Inventory and Monitoring of Terrestrial Riparian Resources in the Colorado River corridor of Grand Canyon: An Integrative Approach

2003 Annual Report

Cooperative Agreement / Assistance Awards
01 WRAG 0044 (NAU) and 01 WRAG 0034 (HYC)

Michael J.C. Kearsley
Neil Cobb
Northern Arizona University

Helen Yard
Helen Yard Consulting

David Lightfoot
Sandra Brantley
Geoff Carpenter
University of New Mexico

Jennifer Frey
New Mexico State University

Submitted to:

Dr. Barbara Ralston, COTR
Grand Canyon Monitoring and Research Center
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001

20 December 2003

TABLE OF CONTENTS

Introduction

Here we present the results of the Terrestrial Ecosystem Monitoring activities in riparian habitats of the Colorado River corridor of Grand Canyon National Park during 2003. This represents the third year of data collection for this project and an opportunity to assess changes in the status of the flora and fauna surveyed by this project (Figure 1) over multiple years. The data were collected during a series of river trips extending from January through September. Table 1 lists the downriver trips taken, and the work performed on each trip. Supplemental work was done during day-trips upstream from Lees Ferry in the Glen Canyon reach before and / or after the Spring and the Fall trips. In the Spring surveys, as in 2002, the vegetation, arthropod, herpetofaunal and small mammal surveys were split between two trips to better control for early-season phenology changes over the 390 km of distance and 450m elevation drop between Glen Canyon Dam and Diamond Creek; surveys downstream of Phantom Ranch were done in early April and those upstream were done in late April and early May.

2003 Precipitation and Hydrograph

Due to several fortunate factors, we were able to achieve the goal of relating productivity in riparian habitats to records of precipitation and the hydrograph in this year. Patterns of both precipitation and discharges from Glen Canyon Dam differed from patterns seen in 2001 and 2002. More importantly, the patterns of precipitation and flows were not correlated so that we have been able to get a glimpse of how each affects resources separately. We expect that as more years of data are collected under differing precipitation and flow regimes, we will be able to strengthen the statistical connection between river flows and riparian community change.

Winter precipitation before the spring 2003 surveys was near seasonal and annual averages, following a near record winter drought in 2002 and a wet winter before the 2001 spring trip. Data collected from the records at the Western Regional Climate Center (http://www.wrcc.dri.edu/summary/) showed that a very dry January which followed a dry December 2002 was offset by a very wet February, so that the overall winter precipitation (October – April) was only slightly below normal. This was important because it followed a very dry winter which was preceded by a very wet one in 2001. Summer (May and June) precipitation was only a third of normal totals and monsoon rainfall before the fall trip (July and August) was only about 75% of normal. The same period in 2001 was slightly drier than normal and in 2002 it was wetter than normal. Although the 2003 precipitation in the same period in Flagstaff (NOAA Station I.D. 023010) was slightly wetter than normal (20% above average), most of the storms ran south of Grand Canyon so that the latter half of 2003 in our study sites was much drier than normal.

The hydrograph was fairly unusual in the first half of 2003 (Figure 2). After a period of low flows with little fluctuations from September through December 2002, flows from January through March of 2003 had similar average flows compared to the previous two years, but much wider fluctuations, consistently topping out around 565 cubic meters per second (20,000 cubic feet per second). These flows were unusual in two ways. First, the top of the hydrographs were consistently higher than they had been in recent years by 15 – 25%. Second, although they were not in the same range as pre-dam flows (see Webb et al. 1999), sustained daily fluctuations of that magnitude (140 – 565 cms) have not been seen since 1990, and they were never part of the pre-dam hydrograph. Studies in other regulated southwestern U.S. river systems have shown that although the status of water relations in riparian habitats is important to the biotic

communities (Stromberg et al 1996, Shafroth et al 1998), the variance from recent years drives patterns of change (Merritt and Cooper 2000). In the second half of the year, flows were slightly below 2002 levels and slightly above 2001 flows.

Although technically one can define trends from only two years of consistently collected data, we believe that this year's findings will present managers with a useful set of tools to assess the impacts of dam management decisions on the plants and animals in riparian habitats. The common theme throughout last year's report was the effect of extremely dry conditions in 2002. Working with data from a spring survey which followed "normal" levels of winter precipitation after unusually wet and dry years meant that we could examine the behavior of plant and animal populations under three different sets of conditions. It also became clear that there are complex and time-lagged effects of climate and the hydrograph on these resources that will require several more years of sampling to sort out. For example, animal populations depleted after the dry year in 2002 did not all show the expected response to increased rainfall we had in 2003. Long-lived perennial herbaceous plants like bunchgrasses which were killed during the drought in 2002 cannot be replaced without several years of consistent growth. It is likely that it will take several years to see all the effects of release from drought conditions and low flows.

Report structure

As in previous years, this report contains separate sections covering each taxonomic group by the investigator(s) who oversee the work on that group. In each section are described the purpose, objectives, methods, and results of the work performed, along with a summary with some interpretation of patterns seen. Pages are numbered sequentially, but figures and tables are numbered so as to be consistent within chapters only.

We first present the results from the integrated sampling in which all taxa are surveyed simultaneously. These are presented in sections in a sort of taxonomic order (vegetation, arthropods, herpetofauna, breeding birds, and small mammals). These sections are followed by a section which covers a first pass at the integration of faunal patterns with vegetation structure. This latter subject will be covered more fully in a synthesis document to be finished in 2004.

After these sections, we present sections on related, but not integrated, studies. First, the results of the vegetation dynamics transect surveys are presented, followed by sections on overwintering birds, raptors, and Southwest Willow Flycatcher surveys. In the final section, we have brought up some problems encountered in the first three years of this monitoring process.

Literature Cited

Merritt,D.M. and Cooper, D.J. 2000. Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River basin, USA. Regulated Rivers Research and Management 16:543-564.

Shafroth, P.B., Auble, G.T., Stromberg, J.C., and Patten, D.T. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18: 577-590.

Stromberg, J.C., Tiller, R., and Richter, B. 1996.: Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6: 113-131.

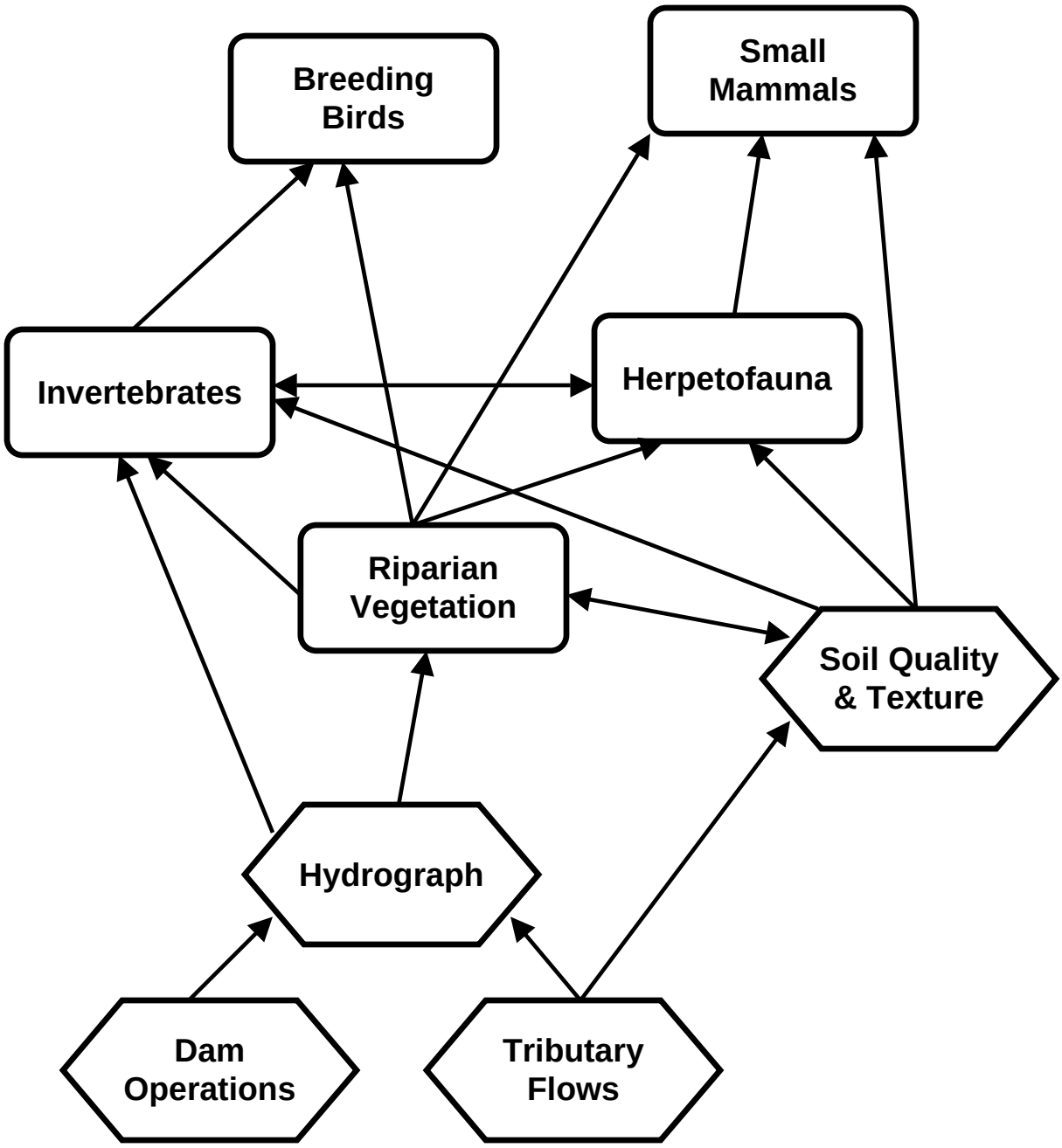


Figure 1. Graphical model of relationships among biotic and abiotic components in the terrestrial riparian habitats of the Colorado River corridor in Grand Canyon. Rectangular areas represent the taxonomic groups surveyed during this project. Hexagonal areas indicate environmental factors (stressors) with effects on the flora and fauna of the riparian ecosystem.

Table 1. Terrestrial Ecosystem Monitoring Project 2002 Field Activities

		Avifauna				Vegetation					
Trip	Dates	Breeding Birds	SWWFL Surveys	Overwintering Birds	Waterbirds	Vegetation Structure	Vegetation Dynamics	Survey Transect Layout	Invertebrates	Mammals	Herpetofauna
1	Jan 19 – Jan 30			X	X			X			
2	Apr 3 - Apr 18	X				X[1]			X[1]	X[1]	X[1]
3	May 1 - May 16	X				X[2]			X[2]	X[2]	X[2]
4	May 15 – May 31		X								
5	Jun 26 - Jul 11	X	X						X	X	X
7	Aug 21 - Sep 5						X		X	X	X

[1] Phantom Ranch to Diamond Creek only
[2] Lees Ferry to Phantom Ranch only

Table 2. Standardized monthly precipitation index for 2000 – 2003. Standardized precipitation is calculated as the difference of a month's total from the long-term average, divided by the standard deviation of that month's observations at that station. Each number below represents the average standardized precipitation from 12 stations in northern Arizona and southern Utah[1].

