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

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

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GCES Phase II Annual Report for 1993 Studies

Submitted to:

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Glen Canyon Environmental Studies
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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 1977; 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; D. Kubly and R. Clarkson, AZGF, pers. comm.; R. Valdez, BioWest, pers. comm.). The low temperature regime of the Colorado River is caused by the release of hypolimnetic waters from Lake Powell by Glen Canyon Dam. Spring and summer temperature conditions 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). 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 colonization by a large mainstream population. Therefore, the 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 critical 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 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; T. Hoffnagle, AZGF, pers. comm.; R. Valdez, BioWest, pers. comm.). In the largest tributary, the Little Colorado River (LCR) at river mile 61, humpback chub spawn successfully all along the lower 14 km (Kaeding and Zimmerman, 1993; R. Clarkson, pers. comm., Arizona Game and Fish Department). 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 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.

STUDY OBJECTIVES

The objectives of U.S. Fish and Wildlife Service (USFWS) fishery studies for Glen Canyon Environmental Studies (GCES) Phase II are:

1. Determine habitat use by humpback chub and other native fishes (Table 1) in the Little Colorado River (LCR).

2. Evaluate the potential for establishing a second spawning aggregation of humpback chub in other tributaries of the Grand Canyon.

3. From the perspective of habitat requirements, evaluate how the humpback chub and native fishes are affected by the operation of the Glen Canyon Dam.

The major purpose of our studies is to address the following reasonable and prudent alternatives 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):

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

3. Implement long-term monitoring to track the status of endangered and native fishes in the Grand Canyon; implement studies to determine responses and impacts of Glen Canyon Dam operations on endangered and native fishes in the Grand Canyon (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 in the Grand Canyon (this corresponds to GCES Conservation Measure 7).

6. Assess the potential effects of a multi-level intake structure (MLIS) on Glen Canyon Dam to endangered and native fishes of the Grand Canyon.

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 is the same as GCES Conservation measures 5 and 6).

Our GCES Phase II study program is split into two components to address the reasonable and prudent alternatives 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.

The specific objectives of 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 objectives of 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.

METHODS

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.

The sampling methodologies used in our LCR study are described in two special reports (Gorman et al. 1992; Gorman 1993) and are not presented here. The intent of our research is to describe the ecology and habitat use by humpback chub in the LCR and to determine the suitability of tributaries for supporting humpback chub populations. Our approach is to use the LCR as a habitat model for the smaller candidate streams; the more closely a candidate stream matches conditions found in the LCR, the more likely that stream will be suitable for humpback chub spawning and as nursery areas for young-of-year fish.

Because research on smaller tributaries was intended to assess habitat suitability relative to LCR, the extent of our research effort in these small tributaries was limited in scope. Sampling methodologies were similar to those used in the LCR (Gorman et al. 1992; Gorman 1993). Stream habitat in the smaller tributaries was measured from the mouth to 8-10 km upstream. Habitat and physico-chemical conditions were measured at 1 m intervals along transects spaced 100 m apart. Habitat was measured at least twice annually, with sampling in the summer (June-August) and winter (December-February) months. Fish were sampled at 1 km intervals from the tributary confluence upstream to the limit of the habitat transects.

RESULTS OF 1993 STUDIES

USFWS STUDIES IN THE LITTLE COLORADO RIVER

Field studies and sampling effort

Ten field study trips were completed in 1993, totaling 69 days in the field (Table 2). Sampling efforts included measuring habitat at 42 ASU hoopnets, 1388 FWS minihoopnets, 803 FWS minnow traps, 243 seine samples, 266 habitat transects, and 71 fish observation transects (Table 3). In contrast to 1992, catch rates of fishes were relatively high (Gorman, et al. 1993). Contributing factors to this apparent increase in fish captures in 1993 was exceptional reproductive success by native fishes and base flow conditions over the four-month period from May through August.

Fish sampling

More than 17,000 fish were sampled in the LCR in 1993 and humpback chub was the predominant species, comprising 58% of all fish caught (Table 4). The predominance of humpback chub is tied to their exceptional reproductive success in 1993; 54% of all fish captured were young-of-year (YOY) humpback chub (Table 5). Speckled dace were the second most abundant species with 34% of all fish caught. Speckled dace did not show the same relative reproductive success as humpback chub; YOY comprised only 56% of speckled dace captured while YOY comprised 91% of the humpback chub sampled (Table 5). Overall, native fishes comprised 99.8% of all fish captured in the LCR in 1993 (Tables 4, 5). As in 1992, catches of exotic fishes (channel catfish, fathead minnow, and plains killifish) increased following summer floods, e.g., September 1993 (Table 4).

During April and May, a peak in numbers of adult humpback chub and bluehead sucker are evident in capture rates (Table 5). This period coincides with the predicted period of peak spawning by humpback chub in 1993 from otolith studies (Dean Hendrickson, pers. comm.). Small YOY fish began to appear in large numbers in June and July and coincided with a decline in numbers of adult fish (Table 5). Capture rates of YOY fish declined by November with humpback chub remaining as the most abundant species. Because YOY flannelmouth sucker exceed 100mm total length (TL) by November, they are included in the 100-200mm category (Table 5).

Length-frequency histograms provide other information about native fish populations in the LCR. The spring influx and summer departure of a portion of the large humpback chub population is evident (Fig. 1). However, there does not appear to be a discernable shift in the size distribution in adult bluehead sucker during the same period, suggesting that the adult population is resident. For flannelmouth sucker, more larger individuals were caught during the summer months. In comparison to humpback chub, the patterns for bluehead and flannelmouth suckers may not be very reliable because of small sample size (Table 5). 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. 1). 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 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. 1). 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 an annual fish. 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. 1).

During 1993 we handled 17,411 fish and had 53 incidental mortalities, of which 33 were humpback chub (Table 6). All of these mortalities were of YOY fish <75 mm TL. Given that we handled more than 15,000 YOY fish, our mortality rate is very small. Most of the mortalities were of fish "dead in net" or regurgitated from adult humpback chub in the net. Humpback chub YOY were especially abundant in the LCR in 1993 and when these fish reached 40-50 mm TL they began to leave the security of shallow edge habitats and venture in to deep water main channel habitats that are used by adult humpback chub. We have no doubt that one of the major food items of adult humpback chub in the summer 1993 was YOY humpback chub. We also noticed that once YOY humpback chub spread out into off-shore habitats, a high proportion of them began to show poor condition factors. During stream walks, it was not uncommon to find dead or dying YOY fish drifting in the water. Late in the summer we acquired field scales that were sensitive to <0.1 g so that we could assess the variance in condition factors we observed in YOY humpback chub. Most of our incidental mortalities were not caused by the sampling but were a coincidence of our sampling with natural mortality factors.

Habitat measures

Stream habitat in 1993 was evaluated from >50,000 habitat sample points. Habitat transects were measured monthly in the Salt and Powell study areas from April through September (Table 3). High water conditions in February and March precluded measuring habitat transects. Additionally, habitat transects were measured in the confluence reach (km 0-1) in August, and transects were measured in the Atomizer-Chute Falls reach in June 1993 (Mattes, 1993). Habitat was also measured in grids around minihoopnets and minnow traps during each of 10 sampling trips (Table 3). An analysis of habitat from 1992 and 1993 is presented in Appendix I.

Experimental habitat transect measures were performed at Powell camp during the May and September trips (Table 3). These research transects were conducted to evaluate the accuracy of various methods of measuring current velocities. We compared the habitat pole (Roubidoux) method with wading rods and current meters (Marsh-McBirney and Swoffer models). Using current meters, velocities were measured at 6/10 of the water column depth and 7.5 cm below the surface and above the bottom over a wide variety of habitat types. Although our analysis of these data is not yet complete, estimated velocities from the pole method are very comparable to that from current meters. Experienced habitat pole users can also accurately classify at least 14 current categories and provide other descriptors for turbulence, laminar flow, and eddies. By recording the time required to measure 100 points for habitat assessment we found the pole method to be 10 times faster compared to using current meters. We identified several factors that contribute to error in measuring and estimating current velocities: non-constancy in stream current velocities (surges), insufficient sampling of currents at various depths in deep (> 1 m) or turbulent water, presence of large rocks in area sampled (< 1m away), short-term averaging of output from current meters, insufficient current readings over time at a fixed point, and inability of current meters to detect lateral and reverse flow. We will provide a complete report on this study in the first quarter of 1994.

Habitat use by fish

Habitat use by fish was assessed with minihoopnet and minnow trap sampling in Powell and Salt study areas (Table 3). Additional habitat use data was obtained by small area seine sampling and in-situ observational surveys. Observational surveys were supplemented by underwater photography and videography. An analysis of sample habitat use data from 1992 and 1993 is presented in Appendix I. Early in 1993 we ceased measuring ASU hoopnets for habitat assessment. Reasons for abandoning this approach are explained in the report contained in Appendix II.

In 1993 we obtained limited habitat use data by humpback chub in spawning condition. During the purported humpback chub spawning season (April-May) we captured 131 adult humpback chub. We are in the process of analyzing these data for correlations between indicators of spawning readiness and habitat factors. By February 15, we will provide a report on this analysis along with proposed sampling strategies that might improve our chances of obtaining a larger more detailed data set for spring 1994.

Hydrology and Water Quality of the Little Colorado River

During the wet winter of 1992-93 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 (Appen. III). 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.

The extensive winter flooding affected water quality in the LCR during the summer of 1993. 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 observational surveys of fishes with working distances exceeding 4 meters. A summary of water quality conditions for 1993 is presented in Appendix III.

Special LCR studies

A detailed habitat mapping survey of the confluence (km 0-1) was conducted during our August trip. Habitat was measured in the inflow zone at high and low

Colorado River flows. This work complements our earlier habitat mapping in 1991 and 1992. The LCR confluence habitat study is intended to provide a base for comparing the confluences of the smaller tributaries in the Grand Canyon. In 1993 we commenced similar confluence mapping studies in Shinumo, Kanab, and Havasu creeks. This work will be extended through 1994. We expect to complete initial analysis of these data by mid-1994.

During fall 1992, GCES and FWS conducted a formal ground survey of the LCR from Blue Springs to the confluence in conduction with aerial photo mapping. All FWS transect locations over the lower 21 km were included in the survey. The purpose of this survey is to provide a highly accurate base GIS map (site 15) to assist is assembling information for future LCR studies and analyses. All FWS sampling sites will be tied to this GIS base map with an estimated accuracy of <5m.

In April a provisional map of the LCR covering the lower 15 km was distributed to LCR researchers by FWS. This map is based on a GCES LCR photo interpreted map dated 28 May 1988. The FWS provisional map shows approximate locations of FWS transects (2 m accuracy) and estimated km values were provided in an accompanying listing of FWS transects. The estimated km values were derived from the GCES map using a highly sensitive digital map measurer. These km values are estimates and not intended for use as a accurate location variable. For sampling sites to be accurately located in the GIS base maps, it is imperative that researchers use the alphameric IDs of FWS transects. Highly accurate km values for FWS transects will be provided when analysis of GCES survey data for a GIS base map is completed.

A special survey was conducted in July from Chute Falls (UFV; 14.848 km) to Salt Camp (SC-2; 10.787 km) to determine the distribution of YOY fishes. This survey was done in conjunction with a water chemistry survey from Blue Springs (USF; km 21) to Salt Camp as part of University of Arizona Graduate Student Bill Mattes' Master's thesis research (below). In the fish survey, YOY bluehead sucker were found as far upstream as UDN (km 13.575; above Triple Drop), and YOY humpback chub were found as far upstream as UBU (km 12.610; below Triple Drop). Mattes' (1993) research indicates that Atomizer Falls appears to be the upper boundary for the distribution of humpback chub and bluehead sucker in the LCR. Our fish survey provides circumstantial evidence that humpback chub and bluehead sucker spawn in the Triple Drop to Atomizer Falls reach (UCE - UFJ; 12.816- 14.592 km), the terminus of their distribution in the LCR.

Other FWS sponsored studies in the LCR

Mattes (1993) completed FWS sponsored thesis research in the LCR in 1993. In 1993 Mattes conducted field trips in April, June, and July (Tables 7, 8, 9). 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. An abstract of his research is provided in Appendix IV.

USFWS STUDIES IN OTHER TRIBUTARIES

The small tributaries were sampled one to ten times in 1993 over the period January through August (Table 7) under subcontract to the University of Arizona Cooperative Fish and Wildlife Research Unit (ACFWRU). 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 8). The Service conducted detailed surveys of Shinumo, Kanab, and Havasu creeks in June-July 1993 (Tables 7, 8). Two Masters theses were completed from the tributary studies, the Paria River (Weiss, 1993) and Shinumo Creek (Allen, 1993). A third thesis focusing on Bright Angel and Kanab creeks is in preparation (Otis, 1994). In early 1994, the ACFWRU will submit a report summarizing their findings for Tapeats and Deer creeks. Because of a dispute between the National Park Service and the Havasupai Tribe over jurisdictional boundaries within the Grand Canyon, analysis of data taken by FWS researchers in Havasu Creek has been suppressed and will not be presented at this time.

As was found in 1992 (Gorman et al. 1993), native fishes were relatively common and abundant in most of the tributaries (Table 9). Speckled dace and bluehead sucker dominated the assemblages of the Paria River and Kanab and Shinumo creeks and the confluence reaches of these streams were used seasonally by flannelmouth sucker and humpback chub. Several streams, Bright Angel, Deer, Shinumo, and Tapeats, supported populations of exotic trout. In particular, Bright Angel and Shinumo creeks supported populations of brown and rainbow trout and Tapeats Creek was dominated by rainbow trout. 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.

Continued tributary studies in 1994 will attempt to expand our database of seasonal habitat characteristics of the lower 4-10 km of the Paria, Bright Angel, Shinumo, Tapeats, Kanab, and Havasu creeks. We will especially focus on the confluence and lower 1 km of these streams to better understand the use of these areas by native and exotic fishes and the impact of fluctuating Colorado River flows. The results of our study will be used to assess the potential of these tributaries to support humpback chub and other native fishes in comparison to the LCR, our model stream. We will also propose management plans that can increase the use of these tributaries by native fishes.

DATA BASES AND ANALYSES

Our data comes from two principal sources: principal contractor studies by the Fish and Wildlife Service Arizona Fishery Resources Office - Flagstaff (AzFRO; Appen. V: Table 1) and subcontracted studies conducted by the University of Arizona Cooperative Fish and Wildlife Research Unit (ACFWRU; Appendix V: Table 2). AzFRO studies focused on the Little Colorado River (LCR) and ACFWRU studies focused on the smaller tributary streams of the Grand Canyon (Paria River, Bright Angel, Deer, Tapeats, Shinumo, Kanab, and Havasu creeks).

AzFRO-LCR studies

Most of the data from the LCR studies have been entered into dBase IV computer files (Appen. V: Table 1). We expect to have all LCR data collected up to November 1993 on computer files by March 1, 1994. All data entered into dBase files are ready for analysis. Some data files are ready to be archived and all 1991-1993 data files will be ready to archive by mid-1994.

More detailed analyses have been conducted on some data sets: 1991 habitat transect data for the lower 21 km of the LCR (Appen. II); ASU hoopnet habitat data for 1991 (Appen. II); September 1992 seining data from the Powell study area (Appen. I); June 1992 and June 1993 minihoop-minnow trap-transect habitat data from USFWS study areas (Appen. I). Bill Mattes, ACFWRU graduate student, completed a Master's thesis project (Mattes, 1993; Append. IV) that addressed the distribution of fishes above Atomizer Falls (km 13.5) in relation to physical habitat and water chemistry.

ACFWRU-tributary studies

Most of the data from the tributary studies have been entered into computer files of various formats (Appen. V: Table 2). At this time these files are still in the possession of ACFWRU. AzFRO anticipates receipt of these files in early 1994 and will prepare them for archival by late 1994.

Detailed analyses of some tributary data are presented in ACFWRU graduate student theses: Paria River (Weiss, 1993; Appen. IV); Bright Angel and Kanab creeks (Otis, 1994; Append. IV); and Shinumo Creek (Allan, 1993; Append. IV). Analyses of data from Tapeats and Deer creeks will be completed in the first half of 1994. Analysis of Havasu Creek data has been frozen by the University of Arizona pending the outcome of a dispute between the Havasupai Tribe and Grand Canyon National Park. A lack of timely and favorable resolution of this situation may pose a significant problem in successfully addressing the conservation measures that are the central focus of our contracted studies.

DISCUSSION

OVERVIEW OF 1993 STUDIES

Habitat and native fishes in the Little Colorado River

Habitat characteristics of the LCR in 1993 changed significantly compared to 1991 and 1992. Prolonged and extensive flooding in the winter of 1992-93 scoured much of the sand and silt out of the stream bed. From late April through August the LCR remained at base flow so that travertine formation continued uninterrupted for four months and no new sediment was brought into the system. The scouring resulted in deeper pools and slower currents throughout the summer of 1993. Furthermore, the combination of these factors resulted in unusual water clarity (< 2 NTUs) throughout the summer months (Appen. III).

The appearance of YOY fishes in May and June indicates that the LCR native fishes (humpback chub, bluehead sucker, flannelmouth sucker, and speckled dace) spawned during or following the declining spring hydrograph. Humpback chub in particular showed spectacular reproductive success. The lack of floods and spates during the summer produced ideal conditions for rearing YOY fishes as indicated by our exceptionally high catch rates and rapid growth rates for 1993 YOY fishes. Several spates in late August and early September did not appear to affect the status of 1993 flannelmouth and bluehead sucker. In 1993 we began to position nets at specific levels in the water column to assess vertical position habitat use (Gorman 1988). Our analysis shows species-specific patterns of use of vertical position that shifts significantly in some species and size classes between day and night sampling periods (Appen. I). To more effectively sample large adult fish in deep, fast water habitats, we will begin to use 1" mesh minihoopnets in 1994. It is our hope that using these large-mesh minihoopnets during the spring spawning season (April-May) will increase our probability of describing habitat used by spawning humpback chub.

Over the next year we will begin to develop habitat models for humpback chub and other native fishes in order to address GCES Conservation Measure #5. Our strategy for developing habitat models for humpback chub and other native fishes is to describe the available habitat in the LCR, describe the habitat use patterns by native fishes in the LCR, compare available habitat in the tributaries with the LCR, and identify tributaries that have matching arrays of habitat types used by humpback chub in the LCR.

Evaluation of habitat data from seine sampling

We have conducted seine sampling, a widely accepted active sampling methodology for habitat assessment, as a test for our passive sampling methodology. In comparison to our minihoopnet and minnow trap data, a preliminary analysis of some September 1992 seining data shows similar patterns of habitat use for speckled dace and juvenile humpback chub (Appen. I). We will continue to use seine sampling to compare with our passive sampling data and also to assess habitat not sufficiently sampled by passive sampling gear, e.g., very shallow margins. Continued use of both methods in the LCR will also help us to interpret habitat use data from the smaller tributaries where there has been a greater reliance on active sampling approaches.

Evaluation of 1991 ASU hoopnet habitat data

Our analysis of 1991 ASU hoopnet habitat data shows that these data are not useful for assessment of habitat use patterns by humpback chub (Appen. II). The major reason for this was that ASU net placement is largely determined by increasing the probability fish capture and not to sample habitat for fish in an unbiased manner. As a result of this problem, we have ceased measuring ASU hoopnets and do not have plans to further analyze this data.

Tributaries and confluence studies

At this time we have adequate data to evaluate only general habitat characteristics of the smaller tributaries of the Grand Canyon. Our study has not adequately addressed seasonal aspects of habitat in these tributaries nor adequately described habitat characteristics of the confluences. In order to address these inadequacies, we plan to continue sampling the larger of the smaller tributaries in 1994 and will focus on the confluence areas, as these areas are more likely to be used by humpback chub. We suspect that recovery efforts for humpback chub in the Grand Canyon will involve management of confluence habitats to enhance native fish populations.

Evaluation of FWS sponsored graduate student research

Four graduate research projects sponsored by FWS were completed in 1993 (Appen. IV). The research topics addressed by these studies were extensions of our project objectives and have served to increase our knowledge of the native fishes and aquatic habitats of the Grand Canyon. These sponsored studies have greatly increased our knowledge of the smaller tributaries and their fish assemblages (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). In 1994 we anticipate sponsoring another ACFWRU graduate student to conduct further studies on the flannelmouth sucker population in the vicinity of the Paria River.

EVALUATION OF ACHIEVEMENT OF FWS STUDY OBJECTIVES

In the LCR we have been successful in addressing specific study objectives (p. 9) 1 and 2 but have been unsuccessful in achieving specific objectives 3 and 4. Objective 3, describing spawning habitat of humpback chub, has proven to be a difficult task; the peak spawning occurs over a short time (2-3 weeks) in the spring when the river is usually flooding and muddy. Due to delays in the start of the project, we have had only one opportunity to address objective 3. We have learned from our past efforts and are confident that this objective can be achieved in the future. Objective 4, LCR river modeling studies, has been officially abandoned but we have collected data that in the future will permit development of instream flow models for the LCR. Furthermore, we have mapped and collected data from the LCR confluence and other Grand Canyon tributary confluences that will permit development of preliminary hydraulic/habitat models. To date, we have addressed the specific objectives for the tributaries but feel that our database is inadequate for a complete assessment.

As we approach the end of FY93, the scheduled end of our contracted GCES field studies, the need for a continuation of FWS field studies through FY94 has become apparent. The reasons for this continuation are as follows:

1. Exceptionally strong 1993 year class of humpback chub in the LCR warrants continued study.

Our field studies are scheduled to end as of 9/30/93. If we cease our studies at that time we will miss a unique opportunity to track the very strong 1993 year class of humpback chub. As yet, we have not had this opportunity in GCES Phase II. Continued studies would allow us to study the ecology and habitat needs of YOY humpback chub through their first year of life. Such knowledge is critical for successful implementation of reasonable and prudent alternatives 2 and 5.

2. Need for further studies on other tributaries in the Grand Canyon.

Our assessment of habitat and fish assemblages in the tributaries is incomplete and our field studies have raised a host of important questions and issues about the tributaries that need to be addressed in light of reasonable and prudent alternatives 5, 6, and 7. The intent of tributary studies was to broadly evaluate the lower 10 km of these streams. From our surveys we have learned that the lower 1 km to the confluence may be the most critical to humpback chub and other native species. At the closure of our 1993 field season we developed study plans that address the role of confluences and lower reaches of tributaries to endangered and native fishes of the Grand Canyon. At present there is no comprehensive and coordinated study program within GCES phase II that focuses on the confluences and lower tributary reaches from a habitat perspective. New study initiatives on these habitats is critical to achievement of alternatives 5, 6, and 7.

3. Need to develop and implement adaptive management and recovery plans, and implement long-term monitoring for endangered and native fishes of the Grand Canyon.

The intent of GCES Phase II was to expand on the information base of Phase I studies. As such, GCES has functioned largely to gather information about endangered and native fishes in the Grand Canyon. With the completion of GCES Phase II, we are in a position to conduct 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 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. We are willing and ready to be a team player.

4. Need to preserve the genetic diversity of declining native fish populations of the Grand Canyon.

USFWS Region 2 will soon begin studies that will lead to the establishment of a sperm bank for native fishes in the Southwest. The purpose of cryopreservation of fish sperm is to assess the genetic diversity of native fish populations, to "bank" this genetic diversity as a hedge against losses from population bottlenecks and declines, and to use this resource to produce genetically appropriate hatchery products should the need arise. We argue that establishment of sperm banks will become critical to the success of reasonable and prudent alternatives 3, 4, and 5. Presently, we are in the process of developing parallel studies to establish a sperm bank for Lake Mohave razorback sucker; our Lake Mohave efforts may become critical for addressing alternative 4.

PROPOSED FIELD STUDIES FOR FY94

In order to address our study objectives for GCES phase II and to more closely address the reasonable and prudent alternatives put forth by USFWS, we are proposing continuation and development of the following field studies:

1. LCR humpback chub and native fish studies.

In order to follow the strong 1993 year class of humpback chub and other native fishes, address the question of spawning habitat for humpback chub, and conduct a Blue Springs-Atomizer Falls survey, we need to make 5 additional 10-day LCR field study trips in FY94. We propose to conduct two trips during early-late spring 1994, and three trips during the summer-fall 1994. In comparison, we have made 10 LCR field study trips in FY93. These field trips will be conducted in conjunction with the Arizona Game and Fish Department (AGF) or Arizona State University researchers. Coordination of USFWS efforts with other study teams will assure that our LCR field studies will be complementary and that duplicate efforts will be eliminated.

2. Grand Canyon tributary studies.

In order to more effectively evaluate the tributaries and their confluences as candidate streams for establishing secondary spawning aggregations of humpback chub, we need to conduct three additional field study trips to study habitat and fishes in the smaller tributaries of the Grand Canyon. Our studies will focus on the confluences and lower reaches of these streams within the boundaries of the Grand Canyon National Park. The Paria River (within Glen Canyon National Park) will be studied during separate field study trips as this stream is easily accessible by car. We anticipate making three 12-day Grand Canyon field study trips (spring, early summer, and late summer 1994). For the Paria River, we anticipate making four 4-day field study trips (fall 1993, spring, early summer, late summer 1994).

3. Cryopreservation of sperm samples to establish a sperm bank for native fishes of the Grand Canyon.

With the assistance of other cooperating agencies we would like to commence collecting sperm samples for humpback chub and other native fishes of the Grand Canyon. We anticipate that sperm samples can be successfully collected in the LCR during scheduled February-April field studies. Following this success, we would recommend attempting to collect sperm from fishes sampled elsewhere in the Grand Canyon. Sperm banks will be maintained at the Dexter NFH and Dr. Holt Williamson (USFWS-Dexter) will coordinate the field collection of sperm samples. It is expected that the Arizona Game and Fish Department will collaborate on the evaluation and use of these sperm samples.

4. Fish health studies to determine the consequences of Glen Canyon Dam operations on epizootics in native fish populations.

At this time there are no organized field studies to address fish health in GCES Phase II. It has become apparent that native fishes and managed trout populations are suffering from an array of epizootics caused by a variety of parasitic organisms. For example, most of the fish handled in Kanab Creek in June 1993 had one or more *Lernia* attached and in the summer of 1993, it was not unusual to find YOY humpback chub in the LCR with attached *Lernia*. Adult humpback chub passing tapeworms has been observed numerous times. Nematode infestations and the health consequences for managed rainbow trout populations in the Lee's Ferry reach have been reported by Arizona Game and Fish. The prevalence and health consequences of *Lernia* and Asiatic tape worm infestations in humpback chub and other native fishes is unknown. In FY-94 we propose developing a study to address the epidemiology of the diseases that affect native fishes in the Grand Canyon. In the development of this study we will address the impact of operation of Glen Canyon Dam and future management scenarios, such as the impact of multi-level intake structures. As we anticipate that this study will become a component of long-term monitoring, the success of this study will depend on coordination among the various resource management agencies involved in GCES. Development of this study will involve the FWS-AzFRO, FWS Region 2 Fish Health Lab in Pinetop, FWS-Dexter National Fish Hatchery, and the Arizona Game and Fish Department.

INTER-AGENCY COORDINATION OF FIELD STUDIES

We propose to coordinate our field studies with those of the Arizona Game and Fish Department (AGF). The study objectives of AGF and USFWS are highly complementary but sufficiently distinct to assure that each agency will be identified with an original product. For example, the focus of AGF studies is to describe the early life history stages of humpback chub in the LCR, track the fate of YOY humpback chub in the mainstem and their use of backwater habitats, identify potential mainstem spawning sites for humpback chub, and evaluate the rainbow trout fishery in the mainstem in light of Glen Canyon Dam management practices. The main focus of USFWS studies is to describe habitat use by humpback chub and other native fishes from post-larval to adult stages in the LCR and from a habitat perspective, evaluate other tributaries for their potential to support reproducing populations of humpback chub. In the LCR, both agencies can accomplish their respective study objectives by jointly executing habitat/fish sampling; AGF can obtain life-history information and USFWS can obtain desired habitat use information for post-larval life history stages of native fishes. In the mainstem and other tributaries, both agencies need to refocus their study objectives or adopt common methodologies to accomplish complementarity. For example, AGF could concentrate on distribution and population parameters of native fishes while USFWS could concentrate on collection of relevant habitat data to address the conservation measures. Alternatively, the two agencies can segregate their efforts by having AGF focus on mainstem areas and USFWS focus its efforts on tributaries, including confluence zones. If the later approach is adopted the two agencies should agree on common sampling methodologies to assure that the two data sets are closely comparable for synthesis of final reports.

It is imperative that AGF and USFWS begin to work closely together in the final stages of GCES. In the future, it can be assumed that the two agencies will need to work together in long-term monitoring, and management and recovery efforts for humpback chub. By setting the ground work for close coordination now, the two agencies can more quickly develop and implement management plans for native fishes in the Grand Canyon.

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TABLE 1. USFWS 1993 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 SC	BHS
Catostomus latipinnis	flannelmouth sucker	native	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. USFWS 1993 LCR studies: field schedule.

	Powell Camp		Salt Camp		Confluence		totals
month	dates	days	dates	days	dates	days	days
Feb	10-17	7					7
Mar	2-5	3	2-5	3			3
Mar	22-26	4	22-30	4			4
Apr	12-21	9	12-21	9			9
May	10-19	9	10-19	9			9
June	8-16	8	8-16	8			8
July	12-21	9	12-21	9			9
Aug	9-17	8	9-17	8	9-12	3	8
Sept	10-18	8	10-18	8			8
Nov[1]			4-8	4			4
totals	9 trips	65 days	9 trips	62 days	1 trip	3 days	69 days

[1] Arizona Game & Fish Department field trip, USFWS personnel assisted.

TABLE 3. USFWS 1993 LCR studies: sampling effort. Abbreviations: MTP - minnow traps, fish and habitat; MNH - minihoopnet, fish and habitat; TRN, 100m - 100 m interval habitat transect outside active fish sampling area; TRN, 20m - 20m interval habitat transect inside active fish sampling area, TRN, research - special study transects; SNE - seine samples, fish and habitat; AHP - Arizona State University hoopnet, habitat; OBS - observational survey transects, fish and habitat. November sampling at Salt Camp was from an AGF research trip.

A. SALT CAMP

sampling gear	Feb 10-17	Mar 2-5	Mar 22-26	Apr 12-21	May 10-19	June 8-16	July 12-21	Aug 9-17	Sept 10-18	Nov 4-8	totals
MTP			17	60	48	90	41	74	39	24	393
MNH		10	25	89	75	117	98	110	69	45	638
TRN, 100 M					4	5	6	6	4		25
TRN, 20 M				16	13	20	15	20	10	6	100
TRN, res											0
SNE		6	10			20	15	34	18	11	114
AHP		7		3							10
OBS							15	18			33

B. POWELL

sampling gear	Feb 10-17	Mar 2-10	Mar 22-30	Apr 12-21	May 10-19	June 8-16	July 12-21	Aug 9-17	Sept 10-18	Nov 4-8	totals
MTP	9			47	56	72	72	94	60		410
MNH	12	21	38	97	103	103	133	144	99		750
TRN, 100 M					6	5	6	5			22
TRN, 20 M	3			18	16	18	18	20	14		107
TRN, res					7				5		12
SNE	21		2	3		43		50	10		129
AHP	31	11									42
OBS							18	20			38

C. TOTAL

sampling gear	Feb 10-17	Mar 2-10	Mar 22-30	Apr 12-21	May 10-19	June 8-16	July 12-21	Aug 9-17	Sept 10-18	Nov 4-8	totals
MTP	9		17	107	104	162	113	168	99	24	803
MNH	12	31	63	186	178	220	231	254	168	45	1388
TRN, 100 M					10	10	12	11	4		47
TRN, 20 M	3			34	29	38	33	40	24	6	207
TRN, res					7				5		12
SNE	21	6	12	3		63	15	84	28	11	243
AHP	31	18		3							52
OBS							33	38			71

Table 4. 1993 USFWS LCR studies: summary of fish captures by species and month.

spp	FEB	MAR	MAR	APR	MAY	JUN	JUL	AUG	SEP	NOV	TOTAL
HBC	9	13	31	62	202	431	3279	4901	1014	223	10165
BHS	1	1	16	17	25	21	447	481	16	4	1031
FMS	0	1	0	1	13	39	61	87	4	5	211
FHM	0	0	1	0	1	0	0	2	14	4	22
CCF	0	0	0	0	0	0	0	0	12	0	12
PKF	0	0	0	0	0	0	0	0	2	0	2
YBH	0	0	0	0	0	1	0	0	0	0	1
CCP	0	0	0	0	0	0	1	1	0	0	2
SPD	3	35	73	116	703	644	1446	2505	274	168	5967
total	13	50	121	196	944	1136	5234	7977	1336	404	17411

KEY:

Species

HBC humpback chub
SPD speckled dace
BHS bluehead sucker
FMS flannelmouth sucker
BNT brown trout
RBT rainbow trout
CCP common carp
FHM fathead minnow
CCF channel catfish
YBH yellow bullhead
PKF plains killifish

TABLE 5. 1993 USFWS LCR studies: native fish captures by size class and sampling date.

A. 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 5. (continued).

B. 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 5. (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 6. 1993 USFWS LCR studies: summary of fish mortalities. M/D - month day. P - sampling period: M, midnight; A, morning; N, noon; P, evening. LOC - USFWS transect ID with net/trap number (-N). GEAR - MNH= FWS minihoopnet; MTP= minnow trap. SPP - species. WT - weight in grams if taken. Comments - MORT= mortality; GEAR 12350 AZGF NET was a 1/8" experimental AZGF minihoopnet.

