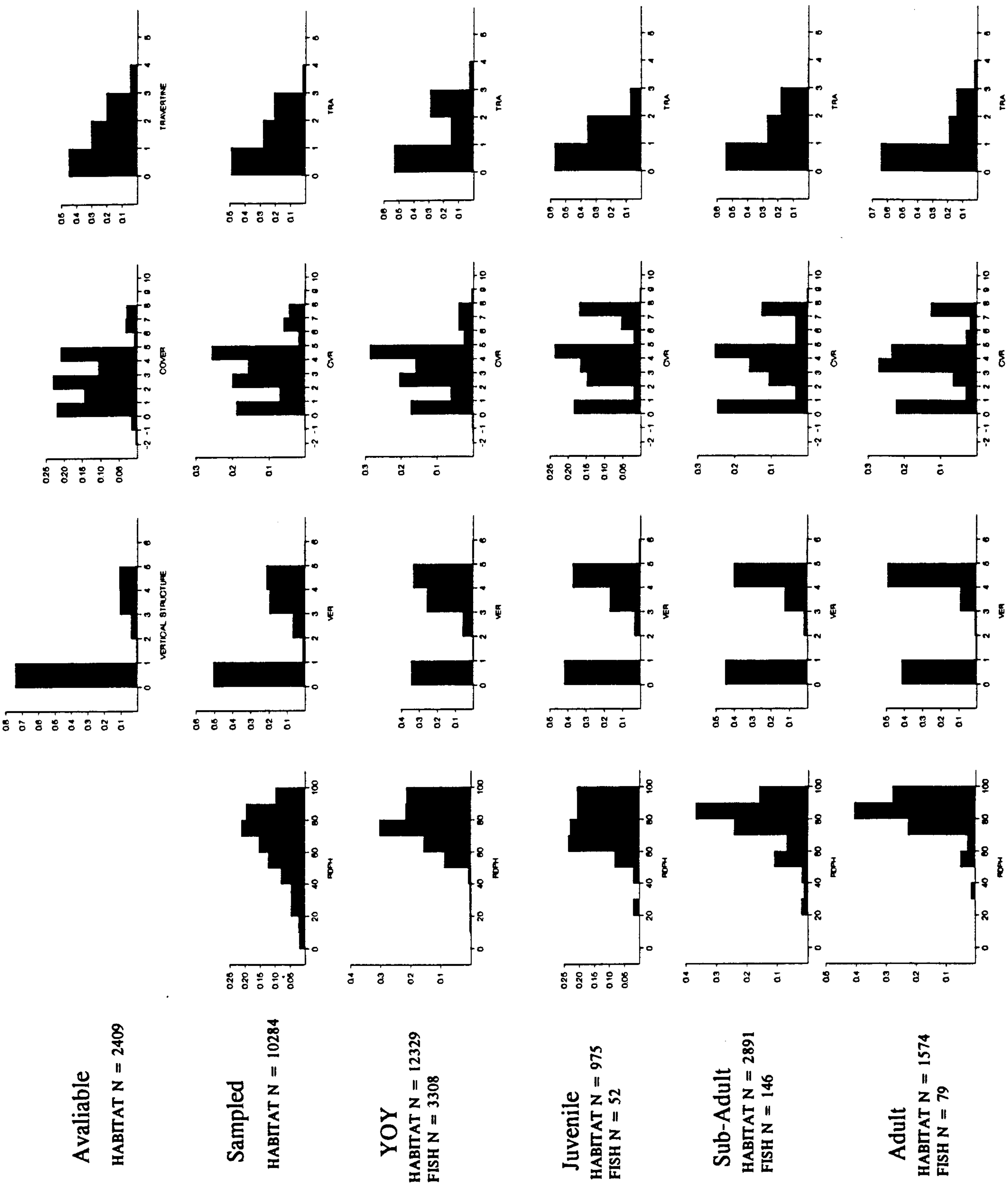
FIGURE 6. **USFWS LCR fish habitat studies: comparison of available habitat in the LCR with habitat use by humpback chub in the LCR**

This figure is provided as a reference for Figure 5.