	Year			
Year	**2000**	**2001**	**2002**	**2003**
January	-0.375	0.468	-0.825	-0.732
February	0.019	0.156	-1.111	1.203
March	0.626	0.313	-0.774	0.022
April	-0.728	-0.006	-0.840	0.011
May	-0.760	-0.510	-0.823	-0.449
June	-0.211	0.463	-0.696	-0.660
July	-0.710	0.141	-0.383	-0.302
August	0.324	0.431	-0.962	0.184
September	-0.637	-0.620	1.238	
October	2.631	-0.729	0.075	
November	-0.481	-0.345	0.079	
December	-0.638	0.393	-0.221	
Total	-0.061	-0.069	-1.154	

[1]Stations (NOAA ID #) included in table: Colorado City (021920), Pipe Springs (026616), Wahweap (029114), Page (026180), Lees Ferry (024819), Bright Angel (021001), Phantom Ranch (026471), Grand Canyon #2 (023596), Temple Bar (028516), Kanab (424508), Mexican Hat (425582), St. George (427516).

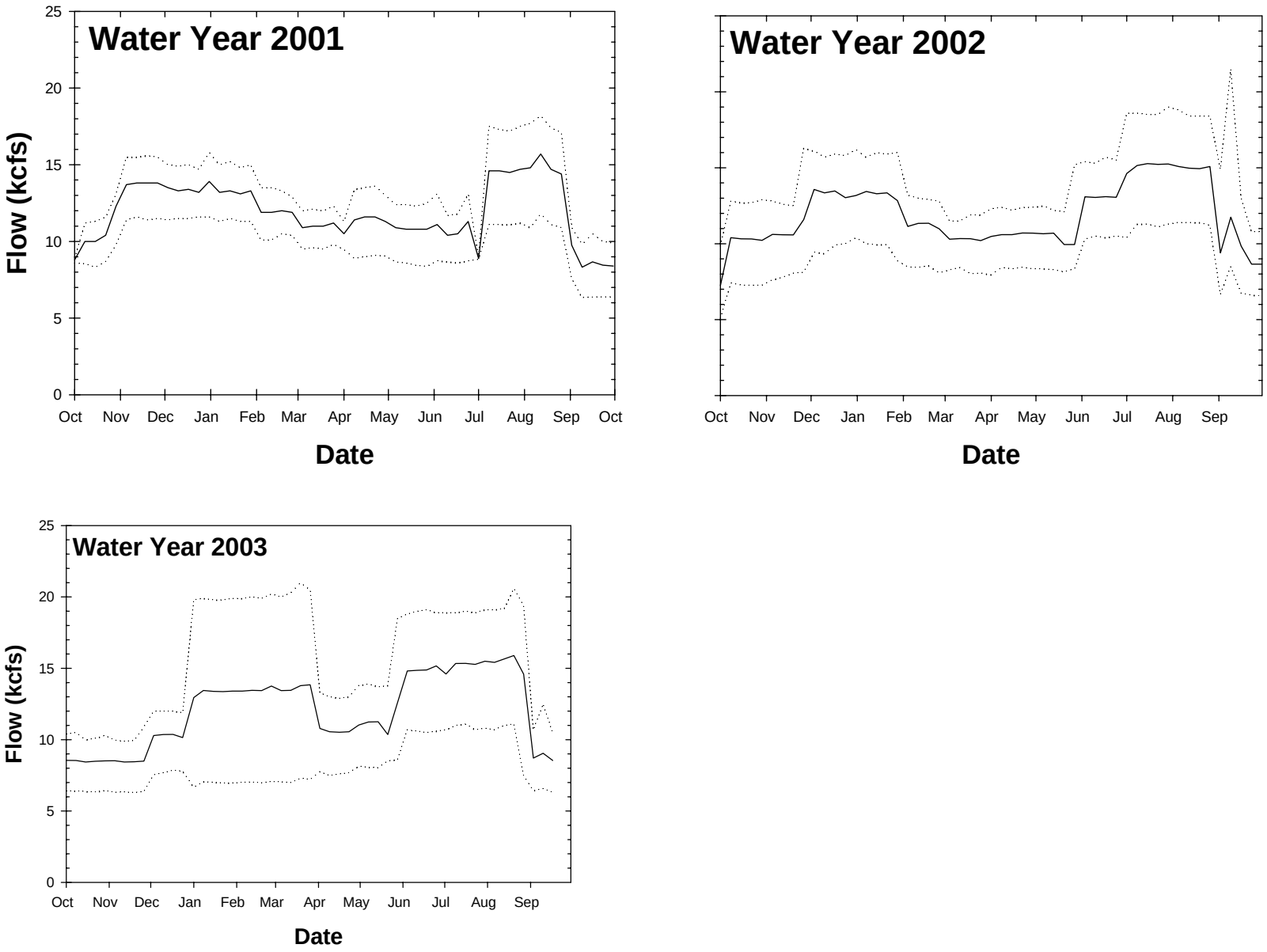


Figure 2. Hydrograph at the USGS Grand Canyon gage 2001-2003. Solid line = weekly mean flow, dotted lines = weekly maxima and minima.

INTEGRATED TERRESTRIAL ECOSYSTEM SAMPLING

Vegetation Structure

Michael Kearsley
Northern Arizona University

Purpose:

The purpose of collecting vegetation structure data is to document and detect trends in the density, three-dimensional distribution, and species composition of riparian vegetation in the three hydrologic zones (shoreline, new high water zone and old high water zone) of the integrated sampling study sites and bird patches. These will be used to derive measures related to primary productivity and biomass of vegetation which can be related directly to the habitat quality for animal taxa of interest in these sites.

Objectives:

In 2003 there were several objectives for the vegetation structure work: 1) to measure total vegetation volume (TVV) of woody species in new high water zone and old high water zone patches where bird surveys were conducted; 2) to measure TVV of woody species on the integrated faunal survey transects where arthropod, herpetofaunal, and mammal surveys take place; 3) To determine whether there has been change in the TVV measures in bird patches and integrated faunal transects over the two years since the initial surveys were conducted in 2001; 4) to determine if investigator impacts could be detected by comparing TVV measures in those plots which had been sampled annually to those which had been surveyed in 2003 only; 5) to collect information on plant species composition and cover on the integrated faunal survey transects; 6) to test for vegetation compositional changes along the survey transects between 2002 and 2003.

Methods:

In the third year of sampling, we employed a number of measurement types in the bird patches and faunal transects. We measured vegetation density and productivity as Total Vegetation Volume (TVV; Mills et al. 1991). We measured the species composition of the faunal transects with visual estimates of cover classes for each species. Sample sites for both bird patches and integrated faunal survey sites were selected by GCMRC personnel. Within the sites, the locations of counts and survey transects were determined by others on this project who were working with the various faunal groups.

Bird patch vegetation structure. At each bird survey location, the site was divided into new- and old high water zones patches, with the 90,000 cfs (2,550 cms) stage elevation being the dividing point between them. In patches where very little or no old high water zone vegetation was present because that area was overly steep or a cliff face, no vegetation survey was conducted. In each vegetated patch, we used tables of random numbers to determine the locations of 20 random points. At each point, we recorded a modification of the TVV measure of Mills et al. (1991) using a telescoping

fiberglass survey rod. For each meter above the ground, the number of decimeters which had live vegetation within 10 cm of the rod would be read to the data recorder, together with the species responsible for the contacts. If more than one species occupied the same decimeter, both were recorded, along with the number of vacant decimeters in that meter.

Because investigators working on vegetation structure in Grand Canyon bird patches had used the original formulation of TVV (e.g., Spence et al. 1998), we converted by passing ours through two processes. First, the original TVV formulation allowed only one "hit" per decimeter, even if it was occupied by several species. We therefore had to revisit those meter sections with multiple species and subtract the number of "vacant" decimeters from 10 to produce a TVV measure equivalent to the original measure. Second, the original TVV measures recorded only "hits" from woody species, as herbaceous species and annuals were not thought to affect the distribution of breeding birds. Using the species identities recorded in the field, we subtracted the number of herbaceous "hits" from the total number of hits at each point to calculate a woody-species-only TVV.

Transect vegetation structure. Each integrated monitoring site was divided into three hydrologic zones: shoreline (water's edge to the 25,000 cfs / 700 cms stage elevation), new high water zone (upper shoreline boundary to 90,000 cfs / 2550 cms stage elevation) and old high water (upper boundary of new high water zone to ca. 150,000 cfs / 5000 cms stage elevation where vegetation grades into desert scrub). In each of these zones, an arthropod pitfall transect consisting of 10 pitfall traps at 10 meter intervals was established (see ARTHROPOD SURVEYS section following). We recorded total vegetation volume data along each transect by taking a TVV measurement point, as described above, at a randomly chosen point 1 meter upslope or riverward of each pitfall cup. Transect TVV data were processed in the same way as the bird patch data, summed across all 10 points, and then converted to a per 20 point quantity to place it in the same range as the bird patch data.

Transect plant species composition. Because arthropods, some herpetofauna, and small mammals are likely to be affected by the productivity of non-woody plant species, we collected composition and cover data on all species around the pitfall traps where TVV data were collected. At each pitfall trap point, we recorded the identity of all species, woody and herbaceous, within 3 m of each pitfall trap. To reduce observer bias and to speed data collection, the total live vegetation cover for each species was measured in broad cover classes (Table 1) at each pitfall. Data were pooled within each transect; species represented on a transect included all species encountered at the 10 pitfall points and cover values were averaged across all points on the transect before analysis.

Hydrograph and precipitation data. In order to determine the contribution of dam discharges to differences between years in vegetation structure, we examined records of discharge from Glen Canyon Dam. Daily minimum, maximum and mean streamflow gage data from the U.S. Geological Survey's gage at Glen Canyon Dam (USGS 2003) were retrieved. For each spring trip, we determined the maximum and minimum flows, as well as the mean flow and a "top of fluctuations" for the 30 days prior to the launch of the trip. Because single days with unusual flows could throw off the analysis, the "top of

fluctuations" was defined as the average plus one standard deviation of the daily flow maxima.

Because we also needed to account for the effects of precipitation on growth, we gathered data on monthly precipitation from rain gages in northern Arizona and southern Utah from the Western Regional Climate Center's website (WRCC 2003). We selected 12 gages to represent the region around Grand Canyon because the three stations at the Canyon itself (Bright Angel R.S., Phantom Ranch, and Grand Canyon N.P. 2) measured only the area in and immediately around the inner gorge. Table 2 lists the gages used and the NOAA station numbers. Because each gage measures a different part of the region with different means and variability, we normalized each month's precipitation total from 2000 – 2003 by subtracting the gage's long term mean (for that month) and dividing the difference by the standard deviation of the long term records for that month. Thus, monthly totals were converted to a monthly deviation from average, scaled to the natural variability in that station. We then calculated a regional normalized rainfall for each month by taking the mean of all 12 gages normalized data for that month.