YEAR	M/D	TIME	P	LOC	GEAR	SPP	#	TL	WT	COMMENTS
SALT										
1993	0609	1845	P	LB-8	MNH	BHS	1	41	0	MORT
1993	0609	1845	P	LB-8	MNH	HBC	1	36	0	MORT; GEAR 12350 AZGF NET
1993	0609	1845	P	LB-8	MNH	HBC	1	33	0	MORT; GEAR 12350 AZGF NET
1993	0609	1845	P	LB-8	MNH	HBC	1	33	0	MORT; GEAR 12350 AZGF NET
1993	0610	0015	M	LB-1	MNH	HBC	1	26	0	MORT; GEAR 12350 AZGF NET
1993	0610	0015	M	LB-1	MNH	HBC	1	27	0	MORT; GEAR 12350 AZGF NET
1993	0610	0045	M	LB-6	MNH	HBC	1	26	0	MORT; GEAR 12350 AZGF NET
1993	0610	0845	A	LB-7	MNH	HBC	1	25	0	MORT; GEAR 12350 AZGF NET
1993	0610	0845	A	LB-7	MNH	HBC	1	30	0	MORT; GEAR 12350 AZGF NET
1993	0610	1430	N	SC1-4	MNH	SPD	1	84	4	MORT; REGUR. BY HBC ADULT
1993	0610	1745	P	SC2-1	MNH	SPD	1	32	0	MORT; GEAR 12350 AZGF NET
1993	0610	1745	P	SC2-1	MNH	SPD	1	36	0	MORT; GEAR 12350 AZGF NET
1993	0614	0015	M	UN-5	MNH	SPD	1	90	5	MORT; REGUR. BY HBC ADULT
1993	0717	1042	A	UAL-2	MNH	HBC	1	47	0	MORT; REGUR. BY HBC ADULT
1993	0718	1131	A	UAM-1	MNH	HBC	1	48	0	MORT; REGUR. BY HBC ADULT
1993	0717	1100	A	UAL-5	MNH	SPD	3	?	0	MORT; REGUR. BY HBC ADULT
1993	0815	1003	A	UI-6	MNH	BHS	1	66	0	MORT
1993	0811	0928	A	LC-4	MNH	HBC	1	59	0	MORT
1993	0812	1050	A	SC2-4	MNH	HBC	1	63	0	MORT
1993	0814	1640	P	UD-1	MNH	HBC	1	62	0	MORT
1993	0814	1745	P	UG-1	MNH	HBC	1	72	0	MORT
1993	0815	0932	A	UK-1	MNH	HBC	1	61	0	MORT
1993	0815	1038	A	UI-4	MNH	HBC	1	58	0	MORT
1993	0814	0955	A	UC-5	MNH	SPD	1	59	0	MORT
1993	0814	1745	P	UG-2	MNH	SPD	1	48	0	MORT
1993	0815	0813	A	UG-1	MNH	SPD	1	50	0	MORT
1993	0815	0813	A	UG-2	MNH	SPD	1	52	0	MORT
1993	0815	0813	A	UG-2	MNH	SPD	1	51	0	MORT
1993	0815	0813	A	UI-1	MNH	SPD	1	50	0	MORT
POWELL										
1993	0713	1649	P	DN-6	MNH	BHS	1	62	0	MORT
1993	0713	1703	P	DN-8	MNH	HBC	1	44	0	MORT
1993	0718	1705	P	EJ-6	MNH	HBC	1	49	0	MORT
1993	0718	1705	P	EJ-6	MNH	HBC	1	63	0	MORT
1993	0718	1705	P	EJ-6	MNH	HBC	1	44	0	MORT
1993	0718	1705	P	EJ-6	MNH	HBC	1	42	0	MORT
1993	0812	0745	A	BD-1	MNH	BHS	1	50	1	MORT
1993	0812	0750	A	BD-2	MNH	FMS	1	60	1	MORT
1993	0811	1812	P	BH-3	MNH	HBC	1	54	1	MORT
1993	0812	0750	A	BD-2	MNH	HBC	1	57	1	MORT
1993	0812	0750	A	BD-2	MNH	HBC	1	41	0	MORT
1993	0812	0750	A	BD-2	MNH	HBC	1	42	0	MORT
1993	0812	0750	A	BD-2	MNH	HBC	1	50	1	MORT
1993	0813	1645	P	CB-1<	MTP	HBC	1	43	0	MORT
1993	0814	0815	A	CF-6	MNH	HBC	1	55	1	MORT
1993	0815	0805	A	CZ-7	MNH	HBC	1	37	0	MORT
1993	0816	0820	A	DF-1	MNH	HBC	1	65	2	MORT

1993	0816	0830	A	DF-3	MNH	HBC	1	50	0	MORT
1993	0816	0950	A	DG-7	MNH	HBC	1	48	0	MORT
1993	0816	0950	A	DG-7	MNH	HBC	1	45	0	MORT
1993	0816	0950	A	DG-7	MNH	SPD	1	39	0	MORT
1993	0816	0950	A	DG-7	MNH	SPD	1	51	0	MORT
1993	0914	0830	A	EA-5	MNH	SPD	1	47	0	MORT

SUMMARY:

species	size range (TL)	number
HBC	25-74 mm	33
SPD	30-90 mm	15
BHS	50-66 mm	3
FMS	60	1
total		52

TABLE 7. 1993 USFWS Grand Canyon tributary studies: field schedule. First number in bold indicates number of trips/month. Numbers following the slash indicate type of sampling (see key below). With the exception of trips indicated with a "*" field trips shown were conducted by ACFWRU under subcontract to USFWS. USFWS-AZFRO LCR data is not included in this table (see Table 2); trips shown for LCR were conducted by ACFWRU student Mattes (1993). June trips indicated with a "*" were conducted by USFWS-AZFRO, June 20-July 3, 1993. Water quality measures for Paria and Havasu included water temperature only; measures in other tributaries included temperature, pH, conductivity and disolved oxygen.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
PA		1/1,4,5	3/1,4,5	2/1,4,5	2/1,4,5	1/1,4,5		1/1,4,5
LCR				1/1,2,3,4,5		1/1,2,3,4,5,8	1/1,8	
BA			1/1,2,4,5			1/2,4,5,8		
SH	1/2,3,4,5		1/4,5,8			*1/1,2,3,4,8,9		
DE	1/1,4,5,8,9,10							
TA	1/1,4,5,8,10							
KA	1/1,2,3,4,5			1/2,3,4,5		*1/1,2,3,4,5,8,9		
HA	1/1,2,3,4		1/1,2,3,4	1/1,2,3,4,5		1/1,2,3,4 *1/1,2,3,4,5,8		

KEY:

SAMPLE TYPES:
1= WATER QUALITY
2= MINNOW TRAPS
3= MINIHOOP GRID HABITAT
4= TRANSECT HABITAT
5= SEINING HABITAT
6= FISH
8= FISH OBSERVATION
9= ELECTROSHOCKING HABITAT
10= ANGLING

TRIBUTARIES:
BA= BRIGHT ANGEL CREEK
SH= SHINUMO CREEK
DE= DEER CREEK
TA= TAPEATS
KA= KANAB CREEK
HA= HAVASU CREEK
PA= PARIA RIVER
LCR=LITTLE COLORADO RIVER

TABLE 8. 1993 USFWS Grand Canyon tributary studies: summary of sampling effort. Numbers in parenthesis indicate data from the USFWS-AZFRO June trip. Values shown for LCR are for ACFWRU student Mattes; USFWS-AZFRO LCR sampling effort is shown in Table 3. Key below describes the various methods of sampling.

SAMPLE TYPE	PA	LCR	BA	SH	DE	TA	KA	HA	totals
MTP		12	16	48 (34)			20 (8)	208 (31)	304 (73)
MNH		98		31 (27)			27 (15)	153 (25)	309 (67)
TRN	228	13	42	130 (53)	6	49	310 (208)	241 (152)	1019 (413)
SEN	204	7	1	16	3	6	59 (37)	53 (52)	349 (89)
OBS			52	5 (5)	1	4	7 (7)	1 (1)	70 (13)
ELC				33 (33)			7 (7)		40 (40)
AGL					11	153			164

KEY:

SAMPLE TYPES:

MTP= MINNOW TRAPS (N sets)
MNH= MINIHOOP GRID HABITAT (N sets)
TRN= TRANSECT HABITAT (N measured)
SEN= SEINING HABITAT (N samples)
OBS= OBSERVATION OF FISH (N surveys)
ELC= ELECTROSHOCKING HABITAT (N locations)
AGL= ANGLING (N minutes spent fishing)

TRIBUTARIES:
BA= BRIGHT ANGEL CREEK
SH= SHINUMO CREEK
DE= DEER CREEK
TA= TAPEATS
KA= KANAB CREEK
HA= HAVASU CREEK
LCR=LITTLE COLORADO RIVER

TABLE 9. 1993 USFWS Grand Canyon tributary studies: summary of fish captures. Numbers in parenthesis indicate data from the USFWS-AZFRO June trip. Values shown for LCR are for ACFWRU student Mattes; USFWS-AZFRO LCR fish captures are shown in Table 4. We are not permitted to show Havasu data at this time (see text).

species	PA	LCR	BA	SH	DE	TA	KA	HA	totals
HBC		1					4 (4)		5 (4)
SPD	633	1357	13	285 (211)			1440 (1149)		3728 (1360)
BHS		2	1	26 (25)			511 (119)		540 (144)
FMS	961		11	1 (1)			264 (68)		1237 (69)
BNT			1	4 (2)					5 (2)
RBT			3	54 (45)	2	14			73 (45)
CCP							8 (1)		8 (1)
FHM		1					65 (2)		66 (2)
PKF							3		3
GSF							3 (2)		3 (2)

KEY:
Species: HBC, humpback chub; SPD, speckled dace; BHS, bluehead sucker; FMS, flannelmouth sucker; BNT, brown trout; RBT, rainbow trout; CCP, common carp; FMH, fathead minnow; PKF, plains killifish; GSF, green sunfish.

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

FIGURE 1. 1993 USFWS LCR studies: length-frequency histograms for native fishes, February-September 1993.

Shown are length-frequency histograms for:

humpback chub, <100 mm TL (1993 YOY);
June, July, August, September

subadult and adult humpback chub, >100 mm TL;
February-May, June-September

speckled dace;
June, July, August, September

speckled dace;
February-May, June-September

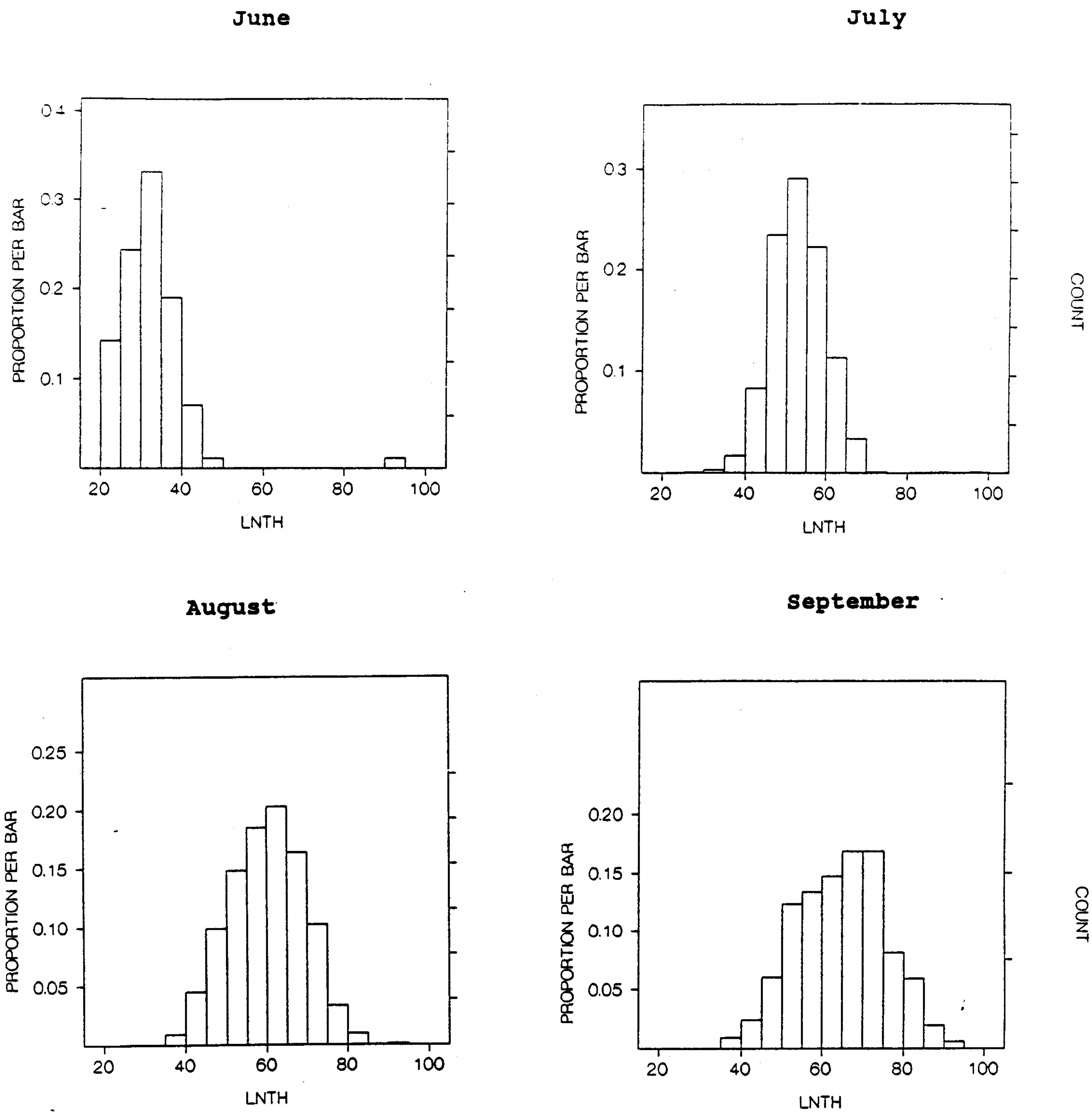
bluehead sucker, < 100 mm TL (1993 YOY);
June, July, August, September

bluehead sucker, > 100 mm TL;
February-May, June-September

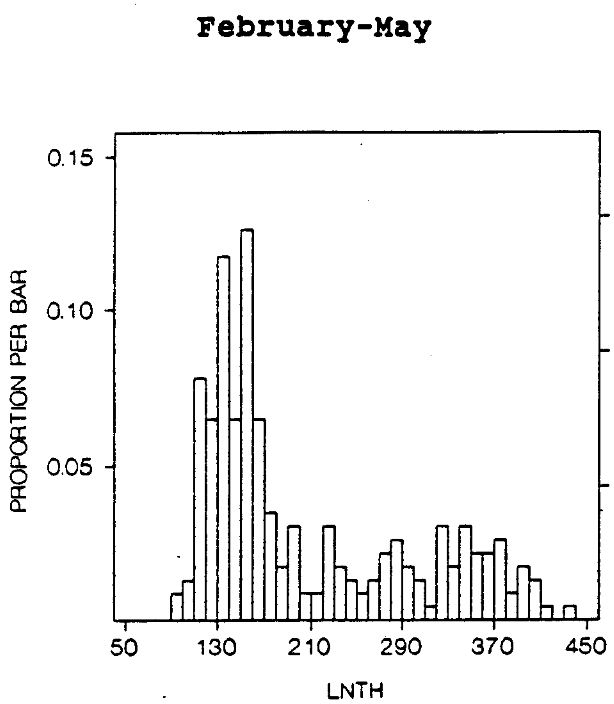
flannelmouth sucker, < 110 mm TL (1993 YOY);
June, July, August, September

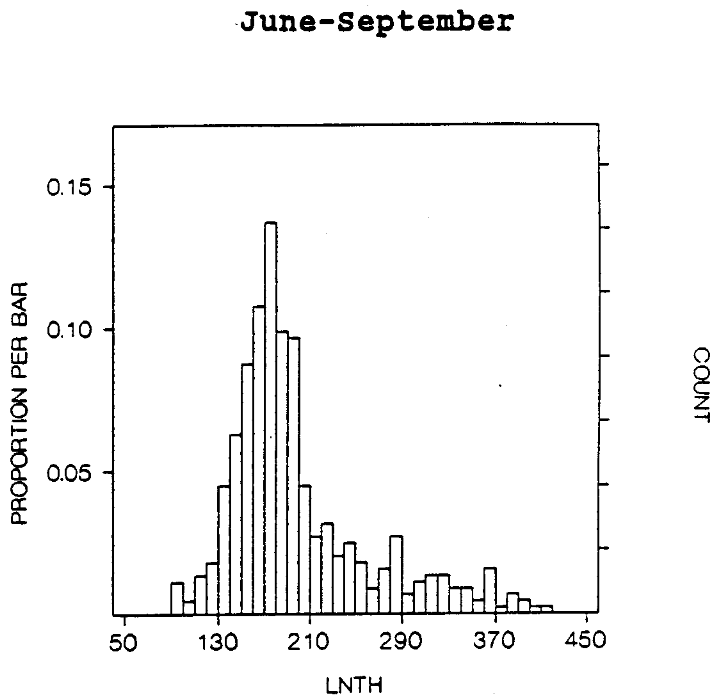
flannelmouth sucker, > 110 mm TL
February-May, June-September

Humpback Chub < 100mm

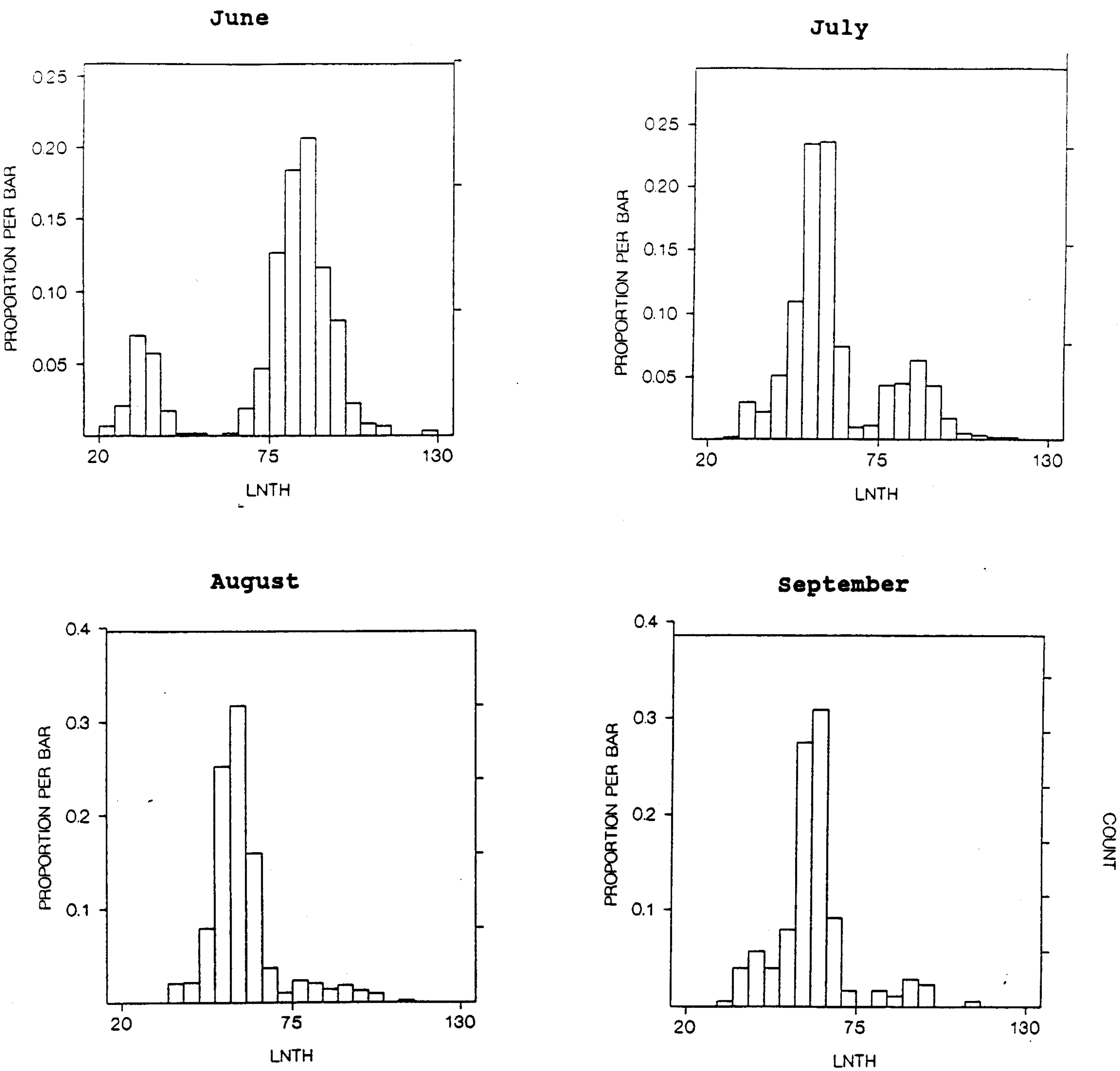


Humpback Chub > 100mm



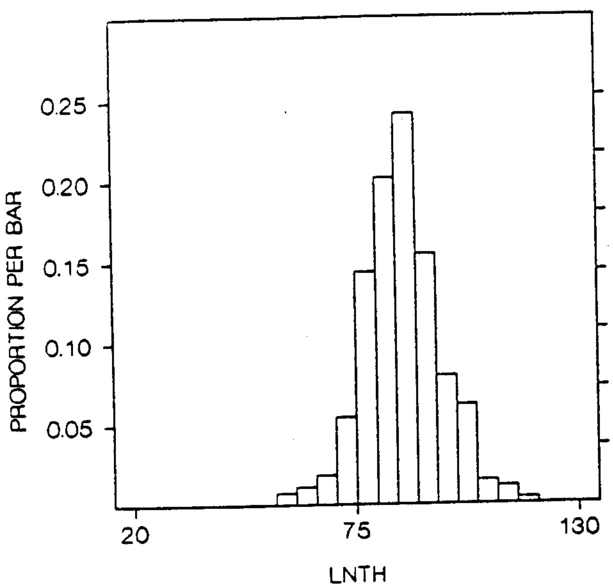


Speckled Dace

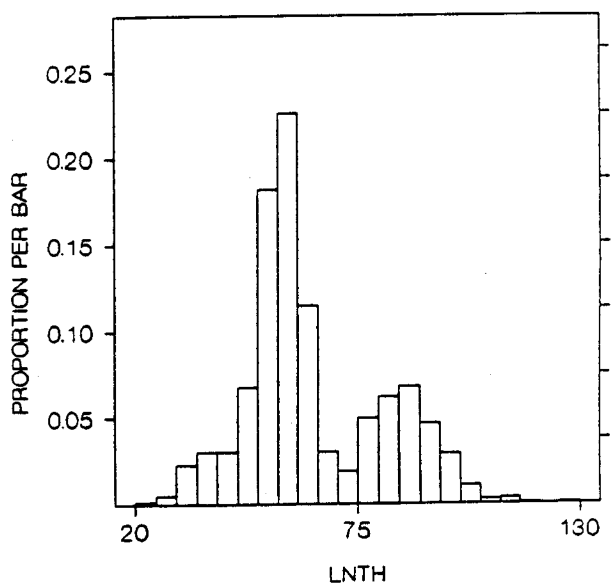


Speckled Dace

February-May

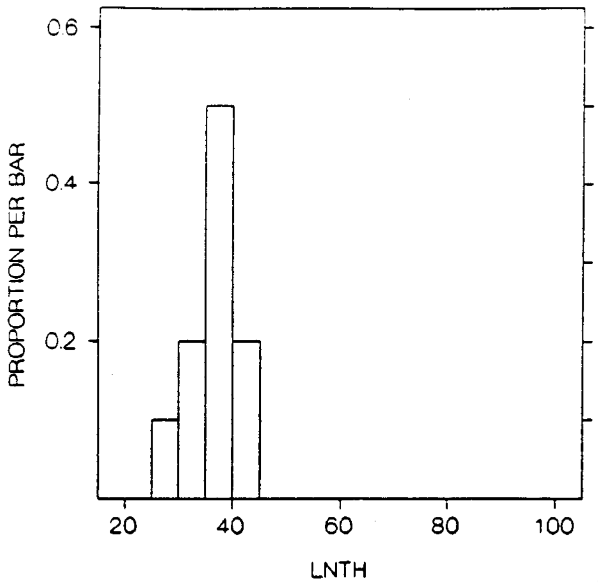


June-September

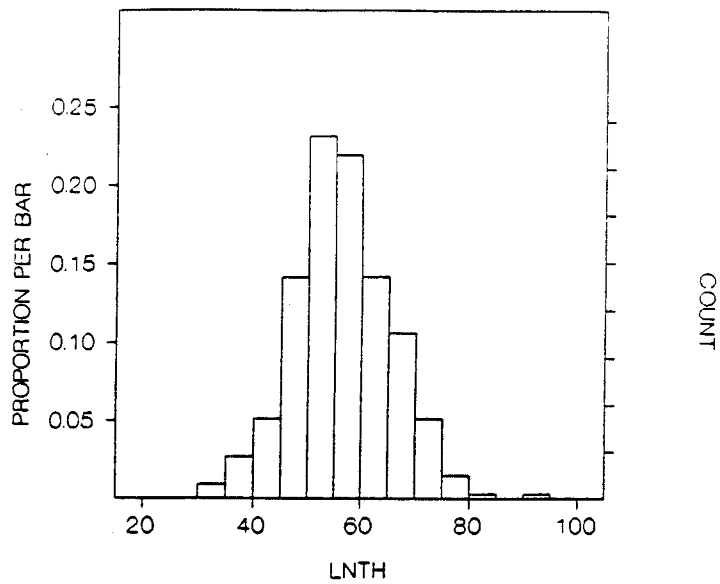


Bluehead Suckers < 100

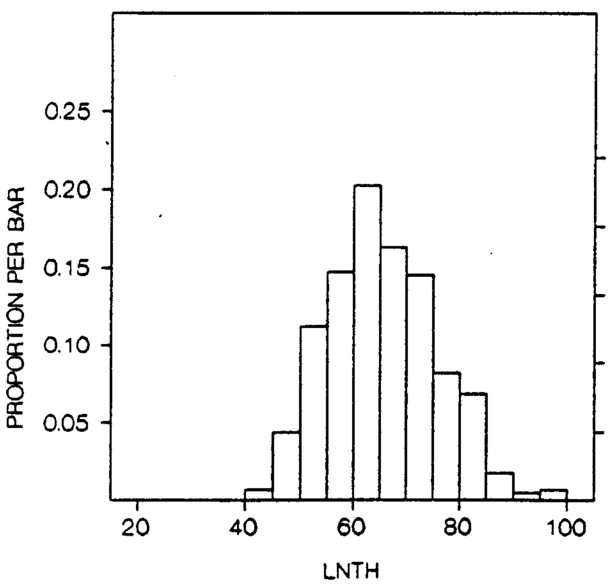
June



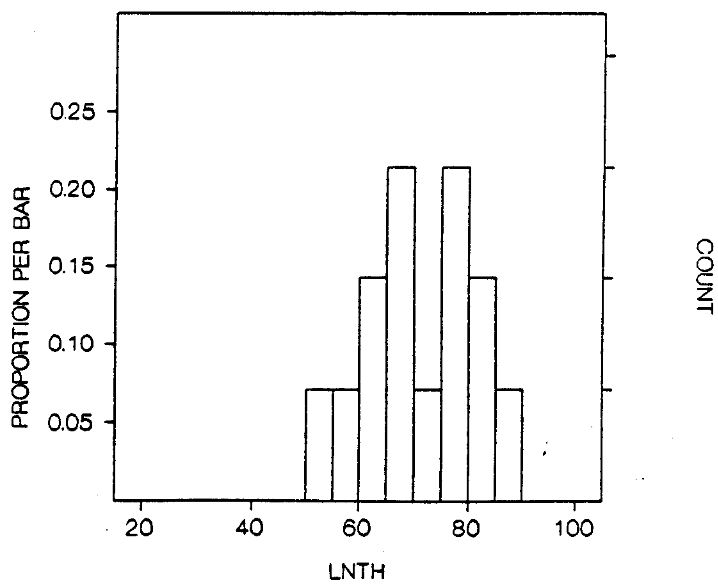
July



August

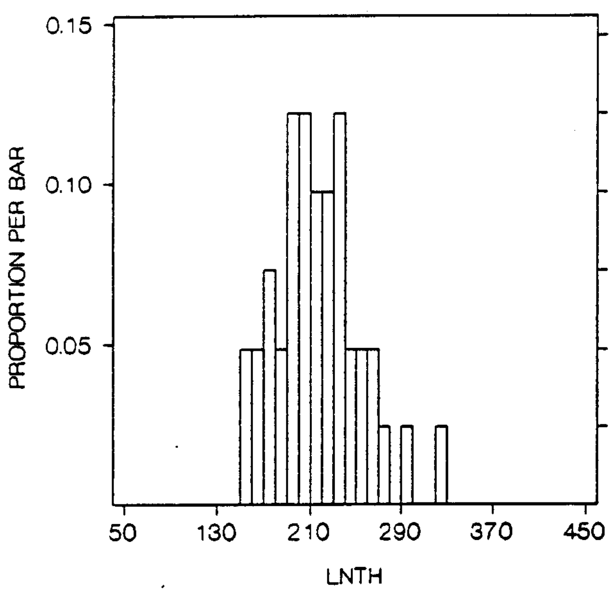


September

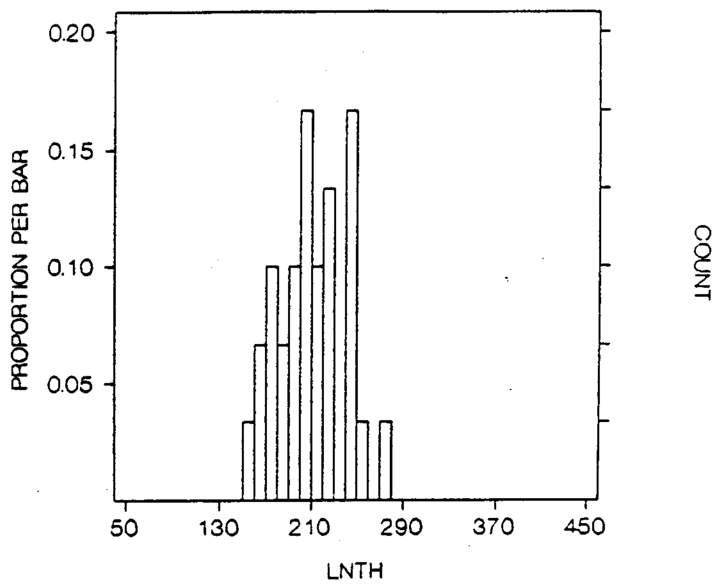


Bluehead Suckers > 100

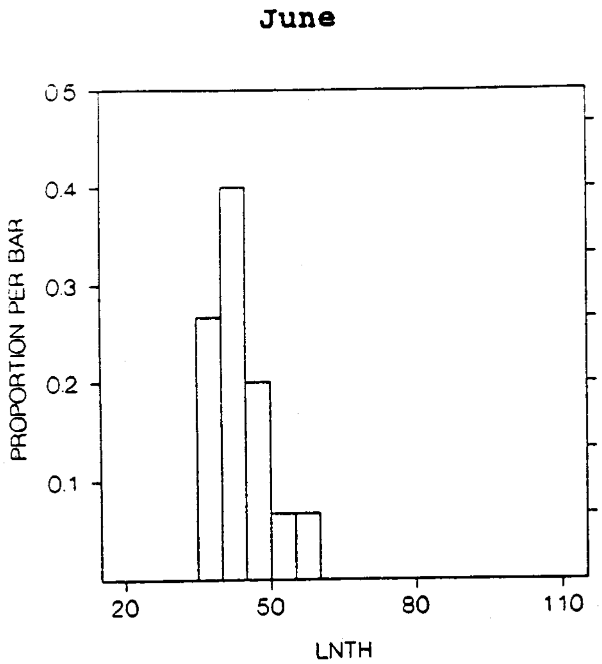
February-May

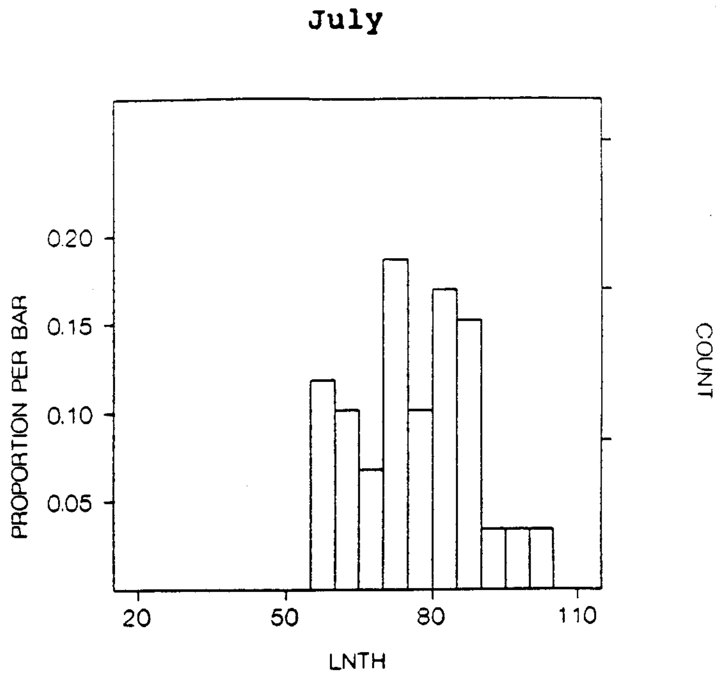


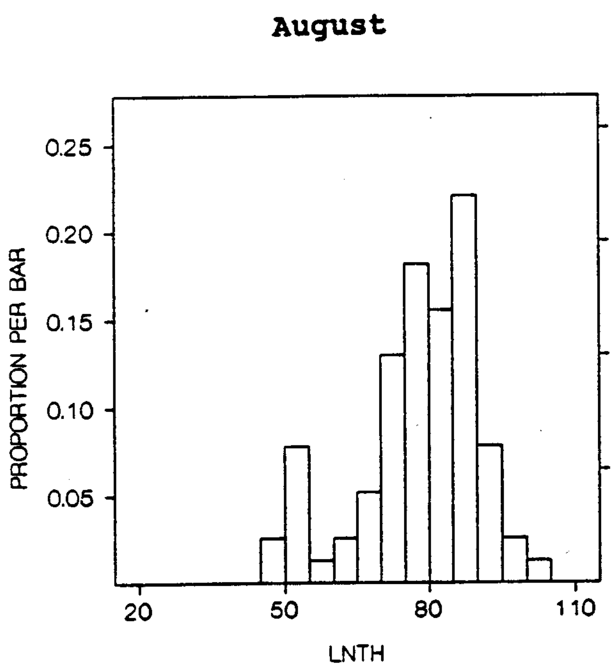
June-September

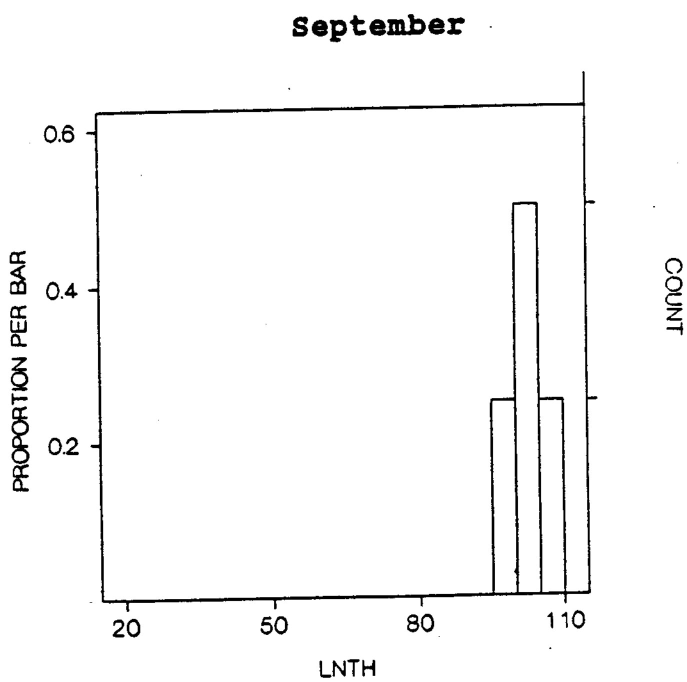


Flannelmouth Suckers < 110



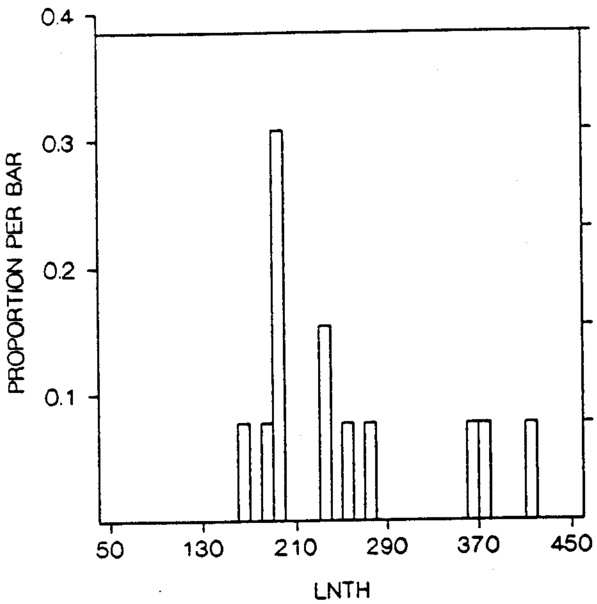




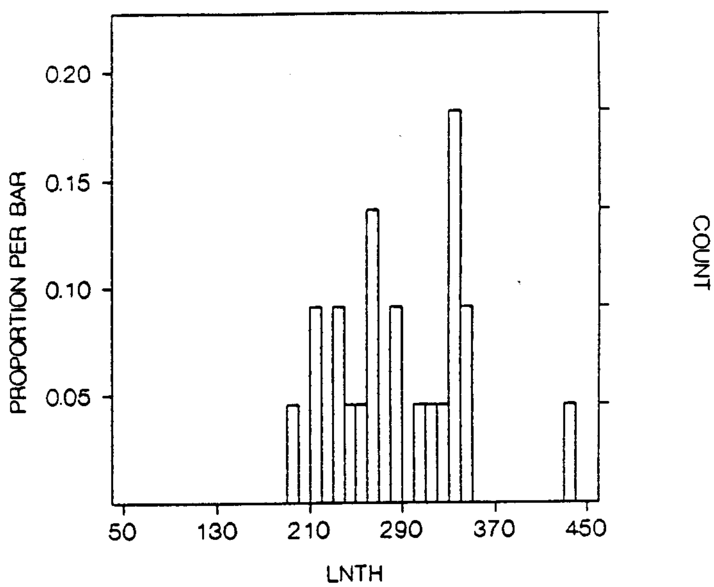


Flannelmouth Suckers > 110

February-May



June-September



APPENDIX I

ANALYSIS OF HABITAT USE BY LCR FISHES: EXAMPLES FROM POWELL STUDY AREA, JUNE 1992 AND JUNE 1993

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 use data from the Powell study area for June 1992 and 1993. A comparative analysis of habitat use data from seine sampling from the Powell study area, September 1992, will also be presented.