Little Colorado River
HBC habitat use
June-July 1993



Little Colorado River
HBC habitat use
June-July 1993



United States Department of the Interior
FISH AND WILDLIFE SERVICE
Arizona Fishery Resources Office

Habitat use by humpback chub, *Gila cypha,*
in the Little Colorado River and other tributaries of the
Colorado River

GCES Phase II Final Report

APPENDIX IX

STATUS OF USFWS DATABASES, ANALYSES, REPORTS, PRESENTATIONS, AND PUBLICATIONS FOR GCES PHASE II, 1991-1994

APPENDIX IX

STATUS OF USFWS DATABASES, ANALYSES, REPORTS, PRESENTATIONS, AND PUBLICATIONS FOR GCES PHASE II, 1991-1994

KEY TO TABLE CODES

LOCATIONS:

LCR0-21. Little Colorado River from -0.5 km (Colorado River) to 21 km (Blue Springs). Transects at 20 intervals were established over the entire lower 21 km. Stream habitat was measured at 20 m intervals from -.5 to 4 km and 9.8 to 12 km, and 100 m intervals for the remainder. A map showing the locations and km values for all 20 m transects was distributed to all GCES researchers on 8 April 1993.

LCRSURV. Little Colorado River from -0.5 to 21 km. GCES and FWS conducted a formal survey of the LCR channel in September 1992. All FWS 20m transects were mapped into the survey. An aerial photographic survey was conducted and tied into the ground survey in October 1992. GCES has subcontracted the analysis of the survey data to produce a highly accurate base map of the LCR canyon bottom and river channel.

LCRCON. LCR confluence, -0.5 to 1.0 km. Stream habitat measures/mapping.

POWELL. Powell Canyon Study Area, 2.5-3.5 km. ASU hoopnets were measured from km 0.0 to 7.0.

SALT. Salt Trail Canyon Study area, 10.7-11.7 km. ASU hoopnets were measured from km 7.0 to 14.0.

BA= Bright Angel creek
SH= Shinumo creek
DE= Deer creek
TA= Tapeats creek
KA= Kanab creek
HA= Havasu creek
PA= Paria river
LCR= Little Colorado River

DATA TYPES:

1= water quality
2= minnow trap habitat
3= FWS minihoopnet grid habitat
4= FWS transect habitat
5= seining habitat
6= fish
7= ASU hoopnet habitat
8= observations of fish (surveys)
9= electrofishing habitat

ARCHIVE ??: Indicates data ready for archiving

ANALYSES & REPORTS: First numbers indicate data types analyzed. Numbers following the slash refer to reports or presentations in which data are analyzed or discussed (see Table 4).

TABLE 1. USFWS-AZFRO databases for Little Colorado River (LCR) studies data 1991-1994.

A. CONFLUENCE AND POWELL STUDY REACHES

TRIP DATE	LOCA-TION	DATA TYPES	STATUS OF COLLECTED DATA: ENTERED (DBASE)	NOT ENTERED	ARCHIVE ??	ANALYSES & REPORTS
Little Colorado River (FWS-Flagstaff)						
7,8/91	LCR0-21	4	4		4	14/ 5,6,11,8b,8c
09/92	LCRSURV	4	4	-	-	GCES LCR survey
08/93	LCRCON	48	4	8		4/8c
06/93	LCRCON	4	4			4/8c
07/91	POWELL	147	47	1	47	147/ 5,6,11,8b,8c
7-8/91	POWELL	12467	247	16	47	147/ 5,6,11,8b,8c
08/91	POWELL	124567	2457	16	47	147/ 5,6,11,8b,8c
10/91	POWELL	17	7	1	7	17/ 5,6,11,8b,8c
12/91	POWELL	136	6	13	6	1/
02/92	POWELL	123467	6	12347	6	1/
04/92	POWELL	147	47	1		1/
06/92	POWELL	123467	23467	1	2346	12346/5,6,11,8b,17,18,8c
07/92	POWELL	123467	2346	17	6	1/
08/92	POWELL	123467	23467	1	6	1/
09/92	POWELL	123546	23456	1	65	156/5,6,11,8b,17,18
11/92	POWELL	1235467	23467	15	6	1/
02/93	POWELL	1235467	2346	157	6	1/
03/93-1	POWELL	1367	1367		6	1/
03/93-2	POWELL	1356	1356		6	1/
04/93	POWELL	123456	123456		6	12346/8c
05/93	POWELL	123456	123456		6	12346/8c
06/93	POWELL	123456	12346	5	6	12346/8b,8c,18,19
07/93	POWELL	123468	12346	8	6	12346/8c
08/93	POWELL	1234568	123456	8	6	12346/ 8,8b,8c
09/93	POWELL	12346	6	1234	6	1/
04/94	POWELL	123456	6	12345	6	16/8c
05/94	POWELL	123456		123456		1/
06/94	POWELL	123456		123456		1/
08/94	POWELL	12346		12346		1/