To generate seasonal measures, we divided the year into three precipitation seasons relevant to the southwestern U.S. region where monsoonal patterns dominate. These were winter precipitation (October – April), summer precipitation (May, June), and monsoon season before the fall trip (July, August). For each station, the precipitation for those months was summed, and the mean for those months was subtracted from the sum. The difference was divided by the mean for those months to produce a proportional deviation from the norm.

Statistical Analyses:

Vegetation structure analysis. To determine whether there were significant changes in TVV of bird patches, we performed an analysis of variance (ANOVA). The first analysis included as independent factors hydrologic zone (new high water , old high water), year (2001, 2002, 2003), canyon width (wide or narrow, per Schmidt and Graf 1990), site (a random effect, nested within canyon width), plus interactions between zone and year, and zone and width. Because we detected a significant interaction between year and zone effects (the two zones behaved differently across the three years), we analyzed each zone separately for differences among years, widths and sites. Pooled TVV values from all three years within a zone were compared with an unbalanced, mixed effects analysis of variance, with year and width as a fixed effects and site as a random effect. Because random effects were in the model, we used the reduced effects maximum likelihood (REML) method to fit the model (SAS Institute Inc., 2001). In cases where the years differed, with the effects of width and site accounted for, we substituted the normalized winter precipitation and one of several elements from the pre-trip hydrograph: maximum flow, minimum flow, mean flow, or top of fluctuations.

To determine changes in TVV values from the integrated sampling transects, we performed a similar set of ANOVAs for shore, new high water and old high water zones, because the interaction of zone by year was statistically significant (at least one of the three zones was changed in different ways during the three years). Data were pooled within each transect and each zone's TVV data were analyzed with a mixed effects,

unbalanced model analysis of variance with site as a random effect and year as a fixed effect. As with the bird patch data, we used the REML method to fit the model. Also, when years differed significantly in TVV within hydrologic zones, we substituted normalized winter precipitation and one of the elements of the pre-trip hydrograph.

Faunal transect cover and composition analysis. To summarize plant species composition data from the faunal sampling transects we calculated cover estimates and compared composition among zones and across years (data were collected ony during 2002 and 2003). First, we derived estimates of total vegetative cover for each pitfall point by converting cover class observations to the midpoint of the range it designated (Table 1). For the transect, each species' cover was calculated as the mean of the 10 observations per transect, and the transect total cover estimates was calculated as the sum of all species' means.

We compared species composition across years and zones with a two-way crossed analysis of similarity (ANOSIM; Clarke 1993) using the Bray-Curtis dissimilarity measure (Faith et al. 1987). The method calculates a test statistic, R, based on comparisons of dissimilarities among samples within the same group to dissimilarities among members of different groups. The difference between the mean rank of among-group dissimilarities and the mean rank of within-group dissimilarities is compared to the results calculated after each of 1000 random permutations of group membership. The proportion of random runs which have larger differences between the among- vs. within group mean rank difference is the probability of your pattern arising from chance alone.

In cases where the ANOSIM analysis indicated a significant difference between years, we used an Indicator Species Analysis (Dufresne and Legendre 1997) to determine which species' abundances differed significantly between 2002 and 2003. The method uses information on species relative abundance within a year and frequency of occurrence in samples within a year to calculate an indicator value for that species in that year. This value is compared to values calculated from 1000 cases in which samples are randomly assigned to one year or the other. The statistical significance of the indicator value is calculated as the proportion of random runs which have higher indicator values than the sample data. Species with indicator values greater than 0.25 and probabilities of less than 0.10 are considered useful indicators (Dufresne and Legendre 1997).

Results:

Bird patch vegetation structure. The overall analysis of bird patch vegetation structure revealed a significant statistical interaction between the effects of year and zone (i.e., the two zones behaved differently in the two years; $F_{(2,201)} = 3.43$, $p < 0.5$) so that each zone was analyzed for interannual changes separately. This pattern resulted from relatively larger changes seen in the new high water zone patches and little change in the old high water zone (Figure 1). TVV in the new high water zone patches was roughly 15% lower in 2002 than it was in 2001, and recovered by nearly that much in 2003 (Year effect; $F_{(2,59)} = 2.59$; $p = 0.083$). In the old high water zone, TVV increased by roughly 20% in 2002 over 2001, and by another 5% in 2003 (Year effect; $F_{(2,45)} = 2.42$, $p = 0.101$). Neither of these changes was statistically significant, and so the analysis was not pursued further.

Faunal transect vegetation structure. Vegetation structure in the faunal transects showed the same patterns as the bird patches, only more strongly. Again, the overall analysis showed a statistical interaction between year and zone effects ($F_{(4,84)} = 4.49$, $p < 0.005$) indicating that at least one of the three zones was behaving differently than the other two (Figure 2). In the shoreline transects, TVV increased in each of the three years, but the pattern not statistically significant ($F_{(2,8)} = 2.65$, n.s.). In the old high water zone, there was a slight decline in TVV each year which was not statistically significant ($F_{(2,8)} = 1.48$, n.s.). In the new high water zone, TVV in 2002 was approximately half of its 2001 levels, then rose to almost the 2001 levels in 2003 ($F_{(2,8)} = 16.03$, $p < 0.005$). To determine the basis for this year-to-year differences, we substituted the pre-trip mean flow and relative precipitation for the winter preceding the trip for the "year" term and re-ran the analysis. Both relative precipitation ($F_{(1,8)} = 19.21$, $p < 0.05$) and mean flow ($F_{(1,8)} = 3.20$, $p < 0.01$) contributed to the "year" effect. The effects of these two factors are presented graphically in Figure 3.

Faunal transect composition change. The two-way crossed analysis of similarity (ANOSIM) showed both zone and year effects. As would be expected, the three zones differed significantly in species composition ($R = 0.538$, $p = 0.001$). In addition, the two years differed significantly in species composition, even when the effects of zone were accounted for ($R = 0.05$, $p = 0.034$). When we compared data from 2002 and 2003 within each zone, we found no shift in the composition of plant species in the shoreline zone ($R = -0.024$, $p = 0.680$), or in the old high water zone ($R = 0.06$, $p = 0.106$), but a significant change in the composition of vegetation along new high water zone faunal transects ($R = 0.115$, $p = 0.015$).

The change in spcies composition within the new high water zone transects detected by the analysis of similarity resulted from changes in the abundances of both woody and herbaceous species, both showing increases in 2003. Tamarisk, arrowweed and mesquite all had higher abundances in 2002 than 2003. Herbaceous species, including annual bromes, six-weeks fescue, Bermuda grass and spiny aster were all more common in 2002 than 2003. Only one species, scratchgrass (Muhlenbergia asperifolia) had higher abundances in 2002 than in 20003. It is reasonable to speculate that the higher abundance of perennial species came about from higher water tables from higher river flows, and that higher levels of annual cover were the result of slightly higher precipitation in 2003.

Summary:

As was the case in last year's report, the data described here have shown significant change in the new high water zone structure between years, but only trends in the shoreline and old high water zones. The change in the new high water zone areas can be attributed to changes in the availability of water in the form of precipitation and groundwater infiltration from river flows.

It is not surprising to find a connection between water availability and riparian vegetation density in the arid southwestern U.S. In other river systems, productivity of woody species has been shown to respond to the levels of surface- and groundwater (Szaro and DeBano 1985, Stromberg and Patten 1990, 1992, Stromberg 1993). Riparian vegetation also responds to degrees of change from previous years (Shafroth et al. 2000).

In riparian habitats of the Colorado River in Grand Canyon, decadal- and semi-decadal scale changes in vegetation resulting from imposition of regulation have been shown for both woody (Pucherelli 1986, Waring 1996) and herbaceous (Stevens et al. 1995) species. Reports of year-to-year change in vegetation abundance (e.g., Stevens and Ayers 1993, Kearsley and Ayers 1999b) have been connected to river flows only anecdotally, except in the case of unusual events (Brian 1987, Kearsley and Ayers 1999a).

In this report, however, we have made a direct link between specific flow levels and vegetation abundance under normal flows. This is important because by refining this connection, we will give managers a way to predict the response of terrestrial riparian habitat quality to decisions made about the hydrograph for the upcoming year. We have been able to create this tool only because a) the sampling design has removed much of the investigator bias from vegetation monitoring and therefore been made more amenable to statistical treatment, b) some extreme values of flow and precipitation took place during the past three years, and c) enough time had elapsed using a single sampling design to detect these patterns. More years of data under different flow and precipitation regimes will further refine this useful tool.

We do not infer that our failure to detect changes in the density of woody vegetation in the shoreline transects reflects a lack of change there, merely a lack of time to detect it. Two factors work against the likelihood of finding trends across years in the shoreline habitats: within year variability and the manner in which shoreline transects are located. First, many of the transects had no vegetation at all, having been scoured by the 20,000 cfs flows during the spring. The presence of many "zero density" sites creates more than the normal amount of variability. Second, this is compounded by the fact that the location of the shoreline transects is defined solely by the upper end of fluctuations during surveys. Generally they are located at a point 0.5 meters above the elevation of the recent fluctuations, rather than at some fixed point. Thus when we were surveying in April 2003, the top end of fluctuations was approximately 370 cms (13,000 cfs) which represented the mean value for flows from January to March and approximately 200 cms (7,000 cfs) below the top end of fluctuations so that the transect points were probably inundated for several hours each day during that period. This was not necessarily the same place which was surveyed in April of 2002, when the top end of fluctuations were at approximately 340 cms (12,000 cfs), or in April of 2001 when flows ranged up to 400 cms (14,000 cfs).

Of all elements in a monitoring program, the passing of time is the single greatest ally of statistical power (Urquhart et al. 1993, Urquhart and Kincaid 1999). Greater variation related to site-specific differences, climatic variability, and moving transects will mask year-to-year trends and so require longer sampling periods to detect those trends. Thus the flows from January to March of 2003 do not appear to have affected the density of vegetation along the shoreline, but more time will likely tell a different story.

Slight decreases in the old high water zone over the past two years likely reflect the results of two consecutive years of below average precipitation and the lagged responses of vegetation. The vegetation density measures are based on woody perennial vegetation, and woody species in these habitats grow very slowly (see Anderson and Ruffner 1987, Bowers et al. 1995). The death and die-back of shrubs and trees in 2002

will not be reversed in a single year, especially if there is below-average precipitation. If there is an underlying trend for vegetation volume in these habitats (as in Pucherelli 1986, Waring 1996), this variability will reduce our ability to detect it or require a longer sampling period to detect it.

Differences between faunal sampling transect and bird patch responses of vegetation density likely are caused by increased variability of bird patches. The transects span consistent elevations within sites, corresponding to approximately 30,000 - 35,000 cfs (850 - 990 cms) in the new high water zone and 85,000 - 100,000 cfs (800 - 990 cms) in the old high water zone. In contrast, TVV measurements in the bird patches take place across habitats representing a much broader range of flows (new high water: 25,000 - 50,000 cfs / 700 - 1400 cms; old high water: 90,000 - 150,000 cfs / 2500 - 4400 cms). In addition, the requirements for TEM sites, including 100^{+} m of habitat across 3 zones in plus camping areas and the presence of old high water zone vegetation, further restricts the ecological range of sites which will be selected. Bird patch areas vary from 160 - 35,000 square meters and as a result represent a broader range of conditions. These differences notwithstanding, the new high water zone vegetation responded in similar ways in the two sets of sites. The differences in old high water zone vegetation responses may be resolved with more time.