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. Favorable reproductive conditions in 1993 have yielded 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 six months to one year in age, and 2) spawning adult humpback chub.

Available habitat and habitat sampled for fish

Transect data consists of habitat measurements taken along established USFWS transects within the Powell study area (km 2.5-3.5; Table 1). 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.

The Powell Study Area transect data (available habitat) for June 1992 (Fig. 1) is very similar to the LCR transect habitat data for 1991 (Appendix II, Fig. 1) 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 and slower modal currents for this particular reach. These changes are the expected result of scouring that occurred with the frequent flooding in 1992. The combined minihoopnet and minnow trap habitat data represented the "habitat sampled for fish" (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). Modal currents are higher than available (probably related to undersampling of very shallow edge 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 represents the spacing distance for our systematic minihoopnet sampling grids (4-5 m). We view these deficiencies as relatively minor, and more importantly, were expected and can be defined or accounted for by comparison of data sets.

Analysis of Powell Study Area transect data for June 1993 was not completed in time for this report but comparisons can be made with sampled habitat (minihoop/minnow trap habitat) (Figs. 2, 3). In 1993 sampled stream habitat was deeper, slower, not dominated by sand and travertine substrates, and contained more vertical structure and cover. These changes can be attributed to the large winter floods in early 1993 (Append. III). These scouring floods removed the finer substrates that are usually deposited in pools. The result was deeper pools, more exposed boulders and cobbles, and slower currents. These winter floods in combination with the extensive flooding conditions in 1992 eroded much of the travertine that formed a consolidated matrix of rocks, cobbles and travertine that covered much of the stream bottom in 1991. The apparent increase in rocks, cobbles, and small boulders in 1993 was a result of the erosion of the travertine bottom throughout 1992 and early 1993. Although base flow conditions in summer 1993 predicted the appearance of $CaCO_3$ ("marl") deposits along stream edges, this substrate remained very rare. Instead, hard travertine deposits formed very rapidly on the expansive areas of exposed cobble and boulder substrate in summer 1993. Our explanation for this goes as follows. In 1991, the LCR channel was dominated by sand substrate. Sand filled the pools causing decreased average depths and increased currents. Travertine precipitated out in quieter areas of pools but was constantly re-entrained into the water by the moderate currents. The suspension of this travertine in the water column caused decreased clarity in the water ($\sim$50-100 NTUs and $<$ .5 m secchi). The predominance of unstable, mobile sand substrate and a shortage of hard, stable substrates for travertine deposition in 1991 realized an abundance of $CaCO_3$ precipitate. This unconsolidated travertine precipitate resembles marl deposits in lakes (hence our name for this substrate). In the summer of 1993 the slower currents and abundance of stable, hard substrates provided sufficient surface area of suitable substrate for travertine deposition and consolidation. As correlates to these conditions, less travertine was entrained in the water column and water clarity was unusually high (<6 NTUs and >3 m secchi).

It is interesting that despite the differences noted in the configuration of habitat discernable from the habitat variable distributions (Figs. 1-3), Principal Component Analyses (PCA) of sampled habitat (Table 3) for the Powell Study Area in 1992 and 1993 are relatively similar. What PCA tells us is that the gross configuration of stream habitat remain relatively unchanged between 1991 and 1992. For example, PC axis 1 represent habitat points arrayed from stream edge to center channel (lateral position gradient). The second PC axis represents an alternative distribution to PC axis 1: the dichotomy between shallow areas with large substrates and deep areas with fine (sand) substrate. The third PC axis represents habitat points arrayed between pool-riffle-race habitats (longitudinal position gradient). The loadings indicate habitat points arrayed between shallow areas with smaller substrates (rocks and cobbles) and faster currents and deep pool habitats with large substrates (boulders) and slow currents. The larger LATP loading for PC axis 3 in 1992 indicates that the shallow areas are often found away from stream edges.

Habitat use patterns for LCR fishes

Habitat use patterns by the fish follow two basic patterns: those that are more diurnally active vs. those that are more nocturnally active (Table 2, Figs. 4, 5). In 1992 speckled dace (SPD) and humpback chub (HBC) show almost opposite patterns of daytime habitat use: SPD are more diurnally active (as shown by catch/hr values, Table 2), use shallow edge areas with small substrate particles (<7) and low cover (<3) (Fig. 4). HBC use deeper water areas with larger substrate particles (>6), greater vertical structure (particularly >2) and greater cover (particularly > 4) (Fig. 4). Daytime habitat use differences in SPD and HBC in 1993 were similar; SPD used shallower habitats with smaller substrates and less cover and vertical structure, but were not as restricted to near edge habitats (Fig. 5). A new variable used in 1993, relative depth (RDPH), showed that HBC uses near bottom areas while SPD is more uniformly distributed in the water column (Fig 5). Unlike HBC, SPD do not show large changes in habitat uses day vs. night periods. SPD show some increase in use of offshore areas at night and a decrease in use of near surface RDPH (Figs. 4, 5). HBC shows larger differences in day vs. night habitat use. During the day, HBC tend to use areas <400 cm (1992; Fig. 4) or < 800 cm (1993; Fig. 5) from stream banks, use larger substrates (particularly 7, 8), slower currents (1992), and increased use of category 4 (1992) or category 7 (1993) cover. At night, HBC tend to move out from stream banks areas (1992) or deep water areas (1993) and use the entire stream channel and expand their use of the water column (1993). Patterns of habitat use between species for day and night periods are summarized in PCA plots of species habitat scores (Figs. 8, 9).

Some of the differences in habitat use between 1992 and 1993 are the result of different age/size structure of the humpback chub population and corresponding differences in habitat use. For 1993 we divided humpback chub into subadult (100-150 mm TL) and adult (>150 mm TL) subgroups. The smaller humpback chub are 1991 year class individuals and most of the larger humpback chub are >200 mm TL. We did not perform an analysis of 1993 YOY humpback chub. Differences in habitat use are evident in habitat use distributions of adult and subadult humpback chub (Fig. 6). During the day adult humpback chub remain in deeper water areas with greater lateral position and at greater relative depth (near bottom). Subadult humpback chub use shallower areas with greater vertical structure and cover and lower water column positions. During the night the two groups continue to use habitat differently. Subadults shift habitat use to shallow areas near shore as well as mid-channel locations with less vertical structure and cover. Their RDPH shifts upwards to lower mid-pelagic positions. At night adult humpback chub expand habitat use into shallower areas closer to stream banks and use of mid-pelagic RDPH increases. However, adults continue to be associated with habitats of relatively high vertical structure and cover. Overall the two size groups are partially segregated on use of depth, lateral position, RDPH, and cover in both day and night periods. The different patterns of habitat use between day and night periods are summarized in PCA plots of species habitat scores (Fig. 9).

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), their habitat use patterns for 1992 are clear and consistent with field observations by a number of investigators. Like the HBC, BHS and FMS daytime habitat use is largely restricted to nearshore habitats and use of midchannel habitats increases noticeably at night (Fig. 7). 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; >0.7 m/sec) 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. The resulting shifts in habitat use during the night leads to considerable overlap in habitat use. Patterns of habitat use for these suckers are summarized in PCA plots of species habitat scores (Fig. 8).

Habitat evaluation studies: active vs. passive sampling

This preliminary 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. Another concern is that the devices themselves constitute a structural modification of the local habitat and attract fishes. Certainly our data have shown that most of these species appear to have a preference for habitats with increased structure. 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. Our sampling methods underscore the importance of sampling night and day periods; most LCR fishes show very different day/night habitat use patterns. If these periods are not sampled separately the data would show a pattern of less habitat specificity. Most active sampling methods are designed for and conducted during the day and do not have comparable night sampling methods; our approach and sampling methodology is unique in providing a balanced picture of day and night habitat use in stream fishes.

Our LCR seine sampling provides a basis for evaluating the accuracy of our passive sampling approach. We employ a seine sampling method unlike other investigators ("area seine sampling"; Gorman 1993); we subjectively identify and sample the smallest homogeneous patches of stream habitat that can be seined. Typically these patches are only a few square meters in area and many such patches are sampled during a particular sampling bout (~50). If fish use habitat non-randomly and have species-specific use patterns, the selection of small, homogeneous patches will allow us to correlate species abundance with smaller variances in habitat use. A preliminary analysis of September 1992 seine samples from the Powell Study Area shows similar daytime patterns of habitat by HBC and SPD from our passive sampling methods (Fig. 10). As with our passive sampling study, HBC and SPD show nearly opposite habitat use patterns. The habitat use distributions from seine samples for the two species are near mirror images. HBC use moderate to deep habitat while SPD are more abundant in shallow areas. SPD are always found in habitats with intermediate currents while humpback chub will use zero and higher current areas. SPD use areas with a mixture of fine substrates and rocks and cobbles while humpback chub use areas of sand and cobbles and boulders. SPD use areas of low and intermediate vertical structure while humpback chub use areas of low and high cover. This initial seine sampling habitat analysis verifies the gross patterns of habitat use detected from our passive sampling methods. We feel our passive sampling method is superior because smaller patches can be sampled, almost all available habitat can be sampled, RDPH use can be determined and comparable data is available for day and night periods. The seine sampling will be useful for assessing habitat use in the very shallow habitat where our traps cannot function (< =10 cm) and will be used to further assess the efficacy of passive sampling methodologies.

Future studies

We are now poised to analyze more of our LCR habitat use data, particularly from 1993. Our large summer 1993 data set will allow us to track ontogenetic changes in habitat use by YOY humpback chub and other native fishes. The long period of stable, base flow conditions in the summer of 1993 will permit us to pool habitat use data on different age/size classes of humpback chub and the more rare adult suckers to more precisely describe their habitat use patterns. At this time, analysis of 1992 data is of lower priority; much of our 1992 data is hampered by very low sample sizes of fish, the result of the perennial flooding in the LCR since 12/91. Deficiencies in our LCR habitat studies include describing habitat use in >6 month old YOY humpback chub through their first year and habitat use by spawning humpback chub. These deficiencies are addressed in our planned LCR habitat studies for 1994. In 1994 we would also like to implement habitat use studies in other smaller tributaries in the Grand Canyon to determine whether species in common with the LCR use habitats in similar ways. These tributary studies will allow us to predict the likelihood of other tributaries to support populations of humpback chub when tributaries have arrays of habitats that match those used by humpback chub in the LCR.

TABLE 1. Variables uses in habitat analyses.
(full descriptions are contained in Gorman, 1993)

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
ADPH (absolute depth of net, surface to midpoint of mouth in cm)
RDPH (relative depth of net, % of total depth of water column)

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 Study Area, 6/92 and 6/93: Summary of sampling effort and capture statistics.

A. Habitat sampling effort, 1992/1993
(all nets and traps were set for a 24 hr period; "sets" are equivalent to trap/net days)

	N	# habitat pts
transects measured	36/ 25	999/1724
minihoop net sets	90/117	1982/2045
minnow trap sets	90/ 90	368/ 304

B. Fish captures, 1992/1993

species	N
humpback chub	
adult (tagable, >150 mm TL)	31/ 39
juvenile (100-150 mm TL)	145/ 34
bluehead sucker	11/ 2
flannelmouth sucker	14/ 2
speckled dace	890/146

C. Overall fish capture statistics, 1992/1993
(total sample period: 8 days; catch period per set: 24 hrs)

species	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	176/73	122/172	65/90	395/375	0.92/0.38	3310/1386
bluehead sucker	11/2	224/235	140/227	347/244	0.06/0.01	216/ 40
flannelmouth sucker	14/2	135/219	77/192	206/247	0.08/0.01	271/ 40
speckled dace	880/146	74/84	54/69	118/125	4.64/0.76	6357/2714

D. Night fish capture statistics, 1992/1993
(sampling period 1800-800 hrs; 14 hrs)

species	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	102/53	131/220	65/90	395/375	0.91/0.47	1932/ 953
bluehead sucker	5/1	207/227	140/227	258/227	0.04/0.00	100/ 20
flannelmouth sucker	9/2	131/219	77/192	206/247	0.08/0.01	176/ 40
speckled dace	282/63	73/84	56/69	115/125	2.51/0.56	1272/1168

TABLE 2. USFWS LCR fish habitat studies, Powell Study Area, 6/92 and 6/93: Summary of sampling effort and capture statistics (continued).

E. Day fish capture statistics, 1992/1993
(sampling period 800-1800 hrs; 10 hrs)

species	N	mean length	min	max	catch/hr	#hab.pts
humpback chub	74/20	109/178	76/109	354/329	0.80/0.25	1378/433
bluehead sucker	6/1	240/244	145/244	347/244	0.08/0.00	116/ 20
flannelmouth sucker	5/0	144/0	127/0	156/0	0.06/0.00	95/ 0
speckled dace	598/83	74/84	54/73	118/106	7.48/1.04	4085/895

TABLE 3. USFWS LCR fish habitat studies, Powell Study Area, 6/92 and 6/93: Summary of PCA analyses of habitat data.

A. Habitat sampled for fish, June 1992

DATA SET: LCR/Powell-6/92, habitat data (minihoop + minnow trap)
sample size: 2150 pts variables entered: DPH, CUR, SUB, LATP
data transformation: $\log_e$ (variable +1)

LATENT ROOTS (EIGENVALUES)	1	2	3	4
	1.857	0.999	0.647	0.497
COMPONENT LOADINGS				
CUR	0.806	0.185	0.210	0.522
LATP	0.755	-0.288	0.437	-0.396
DPH	0.645	-0.482	-0.593	0.001
SUB	0.470	0.806	-0.247	-0.260
PERCENT OF TOTAL VARIANCE EXPLAINED BY COMPONENTS				
	46.414	24.985	16.177	12.424

B. Habitat sampled for fish, June 1993

DATA SET: LCR/Powell-6/93, habitat data (minihoop + minnow trap)
sample size: 2349 variables entered: DPH, CUR, SUB, LATP
data transformation: $\log_e$ (variable +1)

LATENT ROOTS (EIGENVALUES)	1	2	3	4
	1.688	1.181	0.624	0.507
COMPONENT LOADINGS				
CUR	0.790	0.240	0.350	-0.442
LATP	0.807	-0.229	0.197	0.507
DPH	0.453	-0.739	-0.448	-0.218
SUB	0.455	0.724	-0.512	0.084
PERCENT OF TOTAL VARIANCE EXPLAINED BY COMPONENTS				
	42.205	29.521	15.597	13.667

Note: PCA analysis of 1993 data with the dominant substrate 10 (travertine) omitted realizes a < 5% change in the above loadings. This indicates that travertine provides no information; this is because travertine is a dominant and ubiquitous substrate in the LCR.

FIGURE 1. USFWS LCR fish habitat studies, Powell Study Area, 6/92. Available habitat from transect data.

Habitat variables shown:
DPH2, CUR, LATP, SUB, TRA, MAR, SHA, VEG, VER, CVR, CCV

Consult Table 1 for explanation of habitat variable codes.

FWS transect habitat: Powell 6/92

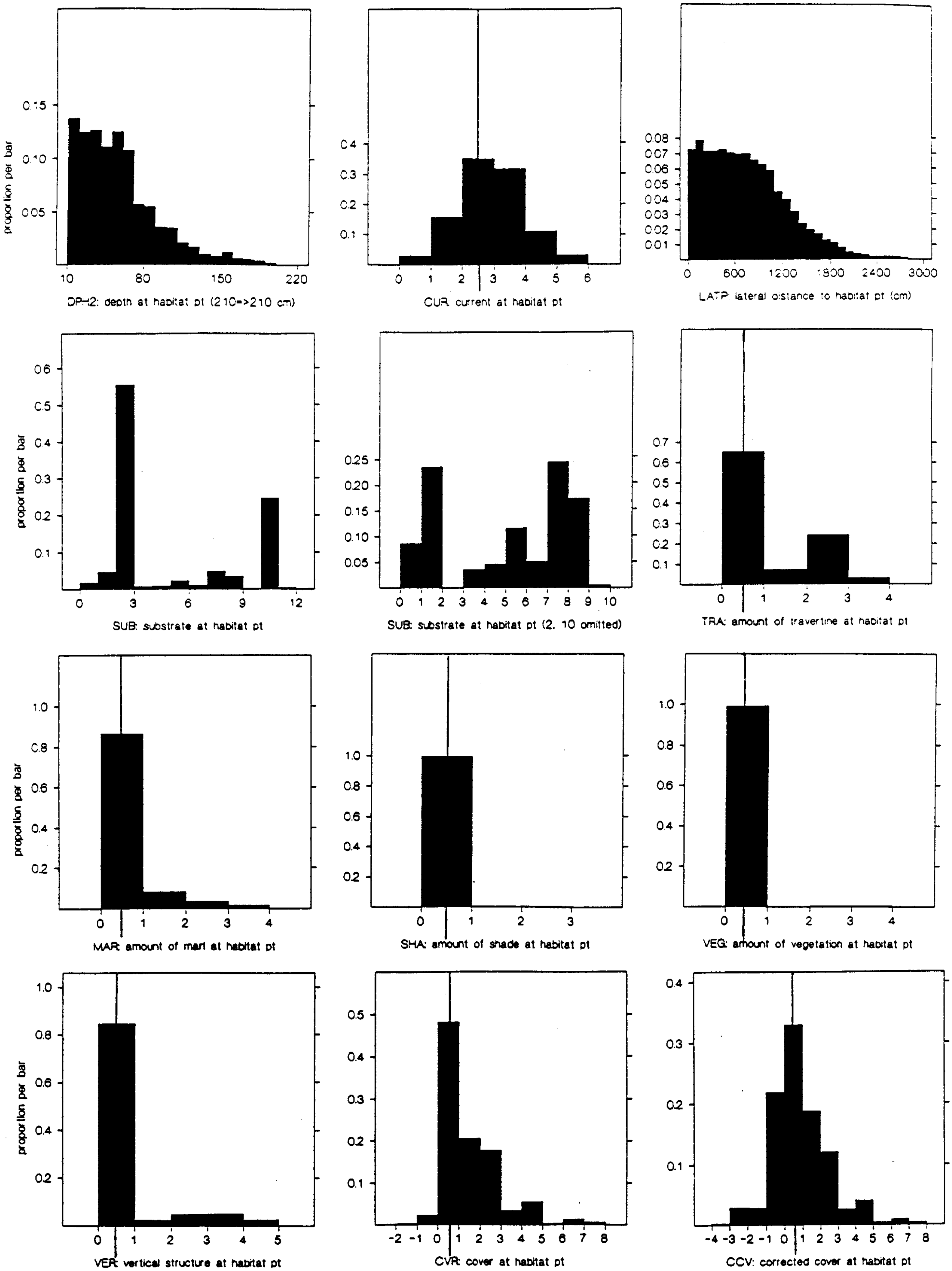


FIGURE 2. USFWS LCR fish habitat studies, Powell Study Area, 6/92: FWS minihoop/minnow trap habitat.

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

Habitat variables shown:
DPH2, CUR, LATP, SUB, TRA, MAR, SHA, VEG, VER, CVR, CCV

Consult Table 1 for explanation of habitat variable codes.

FWS minihoop/minnow trap habitat: Powell 6/92

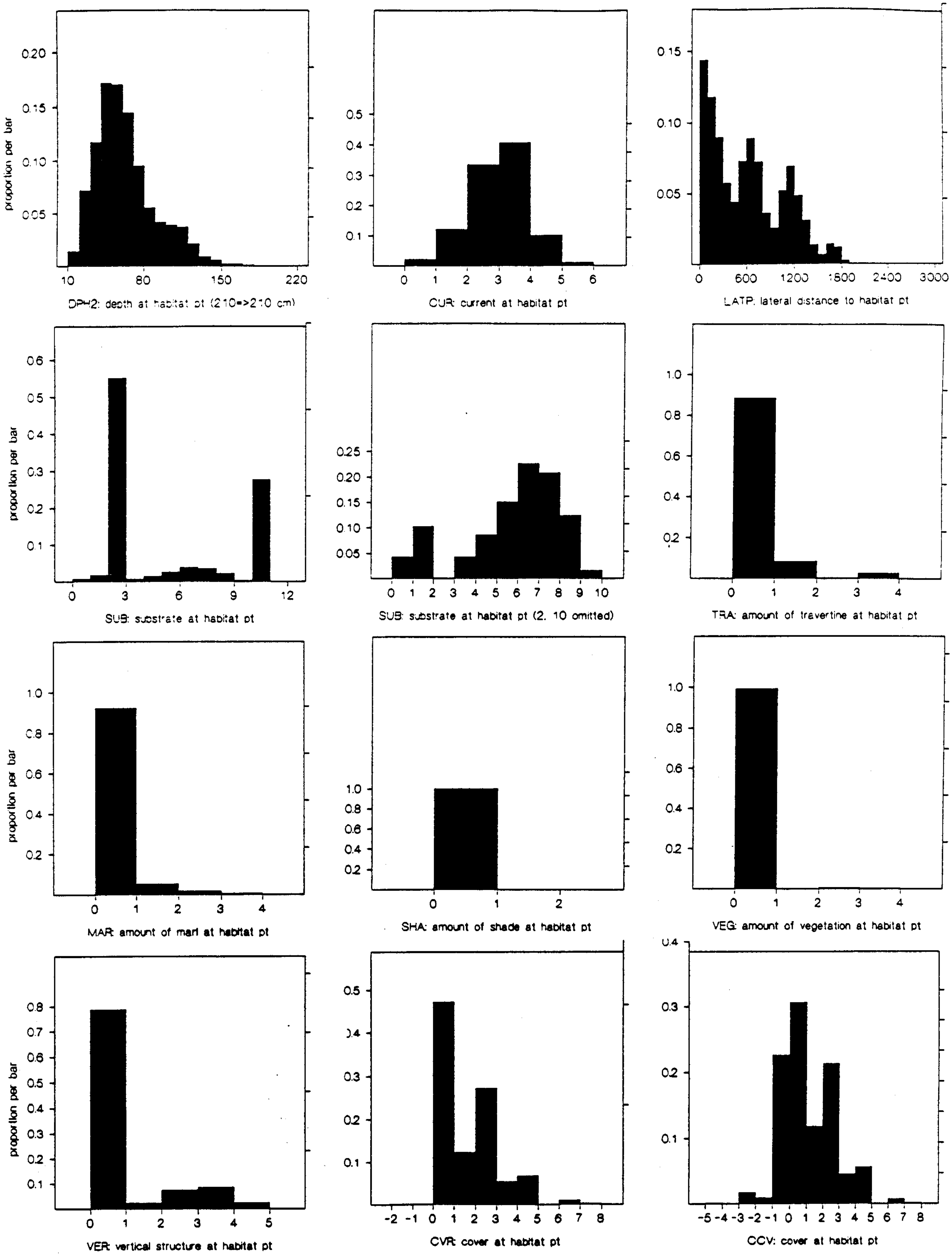


FIGURE 3. USFWS LCR fish habitat studies, Powell Study Area, 6/93: FWS minihoop/minnow trap habitat.

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

Habitat variables shown:
DPH, CUR, SUB, LATP, ADPH, RDPH, VER, CVR

Consult Table 1 for explanation of habitat variable codes.

FIGURE 3. USFWS LCR fish habitat studies, Powell Study Area, 6/93: FWS minihoop/minnow trap habitat.

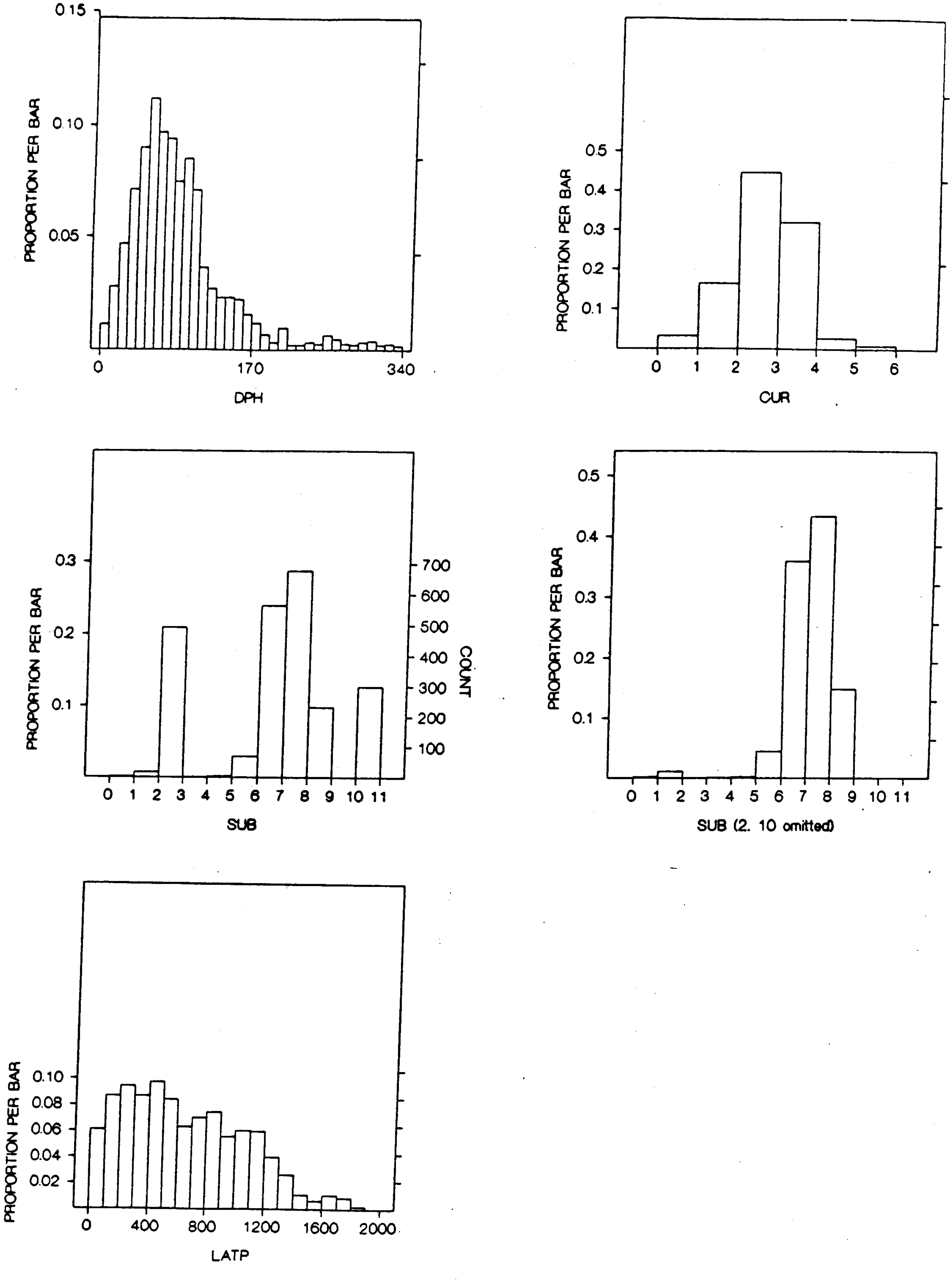


FIGURE 3. USFWS LCR fish habitat studies, Powell Study Area, 6/93: FWS minihoop/minnow trap habitat.

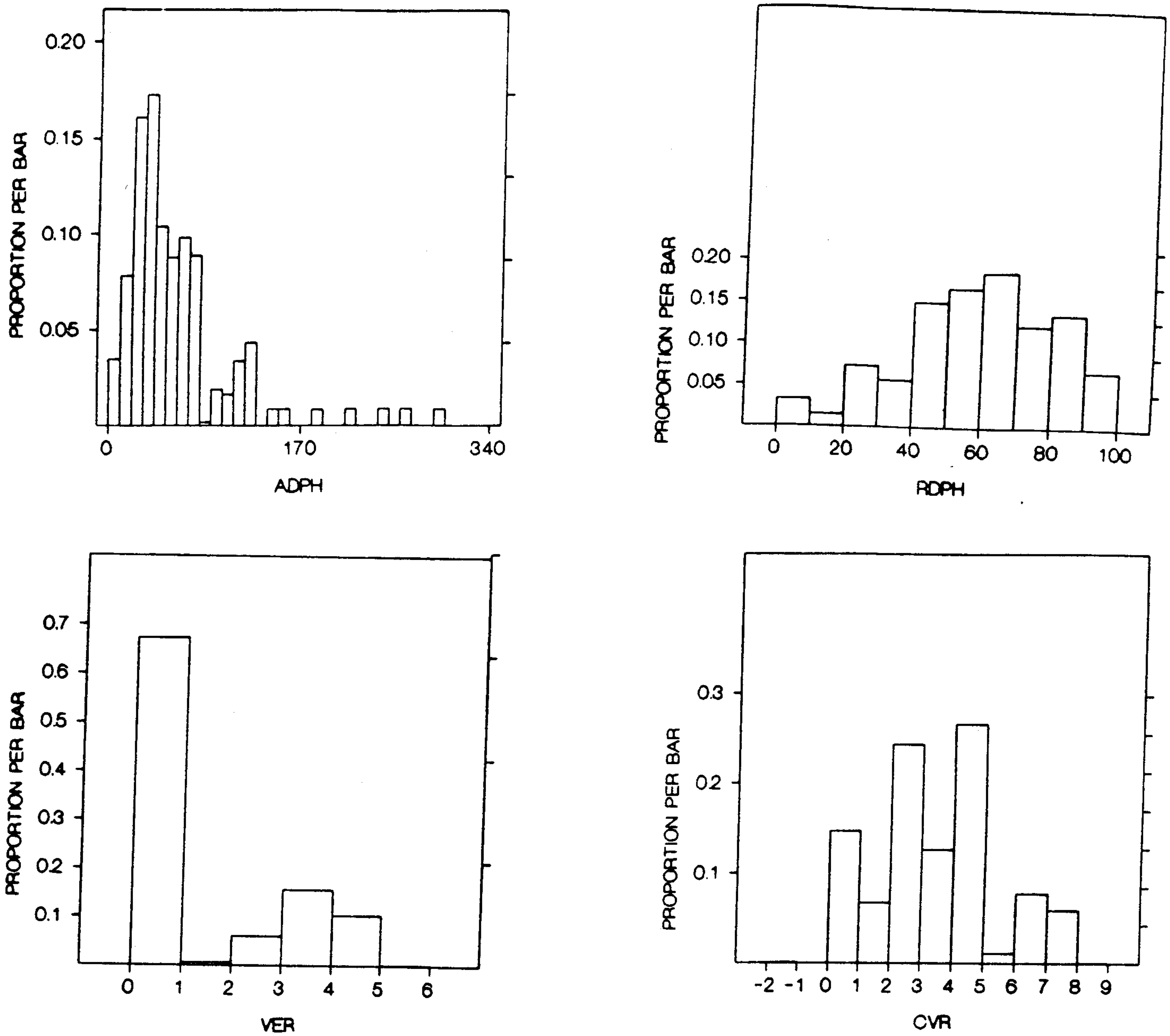


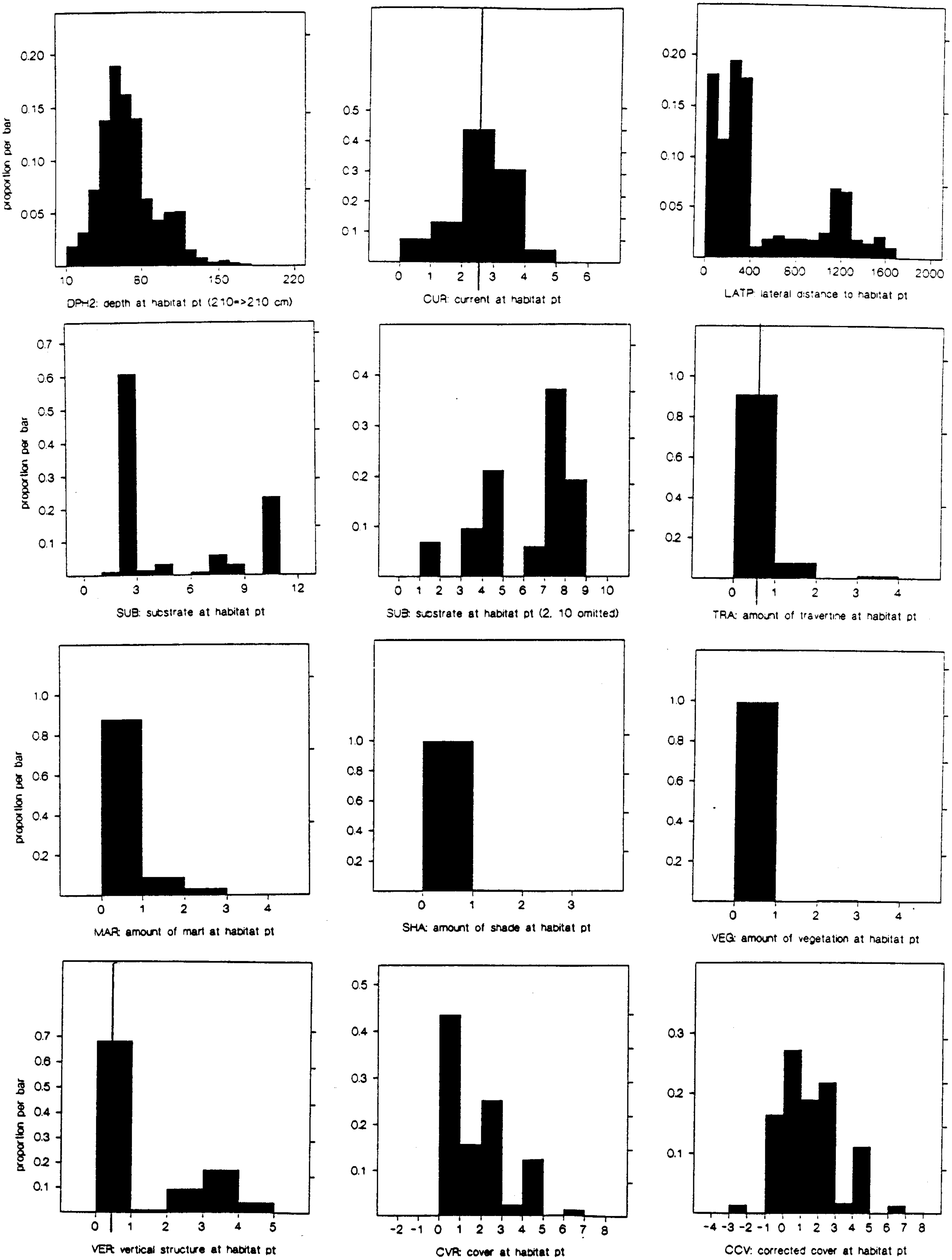
FIGURE 4. USFWS fish habitat studies, Powell Study Area, 6/92: Habitat use by HBC and SPD for day and night sampling periods.