TABLE 1. USFWS-AZFRO databases for Little Colorado River (LCR) studies data 1991-1994 (continued).

B. SALT STUDY REACH

TRIP DATE	LOCA-TION	DATA TYPES	STATUS OF COLLECTED DATA: ENTERED (DBASE)	NOT ENTERED	ARCHIVE ??	ANALYSES & REPORTS
Little Colorado River (FWS-Flagstaff)						
07/91	SALT	1457	457	1	47	147/ 5,6,11,8b,8c
7-8/91	SALT	124567	457	126	47	147/ 5,6,11,8b,8c
08/91	SALT	124567	457	126	47	147/ 5,6,11,8b,8c
10/91	SALT	1267	7	126	7	17/ 5,6,11,9b
12/91	SALT	123467	134	276		1/
02/92	SALT	123467	3	12467		1/
03/92-1	SALT	17	7	1		1/
03/92-2	SALT	17	7	1		1/
04/92	SALT	147	47	1		1/
06/92	SALT	123467	123467		6	12346/
07/92	SALT	7	7			1/
08/92	SALT	123467	123467		6	1/
09/92	SALT	123546		123456	6	1/
11/92	SALT	1234567	4	123567	6	1/
03/93-1	SALT	13567	13567		6	1/
03/93-2	SALT	12356	12356		6	1/
04/93	SALT	123467	123467		6	12346/8c
05/93	SALT	12346	12346		6	12346/8c
06/93	SALT	123456	234616		6	12346/8c
07/93	SALT	1234568	234615	8	6	12346/8c
08/93	SALT	1234568	2345615	8	6	12346/8c
09/93	SALT	123456	234615		6	1/
11/93	SALT	123456	234615		6	1/
04/94	SALT	12346	2346	1	6	12346/8c
05/94	SALT	123456	1	23456		1/
06/94	SALT	123456	1	23456		1/
08/94	SALT	123456	1	23456		1/

TABLE 2. USFWS-AZFRO databases for Grand Canyon tributary studies, 1993-1994.

TRIP DATE	LOCATION	DATA TYPES	STATUS OF COLLECTED DATA: ENTERED (DBASE)	NOT ENTERED	ARCHIVE ??	ANALYSES & REPORTS
06/93	SHINUMO	1234689	4	123689		/ 7,8b,8c
06/93	DEER	1		1		/ 7,8b,8c
06/93	TAPEATS	1		1		/ 7,8b,8c
06/93	KANAB	12345689	4	1235689		/ 7,8b,8c
06/93	HAVASU	1234568	4	123568		/ 7,8b,8c
07/94	BR.ANG.	1234568	4	123568		/ 8c
07/94	SHINUMO	123468	4	12368		/ 8c
07/94	DEER	14	4	1		/ 8c
07/94	TAPEATS	123468	4	12368		/ 8c
07/94	KANAB	123456	4	12356		/ 8c
07/94	HAVASU	1234568	4	123568		/ 8c

TABLE 3. Arizona Cooperative Fish and Wildlife Research Unit (ACFWRU) databases for Grand Canyon tributary studies, 1992-1993. ACFWRU studies were conducted under subcontract to USFWS-AZFRO. Includes USFWS/GCES sponsored graduate studies conducted by Mattes in the LCR.