Literature Cited

Anderson, L.S. and G.A. Ruffner. 1987. Effects of the post-Glen Canyon Dam flow regime on the old high water line plant community along the Colorado River in Grand Canyon. Final Report. U.S. Department of the interior, National Park Service contract IA-4-AA-40-01930. 48 pages.

Bowers, J.E., R.H. Webb and R.J. Rondeau. 1995. Longevity, recruitment and mortality of desert plants in Grand Canyon, Arizona, USA. Journal of Vegetation Science. 6:551-564.

Brian, N.J. 1987. Aerial photography comparison of 1983 high flow impacts to vegetation at eight Colorado River beaches. Final Report. U.S. Department of Interior, Bureau of Reclamation Glen Canyon Environmental Studies Contract IA-4-AA-40-01930. NTIS PB89-180244. iv + 64 pages.

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18:117-143.

Faith, D.P., P.R. Minchin and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio. 69:57-68.

Kearsley, M.J.C. and T.J. Ayers. 1999a. Riparian vegetation responses: snatching defeat from the jaws of victory and *vice versa*. pp. 309-327. *in* Webb R.H., J.C. Schmidt, G.R. Marzonlf and R.A. Valdez, Editors. The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, Washington, DC.

---. 1999b. Status of Grand Canyon riparian vegetation 1998-1999. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement 1425-98-FC-40-22670.

Mills, G.S., J.B. Dunning and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bull. 103:468-479.

Pucherelli, M.J. 1986. Evaluation of riparian vegetation trends in the Grand Canyon using multitemporal remote sensing techniques. Final Report. U.S. Department of the Interior, Bureau of Reclamation, Glen Canyon Environmental Studies Report GCES/18/87. NTIS PB88-183470. 76pp.

SAS Institute Inc. 2001. JMP Statistics and Graphics Guide, Version 4. SAS Institute, Inc., Cary, N.C., 634 pp.

Schmidt, J.C. and Graf, J.B. 1990. Aggradation and degradation of alluvial sand deposits, 1965-1986, Colorado River, Grand Canyon National Park. U.S.G.S Professional Paper No. 1493. 120 pp.

Shafroth, P.B., J.C. Stromberg and D.T. Patten. 2000. Woody riparian vegetation responds to different alluvial water table regimes. Western North American Naturalist. 60:66-76.

Spence, J.R., LaRue, C.T., Muller, J.R., Brown, N.L. 1998. 1997 avian community monitoring along the Colorado River from Lees Ferry to Lake Mead. Unpublished repport. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center, Flagstaff, AZ. 17 pages.

Stevens, L.E. and T.J. Ayers. 1993. Impacts of Glen Canyon Dam on riparian vegetation and soil stability in the Colorado River Corridor, Grand Canyon, Arizona: Final Report. U.S. Department of the Interior, National Park Service Work Order No. CA 8000-8-0002.

Stevens, L.E., J.C. Schmidt, T.J. Ayers and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. Ecological Applications. 5:1025-1039.

Stromberg, J.C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management. 8:225-235.

Stromberg, J.C. and D.T. Patten. 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in the Eastern Sierra Nevada, California, USA. Environmental Management. 14:184-194.

---. 1992. Response of *Salix lasiolepis* to augmented stream flows in the upper Owens River. Madroño. 39:224-235.

Szaro, R.C. and L.F. DeBano. 1985. The effects of streamflow modification on the development of a riparian ecosystem. pp. 211-215. *in* Johnson R.R., C.D. Ziebell, D.R. Patton, P.F. Ffolliott and R.H. Hamre, Editors. Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. First North American riparian conference. USDA Forest Service General Technical Report Rm-120. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

U.S.G.S. 2003. Real time surface water data for USGS 09380000 Colorado River below Glen Canyon Dam, Arizona. Website**:** http://waterdata.usgs.gov/az/nwis/uv?09379910

Urquhart, N.S. and T.M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics. 4:404-414.

Urquhart, N.S., W.S. Overton and D.S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: impact of temporal patterns. pp. 71-85. *in*

Barnett V. and K.F. Turkman, Editors. Statistics for the environment. John Wiley and Sons, New York.

Waring, G.L. 1996. Current and historical riparian vegetation trends in Grand Canyon, using multitemporal remote sensing analyses of GIS sites. Final Report. National Park Service Cooperative Agreement CA 8000-8-0002. 24 pp.

W.R.C.C.2003. Western regional climate summaries: Arizona (http://www.wrcc.dri.edu/summary/climsmaz.html) and Utah (http://www.wrcc.dri.edu/summary/climsmut.html).

Table 1. Percent vegetative cover for six cover classes used in transect plant composition surveys

Class	Percent Cover	Class Midpoint
T (trace)	< 1%	.25%
1	1 – 5 %	3%
2	5 - 25%	15%
3	25 – 50%	38%
4	50 – 75%	63%
5	75 – 100%	88%

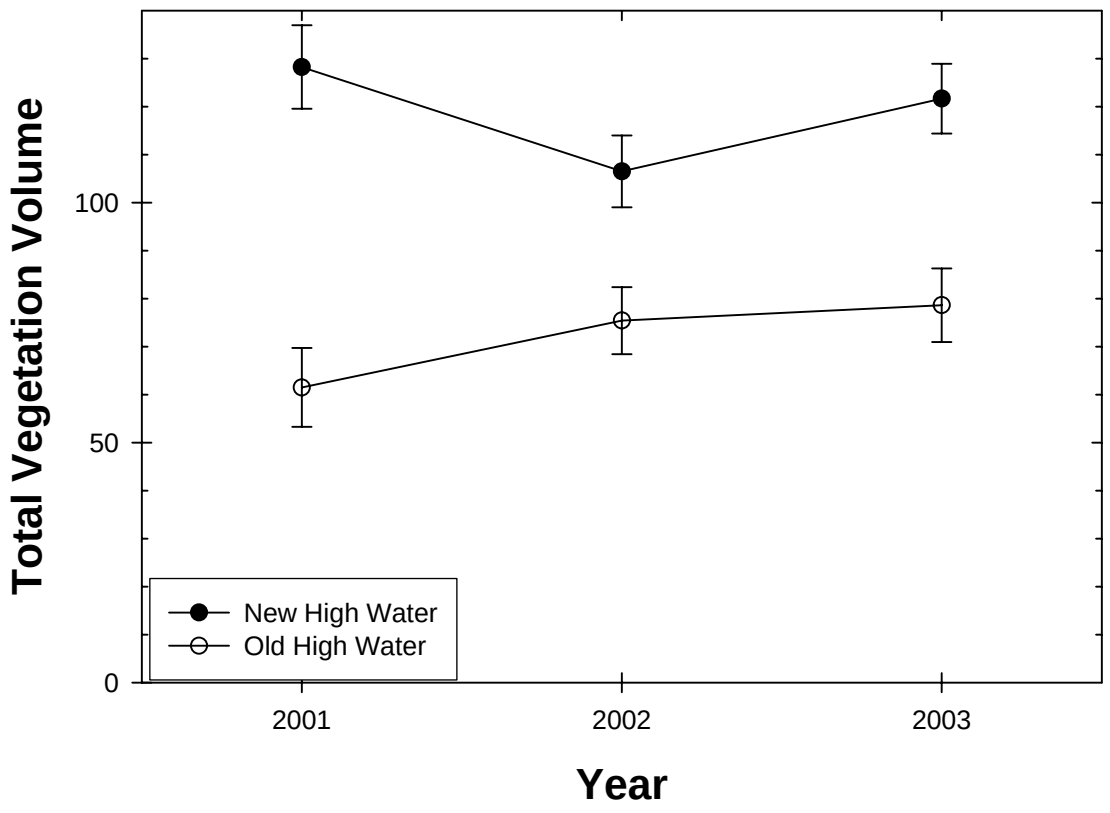


Figure 1. Total vegetation volume measures in new high water and old high water bird patches in from 2001 to 2003. Vertical bars represent +/- 1 standard error.

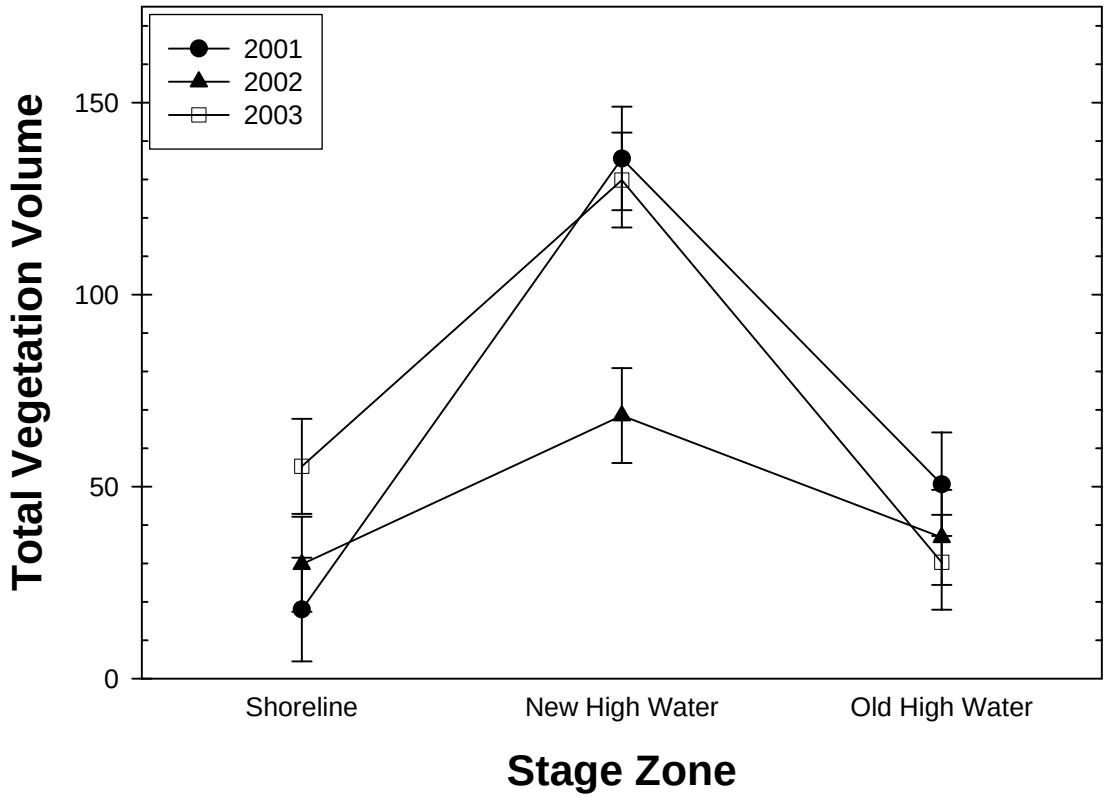


Figure 2. Total vegetation volume measures from faunal transects in the integrated monitoring sites. Vertical bars represent +/- 1 standard error.