Shown are weighted habitat use distributions for HBC and SPD.

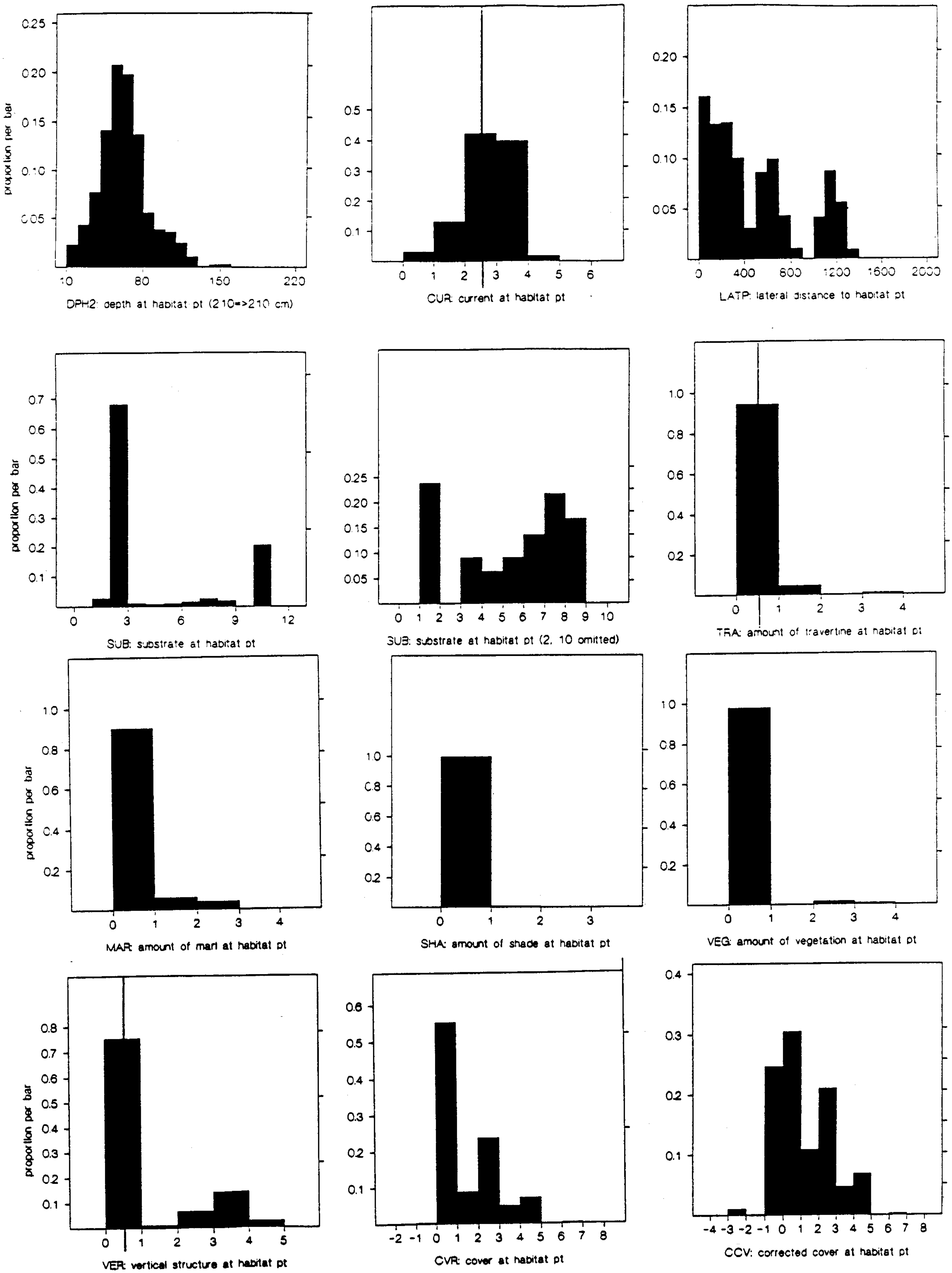
Habitat variables shown:
DPH2, CUR, LATP, SUB, TRA, MAR, SHA, VEG, VER, CVR, CCV.

Consult Table 1 for explanation of habitat variable codes.

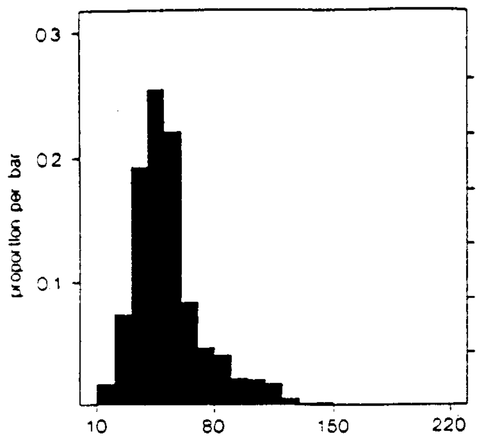
HBC habitat use (day): FWS/Powell 6/92

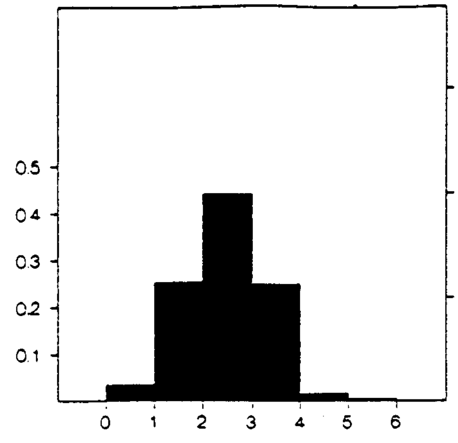


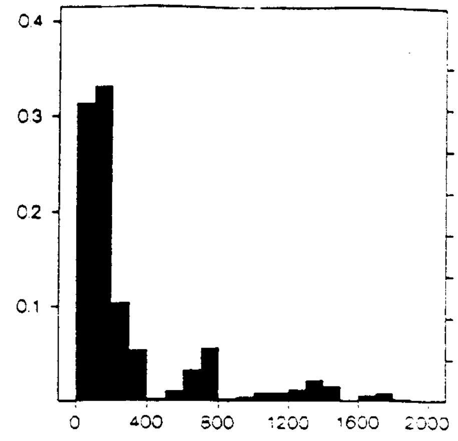
HBC habitat use (night): FWS/Powell 6/92

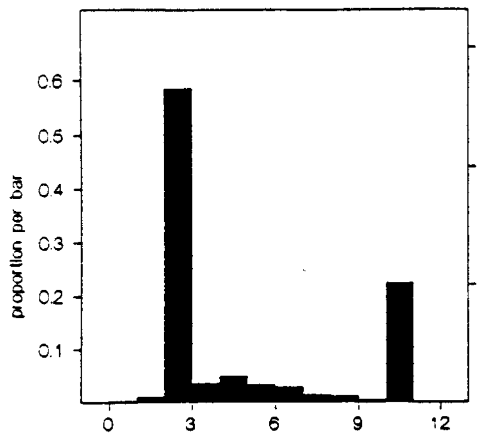


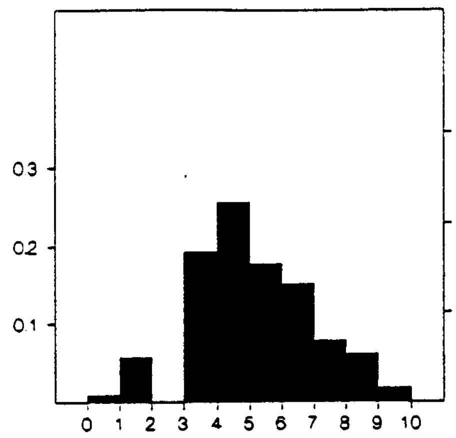
SPD habitat use (night) FWS/Powell 6/92

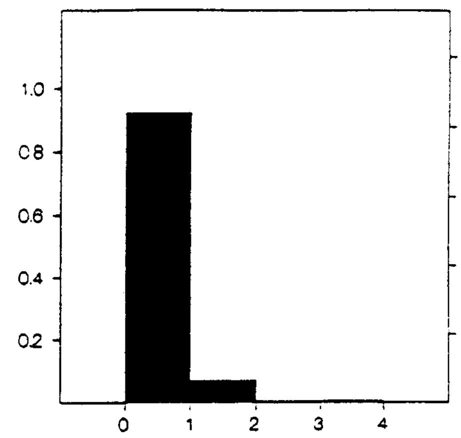


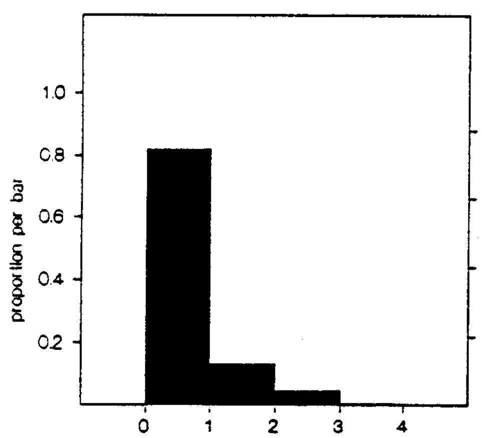


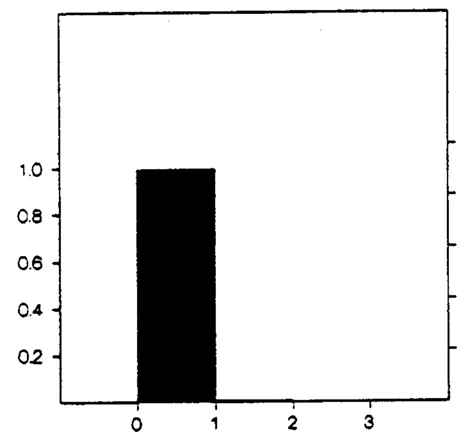


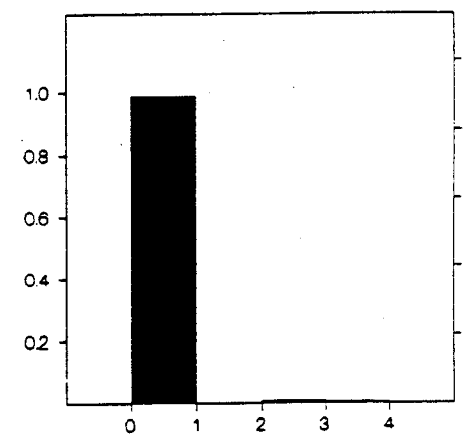


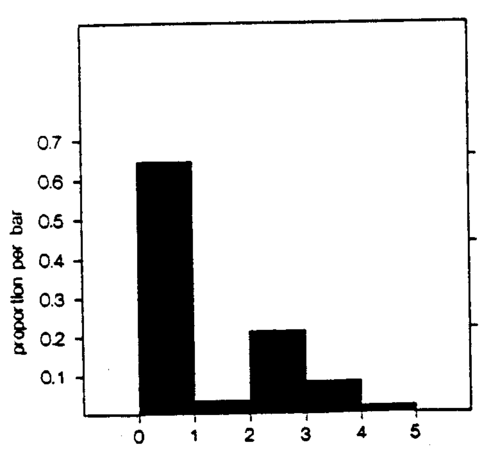


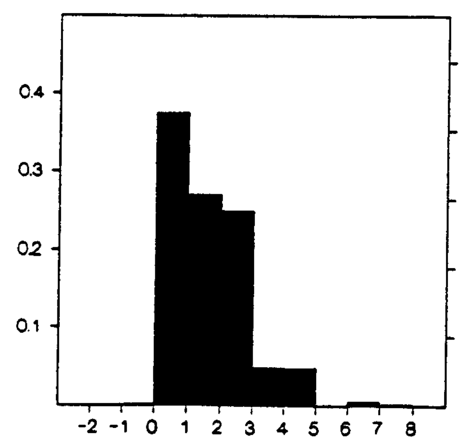


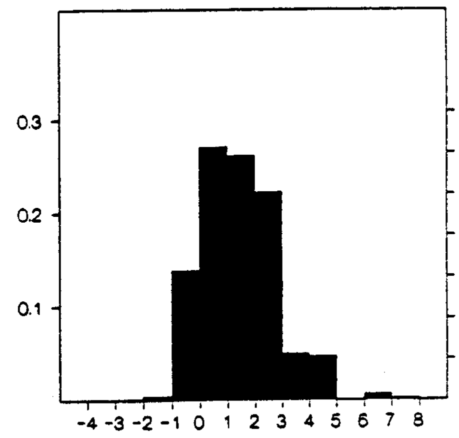












SFD habitat use (day): FWS/Powell 6/92

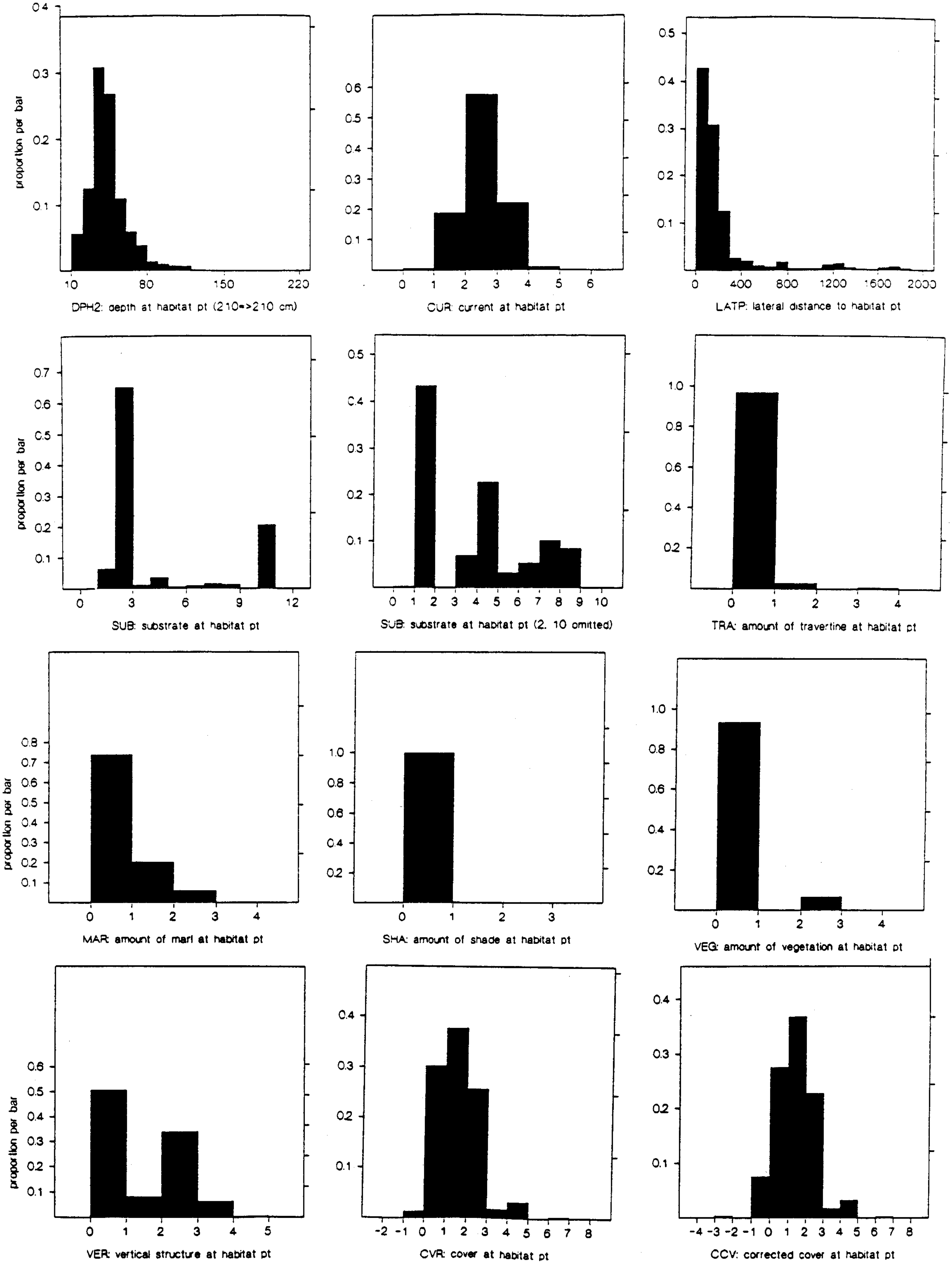


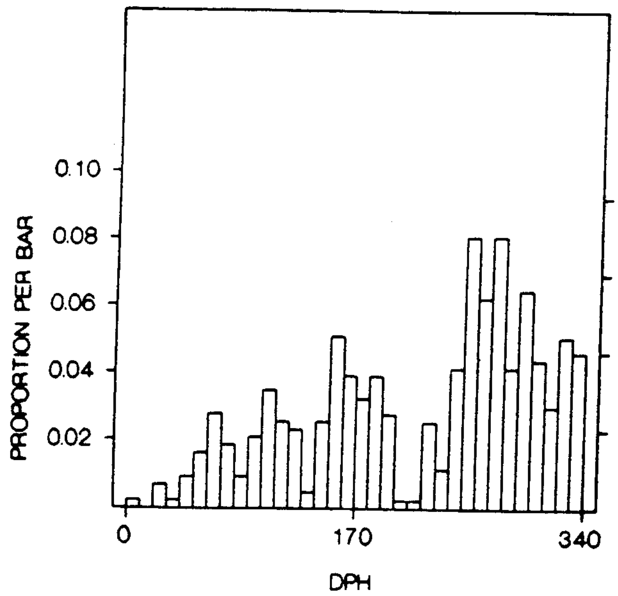
FIGURE 5. USFWS fish habitat studies, Powell Study Area, 6/93: Habitat use by HBC and SPD for day and night sampling periods.

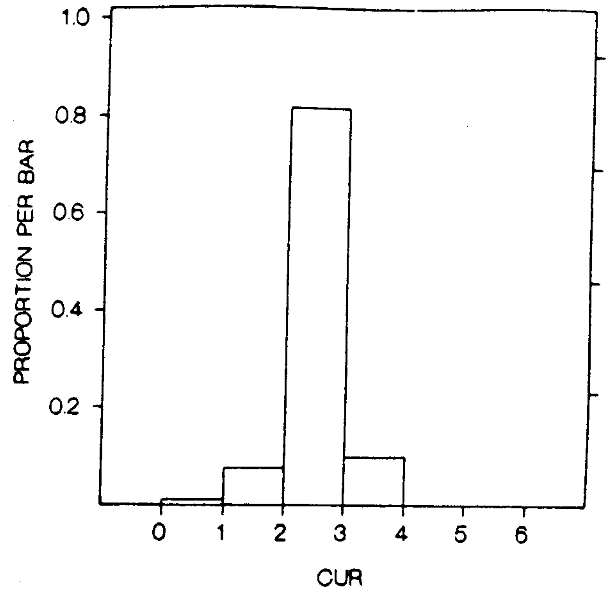
Shown are weighted habitat use distributions for HBC and SPD.

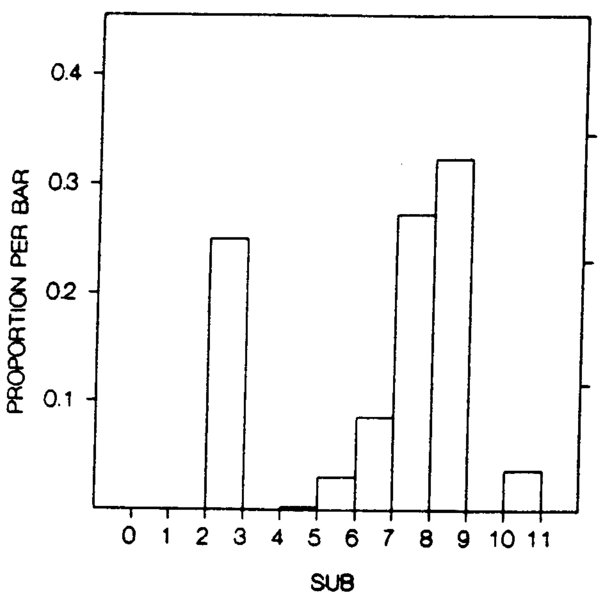
Habitat variables shown:
DPH, CUR, SUB, LATP, ADPH, RDPH, VER, CVR

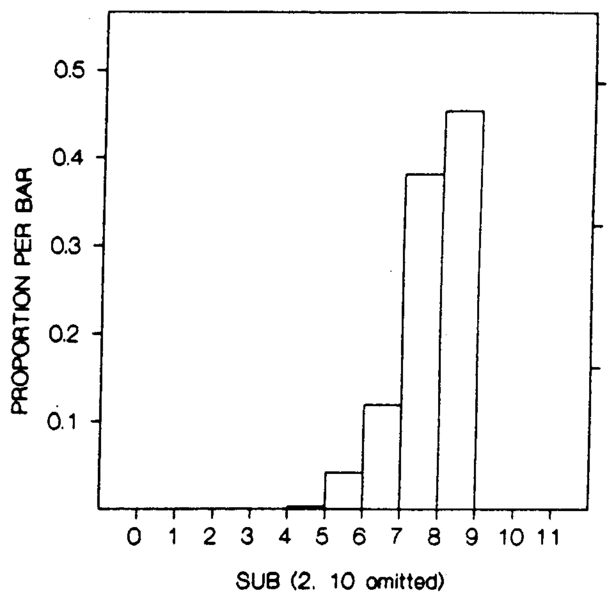
Consult Table 1 for explanation of habitat variable codes.

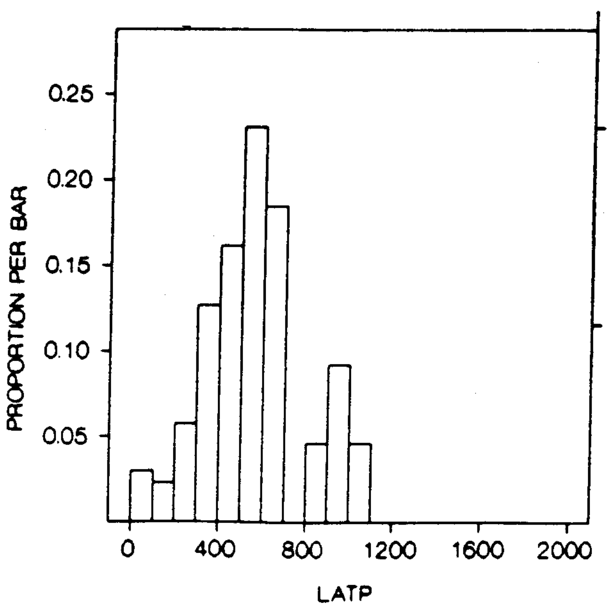
HBC habitat use (day): LCR - Powell 6/93



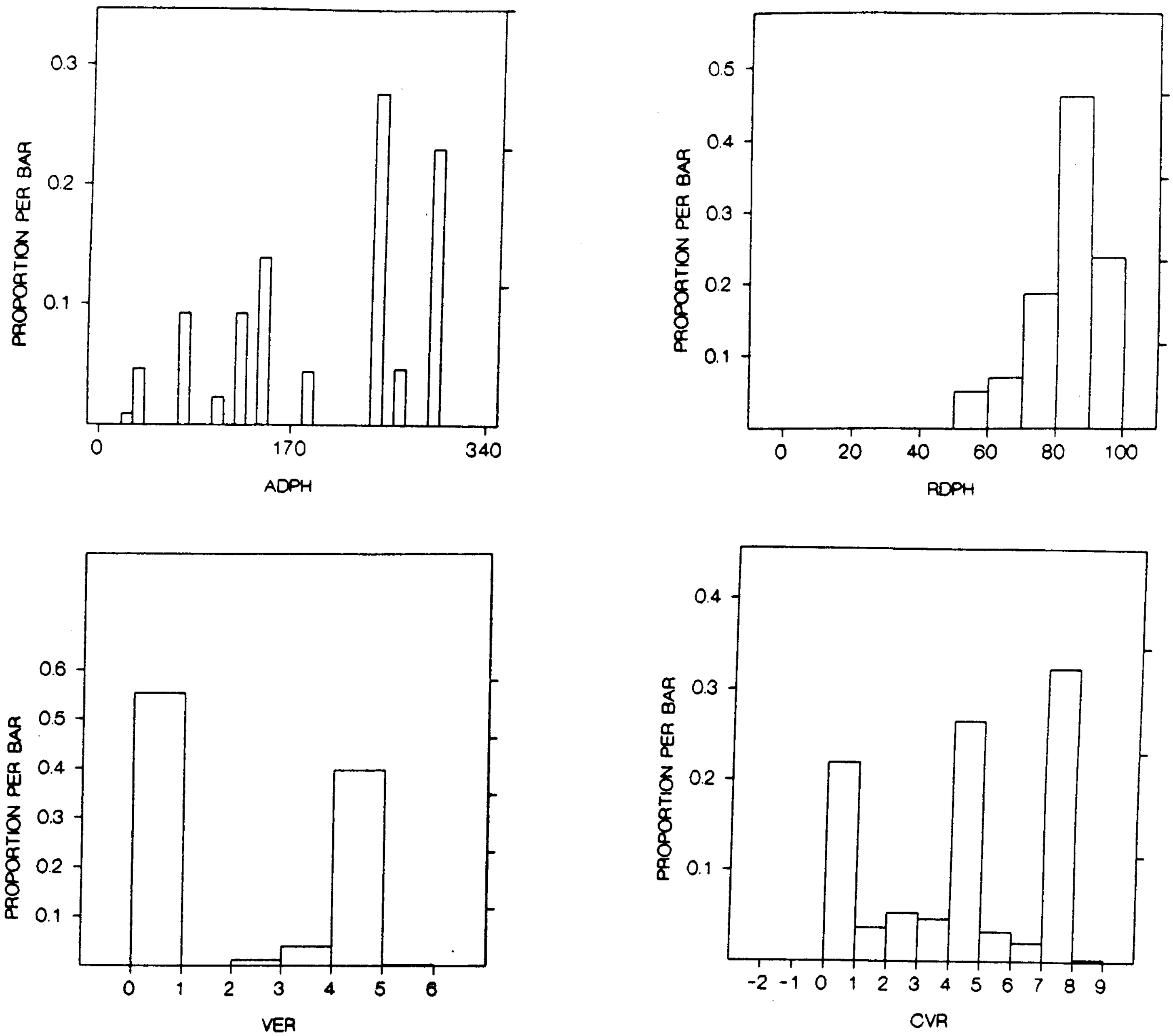




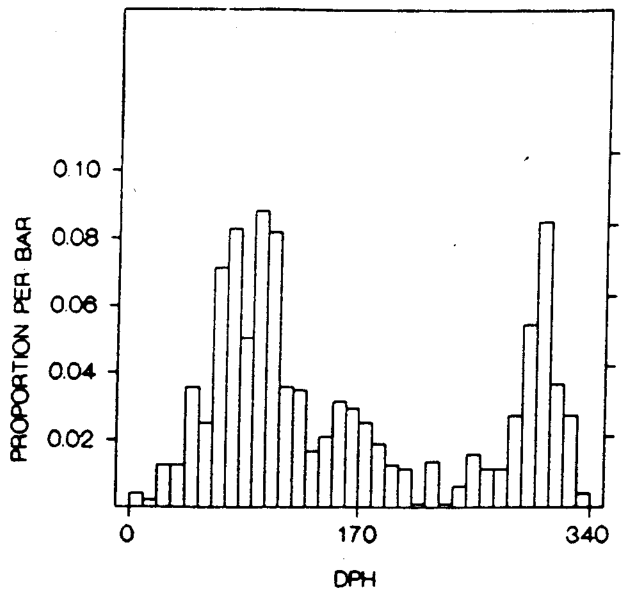


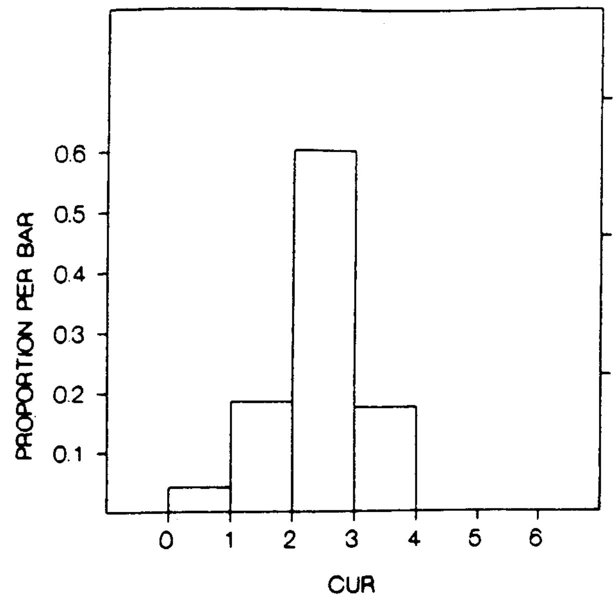


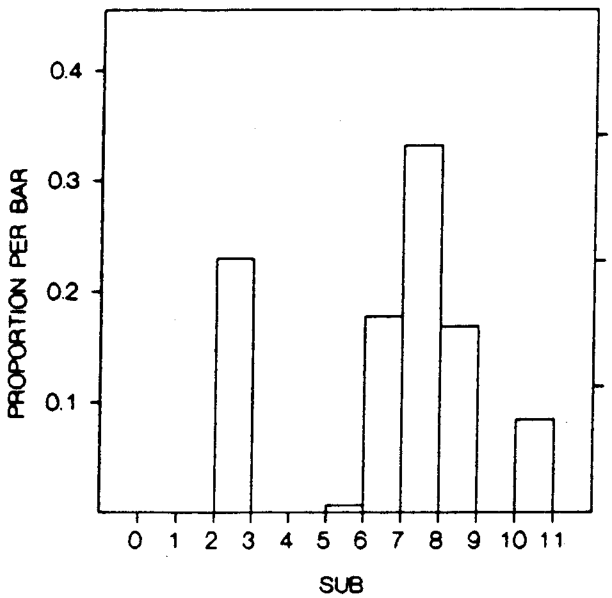
HBC habitat use (day): LCR - Powell 6/93

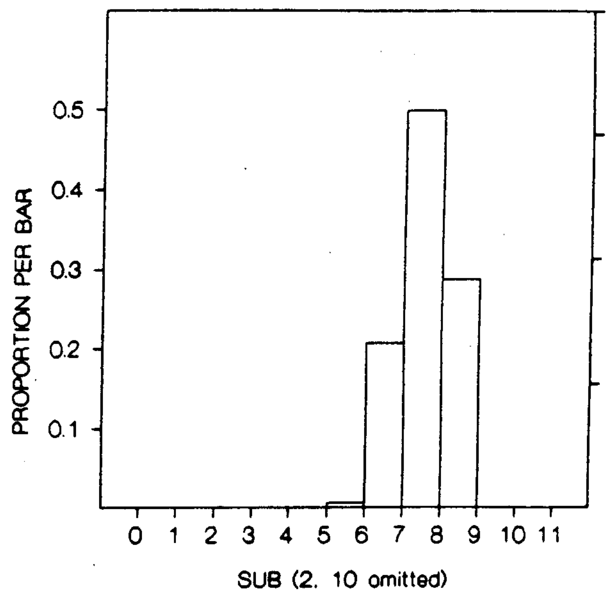


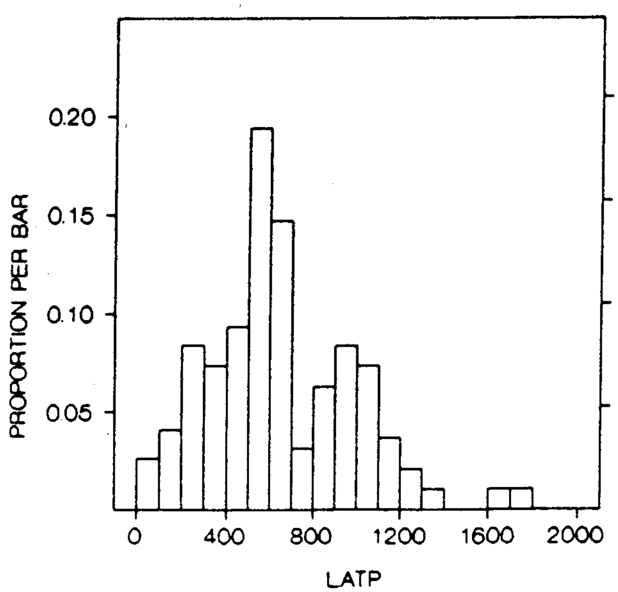
HBC habitat use (night): LCR - Powell 6/93