TRIBUTARY	TRIP DATE	DATA TYPE	COMMENTS
BA	7/91		reconnaissance
BA	1/92	469	
BA	6/92	48	snorkel surveys
BA	9/92	4	turbid water, no fish,site photos
BA	10/92	8	snorkel
BA	11/92	1468	snorkel, photo, 6=angling
BA	3/93	24568	snorkel, photo
BA	6/93	23468	6=angling
SH	8/92	234568	8=snorkel; began 7/31
SH	11/92	56	began 10/31
SH	1/93	23456	
SH	3/93	4568	
SH	6/93	2345689	USFWS trip (see Table 2)
DE	8/92	8	snorkel; began 7/31
DE	1/93	148	snorkel
TA	8/92	48	snorkel; began 7/31
TA	1/93	14568	snorkel
KA	8/92	2345	began 7/31
KA	11/92	1456	depletion seine, photo, start Oct.27
KA	1/93	123456	
KA	4/93	23468	also water temps, photos, drift nets, depletion seine
KA	6/93	2345689	USFWS trip; depletion seining (Tab.2)
HA	8/92	2346	trip began 7/31
HA	10/92	2346	
HA	1/93	23456	
HA	3/93	2346	some water temps
HA	4/93	23456	some water temps
HA	6/93	2346	some water temps
HA	6/93	2345689	USFWS trip (see Table 2)
PA	1/92	456	
PA	3/92	456	
PA	5/92	56	
PA	6/92	56	two trips in 6/92, data lumped
PA	7/92	46	5 not listed but fish were caught
PA	8/92	56	
PA	9/92	56	
PA	11/92	456	
PA	2/93	456	
PA	3/93	456	
PA	3/93	456	
PA	3/93	456	
PA	4/93	456	
PA	4/93	6	dip & drift net; no fish caught
PA	4/93	456	
PA	8/93		
LCR	5/91		FWS reconnaissance trip
LCR	7/92	12346	4=definite data
LCR	8/92	134?6	
LCR	9/92	134?6	
LCR	3/93		reconnaissance
LCR	4/93	1234?6	
LCR	6/93	1234?68	8 = snorkel
LCR	7/93	18	snorkel and other

TABLE 4. USFWS GCES STUDIES, ANALYSES, REPORTS, PRESENTATIONS, 1991-1994.

REPORTS and PUBLICATIONS:

1. Allan, Nathan L. 1993. Distribution and abundance of fishes in Shinumo Creek in Grand Canyon. Unpublished Master's thesis, University of Arizona, Tucson. 76p.

2. Gorman, O.T. 1991a. Proposed low-impact fish sampling protocols for GCES phase II research in the Little Colorado River. Report to Glen Canyon Environmental Studies. U.S. Fish and Wildlife Service, Pinetop Fishery Assistance Office, Pinetop, Arizona. 3p.

3. Gorman, O.T. 1991b. Using hoopnets and other sampling methods to assess microhabitat use by fishes in the Little Colorado River. Report to Glen Canyon Environmental Studies. U.S. Fish and Wildlife Service, Pinetop Fishery Assistance Office, Pinetop, Arizona. 10p.

4. Gorman, O.T. 1992. Habitat characteristics of the Little Colorado River: selection and justification of USFWS study areas. Report to Glen Canyon Environmental Studies. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 21p.

5. Gorman, O.T. 1993a. Stream fish studies operation manual. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 108p.

6. Gorman, O.T. 1993b. Evaluation of USFWS habitat research in the Little Colorado River: Special Report to the Navajo Fish and Wildlife Department. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 25p.

7. Gorman, O.T. 1993c. Report, 19 June - 3 July Grand Canyon tributary research trip. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff. 10p.

8. Gorman, O.T. 1993d. Report, 9-18 August LCR research trip. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff. 10p.