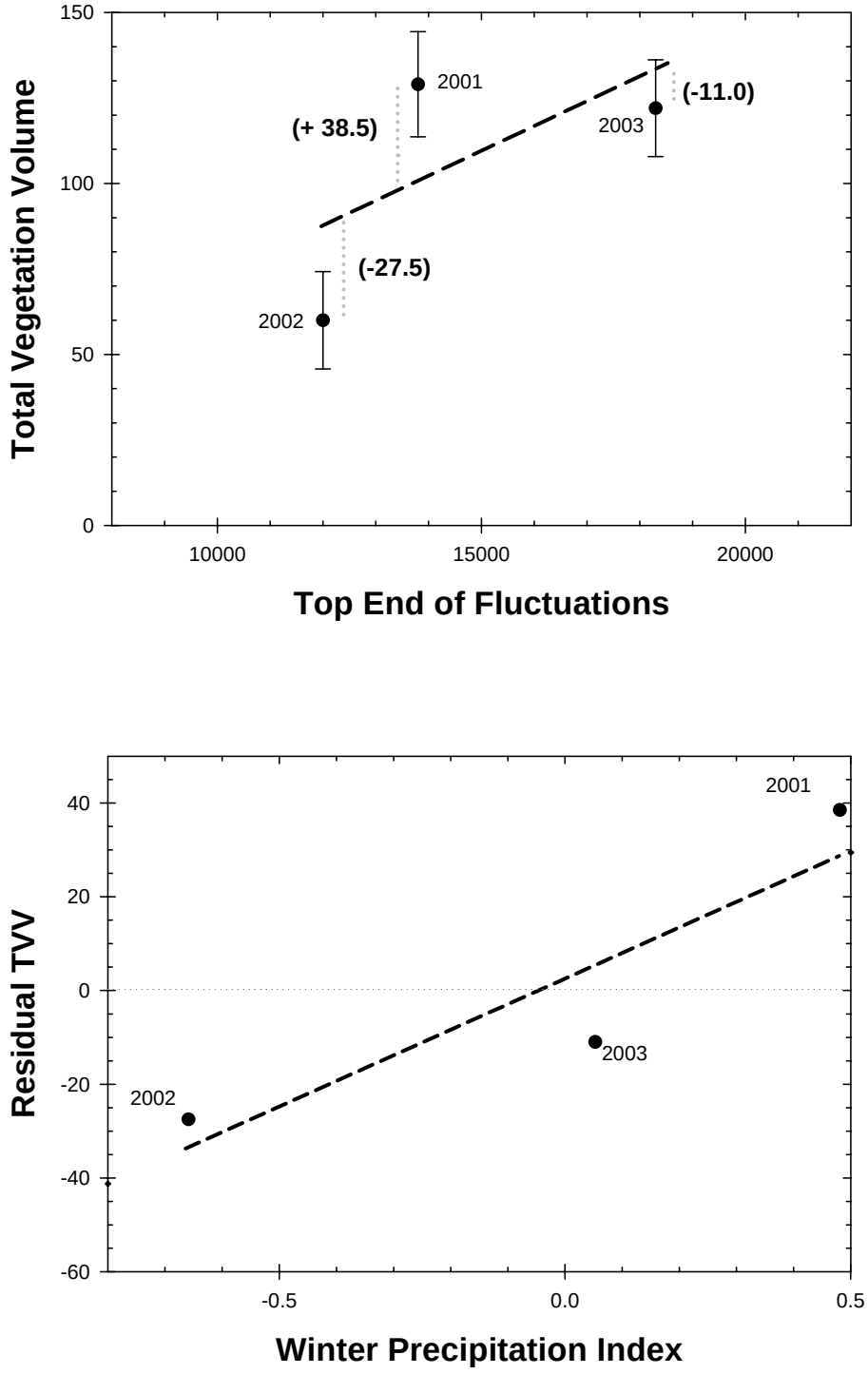


Figure 3. Response of total vegetation volume to water relations. Above: Most of the between-year variation in vegetation density can be explained by the upper end of daily flow fluctuations. Vertical bars represent +/- 1 standard error, the dashed line is the least squares regression fit to the points, and the dotted line represents the deviation from that line (residuals TVV in bottom graph). Bottom: Most of the residual variation from the fit of TVV to flows can be explained by the deviation of precipitation from normal values. Dashed line represents the least squares regression fit.

ARTHROPOD SURVEYS

Comparison of Arthropod Communities among three Hydrologic Zones along the Colorado River, Grand Canyon

Sandra Brantley, David Lightfoot,
University of New Mexico

Neil Cobb, Robert Delph
Northern Arizona University

Purpose:

The main purposes of the arthropod studies are to inventory and characterize the terrestrial arthropod fauna associated with the different river flow stages of riparian environments along the Colorado River in Grand Canyon. Arthropods are important components of the fauna because of the roles they play in ecosystems and in biotic community structure (Wilkie et al. 2003). There are several general questions that we are attempting to answer: Do the three principal river stages or water level zones, Shore (SHOR), New High Water Zone (NHWZ), and Old High Water Zone (OHWZ), support distinct assemblages or communities of arthropod taxa that are specific to each water zone? Are certain arthropod taxa more sensitive to environmental changes resulting from Glen Canyon Dam operation than other taxa? What is the most effective sampling design for monitoring riparian arthropod community dynamics in relation to river level fluctuations resulting from Glen Canyon Dam operation? The monitoring data will ultimately provide information on the effects of dam operation for riparian arthropods in Grand Canyon. The arthropod data also may be integrated with corresponding data for vegetation and vertebrate animals produced from this same research program, and other research questions about riparian terrestrial arthropods in Grand Canyon. For example, long-term interactions between plants and insects or with vertebrate animals in biogeographically restricted locations, may determine the existence of fragmented populations (Leon-Cortes et al. 2003).

Objectives:

The principal objectives for our arthropod studies are to: 1) Determine the species composition and relative abundance of arthropods associated with the OHWZ, NHWZ, and the SHOR environments. 2) Determine microhabitat associations for those arthropods, such as water zone preferences and host plant relationships. 3) Relate arthropod species composition to vegetation and vertebrate animals across the three hydrologic riparian zones. 4) Initiate an effective and efficient sampling design and procedures for comparative monitoring of arthropod communities across the three riparian hydrologic zones over time. 6) To develop a voucher and reference collection for Grand Canyon riparian arthropod specimens representing those taxa found during this project, and 7) To provide basic ecological information on Grand Canyon riparian arthropods to integrate with vegetation and vertebrate animal information produced from this and other research projects; to provide arthropod data for other biological, cultural,

and physical resource information needs; and to assess geomorphic scale trends in populations.

Methods:

Study sites and sampling points. Study site locations were determined by GCMRC personnel and listed in the in the Protocols document of the Request for Proposals. A total of 34 sites were selected for focused sampling of all terrestrial arthropods. Five of the sites were repeatedly sampled in 2001, 2002, and 2003 (river mile: 46.7R, 65.3L, 92.3L, 122.8L, and 198.0L). Ten sites were sampled only in 2001, another set of ten sites was only sampled in 2002, and another set of ten sites were only sampled in 2003. The purpose of selecting new sites was to increase the total number of study sites to obtain a better representation for the canyon.

Three transects were established at each site, one transect representing each of the three water level zones; SHOR, NHWZ, and OHWZ. Each transect was 100 meters long, partitioned into 10 sampling points at 10 meter intervals. The transects were laid out parallel to each other, beginning 20–100 m upstream or downstream from the camp, depending on constraints imposed by the local topography. The transect representing the SHOR was situated one meter above the existing daily highest river level line which was visible as a damp high water line on the shore. The actual daily shoreline fluctuation zone varies over time, depending upon water releases from Glen Canyon Dam. The transects representing the OHWZ and the NHWZ were situated in the middle of each of those zones' range of elevation above shoreline. The NHWZ was the hydrologic zone just above the SHOR and was characterized by vegetation dominated by tamarisk. The OHWZ was the highest elevation hydrologic zone and was characterized by mesquite, desert shrubs and acacia. In terms of size the OHWZ occupied the greatest amount of area for any given site (mean=8055m^2 SE=1033), the NHWZ occupied the next largest amount of beach habitat (mean=5598m^2 SE=688), and the SHOR occupied the smallest area (mean=2251m^2 SE=314). These estimates were based on 66 sites (our 34, plus other vegetation/bird measurement sites) selected throughout the study area.

Sampling periods: Arthropods were quantitatively sampled twice (Spring and Fall) during 2001, 2002 and 2003. The first sampling period in 2001 was April/May, and the second was August/September. In 2002 we sampled the lower and upper reaches on separate trips to accommodate potential phenological differences; earlier development and activity of the same taxa in the lower reaches of the canyon that would bias the sampling. For 2003 we reverted back to the 2001 schedule and did not divide the spring trip into two separate trips. We conducted qualitative sampling of arthropods during summer (June/July) trips each year to compare the mid-summer taxa to those of spring and fall. Data from summer trips will be presented in future reports once all of the identifications have been completed.

Ground-dwelling arthropods: Pitfall or pit traps are a widely used technique used to sample ground-dwelling arthropods, and the technique as been proven to obtain satisfactory abundance estimates for ground-dwelling arthropods (Thomas and Sleeper 1977). Arthropods with different behavior and activity patterns have different biases for capture, but consistent standardized sampling designs are still effective and appropriate for comparative sampling of ground-dwelling arthropods. Quantitative sampling of ground-dwelling arthropods by stage zone was conducted by use of temporary pitfall

traps. Pitfall traps were installed at each of the ten sampling points on each of the three transects per site. Traps were installed in the afternoon (~ 4:00 pm) on the arrival day to a site, and removed the following late morning (~10:00 am) before departing from the site. Each trap consisted of one 16 oz. plastic cup (15 cm tall, 10 cm wide) dug into the soil, with the open top flush with the soil surface. The surrounding soil was backfilled and smoothed around the top of the cup. 100 ml of river water was then placed in the bottom of each cup to drown and hold arthropods that fell into the cup. Traps were collected the following morning by pouring the contents of each of the 10 traps into a single 500 ml. plastic bottle, pooling all 10 traps per transect line. The contents of each 500 ml bottle representing traps from each of the three transect lines were then poured through a fine (1 mm) mesh screen to filter the arthropods from the water. The filtered arthropods were then labeled and placed into a single 50 ml bottle containing 70% ethanol. All sample bottles, each representing ten pooled traps per transect line, per site, per trip (season) were then taken to the lab following each river trip.