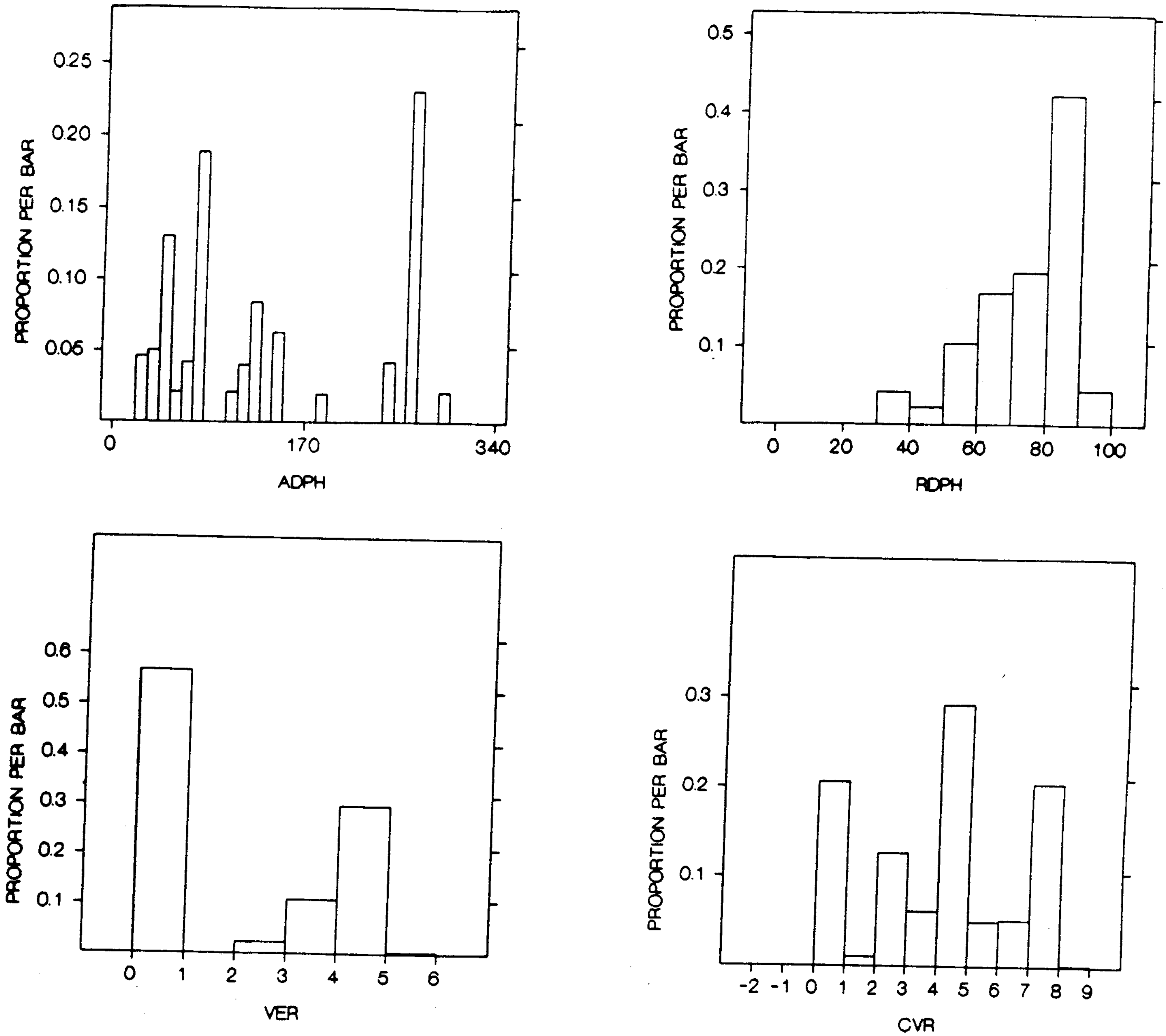




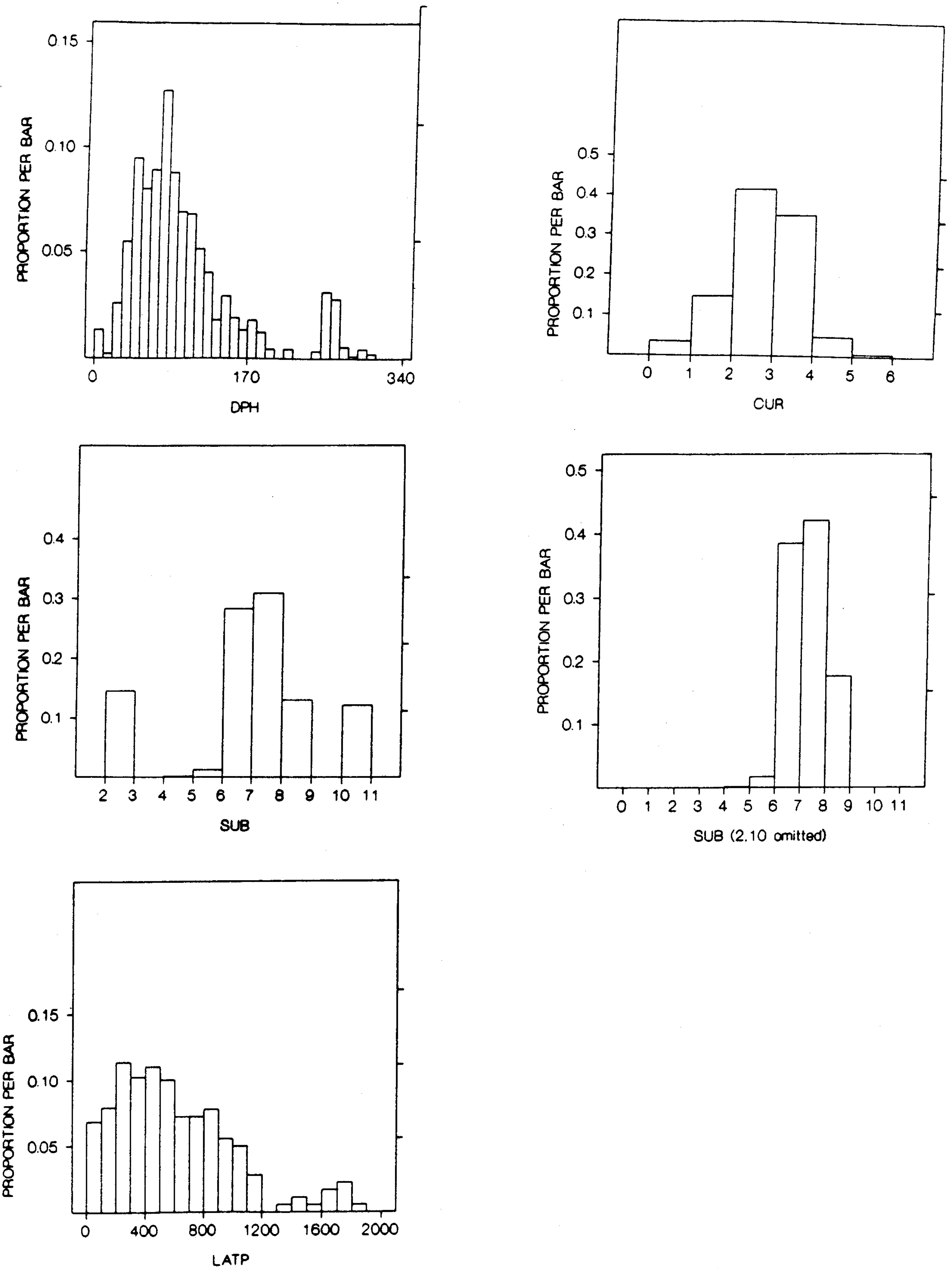




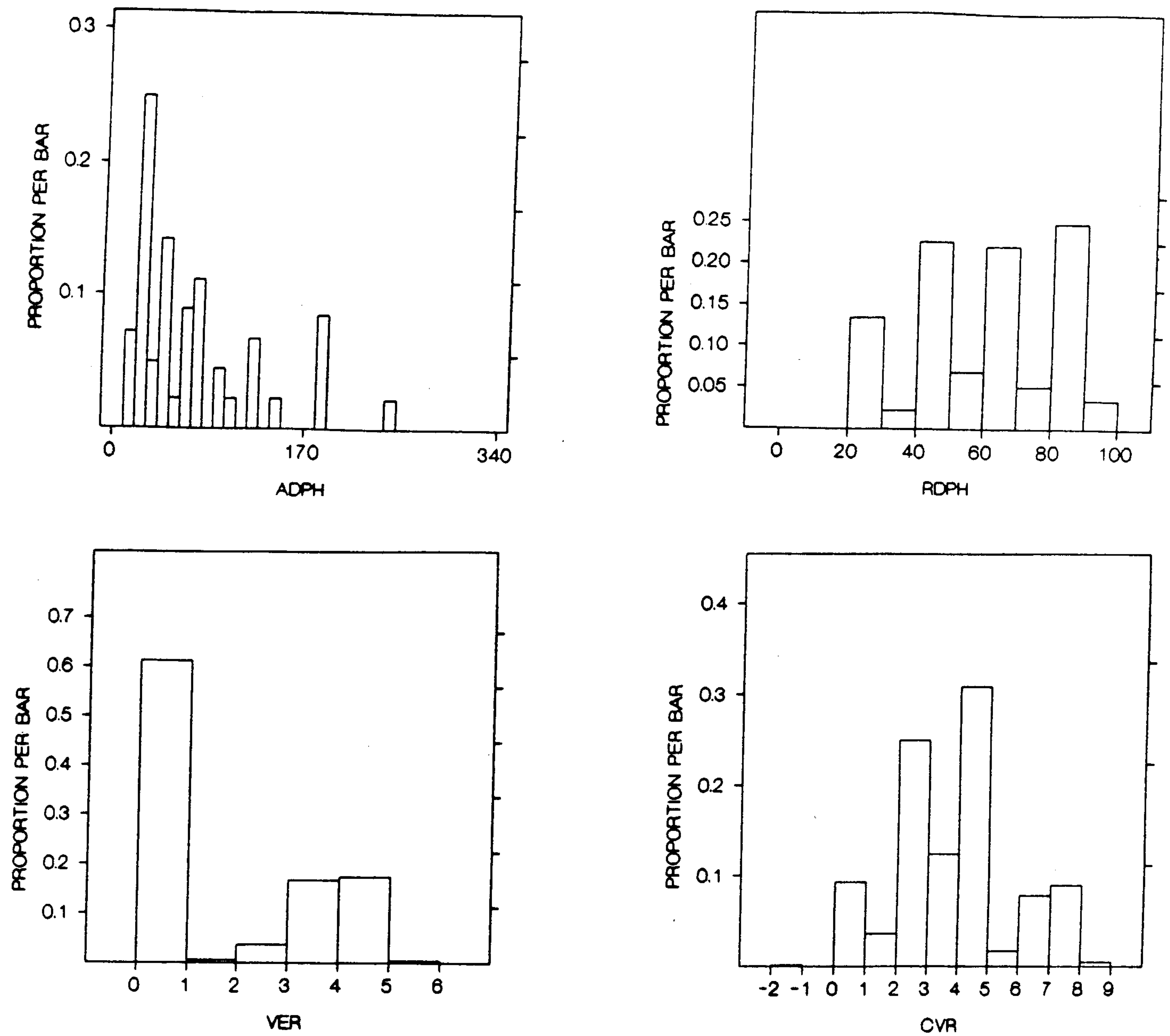
HBC habitat use (night): LCR - Powell 6/93



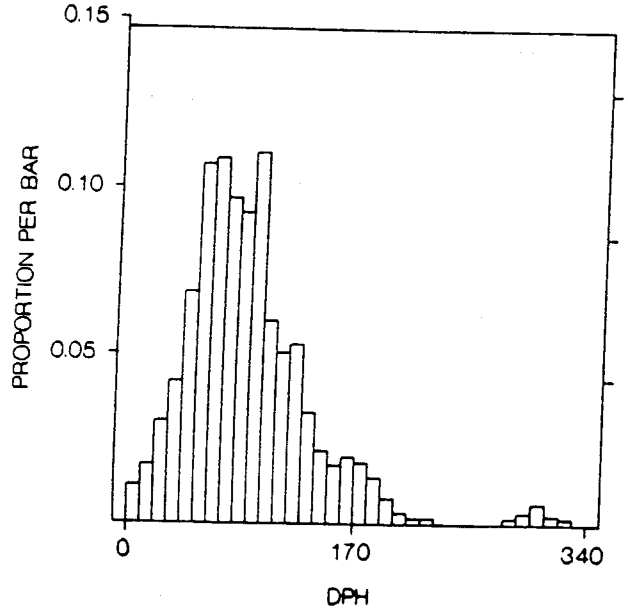
SPD habitat use (day): LCR - Powell 6/93

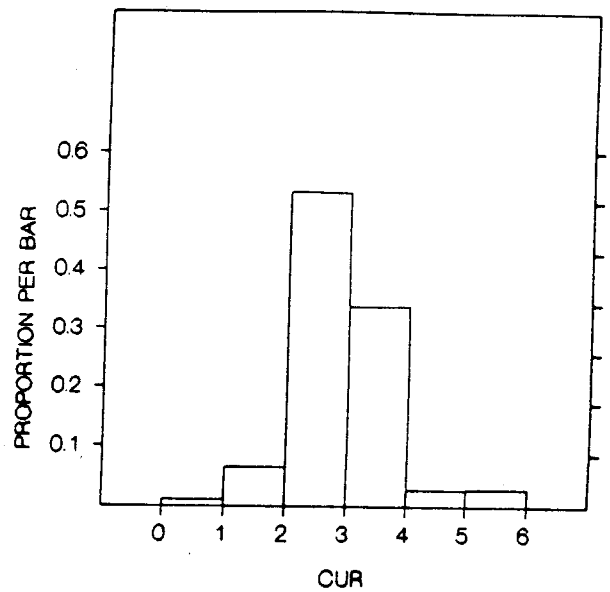


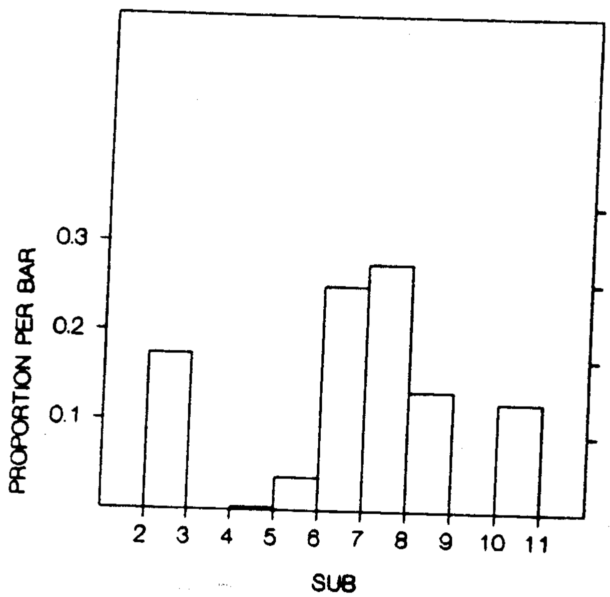
SPD habitat use (day): LCR - Powell 6/93

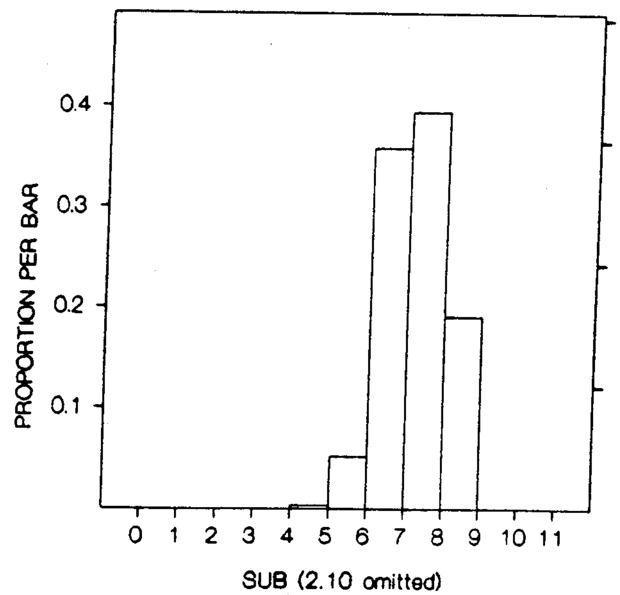


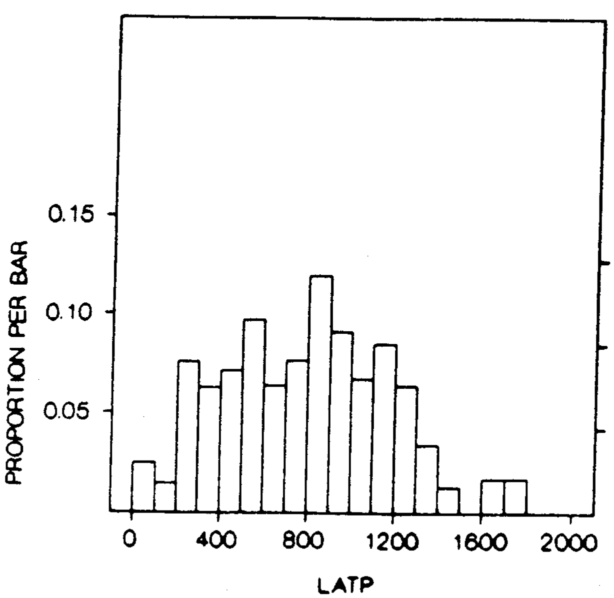
SPD habitat use (night): LCR - Powell 6/93











SPD habitat use (night): LCR - Powell 6/93

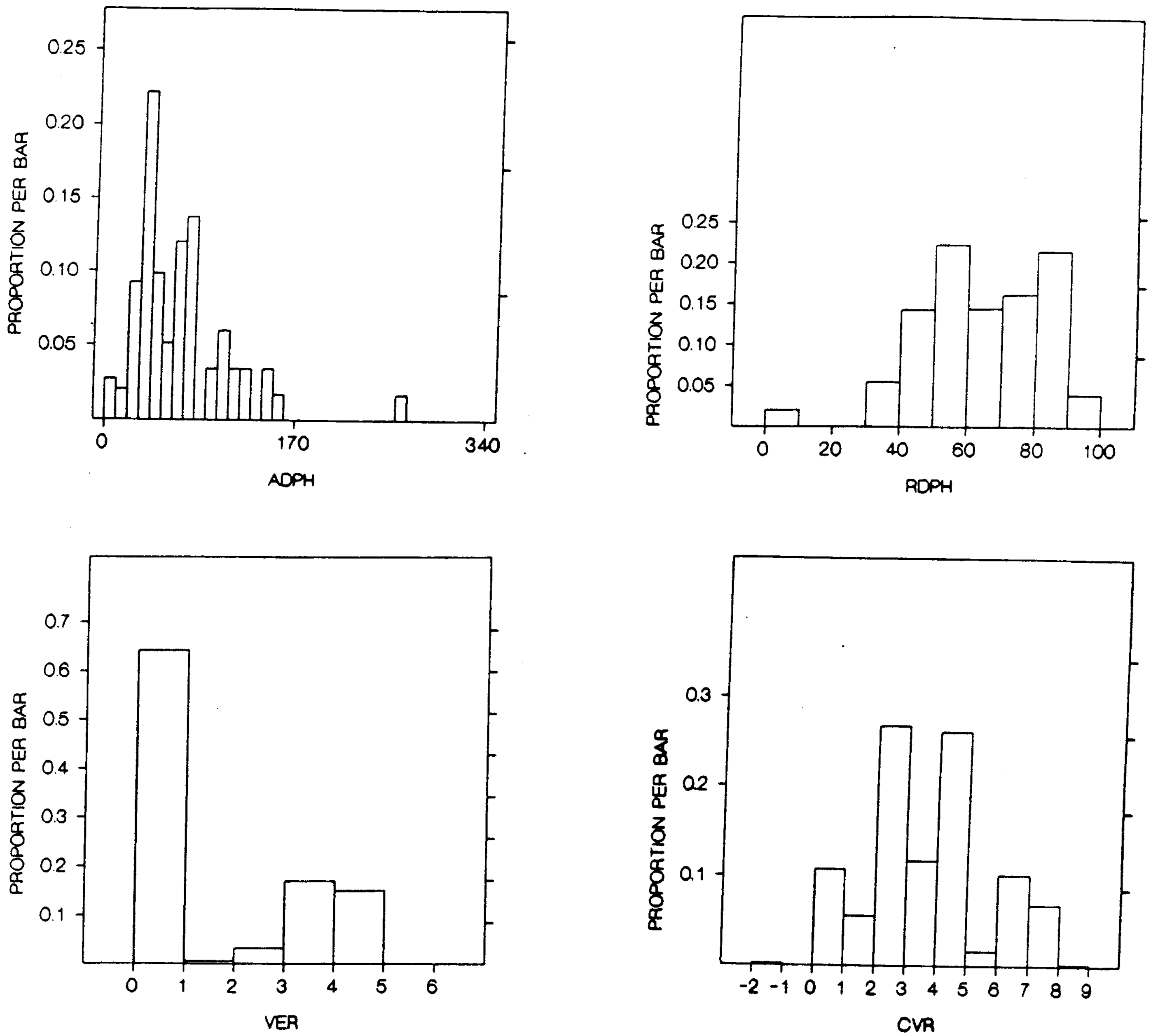


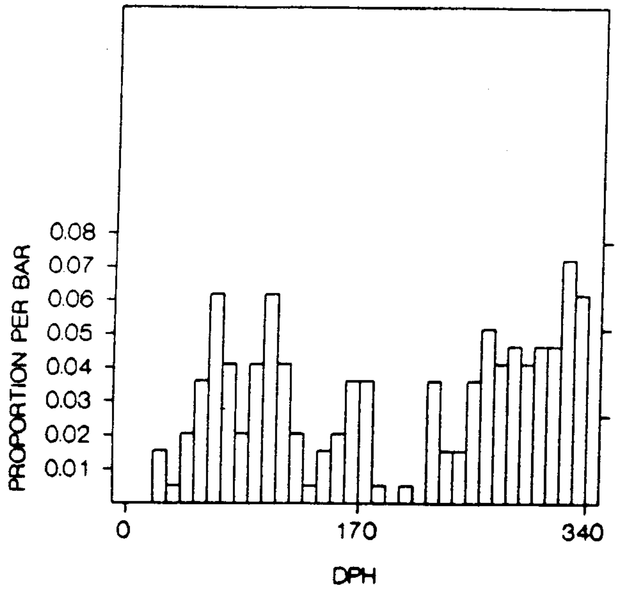
FIGURE 6. USFWS fish habitat studies, Powell Study Area, 6/93: Habitat use by subadult and adult HBC for day and night sampling periods.

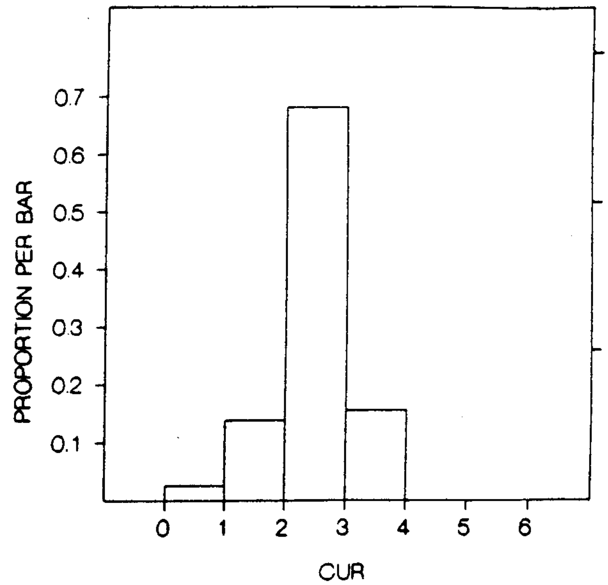
Shown are weighted habitat use distributions for sub adult and adult HBC. Subadult fish (100-150mm TL) represent 1991 year class humpback chub and adult fish (>150 mm TL) are larger individuals ranging from 151-375 mm TL.

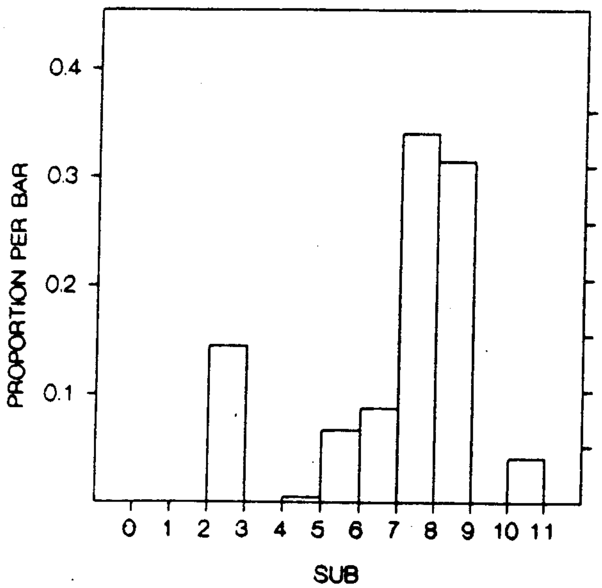
Habitat variables shown:
DPH, CUR, SUB, LATP, ADPH, RDPH, VER, CVR

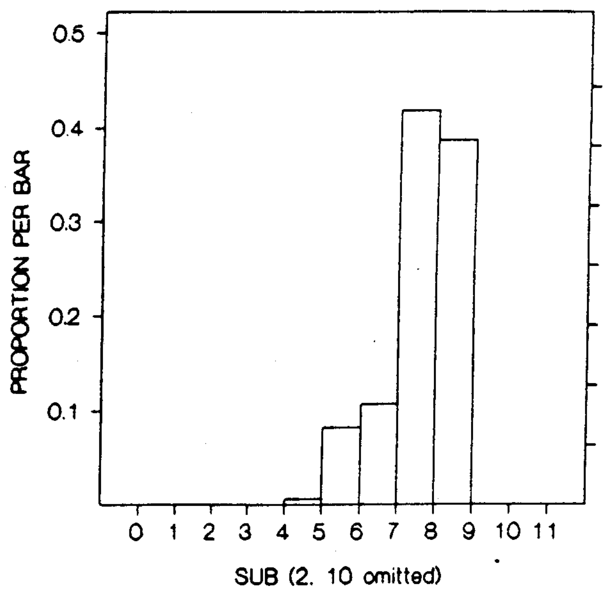
Consult Table 1 for explanation of habitat variable codes.

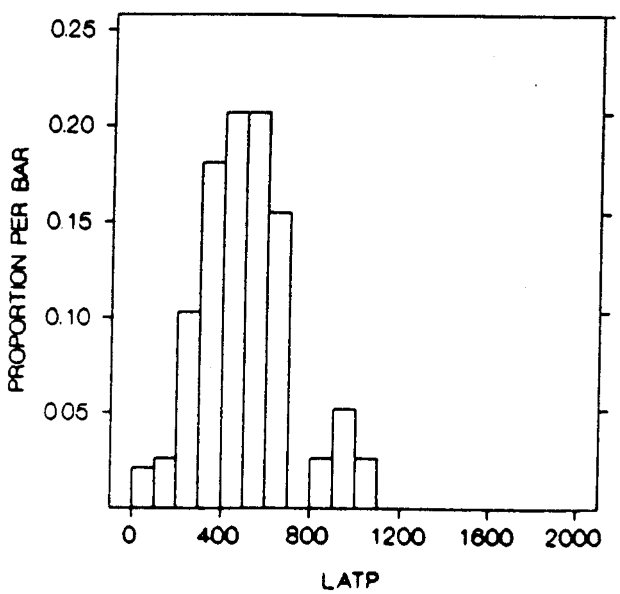
HBC subadult habitat use (day) LCR - Powell 6/93



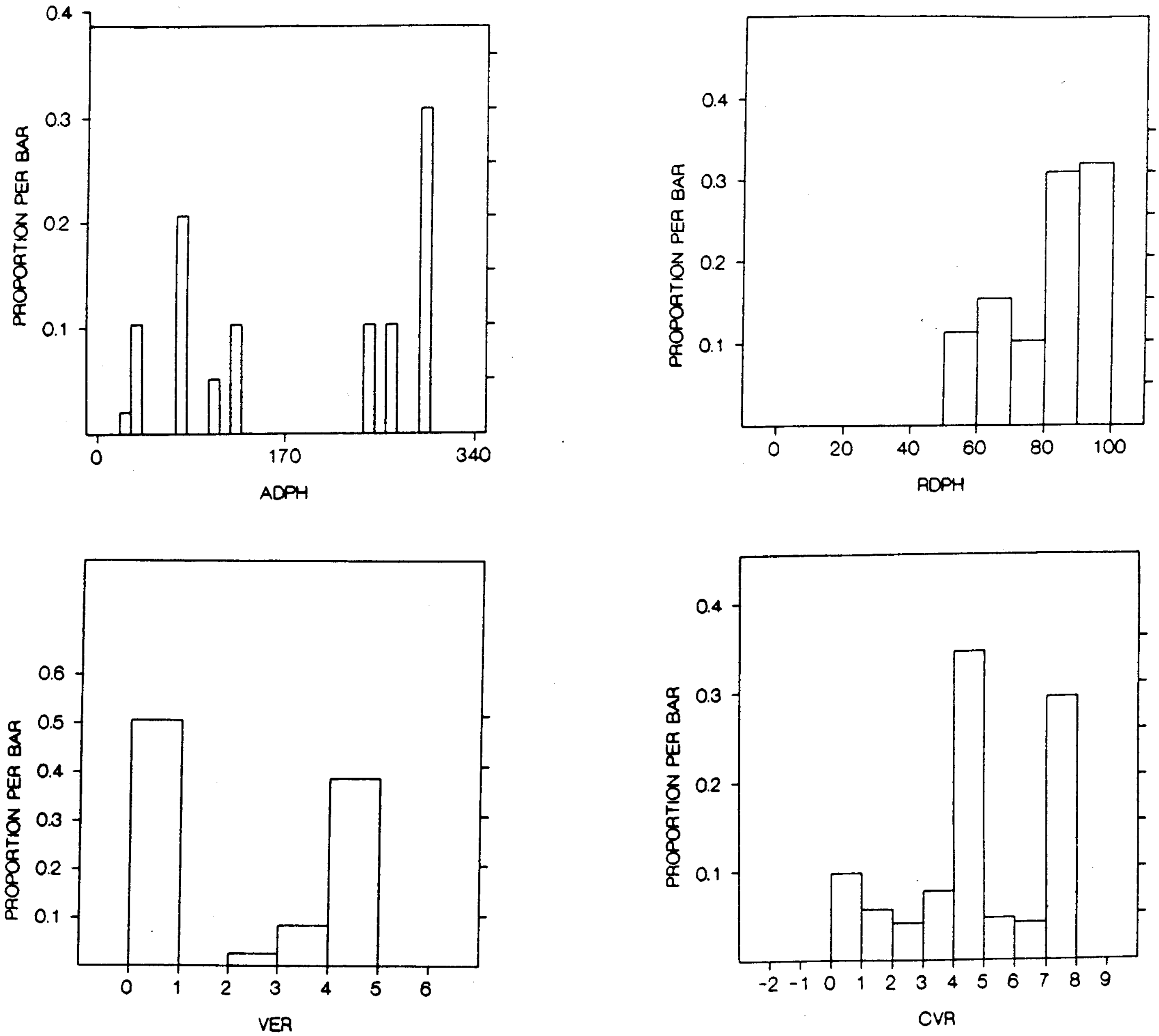




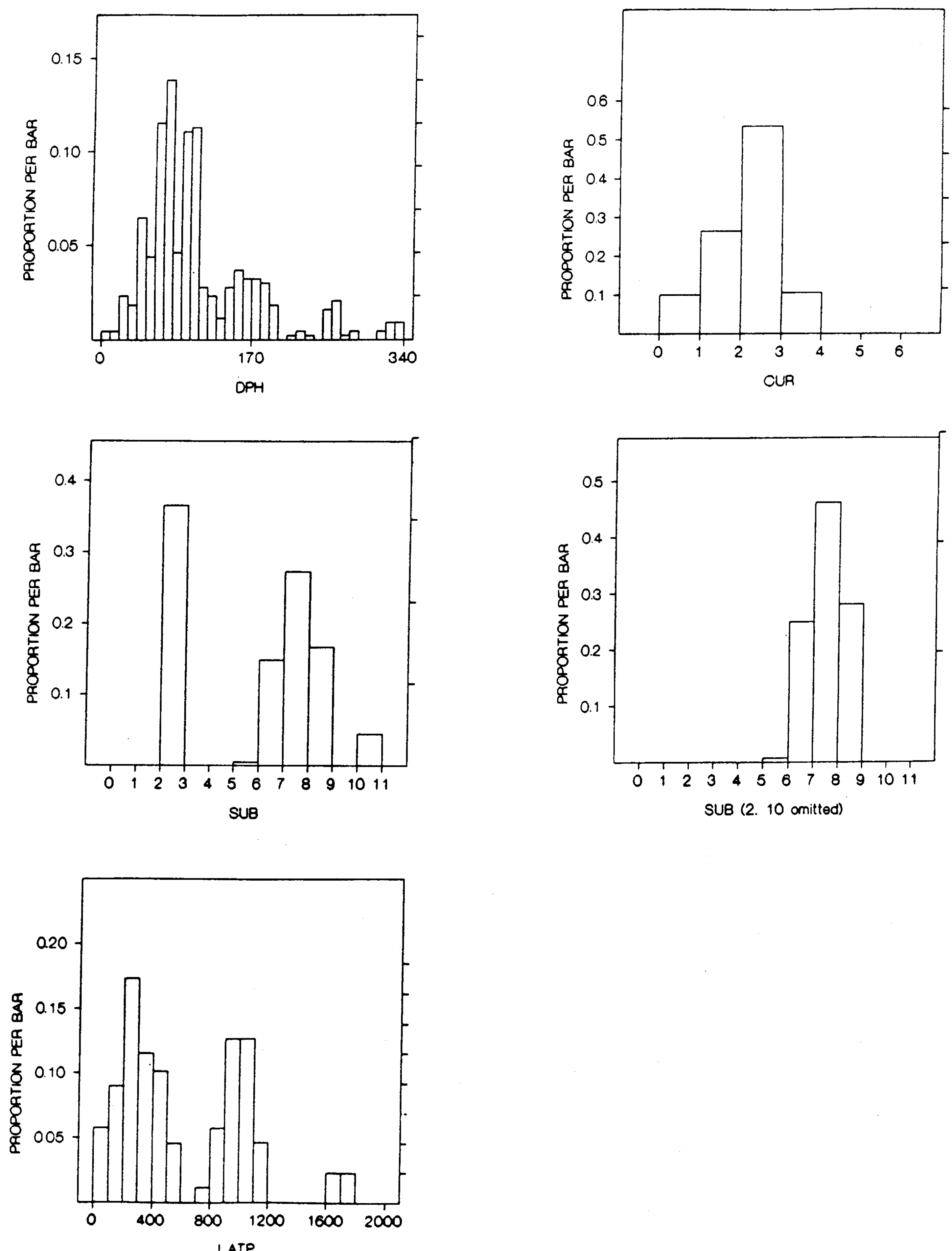




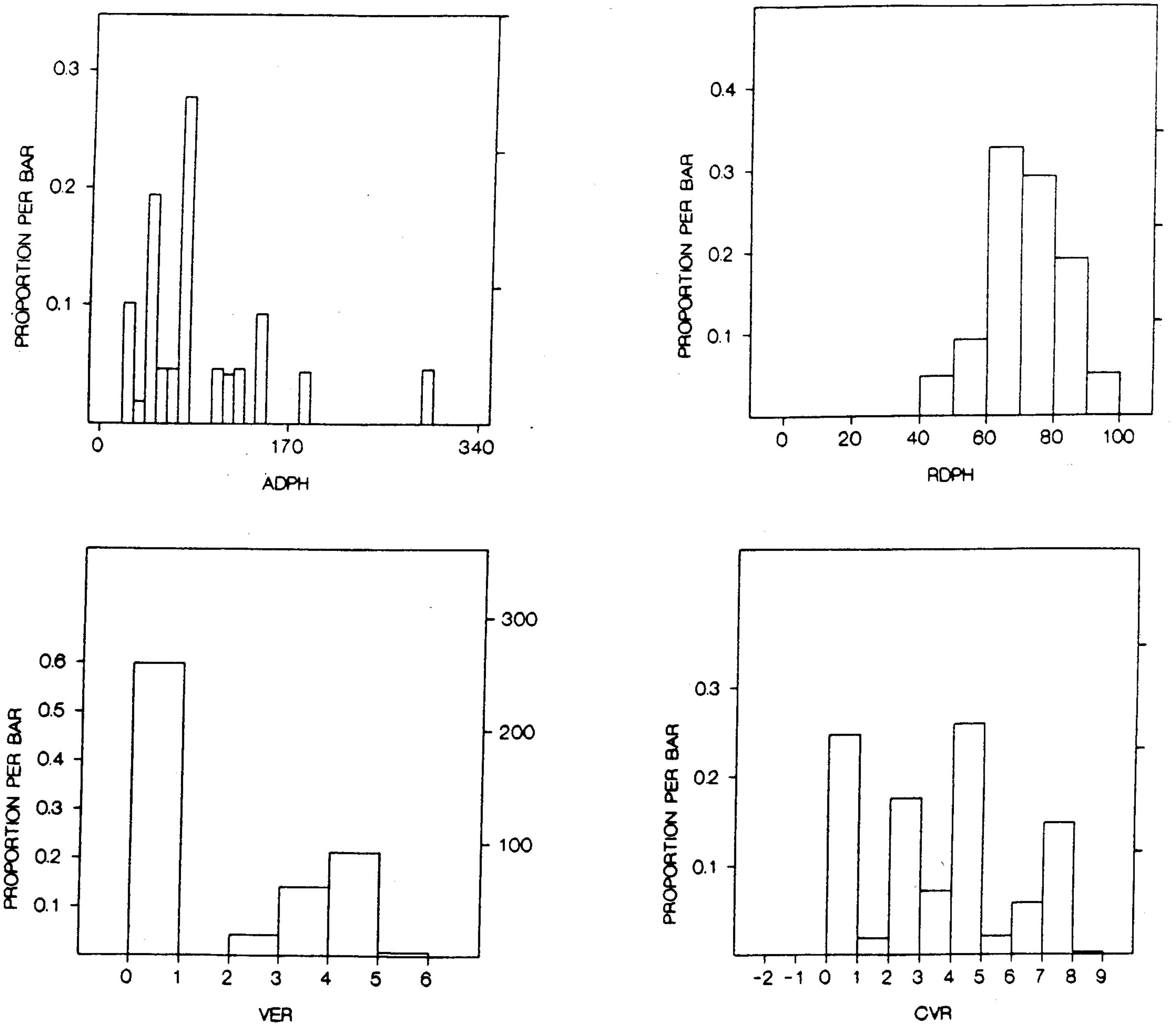
HBC subadult habitat use (day) LCR - Powell 6/93