8b. Gorman, Owen T. 1994. Glen Canyon Environmental Studies Phase II Annual Report, 1993. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado

River and other tributaries of the Colorado River. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona. 129p.

8c. Gorman, Owen T. 1994. Glen Canyon Environmental Studies Phase II Final Report. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Flagstaff, Arizona.

9. Gorman, O.T., S.C. Leon, and O.E. Maughan. 1991. Draft EIS technical report, December 1991. Habitat use by the humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. U.S. Fish and Wildlife Service and Glen Canyon Environmental Studies, Flagstaff, Arizona.

10. Gorman, O.T., S.C. Leon, and J.N. Hanson. 1992. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River: USFWS general study plan for the Little Colorado River. Report to Glen Canyon Environmental Studies. U.S. Fish and Wildlife Service, Pinetop Fishery Assistance Office, Pinetop, Arizona. 8p.

11. Gorman, O.T., S.C. Leon, and O.E. Maughan. 1993. GCES Phase II Annual Report, 1992 Research. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office, Pinetop, Arizona. 34p.

12. Mattes, William P. 1993. An evaluation of habitat conditions and species composition above, in, and below the Atomizer Falls complex of the Little Colorado River. Unpublished Master's thesis, University of Arizona, Tucson. 105p.

13. Otis, Edward O. 1994. Distribution, abundance, and composition of fishes in Bright Angel and Kanab Creeks, Grand Canyon National Park, Arizona. Unpublished Master's thesis, University of Arizona, Tucson. 196p.

13b. Otis, Edward O. and E. O. Maughan. 1994. Aquatic habitat availability in Bright Angel, Tapeats, Deer, and Kanab Creeks, Grand Canyon National Park, Arizona. Final Report to U.S. Fish and Wildlife Service, Pinetop Fishery Assistance Office, Pinetop, Arizona. 76p.

14. Weiss, Steven J. 1993. Population structure and movement of flannelmouth sucker in the Paria River. Unpublished Master's thesis, University of Arizona. 130p.

PRESENTATIONS:

15. Gorman, O.T., S.C. Leon, and O.E. Maughan. 1992. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Paper presented at the annual meeting the American Society of Ichthyologists and Herpetologists, Champaign, Illinois.

16. Gorman, O.T., S.C. Leon, and O.E. Maughan. 1992. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Paper presented at the annual meeting the Desert Fishes Council, Mesa, Arizona.

17. Gorman, O.T. and S.C. Leon. 1994. Habitat use by native fishes in the Little Colorado River and other tributaries of the Colorado River in Grand Canyon. Presented at the 1994 annual American Fisheries Society, Western Division meetings at Flagstaff, Arizona.

18. Gorman, O.T and S.C. Leon. 1993. Habitat use by humpback chub, *Gila cypha*, and other native fishes in the lower Little Colorado River, Arizona. Paper presented at the 1993 annual meeting of the American Society of Ichthyologists and Herpetologists at Austin, Texas.

19. Gorman, O.T and S.C. Leon. 1993. Habitat use by the endangered humpback chub, *Gila cypha*, in the Little Colorado River in the vicinity of Grand Canyon. Paper presented at the Second Biennial Conference of Research on the Colorado Plateau, Flagstaff, Arizona.

20. Gorman, O.T., S.C. Leon, and J.M. Seals. 1993. Habitat use by native fishes in the Little Colorado River in the vicinity of the Grand Canyon. Paper presented at the 1993 annual meeting of the Desert Fishes Council, Monterrey, Nuevo Leon, Mexico.

21. Mattes, W.P. and O.E. Maughan. 1993. Longitudinal gradients of several habitat variables downstream of Blue Springs on the Little Colorado River, Arizona. Paper presented at the annual meeting of the Desert Fishes Council, Monterrey, Mexico.

22. Weiss, S., and O.E. Maughan. 1993. Use of the Paria River by flannelmouth sucker. Paper presented at the annual meeting of the Desert Fishes Council, Monterrey, Mexico.