Plant-dwelling arthropods: Arthropods that live on vegetation are taxonomically and ecologically different from those that occur on the ground. Plant-dwelling arthropods were quantitatively sampled from the entire vegetation foliage volume or area adjacent to each of the ten pitfall sampling points along the three water zone transects at each site using muslin cotton insect sweep nets measuring 38 cm across and 65 cm deep. Insect sweep nets are a well established and standard method for sampling arthropods on plant foliage (Lightfoot & Whitford 1989). All plant foliage (all plant species) in a volume 2 meters radius from each pitfall trap were swept with the insect sweep nets to dislodge and collect all arthropods resting on the foliage. The number of sweeps taken was a function of the amount of plant foliage present at each sample point. All sweep samples were taken during early morning hours (1-2 hours after sunrise) when foliage arthropod mobility was low, and arthropods less likely to escape. The contents of each point sweep were placed into a one-gallon plastic zip-lock bag. Sweep samples from each of the ten sample points per transects were pooled into one bag, representing one foliage arthropod sample per transect line, per study site. The quantitative foliage sweep samples were field sorted to remove the arthropods from the plant material. All individual arthropods per sample were placed into 20-50 ml glass storage vials containing 70% ethanol. For taxa that are best preserved dry. Those dry specimens were placed in tissue paper, and sealed in small plastic containers with naphthalene as a preservative. All samples were then taken to the lab following each river trip.

In addition, qualitative sweep samples were taken from the dominant plant taxa in each of the three water zones at each site. The foliage of each plant species was swept, and the contents of each sweep sample placed into a one-gallon clear plastic zip-lock bag. Sweeping was continued until no new arthropod taxa were observed in the samples representing each plant species. Sweep samples were pooled into one sample per plant species per water zone per site. A representative sample of each arthropod taxon was taken from each sample in the field and placed into small storage vials containing 70% ethanol or naphthalene, depending upon which preservative was appropriate. All labeled samples were taken to the lab where taxa are being identified to the species level. Data from these samples are providing us with information on the arthropod taxa associated with the various plant species along the river corridor. Those data additionally allow us to

compare arthropod species diversity associated with given plant species across the three water level zones.

Flying insects. To gather comparative data on flying insects in each water zone, malaise traps (tent-like flight interception traps) and black light traps (Southwood 1978) were used to sample flying insects in the day and night, respectively. One malaise trap was installed in the middle of each of the 100 meter sampling transects in each of the three water zones at each site. The traps were erected in the afternoon (4:00 pm) at the beginning of each site visit, and disassembled the next morning (10:00 am) before departing the site. Each of the three malaise trap containers was emptied and the insects were sorted in the field, and placed into small glass vials with 70% ethanol, or small plastic containers with naphthalene, depending upon the insects. Those samples were then taken to the lab following each river trip.

We used black-light (UV) traps to sample night-flying insects. Our black light traps consisted of a fluorescent black light suspended over a 3-gallon bucket containing a pyrethroid insecticide no-pest strip. A large plastic funnel (40 cm top diameter, 10 cm bottom diameter) was placed on top of the bucket, and the light source suspended just inside the top of the funnel. Each light trap was connected to a power source with a timing device. The lights were turned on at sunset, and run until midnight (12:00 am). The light trap buckets were collected at sunrise, and all insects were removed and placed into vials with ethanol or naphthalene. Those samples were then taken to the lab following each river trip.

General Collecting. To enhance our ability to inventory many arthropods, we also conducted general collecting at each site as time permitted. General collecting involves searching all environments and habitats in the riparian corridor for arthropods, capturing and preserving the specimens. Techniques include searching and capturing active flying insects with a light aerial net, collecting arthropods on the ground surface, looking under rocks and other objects for arthropods, collecting insect pollinators on flowers, sweeping vegetation with sweep nets, collecting parasites (e.g., fleas and mites) from vertebrate animals, sweeping the air immediately above the shore line for shore insects, and searching for scorpions at night with a portable black-light. All specimens obtained during general collecting were placed in vials with 70% ethanol or naphthalene, and labeled as to habitat and water level zone. Those samples were then taken to the lab following each river trip.

Specimen processing, identification, and voucher collection preparation. Because there are so many arthropod taxa, most arthropods must be collected in the field and identified in the laboratory. Voucher specimens must be prepared, identified, and placed in voucher specimen collections. Sample sorting and identification involves tens of thousands of specimens from each river trip. Many specimens must be sent to taxonomic experts for correct identification. This entire process generally takes one to three years for specimens obtained on a particular river trip.

All samples and specimens collected in the field on river trips were stored in vials or other containers with labels including information as to site, date, water level zone, habitat, and collection method. All samples were taken to arthropod museum labs at NAU (Northern Arizona University, Arthropod Museum) or UNM (Division of Arthropods, Museum of Southwestern Biology) where all arthropod samples are sorted and counts of numbers of individuals by taxa are recorded. Voucher specimens

representing each taxon are currently being preserved and labeled as museum specimens. We are building a voucher specimen collection at both NAU and UNM for this project. All count data are being entered into computer database files for statistical analyses.

Arthropod analyses. We have produced three principal arthropod data sets representing the three principal quantitative sampling methods; 1) ground-dwelling arthropods collected from pitfall traps, 2) plant-dwelling arthropods collected from vegetation sweep net samples, and 3) flying insects collected from UV light traps and malaise traps. We used parametric analysis of variance (ANOVA) to test for differences in arthropod species richness and for differences in arthropod abundances between water zones, seasons, and years. The same analyses were run on each data set separately.

Non-parametric Multi-Response Permutation Procedures (MRPP) analyses also were performed for the ground-dwelling and plant-dwelling arthropod data. MRPP was used to confirm results of the ANOVA procedures, since arthropod count data are often not normally distributed. MRPP was performed on matrices represented by taxa which have contributed 18 or more individuals to the count data over the 3-year study (based on 2 sample times per year, 3 water zones, and 3 years); 38 species of ground arthropods, and 45 species of plant arthropods.

We pooled data for individual species into ecological functional/taxonomic groups or operational taxonomic units (OTU's) that are relevant to the purposes of this study. Techniques such as designation of OTU's for rapid post field sample processing continue to be effective (Wilkie et al. 2003). The Results section below shows analyses for all arthropods combined (for each sampling method) and for the arthropod functional/taxonomic groups (see the Results for listings of those functional/taxonomic groups). Detailed species-level analyses will be performed in the future once we have identified more of the arthropod taxa to the species level (2004 and 2005).

Insects have relatively short life cycles and high mobility, and therefore, exhibit rapid responses to environmental change, particularly in comparison to long-lived vertebrates (Evans and Bellamy 1996, Young 1994). Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) was used to determine if any arthropod species sampled from this study are appropriate water zone indictor species. ISA analysis was performed on ground-dwelling and plant-dwelling arthropod data only, since those sampling methods provide more precise water zone associations than light or malaise traps. ISA was performed on matrices represented by taxa which have contributed 18 or more individuals to the count data over the 3-year study (based on 2 sample times per year, 3 water zones, and 3 years); 38 species of ground arthropods, and 45 species of plant arthropods.

Results

Ground-dwelling Arthropods.

From 2001-2003 we have sampled and identified 180 species of **ground-dwelling arthropods** from our pitfall trap samples. Arthropod species richness (counts of species) was significantly different in 2003 ($p=0.002$), with more species in the old high water zone (OHWZ) during spring of 2003, and more species in the NHWZ during fall of 2003 (Figure 1). Total counts of all individual ground arthropods were significantly different ($p<0.0001$) between seasons in 2003 but not among zones, although the trend showed more individuals were captured in the OHWZ (Figure 2). The majority of individuals were ants, which were highly variable among sites and zones. Species richness dropped somewhat since spring 2001. The patterns in abundance, however, showed a different pattern, with overall declines in 2002 and increases in 2003, especially in the OHWZ. The large abundance in the OHWZ in spring 2001 was primarily due to the true bug *Nysius* sp. (Figure 2).

MRPP analysis of ground arthropod taxa revealed that the species composition of ground arthropods were significantly different ($p<0.0001$) between the three water zones over the 3-year period. The species composition of spring and fall ground arthropod assemblages were significantly different over the 3-year period, and ground arthropod assemblages were significantly different ($p=0.003$) between the three years.

Two species (both introduced) of **isopods** (sow-bugs) were significantly ($p=0.004$) more abundant in the SHOR during both spring and fall of 2003 (Figure 3). Both species of isopods require moist conditions, and were associated with damp shoreline environments. In spring 2002 as many isopods were collected from the NHWZ as the SHOR, a pattern not seen before or since. Darkling beetle and ant abundance also was high in spring 2002 but not spiders, ground beetles or crickets.

Forty-six species of ground-dwelling **spiders** were significantly ($p=0.05$) more abundant in the SHOR zone during both spring and fall of 2003 (Figure 4). Most of those spiders were 2 species of wolf spiders, one restricted to shoreline (*Arctosa littoralis*) and one (*Schizocosa* sp. near *celerior*) found along the shore and in NHWZ. Several species of jumping spiders were also especially abundant along the shoreline. Wolf spiders made up most of the individuals collected, but gnaphosid ground spiders made up most of the species collected (see species list in Appendix). These two families are co-dominants in much of the world for wandering hunting spiders. Over the three years of this study spider numbers have remained relatively stable.

Seven species of **crickets** were significantly ($p=0.01$) more abundant in the SHOR than either the NHWZ or the OHWZ during 2003 (Figure 5). Seasons were not significantly different. Most individuals of crickets captured were a species (*Eunemobius carolinus*) that was restricted to damp environments found along the shoreline. The second most abundant species is a riparian specialist (*Gryllus alogus*), found under dense vegetation along rivers in the Southwest. Those species (*Gryllus* undescribed species number 1 (personal comm., D. B. Weissman, Department of Entomology, California Academy of Sciences), *Cycloptilium comprehendens*) found in the OHWZ were desert rock-slope specialists, typically not found near the river.

The abundance of 7 species of ground and plant dwelling **lygaeid seed bugs** was not significantly different across the three water zones during spring or fall 2003 (Figure 6). A single species of *Nysius* was very abundant during the spring of 2001 only, and significantly most abundant in the OHWZ. *Nysius* was associated with particularly dense stands of the spring annual tansy-mustard (*Descurania*) in the OHWZ during the El Nino spring of 2001. That species has not been abundant since the El Nino of 2001.

Twenty-seven species of **carabid ground beetles** were significantly ($p=0.008$) most abundant in the SHOR zone during both spring and fall 2003 (Figure 7). Ground beetle abundance showed no significant difference between seasons. Most of these were shoreline environment specialists, restricted to damp soils near water. As with the spiders above, the ground beetles are predators and tend to occur in many species, but with few individuals from each taxon. Their numbers also tended to be stable (except for the increase in spring 2001).

Fifteen species of **darkling beetles** were not significantly different across the three water zones or the two seasons, although the trend ($p=0.09$) in 2003 was toward a greater abundance in the fall (Figure 8). These beetles are habitat generalists and many species are common in deserts. The life cycle spans several years both for the larva and the adult. Therefore, it is unclear what caused the increase in numbers in spring 2002; factors could have occurred several years earlier to favor high survival of the larvae.

Twenty-one species of **ants** formed the most abundant group of ground arthropods (Figure 9) over the three years of the study. In spring of 2003, however, numbers were low, perhaps due to drought conditions affecting the seed production many species depend on as food. By fall 2003 ant numbers were significantly higher ($p=0.0003$). At Grand Canyon ants were consistently more abundant in the OHWZ (the large numbers in fall 2002 were due to *Dorymyrmex insana*, *Forelius pruinosus* and *Pogonomyrmex maricopa*) until 2003. Continued long-term study will show whether the earlier pattern is re-established. The most widely distributed ant species in Grand Canyon is *P. maricopa*, a seed harvester. Other common species included *D. insana*, predator/scavenger of other insects; *F. pruinosus*, predator/scavenger of other insects and nectar feeders; *Pheidole ceres*, another seed collector, and *Solenopsis xyloni*, a native fire ant.