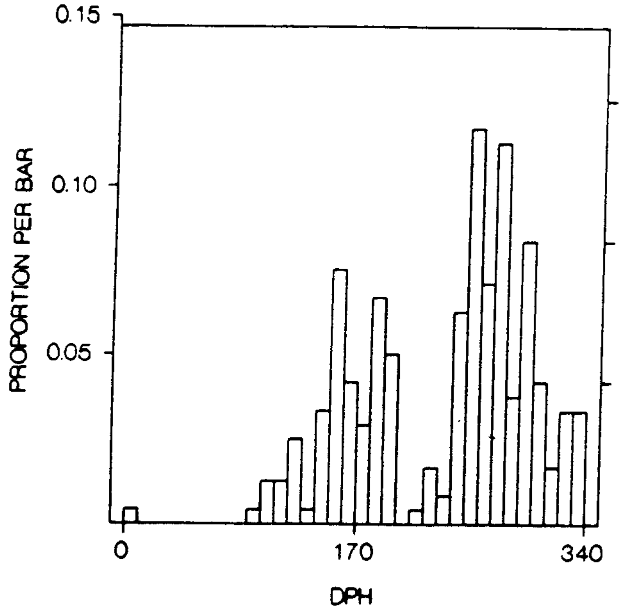
HBC subadult habitat use (night) LCR - Powell 6/93

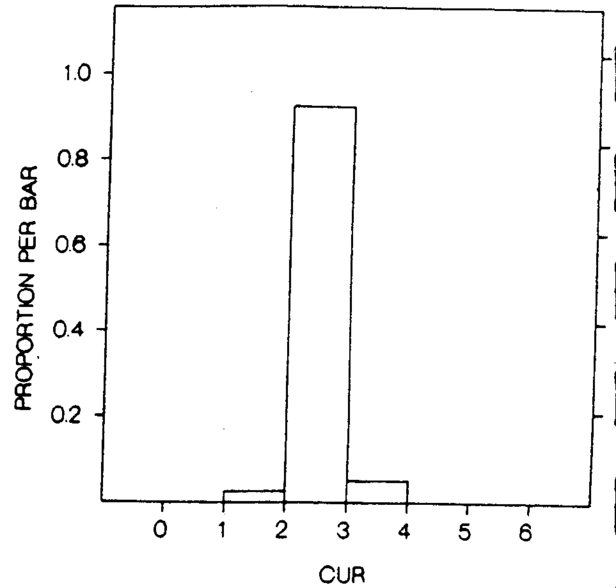


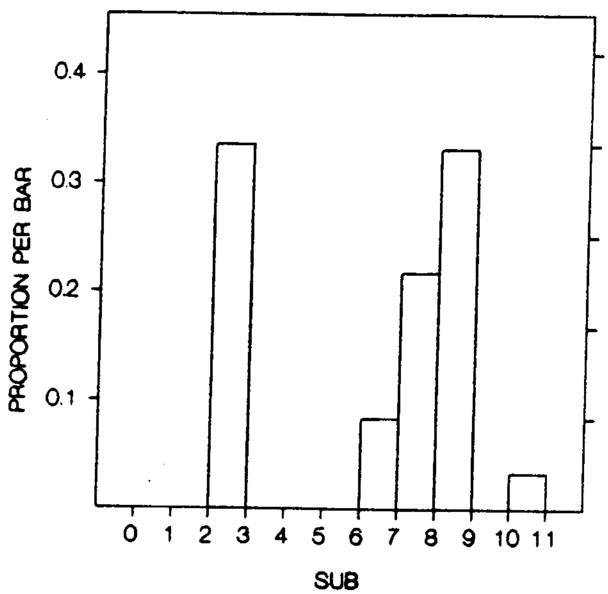
HBC subadult habitat use (night) LCR - Powell 6/93

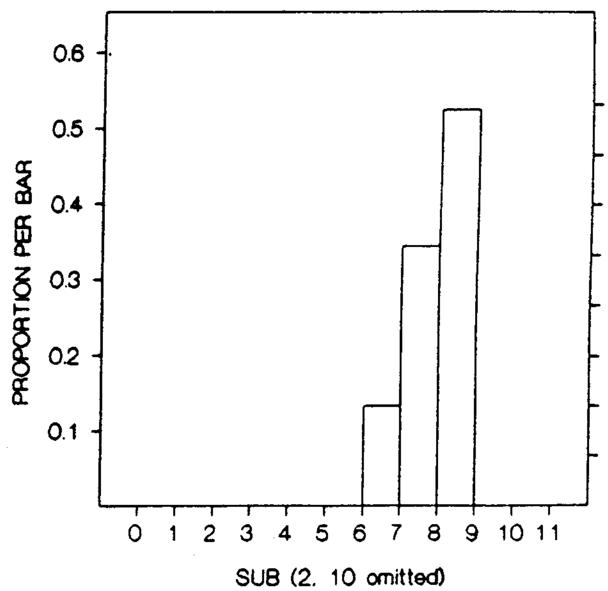


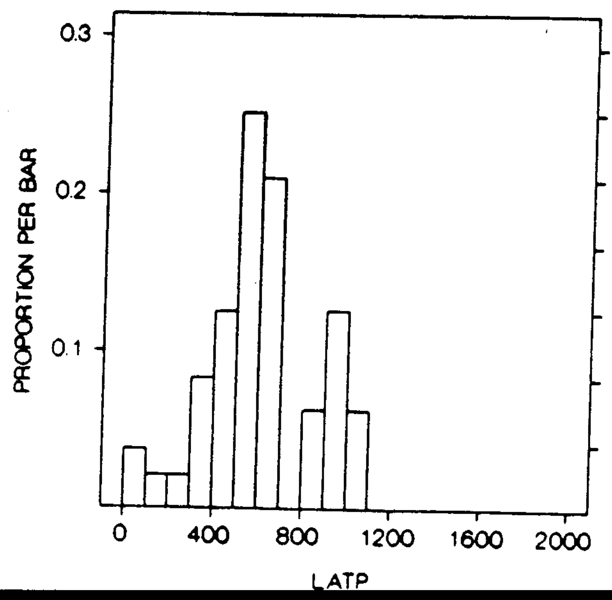
HBC adult habitat use (day) LCR - Powell 6/93



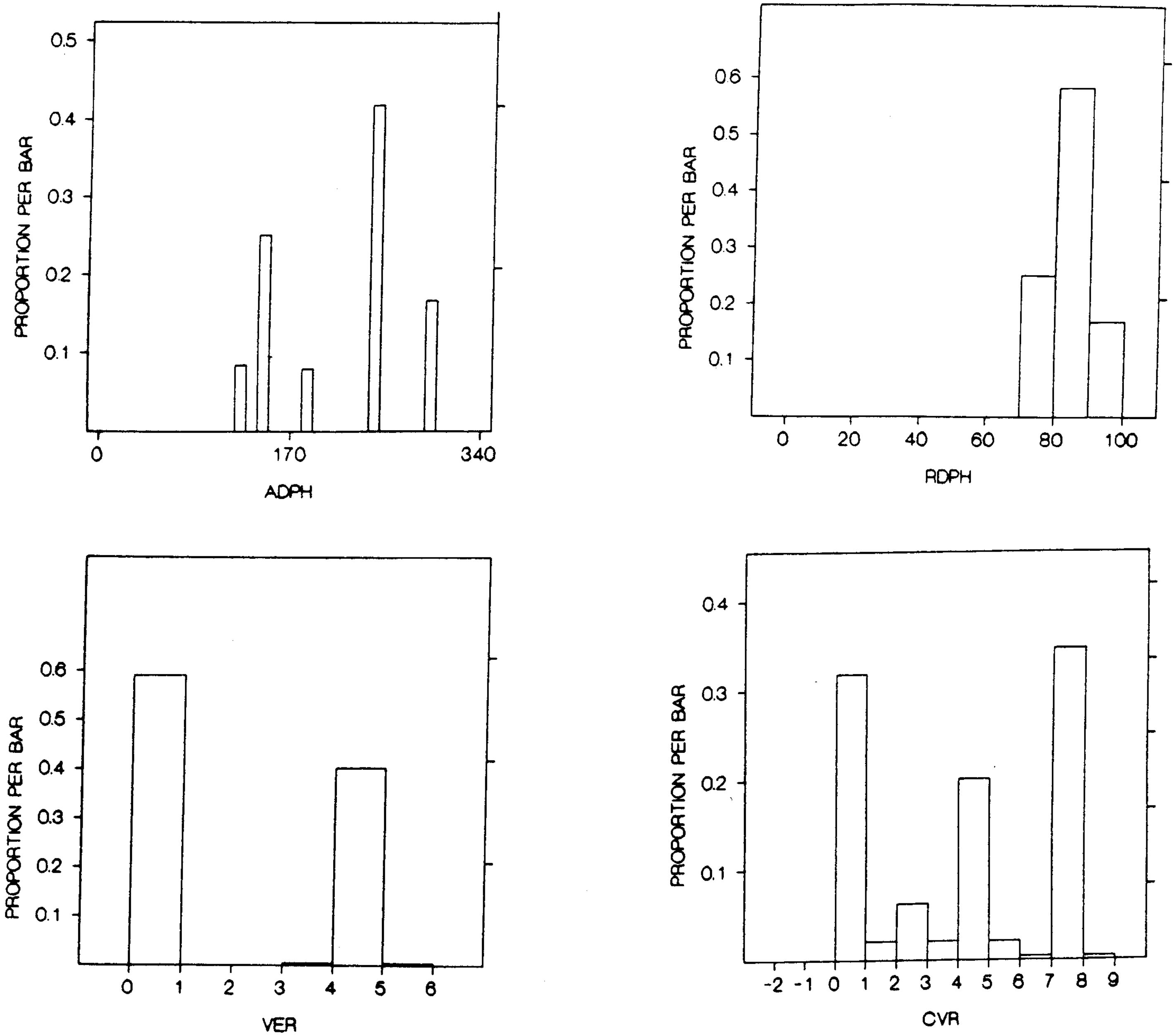




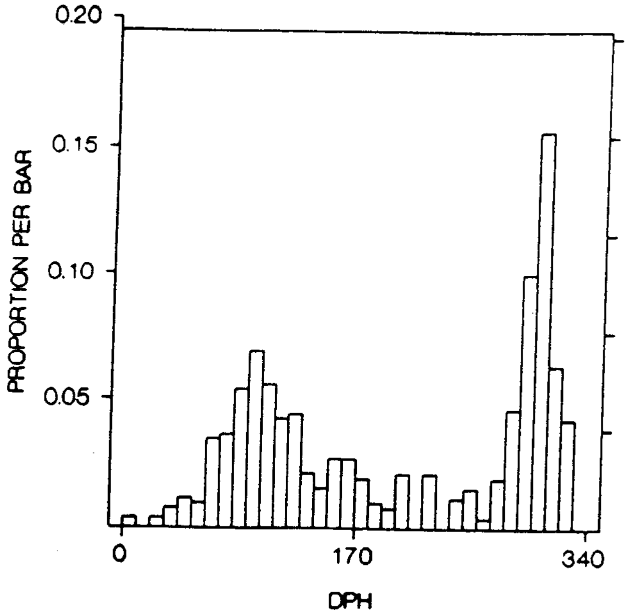


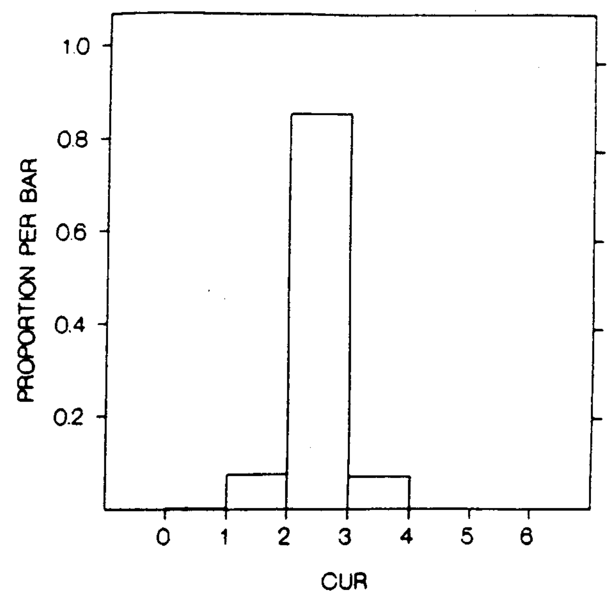


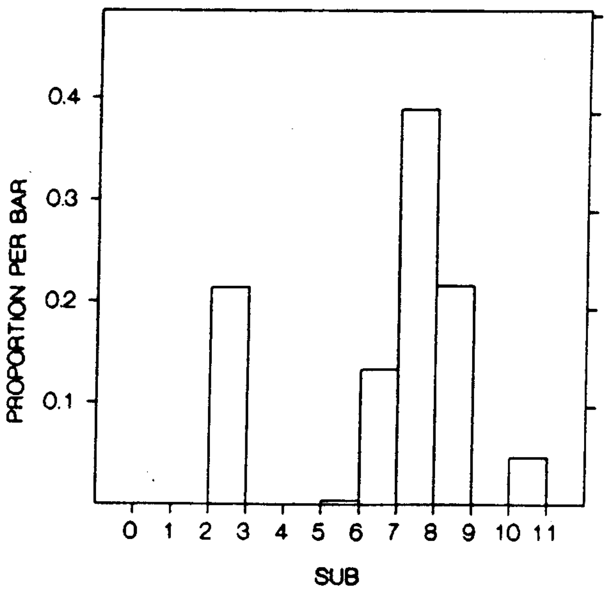
HBC adult habitat use (day) LCR - Powell 6/93

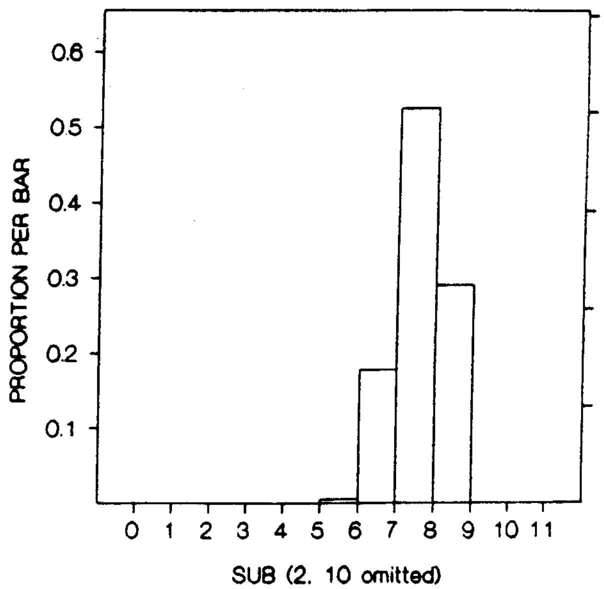


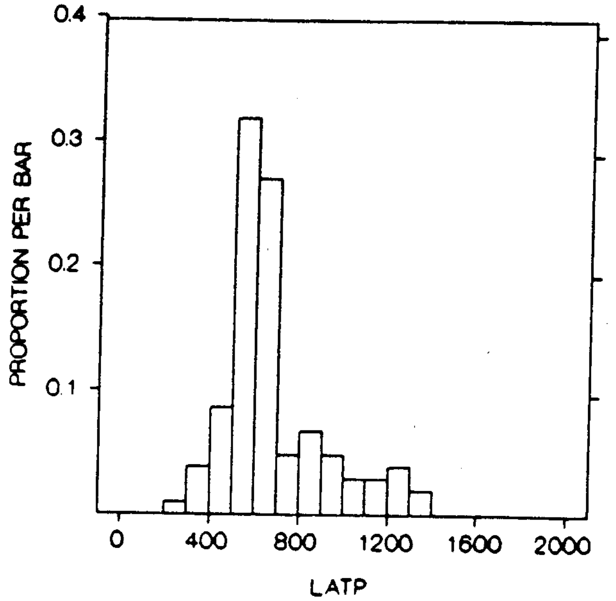
HBC adult habitat use (night) LCR - Powell 6/93











HBC adult habitat use (night) LCR - Powell 6/93

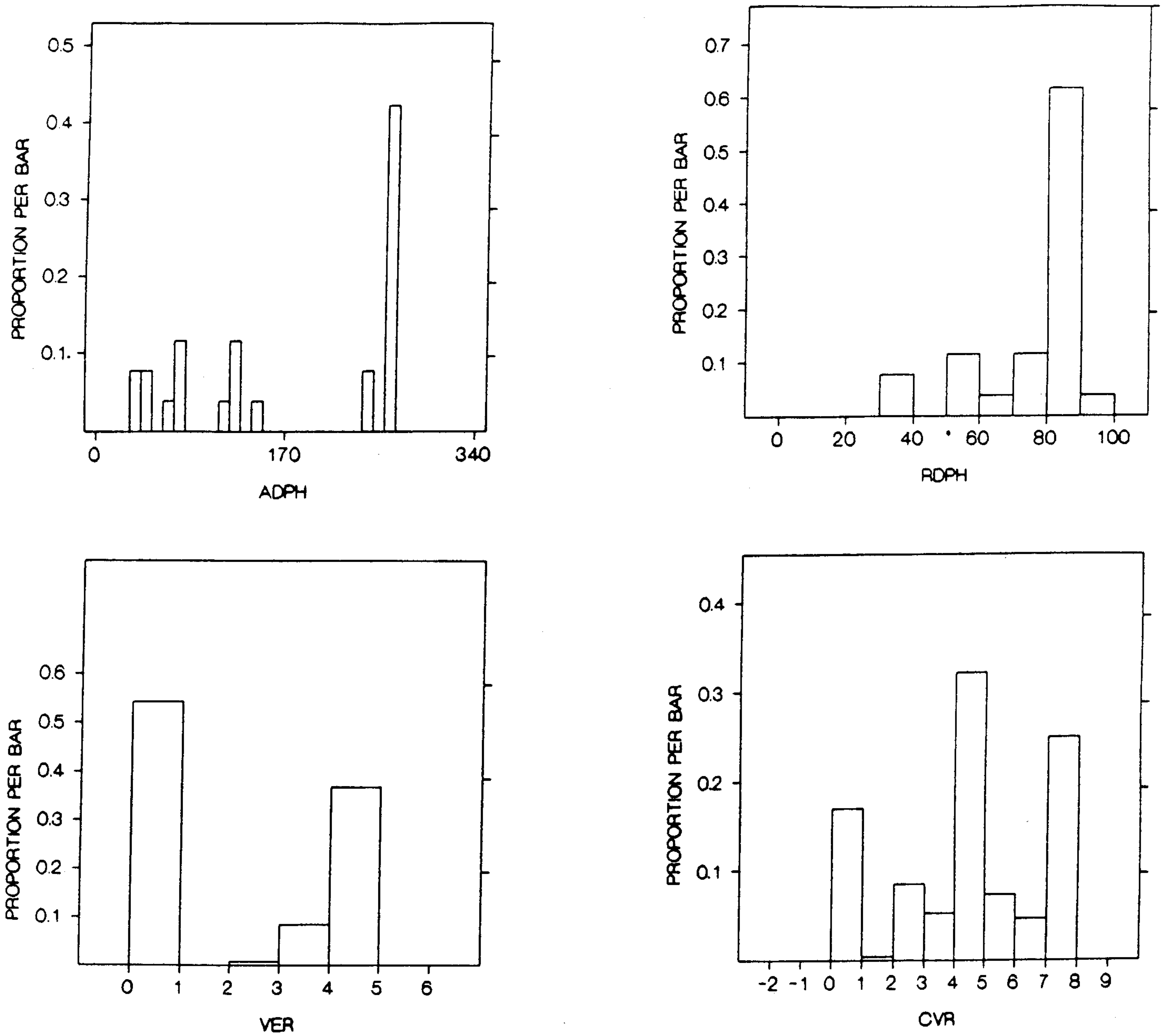


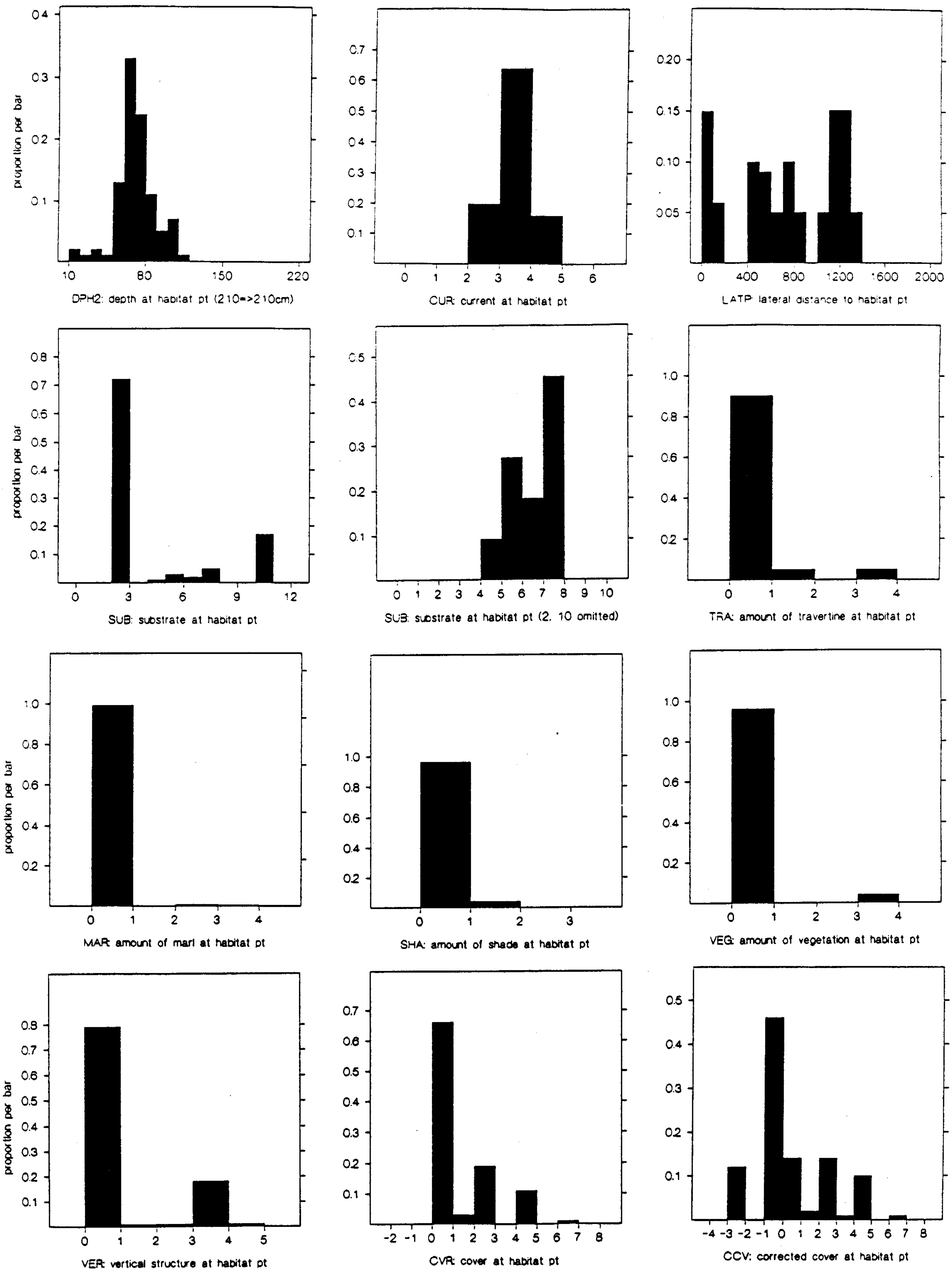
FIGURE 7. USFWS fish habitat studies, Powell Study Area, 6/92: Habitat use by BHS and FMS for day and night sampling periods.

Shown are weighted habitat use distributions for BHS and FMS.

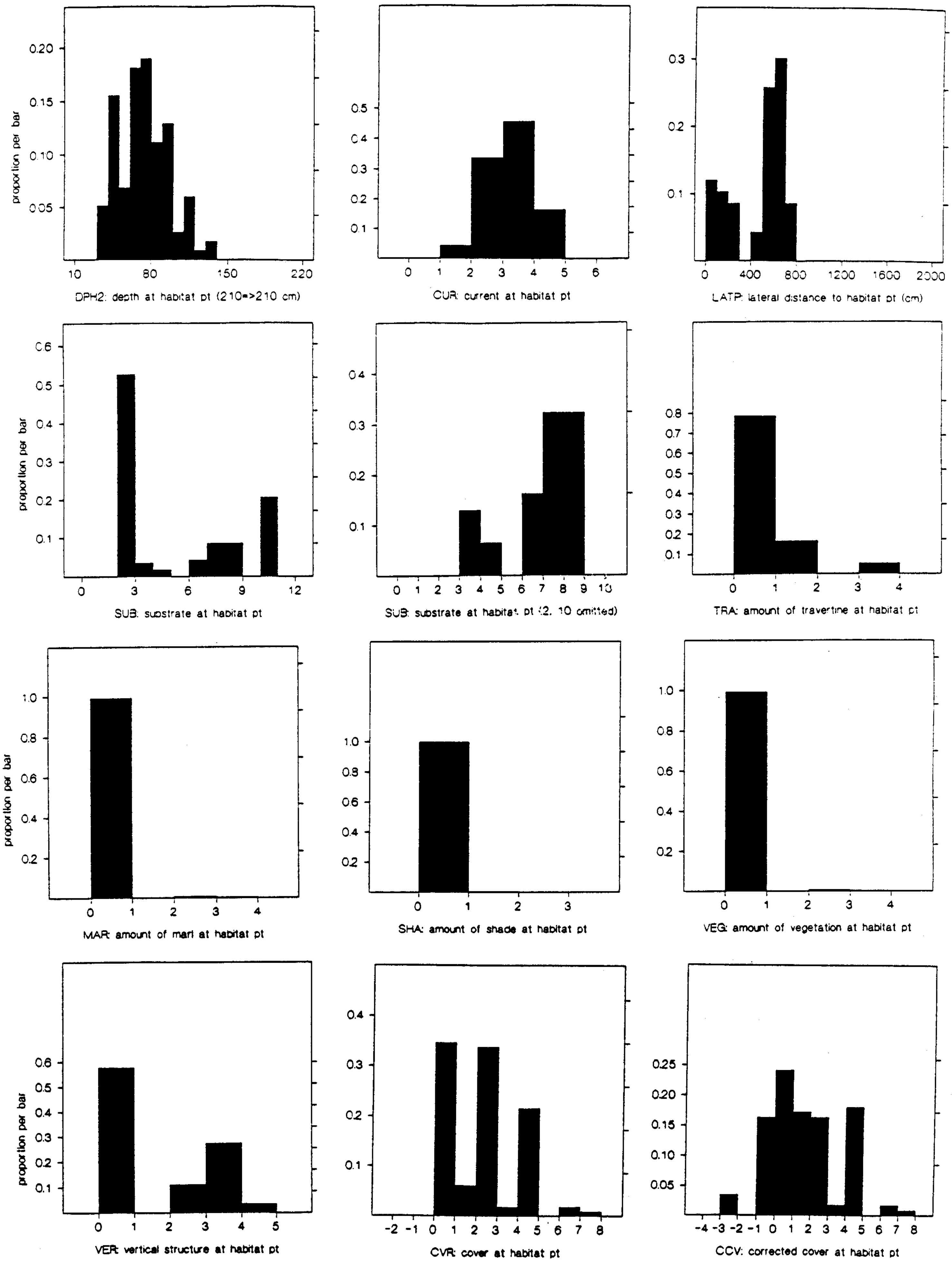
Habitat variables shown:
DPH2, CUR, LATP, SUB, TRA, MAR, SHA, VEG, VER, CVR, CCV.

Consult Table 1 for explanation of habitat variable codes.