ISA resulted in 17 species of ground arthropods that were statistically significant ($p<0.05$) as indicator taxa for the three water zones; 5 species are indicators of the SHOR, 4 species are indicators of the NHWZ, and 8 species are indicators of the OHWZ (Table 1).

Plant-dwelling Arthropods.

From 2001-2003 we have sampled and identified 396 **species of plant-dwelling arthropods** from our vegetation sweep net samples. During 2003, arthropod species richness (counts of species) was significantly ($p=0.005$) greater in the SHOR than the OHWZ, but the SHOR and NHWZ were not significantly different, and the NHWZ and OHWZ were not significantly different from each other (Figure 10). Species richness was significantly ($p=0.005$) higher during the spring than the fall of 2003. There was not a significant zone-season interaction. Over the entire three year period (2001-2003) there was no significant ($p<0.05$) difference in plant-dwelling arthropod species richness across the three water zones.

MRPP analysis of plant arthropod taxa revealed that the species composition of ground arthropods were significantly different ($p<0.0001$) between the three water zones over the 3-year period. The species composition of spring and fall ground arthropod assemblages were significantly different ($p<0.0001$) over the 3-year period, and ground arthropod assemblages were significantly different ($p<0.0001$) between the three years.

Total **counts of all individual plant arthropods** were significantly ($p=0.01$) greatest from the SHOR and NHWZ respectively during both the spring and fall of 2003 (Figure 11a.) Counts of plant-dwelling arthropods were significantly ($p=0.01$) greater during the spring than during the fall of 2003. High counts of plant-dwelling arthropods during the spring were due to large numbers of one species of aphid that was especially abundant on vegetation along the SHOR and NHWZ during the spring of 2003. That species of aphid was absent during the fall of 2003. High numbers of plant-dwelling flies in the SHOR during 2003 also contributed to the higher overall arthropods on plants in the SHOR. High numbers of plant-dwelling arthropods during the fall of 2003 were largely due to many species of flies that were especially abundant along the shoreline.

The abundance of 45 species of plant-dwelling **spiders** was not significantly different across the three water zones during 2003 (Figure 12). Plant-dwelling spiders were dominated by several species of jumping spiders (Salticidae) and crab spiders (Thomisidae; *Misumenops* spp.), and the same species tended to occur on a variety of plant species across the three water zones. Overall three years, the abundance of plant-dwelling spiders did not differ significantly across the three water zones.

The abundance of 41 species of **plant bugs (Hemiptera**; Miridae) and other less frequent true bugs (Hemiptera) were not significantly different across the three water zones during 2003 (Figure 13). Several species of mirid plant bugs were especially common on herbaceous plants near the shoreline. Over the three years, the abundance of plant bugs did not differ across the three water zones.

The abundance of 65 species of **plant hoppers (Homoptera**; Cicadellidae, Psyllidae, Cixiidae) and aphids (Homoptera; Aphidae) were not significantly different across the three water zones during 2003 (Figure 14). Mean numbers were much higher in the SHOR, but large variances among sample counts accounted for a lack of statistical differences. A single species of aphid was especially abundant on herbaceous vegetation along the shoreline during the spring. That species of aphid was rare in fall samples, which were instead dominated by many species of leafhoppers, also associated with herbaceous shoreline vegetation. Overall, many species of native leafhoppers out-numbered the introduced tamarix leafhopper (*Opsius stactogalus*), which is host specific to tamarix or salt-cedar (*Tamarix ramosissima*). Over the three years, plant hopper and aphid abundance was significantly ($p=0.04$) greater in the SHOR than the other water zones. Plant hoppers and aphids reached peak abundances in spring of 2003.

The abundance of 59 species of **plant-dwelling beetles** was not significantly different across the three water zones during 2003 (Figure 15). The great abundance of plant-dwelling beetles in the OHWZ during the spring was due to two species of weevils (Curculionidae) associated with cat-claw acacia (*Acacia gregii*) and mesquite (*Prosopsis glandulosa*). Those species of weevils were not common during the fall of 2003. In contrast, plant dwelling beetles were significantly more abundant in the OHWZ during the spring of 2001 and spring of 2002. Over the three years, plant-dwelling beetles were significantly ($p=0.007$) more abundant in the OHWZ than the other water zones, and

significantly (p=0.01) more abundant in the spring than the fall. The weevils associated with acacia and mesquite accounted for those differences.

The abundance of 12 species of **caterpillars** on plants was not significantly different across the three water zones during the spring or fall of 2003 (Figure 16). Caterpillar numbers were considerably lower during 2003 compared to 2001 and 2002 when caterpillars were significantly more abundant in the OHWZ, but only during the spring. The most common caterpillars on plant foliage were inchworms of geometrid moths (Geometridae; *Semiothisa* spp.), which were associated with cat-claw acacia and mesquite. Geometrid larvae are well adapted to harsh environments and feed on a variety of plant taxa (Beck et al. 2002, Brehm and Fiedler 2003). Over the three years, plant-dwelling caterpillars were significantly (p=0.0003) more abundant in the OHWZ than the other water zones, and significantly (p=0.02) more abundant in the spring than the fall, and exhibited a significant (p=0.0002) zone-season interaction.

The abundance of 94 species of **plant-dwelling flies** (Diptera) was significantly (p=0.001) most abundant in the SHOR during both the spring and fall of 2003 (Figure 17). Many species of muscoid flies were associated with damp shoreline environments, and adults of aquatic midges (Chironomidae) were common on shoreline vegetation. Over the three years, plant-dwelling flies were significantly (p=0.0001) more abundant in the SHOR than the other water zones, but there was no significant seasonal difference in fly abundance. Overall, fly abundance on plants was greatest in 2003.

The abundance of 17 species of **plant-dwelling ants** was not significantly different in abundance across the three water zones during the spring or fall of 2003 (Figure 18). The most abundant ants on vegetation were *Forelius pruinosus* and *Dorymyrmex insana.* Those ant species occurred on a variety of plant species. Overall, ant abundance on plants tended to increase over the three-year period, but was not significantly different over time.

ISA resulted in 12 species of plant arthropods that were statistically significant ($p<0.05$) as indicator taxa for the three water zones; 6 species are indicators of the SHOR, 1 species is and indicator of the NHWZ, and 5 species are indicators of the OHWZ (Table 1).

Moths.

We have collected 347 taxa of moths since 2002 from our black-light and malaise samples. Of the 347 taxa of moths, 154 taxa we collected by malaise traps, and 327 taxa were collected by light traps. In addition, a new species of noctuid moth in the genus *Schinia* was discovered (Pogue, in prep.), which may be an endemic species to Grand Canyon (Pogue, personal comm.). Malaise traps collected an average of 3.52 (+ 0.21) taxa and 31.1 (+3.0) individuals per trap, while light traps collected an average of 13.6 (+0.68) taxa and 190.9 (+44.4) individuals per trap. Only 20 taxa (6%) of Lepidoptera were not collected in the light traps, and light traps contained six times more individuals. Thus, because most taxa were represented in both traps, we combined data from malaise and light traps, as well as data from fall and spring collections.

We present data for all three years for all of the moths (i.e., non-butterfly Lepidoptera) and for the largest five groups (4 families + Microlepidoptera) of moths. The four moth families are: owlet moths (Noctuidae), looper moths (Geometridae), tiger moths (Arctiidae), and pyralid moths (Pyralidae). The Microlepidoptera comprise at least

six families of small moths that are poorly known taxonomically and not easily distinguishable from each other.

Generally the overall diversity (Figure 19) and abundance of moths (Figure 20) and the abundance of major moth taxa (Figures 21-25) showed the same pattern, where highest diversity and abundance occurred in non-drought years (2001) and in the OHWZ. The only exception to this pattern was the abundance of pyralid moths. Pyralids did not show highest abundances in the OWHZ, although they were consistently higher in that zone. Also pyralids were most abundant in 2003 and not 2001 like the other moth taxa. On the other hand, the tTiger moths, which were primarily represented by *Cisthene angelus*, were especially abundant in 2001 and uncommon to rare in the other years (Figure 24). The two most common moths, the owlet and looper moths, both showed similar patterns of highest abundance in the OHWZ, especially in 2001.

Unlike other sampling methods/arthropod taxa mentioned in the arthropod section of this report, we found little differences between the SHOR and the NHWZ. The Microlepidoptera (Figure 22) and to a lesser degree the owlet moths (Figure 21) did show a linear trend of increasing abundance from shore, through NHWZ to OHWZ. Our results from the malaise/light trap data of adult moths agree with the data on moth larval abundance (Figure 16).

River Stage and Rainfall

Two spikes in arthropod abundance have occurred during the spring of 2001, and during the spring of 2003. Ground arthropods, plant arthropods and moths all exhibited high numbers of individuals during those times. High arthropod abundances during spring of 2001 appear to have resulted from the El Nino winter rain event of 2000/2001. All arthropod abundances were high across all water zones. Plant-dwelling arthropods and moths were abundant during that time, especially in the OHWZ. We sampled and observed high densities of moth larvae (caterpillars) on the mesquite and cat claw acacia trees, and captured large numbers of moths in light traps. The tiger moth (*Cisthene angelus*) was especially abundant. *Cisthene angelus* belongs to a genus of moths that feed on lichens, and the larvae likely feed on the lichen component of the cryptobiotic soil crusts that are especially well developed in the OHWZ. The seed bug (*Nysius* sp. 1) also was especially dense in the OHWZ during spring of 2001, and we observed those seed bugs to be associated with dense stands of tansy mustard (*Descurania* sp.) that was especially dense in the OHWZ as a result of the high amounts of winter rainfall. Regional rainfall amounts for the remainder of the 3-year period (2001-2003) were light and below average.

The other spikes in arthropod abundance were in the SHOR zone during spring of 2003. Spring of 2003 was relatively dry, and we attribute that spike in arthropods to the high river stages (maximums of around 20,000 cfs January-April) of 2003, since increased abundances were largely restricted to the SHOR and NHWZ. In contrast to spring of 2001, there were low numbers of plant bugs in the OHWZ, and few moths in traps during spring of 2003. 2002 was a drought year, and river stages were relative low (near 10,000

to 15,000 cfs) throughout that year. Arthropod abundances were generally low across all river stage zones throughout 2002.

We do not have enough replication of sampling over time (seasons and years) to statistically test for relationships between precipitation and river stage, and arthropod abundances. At this time only 6 sample time intervals are available from 3-years of sampling (twice each year). If monitoring continues, we should have sufficient time intervals to begin testing relationships between rainfall and river stage in 3-5 years.