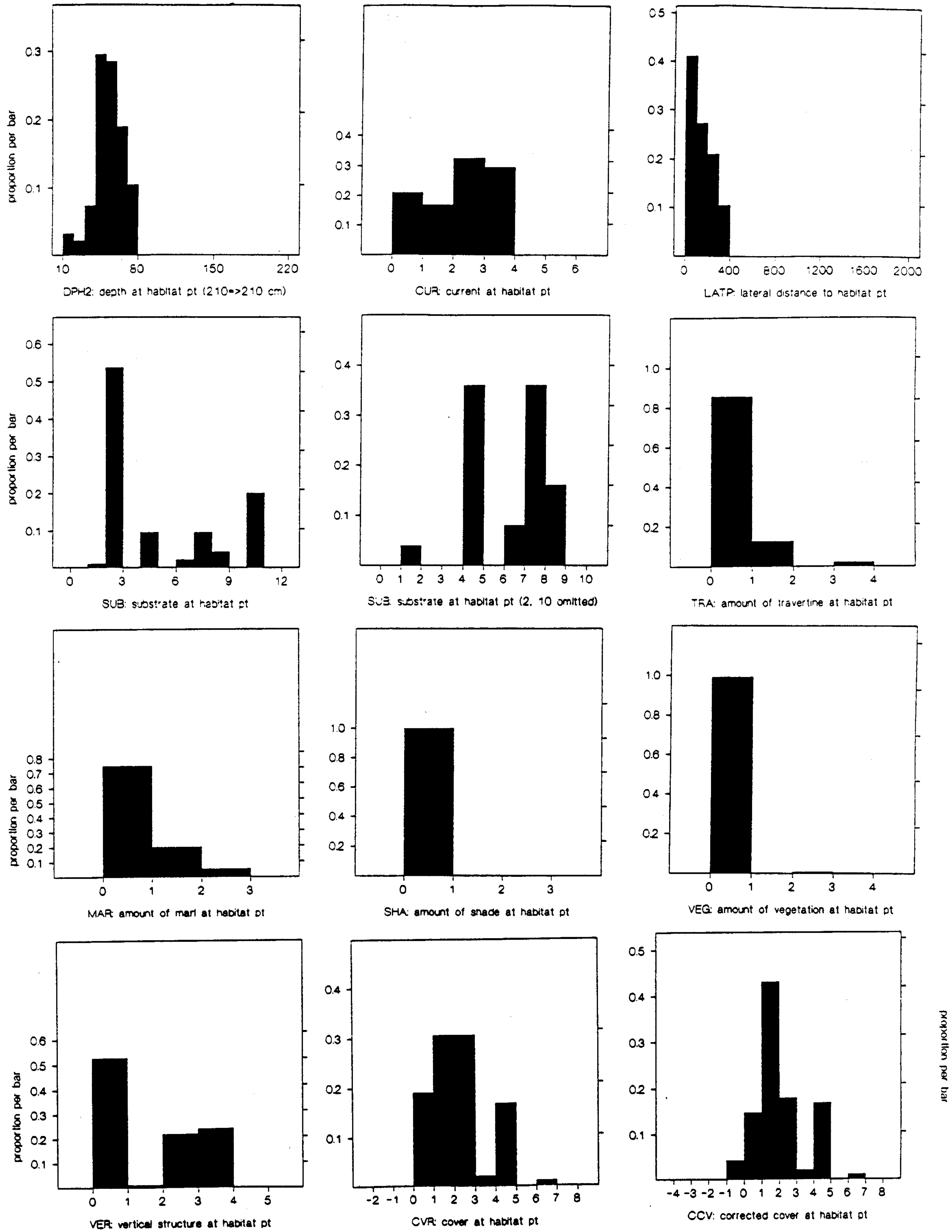
BHS habitat use (night): FWS/Powell 6/92



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



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



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

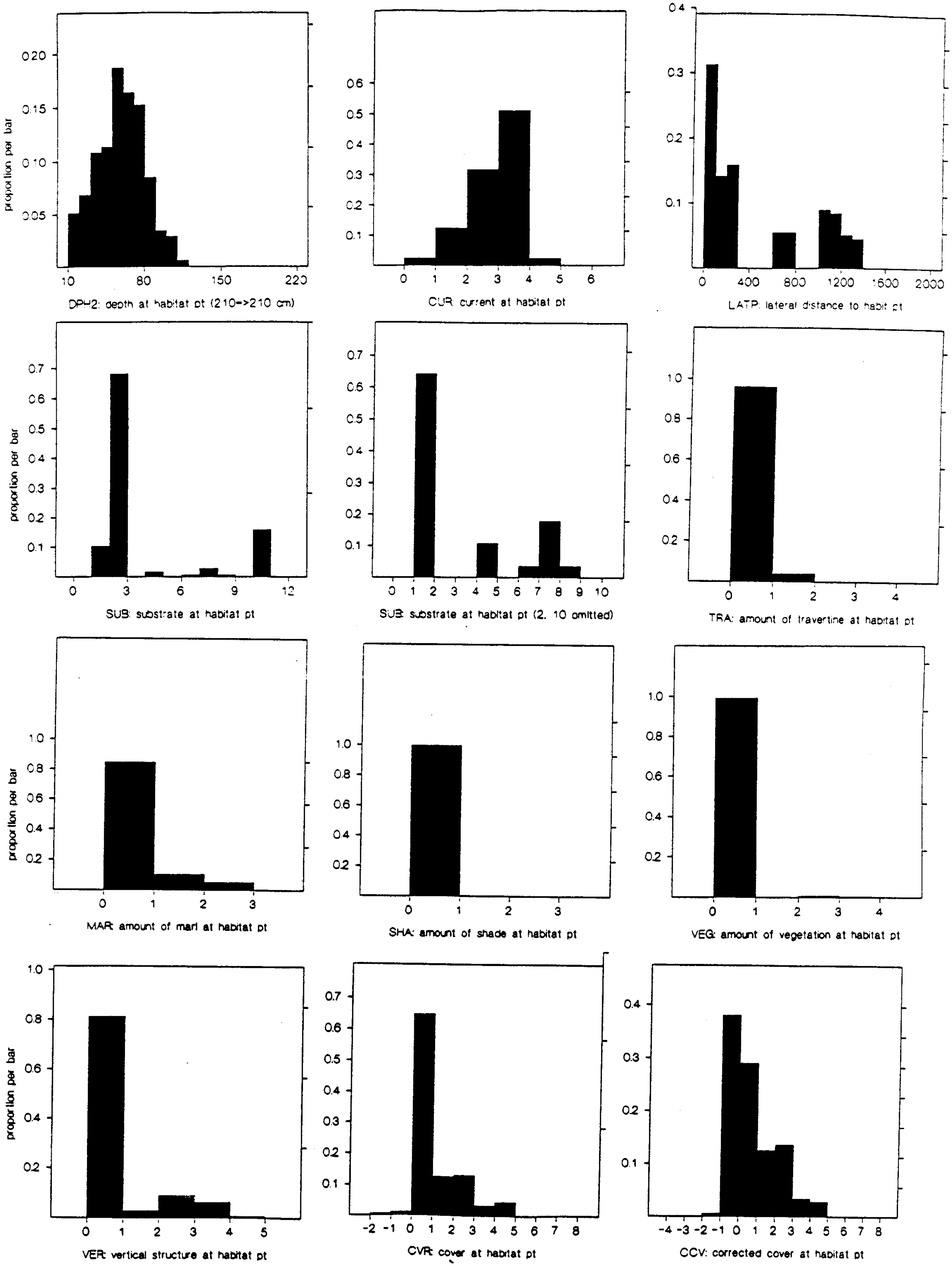


FIGURE 8. USFWS fish habitat studies, Powell Study Area, 6/92: Habitat use by LCR fishes displayed in principal component space for day and night periods.

Species shown:
HBC, SPD, BHS, FMS

Ellipses represent the area containing 50% of the habitat points for a particular species. Consult Table 3 for principal component loadings for habitat variables.

FIGURE 8. **USFWS fish habitat studies, Powell Study Area, 6/92: Habitat use by LCR fishes displayed in principal component space for day and night periods.**

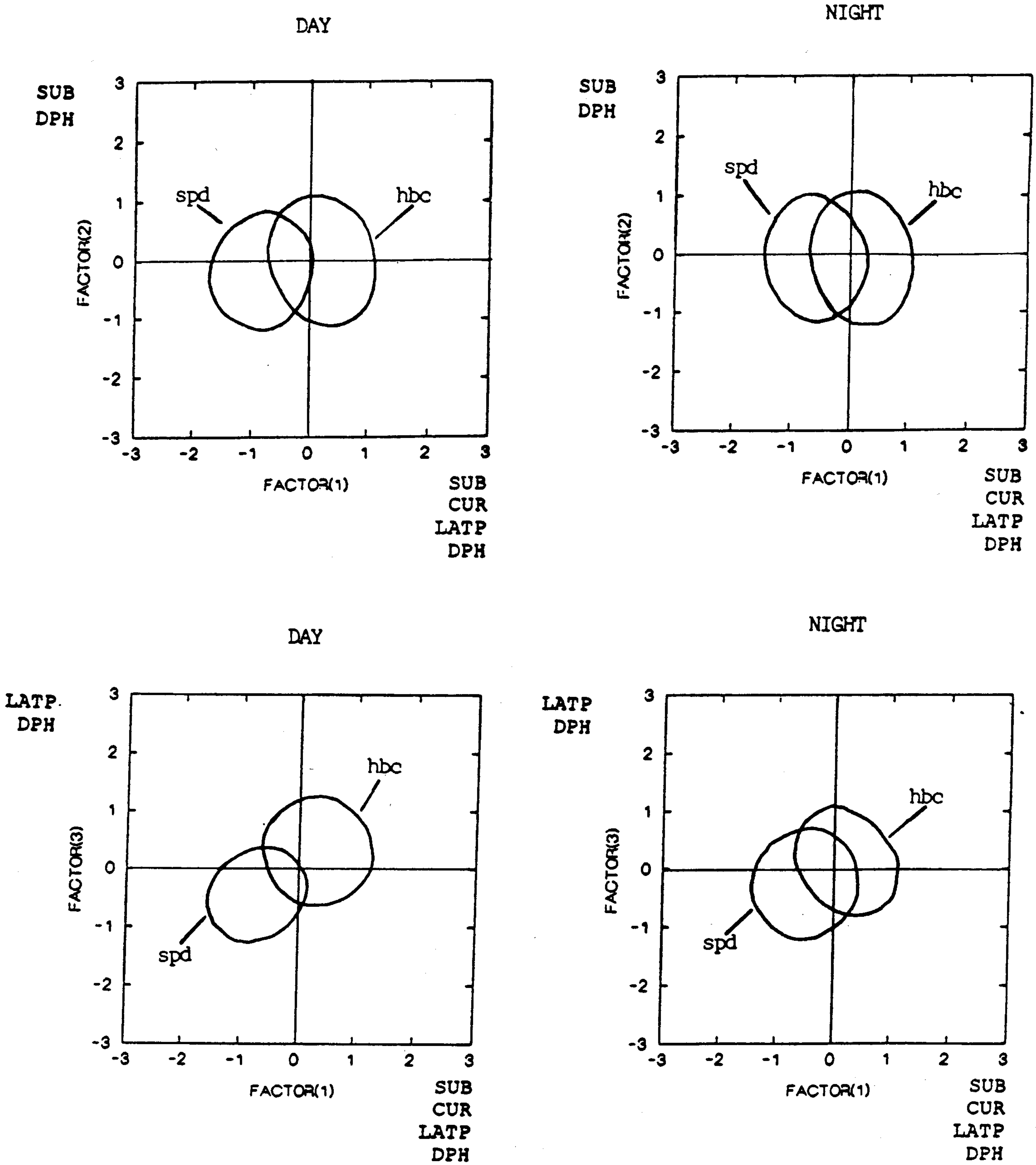


FIGURE 8. USFWS fish habitat studies, Powell Study Area, 6/92: Habitat use by LCR fishes displayed in principal component space for day and night periods.

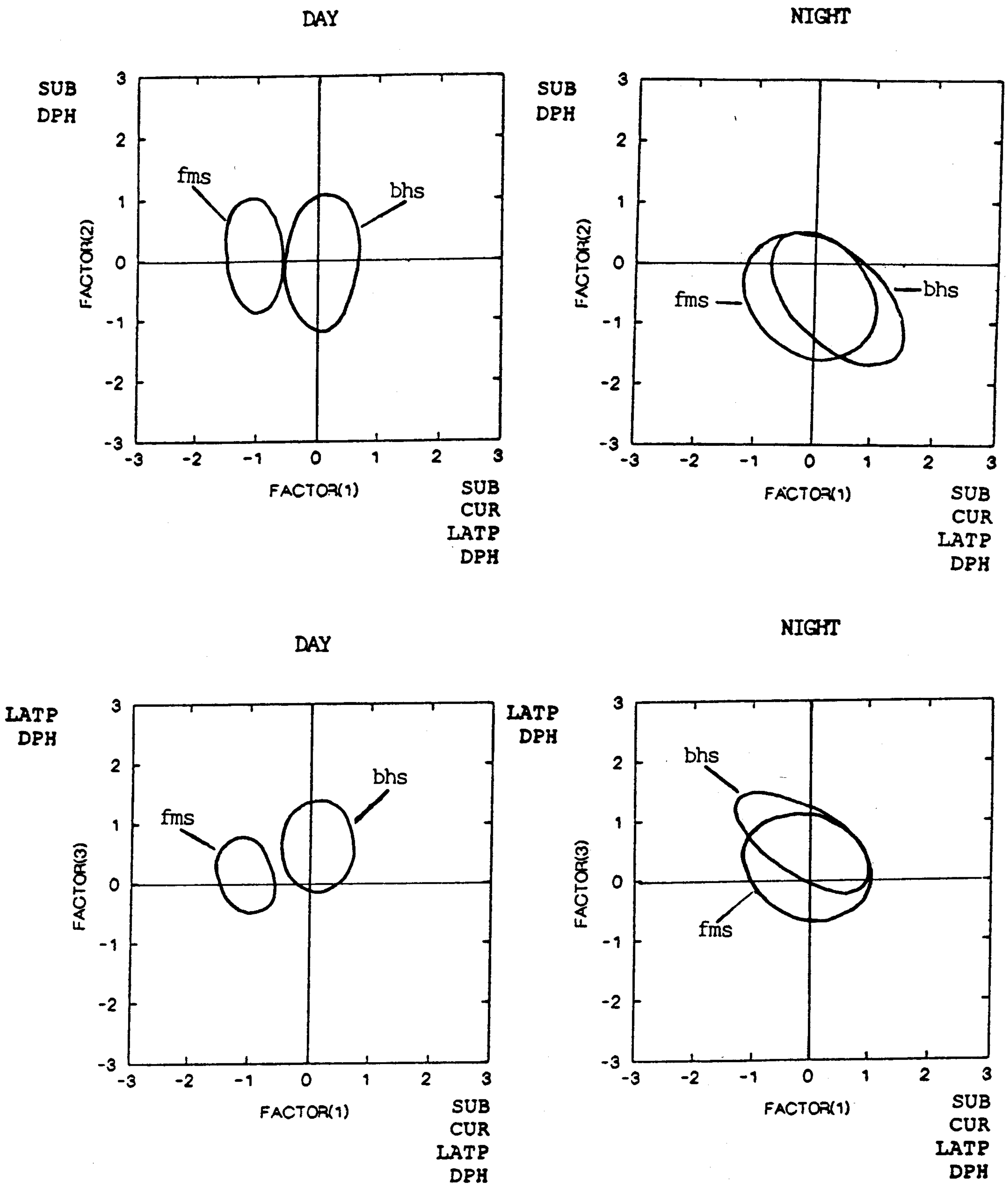


FIGURE 9. USFWS fish habitat studies, Powell Study Area 6/93: Habitat use by LCR fishes displayed in principal component space for day and night periods.

Species shown:
SPD, HBC, HBC (juveniles, <=150 mm TL), HBC (adults, >150 mm TL)

Ellipses represent the area containing 50% of the habitat points for a particular species. Consult Table 3 for principal component loadings for habitat variables.

FIGURE 9. USFWS fish habitat studies, Powell Study Area 6/93: Habitat use by LCR fishes displayed in principal component space for day and night periods.

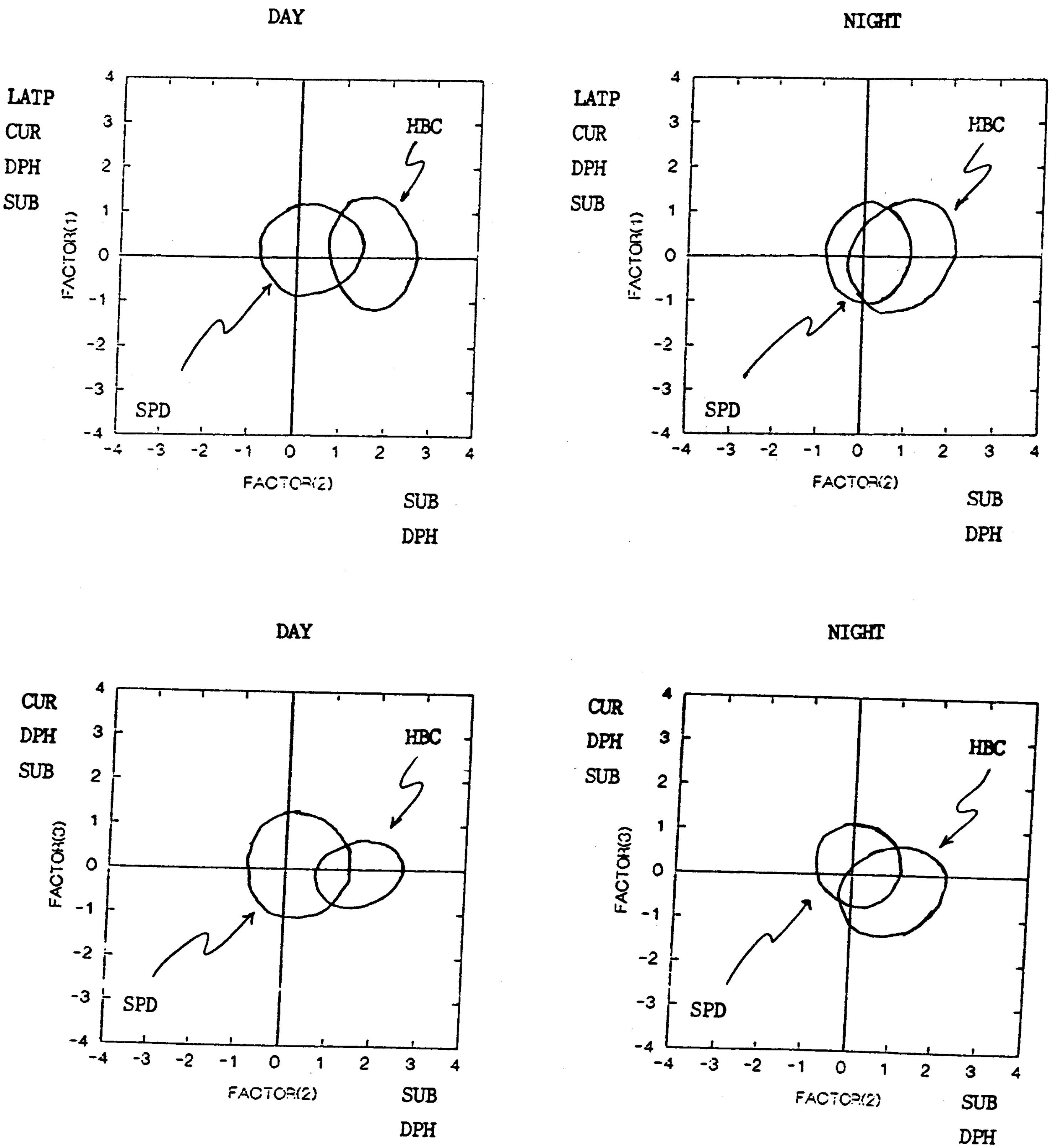
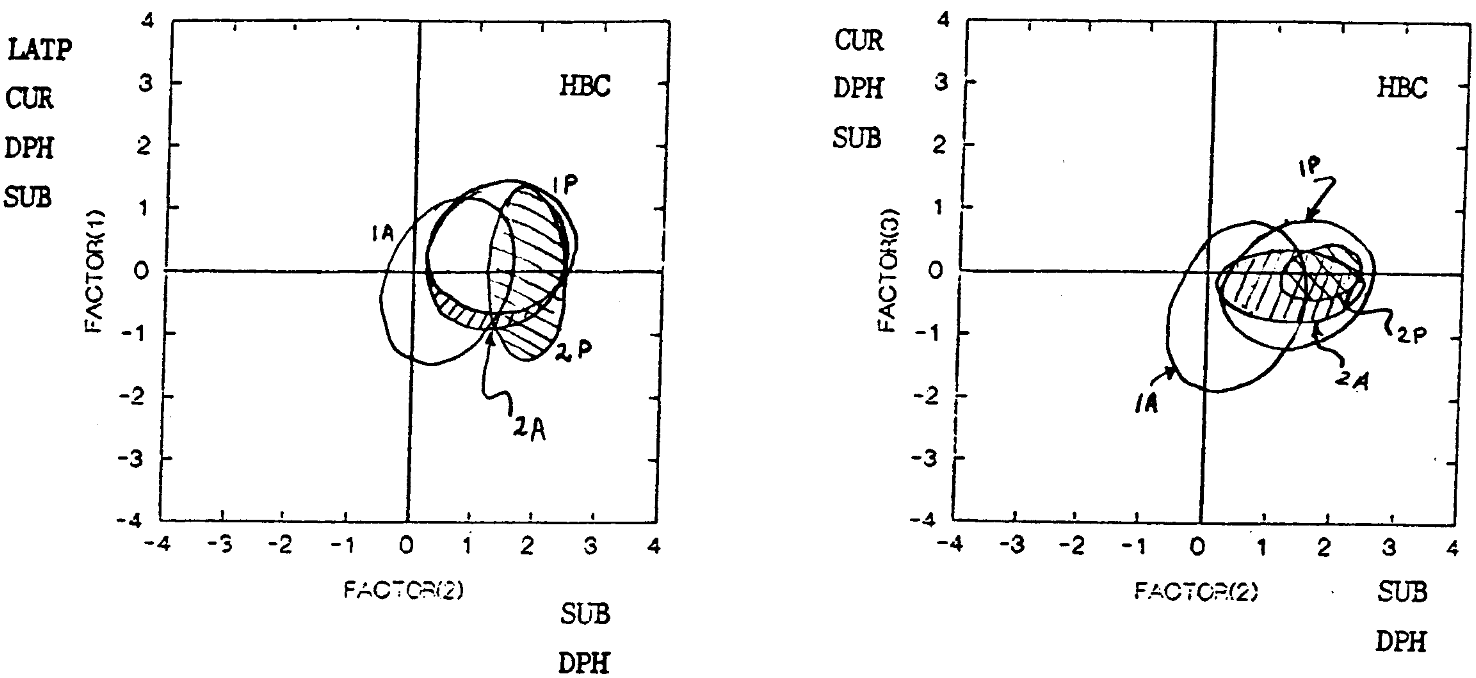


FIGURE 9. USFWS fish habitat studies, Powell Study Area 6/93:
Habitat use by LCR fishes displayed in principal component space for day and night periods.



P = DAY
A = NIGHT
1 = JUVENILE (<150 mm TL)
2 = ADULT (>150 mmTL)

FIGURE 10. USFWS fish habitat studies, Powell Study Area 9/92: Daytime habitat use by HBC and SPD from seine sampling.

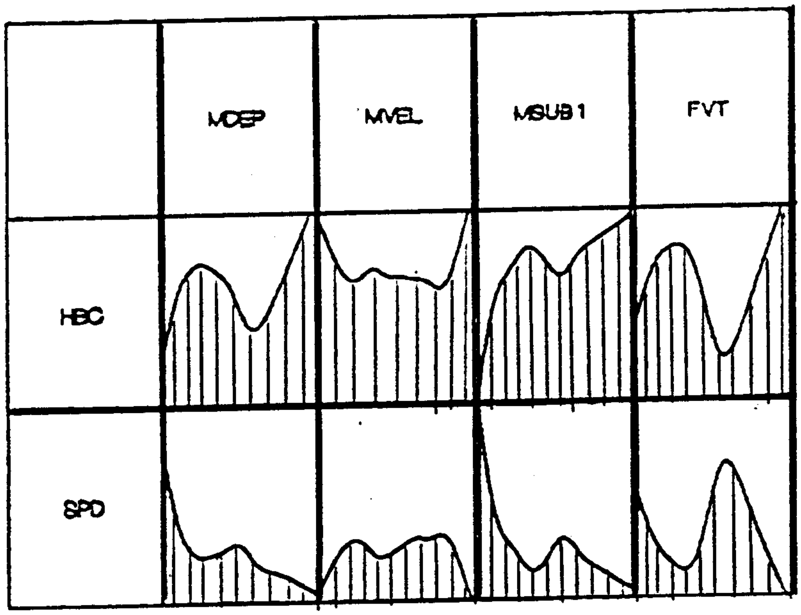
Shown are weighted habitat distributions for:

variable	
MDEP =	mean depth (DPH)
MVEL =	mean velocity (CUR)
MSUB1 =	mean primary substrate (SUB)
FVT =	frequency of vertical structure (VER)

sample size data *(n)*	
seine samples	63
habitat points	1,108
HBC (humpback chub)*	70
SPD (speckled dace)	100

*HBC in this analysis were 1991 year class juveniles, <=150 mm TL.

FIGURE 10. USFWS fish habitat studies, Powell Study Area 9/92:
Daytime habitat use by HBC and SPD from seine sampling.



APPENDIX II

1991 LCR HABITAT DATA FROM USFWS TRANSECTS AND EVALUATION OF HABITAT FROM ASU HOOPNETS

Introduction

The intent of this analysis is to assess available habitat in the LCR from USFWS transect data and evaluate the representativeness of habitat sampled by ASU hoopnets. Originally, it was envisioned that USFWS would use ASU hoopnet sampling to assess habitat use by humpback chub. However, no sampling design or protocols were adopted that would assure that ASU hoopnets would sample the available habitat in the LCR in an unbiased manner.

A comparison of habitat data from USFWS 100m transects and ASU hoopnets during the period of July - October 1991 is provided (Figs 1, 2). The sampling was conducted during a period of prolonged stable base flow in the LCR; no floods or significant spates were recorded in this period. During this period, conditions were ideal for setting hoopnets in a wide variety of stream habitats and FWS technicians were allowed to select some mid-channel sampling sites for ASU hoopnets. From December 1991 through spring 1993, the LCR flooded frequently and was often well above the base flow provided by the output of Blue Springs. The high flow conditions generally precluded setting nets other than along stream banks. Thus, the habitat data from the July-October 1991 period provides the best picture of opportunistic use of ASU hoopnet sampling as a means to assess habitat use by humpback chub.

Available habitat

Typical habitat in the LCR (Fig. 1) during the summer of 1991 was: <100 cm deep (mean= 47 cm); moderate current (0.3-.07 m/sec; faster currents were rare); dominated by marl (#0; precipitated $CaCO_3$), sand (#2), and travertine (#10) substrates; usually within 12 m of the stream bank (mean channel width 16 m, SD=6.2 m); typically without vertical structure; lacking in cover and aquatic vegetation (*Phragmites* and *Typha* vegetation was rare (VEG=3); most vegetation consisted of algae, pondweeds, and sedges (VEG=1,2)); and without shade.

ASU hoopnet habitat

Casual inspection of the FWS transect and ASU hoopnet habitat distributions (Figs. 1 and 2) shows that habitat sampled by ASU hoopnets was not very representative of the available habitat (Fig 1). Areas sampled were generally >100 cm deep and points >200 cm represented 12% of all habitat sampled; these areas represented <1% of the available habitat (Fig 1.) ASU nets were typically set within 3 m of stream banks and modal currents were slow; these results stem from undersampling of mid channel habitats. Predominant substrates were sand, travertine, large boulders (#8), and marl; there was noticeable bias in setting nets by large instream boulders and away from shallow areas with fine substrates. ASU nets were set in areas with much vertical structure; more than 30% of the habitat had 3 or greater vertical structure. This figure represents a 6-fold increase over available structure. Habitat sampled by ASU nets contained much more cover than was available; there is a noticeable bias in sampling areas with cover values >2 (these represent deep water habitats with vertical structure, overhanging ledges, undercut banks, and little current). About 5% of all habitat points around ASU nets had *Phragmites* or *Typha*; this represents a greater than 5-fold increase over available. In contrast, smaller vegetation (categories 1,2) were greatly under-represented in the ASU hoopnet samples. ASU hoopnets showed at least a 3-fold increase in shaded habitat compared to available habitat.

Habitat use evaluation with ASU hoopnet data

Comparison of ASU hoopnet habitat data with available habitat data indicates that the selection of hoopnet sampling locations was biased. The most commonly selected areas were in deep water (>100 cm) around large boulders (> 300 cm size) and next to stream edges with sharp drop-offs, overhanging ledges, and undercut banks with phragmites and shade. Although a some nets were set in mid channel locations as directed by USFWS personnel, these samples were relatively infrequent and not enough to offset the general bias in selection of sampling sites. Considerations taken in selecting sites for sampling with ASU hoopnets were: 1) maximize catch of fish per unit effort; habitat types known to yield high capture rates were especially sought after, 2) the need to tie off or anchor nets precluded most mid channel sites and favored stream edge sites that facilitated net anchoring, and 3) the large size of the ASU hoopnets (1 m dia) precluded sets in water less than 75 cm deep.

The lack of representativeness of ASU hoopnet habitat data makes this data undesirable for assessing habitat use by humpback chub. For this reason the Service has ceased measuring habitat at ASU hoopnets and has no plans to further analyze habitat data from ASU hoopnets.

We have previously suggested that the value of the ASU hoopnet sampling for habitat assessment in the LCR could be increased by randomization of sampling sites and adoption of FWS sampling protocols (Gorman, 1992). However, we understand that randomization of net sets would increase the level of work required to set nets and would reduce catch rates.

APPENDIX II

1991 LCR HABITAT DATA FROM USFWS TRANSECTS AND EVALUATION OF HABITAT FROM ASU HOOPNETS

TABLE 1. Habitat variables used in USFWS GCES studies (full descriptions are contained in Gorman, 1993).

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)

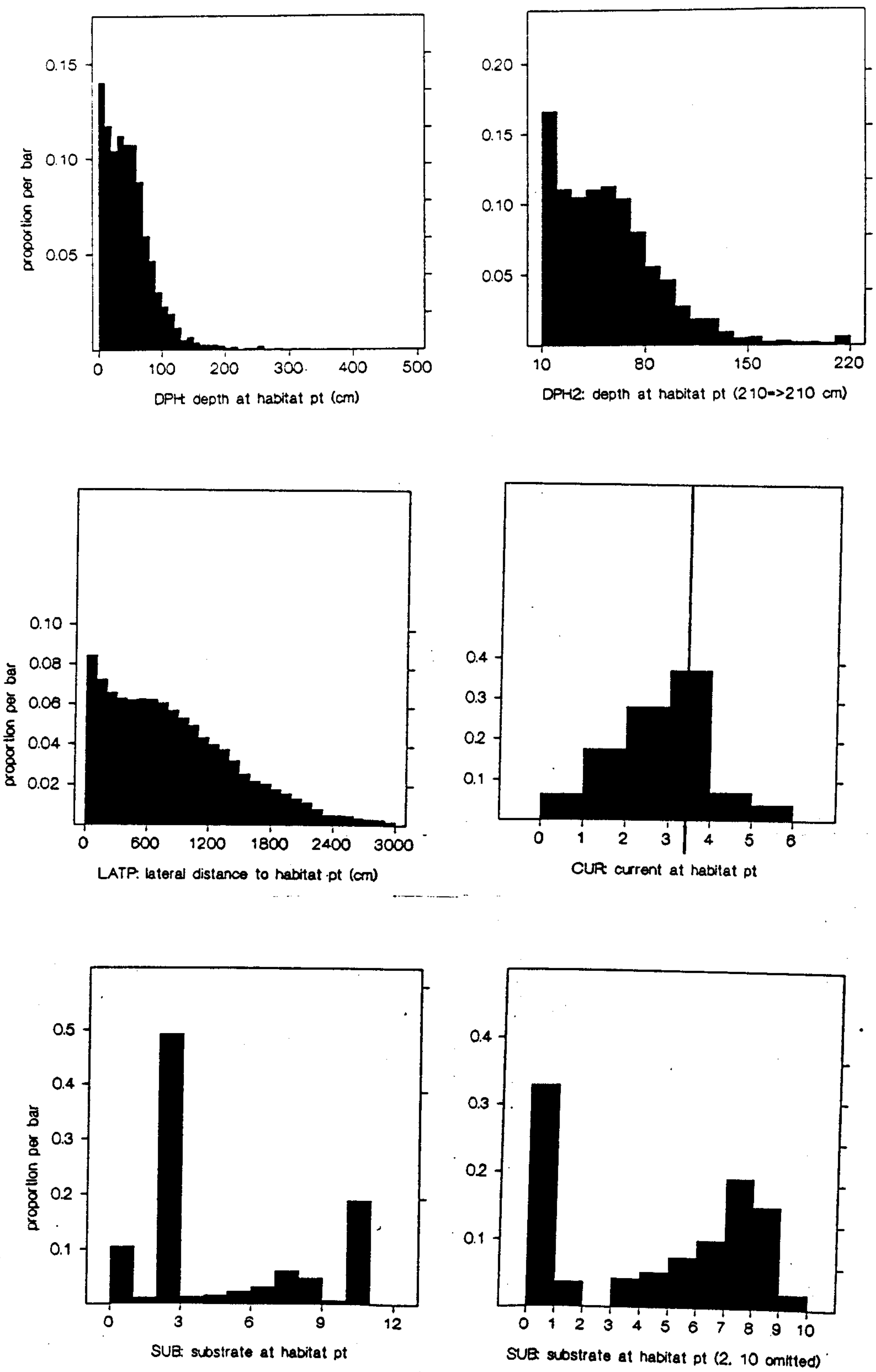
APPENDIX II

1991 LCR HABITAT DATA FROM USFWS TRANSECTS AND EVALUATION OF HABITAT FROM ASU HOOPNETS

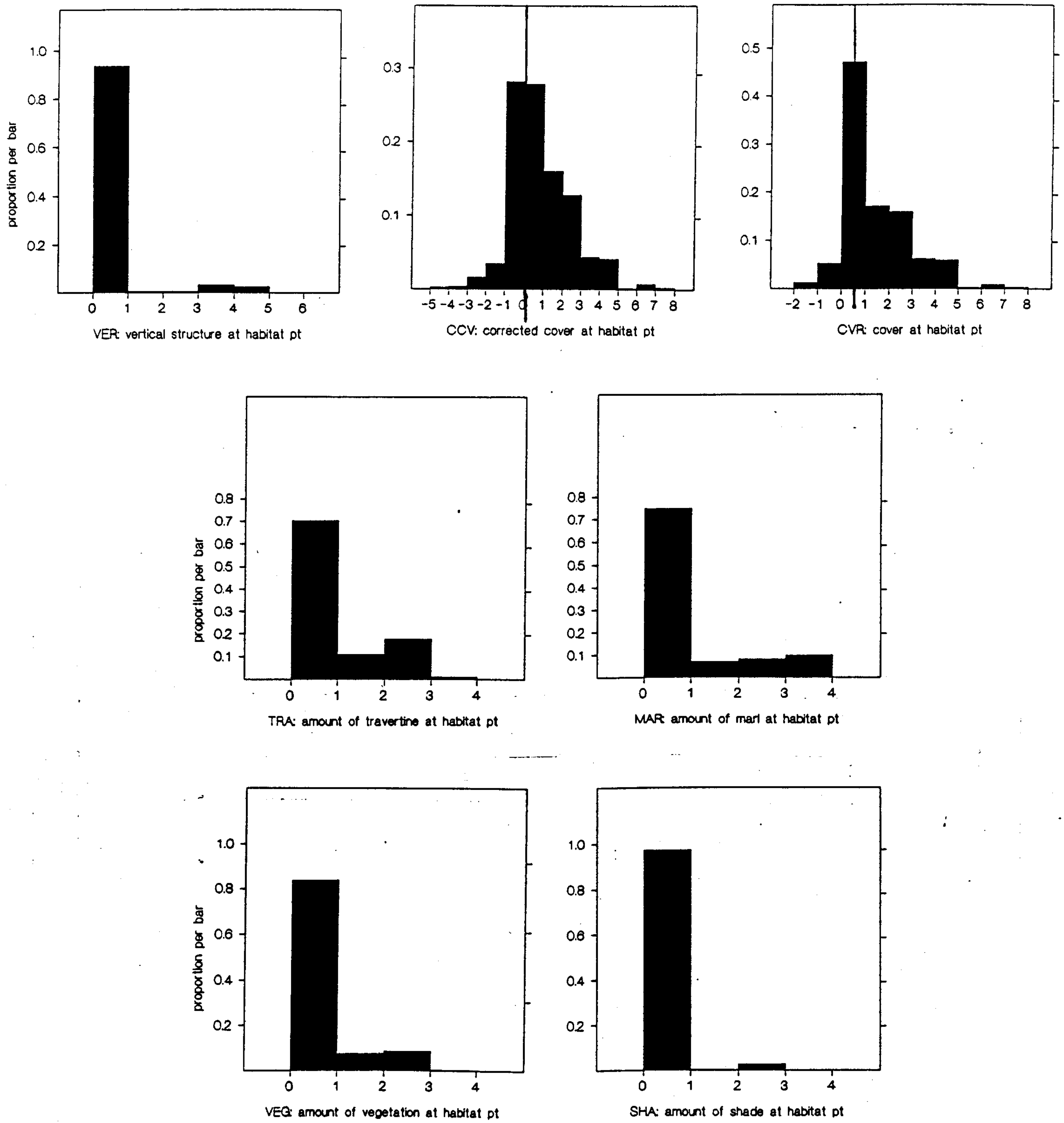
Figure 1. 1991 available habitat in the LCR from USFWS habitat transect data.

Data shown represents available habitat in the Little Colorado River. Data is from USFWS LCR habitat transects in the 0-15 km reach at 100m intervals taken July-August 1991. Sample size is 150 transects and 5,143 habitat sample points.

1991 transect habitat (LCR)



1991 transect habitat (LCR)



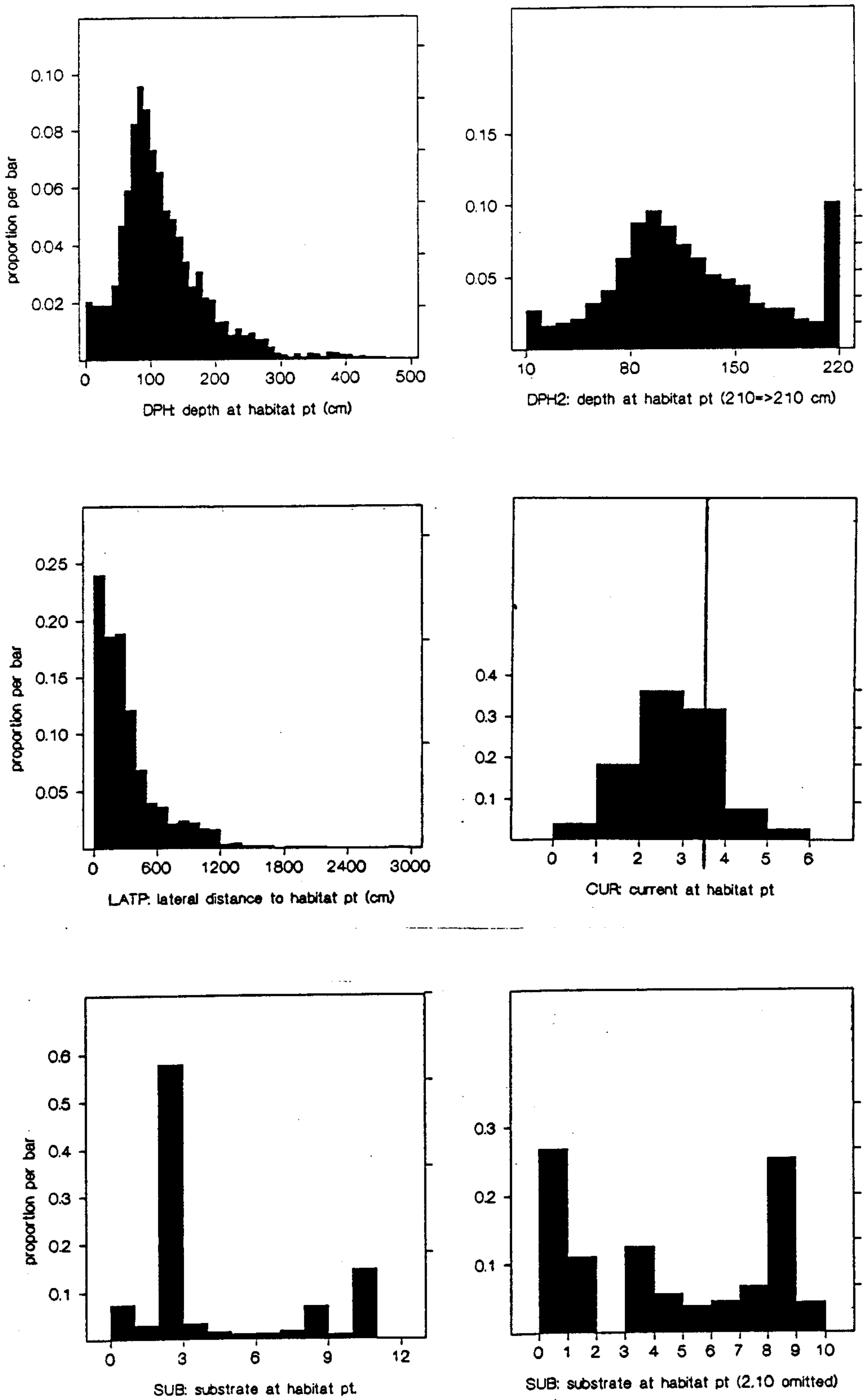
APPENDIX II

1991 LCR HABITAT DATA FROM USFWS TRANSECTS AND EVALUATION OF HABITAT FROM ASU HOOPNETS

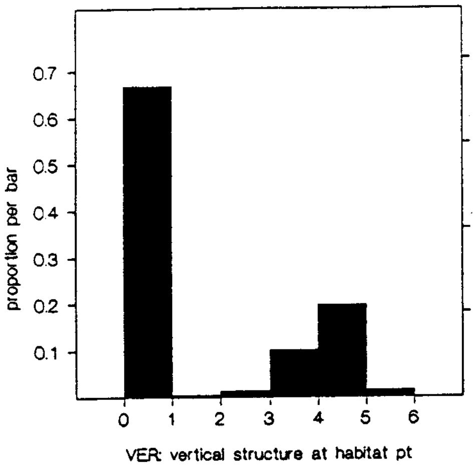
Figure 2. 1991 habitat sampled by ASU hoopnet in the LCR.

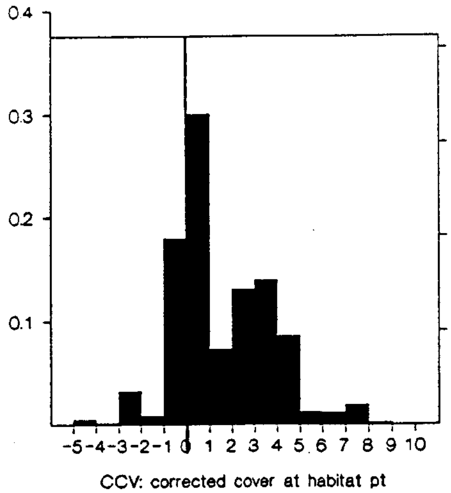
Data shown represents habitat measured at ASU hoopnets in the Little Colorado River. Data is from all net sets measured in the 0-15 km reach and over the period July-October 1991. Sample size is 305 net sets and 5,495 habitat sample points.

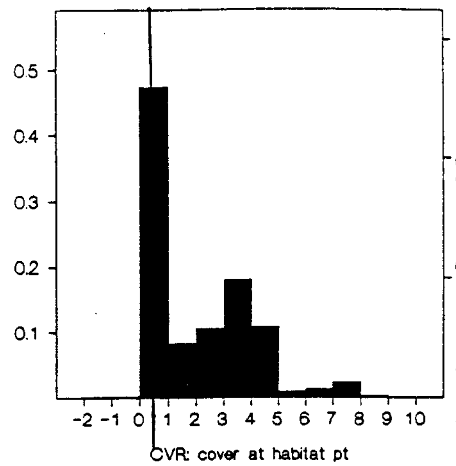
1991 ASU hoopnet habitat (LCR)

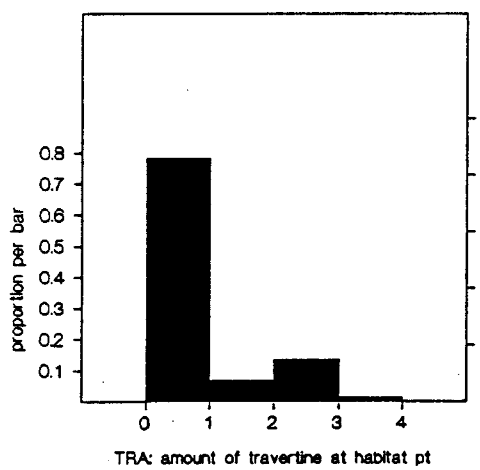


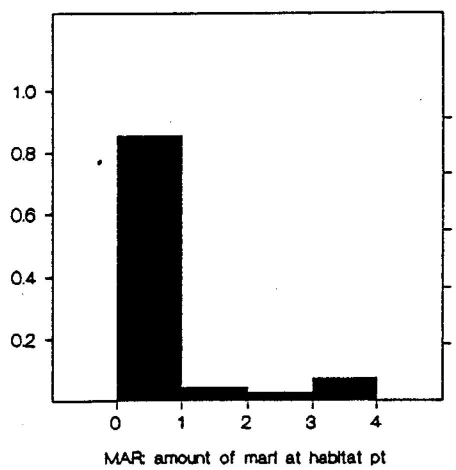
1991 ASU hoopnet habitat (LCR)

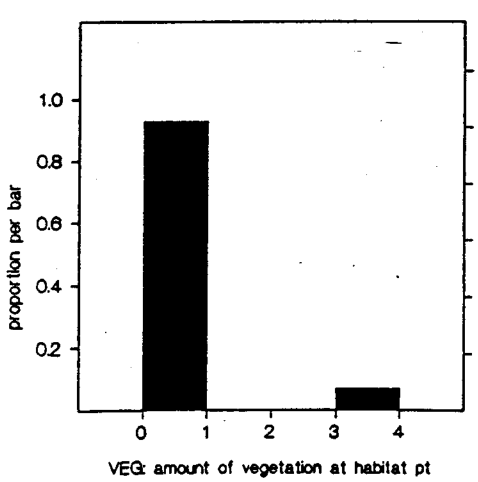


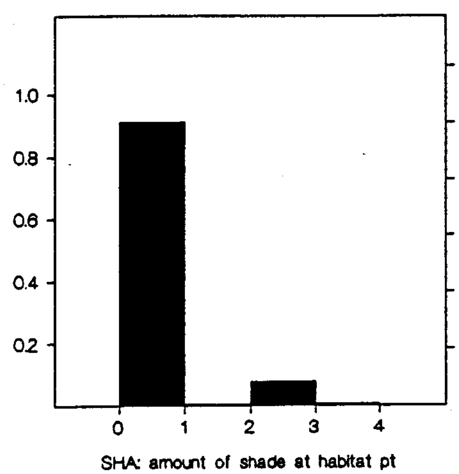












APPENDIX III

1993 SUMMARY OF WATER QUALITY AND HYDROLOGY FOR THE LITTLE COLORADO RIVER

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). 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 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
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 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 9-18

	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 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 9-18

	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

APPENDIX III

1993 SUMMARY OF WATER QUALITY AND HYDROLOGY FOR THE LITTLE COLORADO RIVER

B. October 1992 - December 1993 hydrographs

Figure 1. Hydrograph, Little Colorado River at Cameron, AZ.

Maximum daily discharge data (MAXQ) is plotted for the period 1 October 1992 through 1 December 1993. Flat steps shown during two January-March flood events were caused by gauge malfunction. The peak discharge in early January exceeded 17,000 cfs and the peak discharge in late February exceeded 15,000 cfs (see Fig. 2).

Figure 2. Hydrograph, Little Colorado River at Grand Falls, AZ.

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

Figure 3. Hydrograph, Little Colorado River at Cameron and Grand Falls, AZ.

Maximum daily discharge data (MAXQ) is plotted for the period 1 October 1992 through 1 December 1993. This plot is a superimposition of Cameron and Grand Falls discharge data (Fig. 1 + Fig. 2).

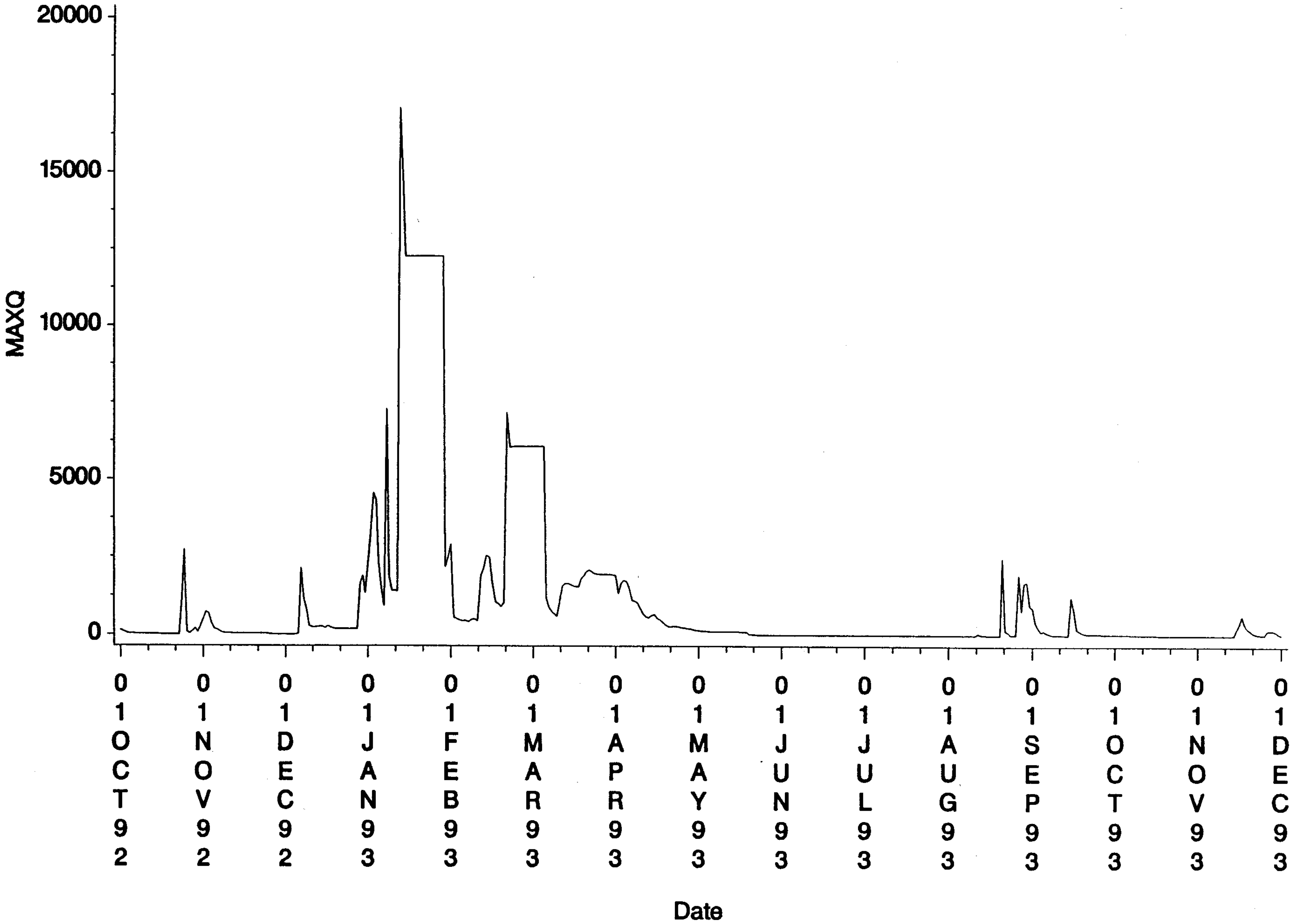
Figure 4. Hydrograph, Colorado River at Lees Ferry and Phantom Ranch, AZ.

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.

Little Colorado River near Cameron, AZ

Station: 09402000

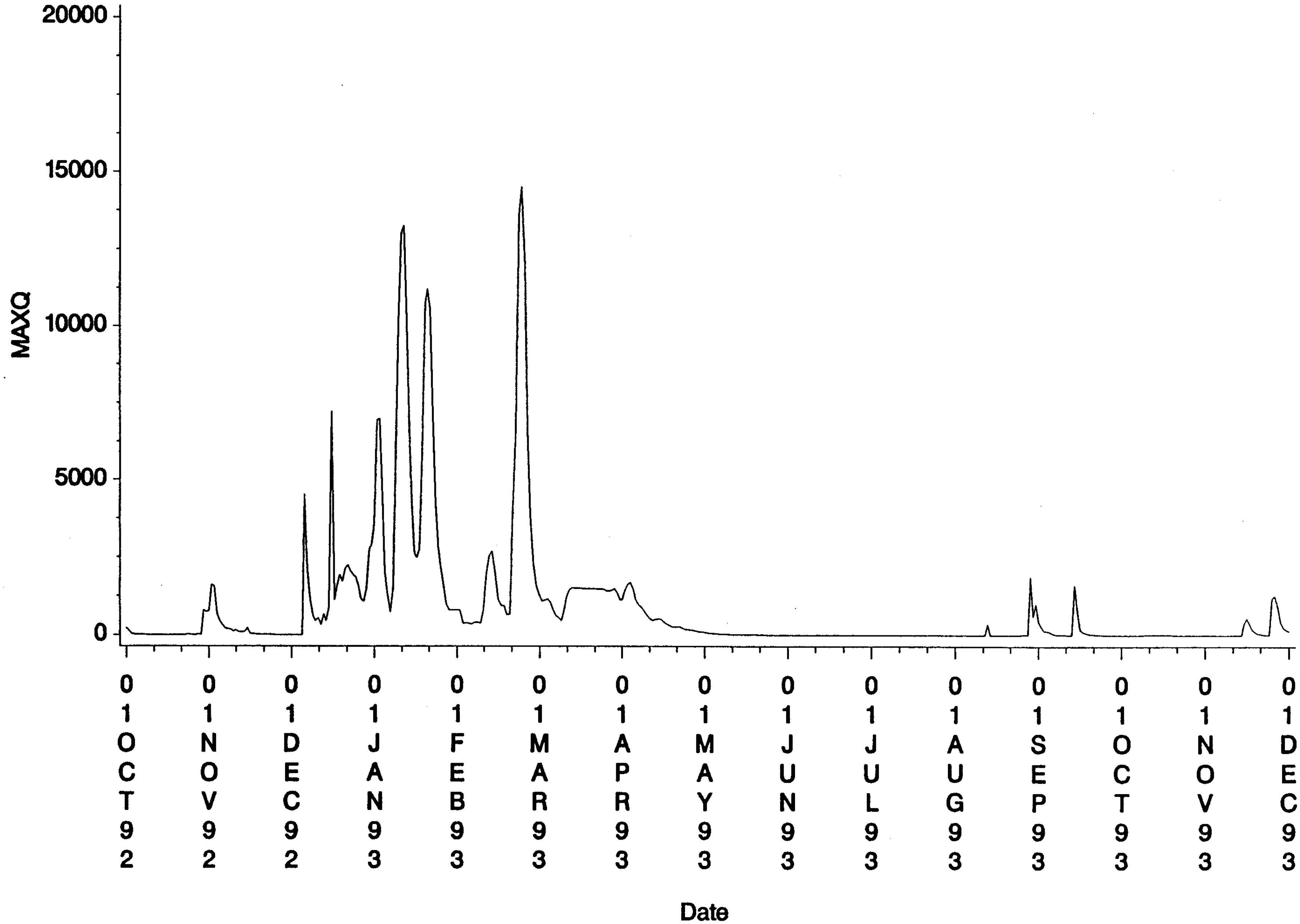
USGS Gaged Discharge – Provisional Data



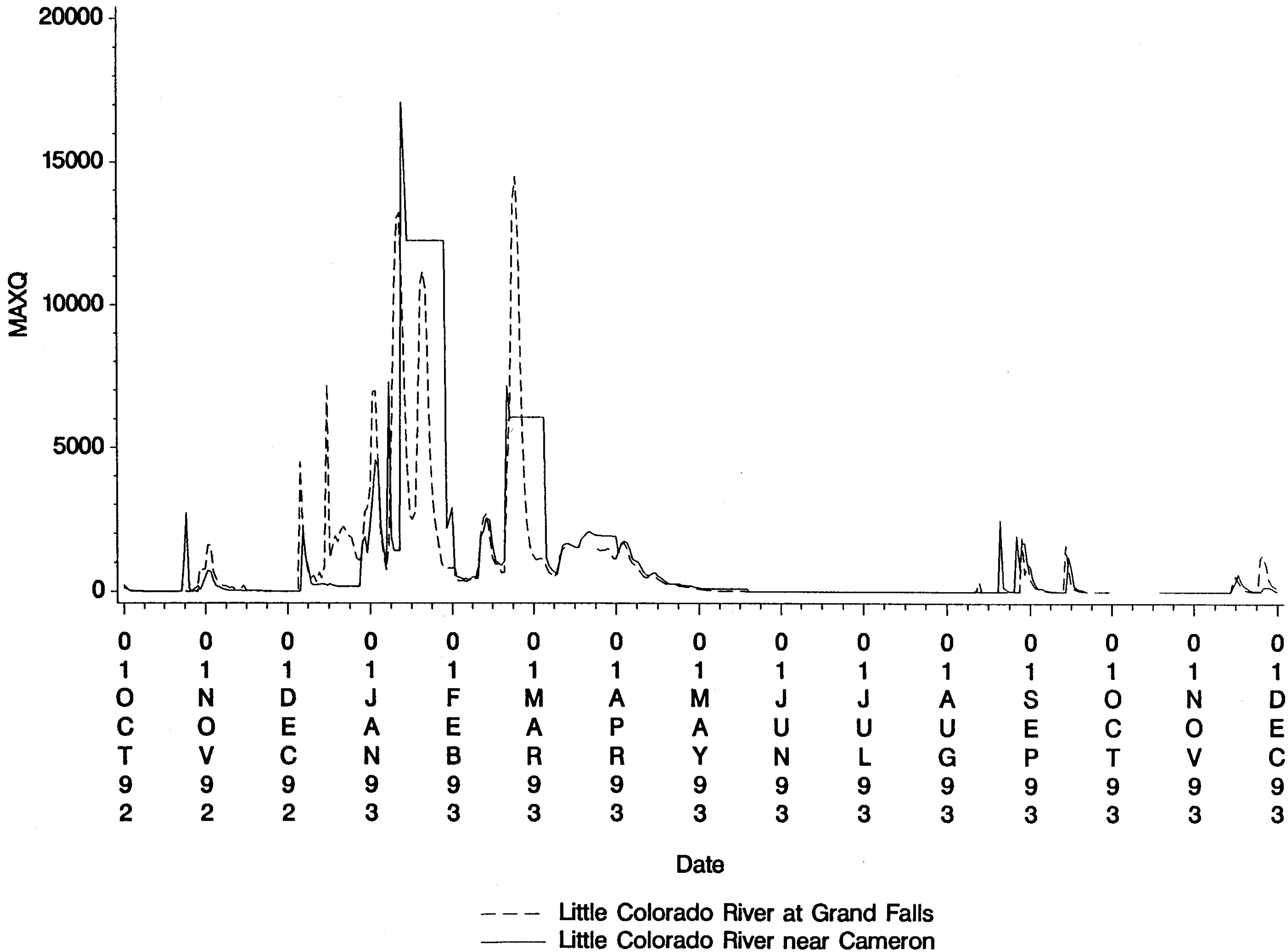
Little Colorado River near Grand Falls, AZ

Station: 09401000

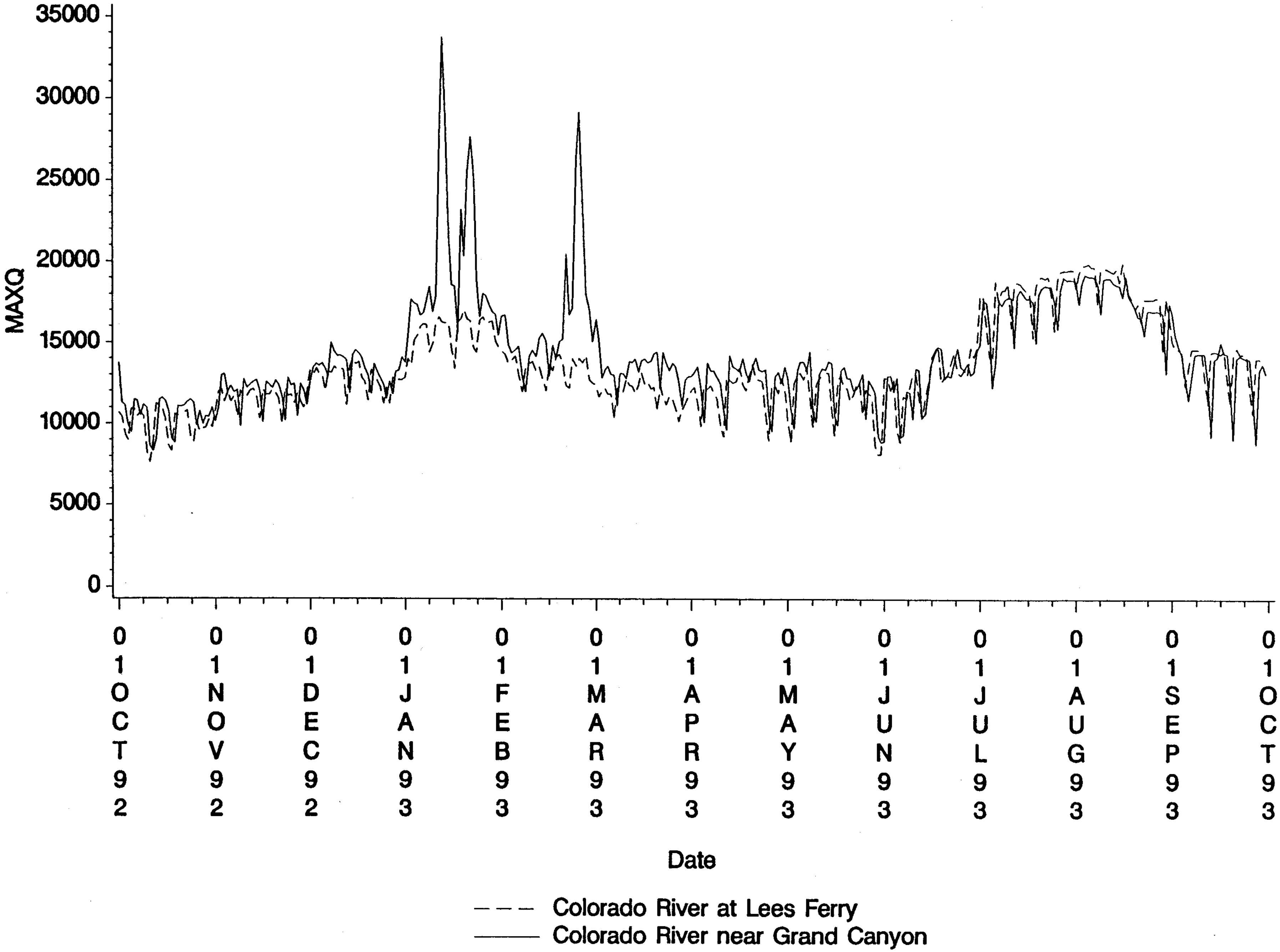
USGS Gaged Discharge – Provisional Data



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



Maximum Daily Discarge at Lees Ferry and Phantom Ranch
1993
USGS Gaged Discharge – Provisional Data



APPENDIX IV

USFWS sponsored research in GCES, 1991-1993: abstracts of graduate theses

Distribution and abundance of fishes in Shinumo Creek in the Grand Canyon

Nathan L. Allan

November 30, 1993

Masters thesis, University of Arizona, Tucson, AZ. 76p.

ABSTRACT

Bluehead sucker (*Catostomus discobolus*) and speckled dace (*Rhinichthys osculus*) were the only native species in Shinumo Creek above a waterfall located about 120 m upstream from the confluence of Shinumo Creek and the Colorado River. Rainbow trout (*Oncorhynchus mykiss*) was the only introduced species found upstream of the waterfall. I attribute the coexistence of the native and introduced species to differential use in resources and the similarly small size of bluehead sucker and rainbow trout. Mean total length of bluehead suckers was 160 mm and the largest fish capture was 230 mm (n=77). Mean length of rainbow trout was 149 mm (maximum=300 mm; n=46). Bluehead suckers in Shinumo Creek were smaller than individuals observed in the mainstem Colorado River. Small size may be a response to the decreased size of the habitat available. The permanence of the waterfall barrier near the mouth of Shinumo Creek is a result of regulation of the Colorado River that prevents inundation of the waterfall.

An evaluation of habitat conditions and species composition above, in, and below the Atomizer Falls complex of the Little Colorado River

William P. Mattes

November 11, 1993

Masters Thesis, University of Arizona, Tucson, AZ. 105p.

ABSTRACT

Water chemistry (carbon dioxide, ph, alkalinity, hardness, and turbidity) and physical habitat (depth, velocity and substrate) changed gradually on the Little Colorado River, Arizona, downstream from Blue Springs (river kilometer 11.40 to 21.06). Fish distribution is correlated with changes in water chemistry and physical habitat. Monthly trends in water chemistry and physical habitat depended upon seasonal conditions: summer rain runoff (July and September 1992), spring runoff (April 1993), and base flow (June and July 1993).

Selected aspects of the ecology of native and introduced fishes in two Colorado River tributaries in the Grand Canyon

Theodore Otis

February 1994
(projected date of completion)
Masters Thesis, University of Arizona, Tucson, AZ.

ABSTRACT

Non-native brown and rainbow trout were resident year round in Bright Angel Creek, while flannelmouth and bluehead suckers generally occurred only during spawning (March for flannelmouths, and apparently April-May for blueheads) and initial rearing of juveniles (blueheads only). The lower kilometer of Bright Angel Creek was used for spawning by flannelmouth suckers, while spawning bluehead suckers penetrated at least 3 km upstream. Flannelmouth suckers generally spawned at depths between 20-40 cm, currents between 0.4-0.8 m/s, and over medium sized, loosely compacted substrates. Speckled dace also reproduce in this stream, however their abundance was greatly reduced relative to levels reported by previous investigations. Low abundance of speckled dace may be due in part to a shift in community structure. The piscivorous brown trout has become the dominant species in the steam in recent years. Availabilities of three habitat parameters (depth, current, substrate) varied considerably between sample periods, however, generally >75% of available depths were <40 cm, currents most frequently occurred in the range 0.3-0.7 m/s, and substrates were coarse (rock and cobbles).

Four native and six non-native fish species were encountered in Kanab Creek and its confluence with the Colorado River; spawning was documented for *Catostomus discobolus* and *Rhinichthys osculus*. Small bluehead suckers (<150 mm TL) were resident year round below a physical barrier occurring 6.2 km upstream. Larger individuals (>200 mm TL) began entering the stream in late winter and spawned in April and early May. Suckers spawned in shallow waters (<25 cm), slow currents (<25 m/s), and over small loosely compacted substrates (pebble, gravel). Very few adult native fish occurred in the stream after May (except *R. osculus*). During the spring of 1993, water temperatures increased, dissolved oxygen decreased, and the incidence of the parasite *Lernia cyprinaceae* increased. Adult flannelmouth suckers generally used only the confluence area, however, small numbers of juveniles (<100 mm TL) were found sporadically in the lower 3 km of the stream. Habitat parameters (depth, current, and substrate) varied in availability between seasons. However, depths were generally shallow (<30 cm), currents slow, and substrates diverse.

Spawning, movement and population structure of flannelmouth sucker in the Paria River.

Steven J. Weiss

December 15, 1993

Masters Thesis, University of Arizona, Tucson, AZ. 153p.

ABSTRACT

Spawning flannelmouth sucker, *Catostomus latipinnis*, in the Paria River averaged 478 mm (n = 246) total length (TL). This was 53 mm longer ($p < 0.001$) than the mean length of spawning fish taken from the same location in 1981 (425 mm, TL, N = 286). Sub adult flannelmouth were common in the Paria in 1981 but no post-larval fish < 379 mm, TL were caught in 1992 or 1993. There is no evidence that juvenile flannelmouth have reared in the Paria River/Glen Canyon area in the last 12 years. However, some adult fish appear to enter the population from downstream locations.

In 1992 and 1993, spawning occurred throughout the lower 10 kilometers of the Paria. Young-of-the-year were seen in 1992 but could not be found shortly after hatching. No young-of-the-year were seen in 1993.

Growth of adult sized fish is very slow. Based on extrapolations from recaptures, longevity may approach 30 years. Recaptures from fish marked in other studies were originally tagged as far as 229 km downstream from the mouth of the Paria.

APPENDIX V

STATUS OF USFWS DATABASES, ANALYSES, REPORTS, PRESENTATIONS, AND PUBLICATIONS FOR GCES PHASE II, 1991-1993

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 1991-1993.

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	4/ 5,6,11
09/92	LCRSURV	4	4	-	-	GCES LCR survey
08/93	LCRCON	48		48		
06/93	LCRCON	4	4			
07/91	POWELL	147	47	1	47	47/ 5,6,11
7-8/91	POWELL	12467	247	16	47	47/ 5,6,11
08/91	POWELL	124567	2457	16	47	47/ 5,6,11
10/91	POWELL	17	7	1	7	7/ 5,6,11
12/91	POWELL	136	6	13	6	
02/92	POWELL	123467	6	12347	6	
04/92	POWELL	147	47	1		
06/92	POWELL	123467	23467	1	2346	2346/ 5,6,11,17
07/92	POWELL	123467	2346	17	6	
08/92	POWELL	123467	23467	1	6	
09/92	POWELL	123546	23456	1	65	56/ 5,6,11,17
11/92	POWELL	1235467	23467	15	6	
02/93	POWELL	1235467	2346	157	6	
03/93-1	POWELL	1367	36	17	6	
03/93-2	POWELL	1356	356	1	6	
04/93	POWELL	123456	2346	15	6	
05/93	POWELL	123456	6	12345	6	
06/93	POWELL	123456	2346	15	6	2346/ 18,19
07/93	POWELL	123468	2346	18	6	
08/93	POWELL	1234568	623	1458	6	/ 8
09/93	POWELL	12346	6	1234	6	
07/91	SALT	1457	457	1	47	47/ 5,6,11
7-8/91	SALT	124567	457	126	47	47/ 5,6,11
08/91	SALT	124567	457	126	47	47/ 5,6,11
10/91	SALT	1267	7	126	7	7/ 5,6,11
12/91	SALT	123467	34	1276		
02/92	SALT	123467	3	12467		
03/92-1	SALT	17	7	1		
03/92-2	SALT	17	7	1		
04/92	SALT	147	47	1		
06/92	SALT	123467	123467		6	2346
07/92	SALT	7	7			
08/92	SALT	123467	123467		6	
09/92	SALT	123546		123456	6	
11/92	SALT	1234567	4	123567	6	
03/93-1	SALT	13567	13567		6	
03/93-2	SALT	12356	12356		6	
04/93	SALT	123467	123467		6	
05/93	SALT	12346	16	234	6	
06/93	SALT	123456	1236	45	6	
07/93	SALT	123468	6	12348	6	
08/93	SALT	1234568	6	123458	6	
09/93	SALT	123456	6	12345	6	
11/93	SALT	123456		123456	6	

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

TRIP DATE	LOCATION	DATA TYPES	STATUS OF COLLECTED DATA: ENTERED (DBASE)	NOT ENTERED	ARCHIVE ??	ANALYSES & REPORTS
06/93	SHINUMO	1234689		1234689		/ 7
06/93	DEER	1		1		/ 7
06/93	TAPEATS	1		1		/ 7
06/93	KANAB	12345689		12345689		/ 7
06/93	HAVASU	1234568		1234568		/ 7

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 FWS-AZFRO 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	FWS trip (see Table 1
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	FWS trip; depletion seining (Table 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	our trip
HA	6/93	2346	
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, 1991-1993.

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.

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.

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