Exotic Arthropods

We have identified five species of arthropods from our surveys that are exotic, introduced species, not native to Grand Canyon. The tamrisk leafhopper (*Opsius stactogalus*) was intentionally introduced to the Southwest United States as a biological control agent for tamarix. We found *O. stactogalus* on tamarix throughout Grand Canyon, often very abundant, but we did not observe any visible impact on tamarix health. *O. stactogalus* was found only in association with tamarix in both the NHWZ and SHOR. The two species of isopods, *Armadillidium* sp. (probably *vulgare*) and *Porcellio* sp. (probably *laevis*), were found only along the SHOR in damp microenvironments near the water. Both species are originally from Eurasia, and have become naturalized throughout North America in moist environments. The Field Cockroach (*Blatella vaga*), which is native to Africa and now naturalized in riparian areas throughout the Southwest, was found in the SHOR at several sites in Grand Canyon. In Grand Canyon, the Field Cockroach was always observed to be associated with dense stands of exotic Bermudagrass (*Cynodon dactylon*) near the river shore. The European Honey Bee (*Apis mellifera*) was observed commonly throughout Grand Canyon. Foraging workers were especially common on tamarix flowers throughout the spring and early summer months.

At this time, we are not aware of any other exotic arthropods in Grand Canyon. All five of the exotic species listed above were associated with exotic plants (tamarix and Bermudagrass), or high disturbance shoreline environments. No exotic arthropods are known from the indigenous, now non-disturbed OHWZ. Since the terrestrial riparian zone of Grand Canyon is now a human-altered environment as a result of Glen Canyon Dam, monitoring of exotic arthropod species is particularly important since exotic arthropods are known to colonized human-altered river environments in the Southwest (Ellis et al. 2000). Since exotic species must compete with native species for food and habitat resources, the impacts of exotic arthropod species on the ecology of the Grand Canyon riparian ecosystem(s) should be given consideration in research efforts.

Summary and Conclusions

To date we have recognized 923 taxa of arthropods, including 180 species of arthropods that live on the ground, 396 species of arthropods that live on plants, and 347 moth taxa. There was little overlap between the species composition of ground-dwelling and plant-dwelling arthropods, except for ants, and almost no overlap between these sampling methods and malaise/night light sampling. These results demonstrate that our sampling methods (pitfall traps, malaise, night light, and sweep nets) were appropriate to

sample the different arthropod faunas associated with the different ground and vegetation habitats.

The large number of arthropod taxa, showing various relationships to water zones and seasons, provides us with a broad range of potential monitoring species to serve as indicators of environmental change. Such environmental changes may be associated with variation in river stages from dam operation and annual climate variation.

Ground arthropod species composition and abundance are greatly determined by soil texture and moisture conditions, as well as overall habitat structure resulting from variation in topography and vegetation structure and cover. We have identified large series of ground-dwelling arthropod species that are associated with each of the three water zones, including 18 species that are significant indicator taxa for the different water zones.

Plant-dwelling arthropods provide us with a number of species that reflect the taxonomic composition and the physical structure of vegetation, as well as plant productivity. Leaf-chewing insects such as caterpillars and beetles often respond to changes in plant productivity in different ways from plant sap-feeding insects such as plant bugs, plant hoppers, and aphids. We have identified all of these insect groups from our samples, and demonstrated water zone, seasonal, and annual patterns, including 12 species that are indicators taxa for the water zones.

The night light and malaise sampling methods are excellent ways to sample moth communities. Essentially all moths are herbivores as larvae, although sampling adults of this large and important group is typically easier and a more complete way to assess moth communities than collecting larvae on foliage. We found consistently higher numbers and species richness of moths in the OHWZ and no differences between the other two zones. The one caveat is that we do not know the degree to which night-lights in the OHWZ attract more moths because they are usually located in more open habitats that are higher in elevation; thus attracting moths from a larger area than for shoreline and NHWZ. The data indicate that moth abundance is relatively sensitive to annual precipitation, regardless of the water zone.

Longer-term temporal trends are just starting to appear from our data. We found plant-dwelling caterpillars and beetles to be significantly more abundant in the OHWZ on acacia and mesquite during the spring periods of 2001 and 2002, but then declined dramatically in 2003. In contrast, plant aphids increased dramatically during spring of 2003. The inverse relationships in major groups of plant-feeding insects indicate ecological relationships such as climate-river stage-plant-insect-predator types of interactions are likely occurring, and are reflected in our data. However, we will need additional years of arthropod, rainfall, and river stage data before we can begin testing for relationships between those.

As food resources for higher-level consumers such as birds, reptiles and amphibians, and mammals, the abundance of ground-dwelling, plant-dwelling, and aerial arthropods are important factors determining the species composition and population dynamics of those higher animals. For example, studies have shown that most bat species and passerine birds feed extensively on moth adults and moth larvae respectively (Findley 1983, Kunz and Whitaker 1983, Holmes & Schultz 1988, Hooks et al. 2003). In order to understand the trophic dynamics of terrestrial riparian communities in Grand

Canyon, we must understand the relationships between the physical environment, plants, arthropods, and vertebrate animals.

Five exotic arthropod species have been identified from the riparian corridor of Grand Canyon. Two of those species are associated with exotic tamarix, and one with exotic Bermudagrass. Two species are associated with the constantly fluctuating shoreline. Since the riparian corridor of Grand Canyon is now a human-altered environment, we believe that any long-term monitoring studies should include these exotic species as indicators of environmental change. Those exotic species compete with native species for food and habitat resources.

We continue to develop the reference/voucher specimen collections of arthropods from this project. We are working with approximately 1200 species and over 200,000 individuals. We will continue the task of identifying as many taxa as possible to the species level. We continue to examine our data relative to the spatial and temporal distributions of individual arthropod species to identify particular taxa that will best serve as bioindicators of environmental change appropriate for the purpose of this TEM project.

Results to date demonstrate that arthropods are a diverse and abundant group of organisms that provide robust data as bioindicators of environmental change in Grand Canyon.

Literature Cited

Beck, J., Schulze, C.H., Linsenmair, K.E. & Fiedler, K**.** 2002. From forest to farmland: diversity and community structure of geometrid moths along two habitat gradients on Borneo. Journal of Tropical Ecology 17:33-51.

Brehm, G. & Fiedler, K. 2003. Faunal composition of geometrid moths changes with altitude in an Andean montane rain forest. Journal of Biogeography 30, in press.

Dufrene, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67:345-366.

Ellis, L. M, C. Molles, Jr., C. S. Crawford, and F. Heinzelmann. 2000. Surface-active arthropod communities in native and exotic riparian vegetation in the middle Rio Grande Valley, New Mexico. The Southwestern Naturalist 45(4):456-471.

Evans, A. V. and Bellamy, C. L. 1996. An Inordinate Fondness for Beetles. New York.pp. 92.

Findley, JS. 1983. Morphological and dietary structuring of a Zambian insectivorous bat community. Ecology 64:625-630.

Holmes R.T. & J.C. Schultz. 1988. Food availability for forest birds: effects of prey distribution and abundance on bird foraging. Canadian Journal of Zoology 66:720-728.

Hooks, C.R.; R.R. Pandey, M.W. Johnson. 2003. Impact of avian and arthropod predation on lepidopteran caterpillar densities and plant productivity in an ephemeral agroecosystem. Ecological Entomology 28:522-532.

Leon-Cortes, JL, Lennon, JJ, Thomas, CD. 2003. Ecological dynamics of extinct species in empty habitat networks. 2. The role of host plant dynamics. Oikos 102:465-477.

Lightfoot, D.C. and W.G.Whitford. 1989. Interplant variation in creosotebush foliage characteristics and canopy arthropods. Oecologia 81:166-175.

Thomas, D and Sleeper, E. 1977. The Use of Pit-Fall Traps for Estimating the Abundance of Arthropods with Special Reference to the Tenebrionidae (Coleoptera). Annals of The Entomological Society of America 70:242-248.

Kunz, T.H. & J.O. Whitaker. 1983. An evaluation of fecal analysis for determining food habits of insectivorous bats. Candian Journal of Zoolology, 61:1317-1322.

Wilkie, L, Gerasimose, C, Gray, M. 2003. A Quality Control Protocol for Terrestrial Invertebrate Biodiversity Assessment. Biodiversity and Conservation 12:121-146.

Young, S. 1994. Insects That Carry a Global Warning. New Scientist 14: 32.

Table 1a. Ground and plant associated arthropod species that were statistically significant ($p<0.05$) indicators of one of the three water-level zones along the riparian corridor of Grand Canyon based on Indicator Species Analysis. "Value" is the observed indicator value score, "p" is the significance level.

Ground Arthropods

Order	Family	Genus	Species	Water Zone	Value	p
Isopoda	Porcellionidae	Porcellio	01	SHOR	17.6	0.002
Aranea	Pholcidae	*Psilochorus*	01	OHWZ	8.2	0.039
Aranea	Lycosidae	*Arctosa*	*littoralis*	SHOR	34.8	0.001
Aranea	Lycosidae	*Pardosa*	01	NHWZ	21.7	0.021
Orthoptera	Gryllidae	*Gryllus*	*alogus*	NHWZ	8.8	0.015
Orthoptera	Gryllidae	*Gryllus*	01 (*sp.nov.*)	OHWZ	6.5	0.037
Othroptera	Gryllidae	*Eunemobius*	*carolinus*	SHOR	27.6	0.001
Dictyoptera	Polyphagidae	*Arenivaga*	01	OHWZ	8.6	0.041
Hemiptera	Lygaeidae	*Nysius*	01	OHWZ	9.5	0.011
Coleoptera	Carabidae	01	01	SHOR	13.1	0.001
Coleoptera	Carabidae	*Bembidion*	01	SHOR	23.9	0.001
Coleoptera	Tenebrionidae	*Metaponium*	*convexicolle*	OHWZ	17.4	0.005
Coleoptera	Tenebrionidae	*Triorophus*	01	OHWZ	12.4	0.001
Hymenoptera	Formicidae	*Crematogaster*	*depilis*	OHWZ	13.8	0.015
Hymenoptera	Formicidae	*Leptothorax*	*muscorum*	NHWZ	8.5	0.013
Hymenoptera	Formicidae	*Pogonomyermex*	*maricopa*	OHWZ	33.8	0.006
Hymenoptera	Mutillidae	01	01	NHWZ	17.9	0.004

Plant Arthropods

Order	Family	Genus	Species	Water Zone	Value	p
Aranea	Philodromidae	*Ebo*	01	NHWZ	8.8	0.034
Aranea	Thomisidae	*Misumenops*	*californicus*	OHWZ	16.5	0.001
Homoptera	Cicadellidae	01	03	SHOR	8.7	0.021
Homoptera	Cicadellidae	01	14	SHOR	5.1	0.037
Homoptera	Cicadellidae	01	35	SHOR	5.7	0.027
Thysanoptera	Thripidae	*Frankliniella*	01	SHOR	5.2	0.045
Coleoptera	Curculionidae	01	03	OHWZ	14.5	0.001
Lepidoptera	Geometridae	*Semiothisa*	01	OHWZ	17.2	0.001
Lepidoptera	various	various	immature	OHWZ	14.2	0.001
Diptera	Muscidae	01	20	SHOR	8.9	0.021
Diptera	Chironomidae	various taxa	various taxa	SHOR	18.9	0.003
Hymenoptera	Formicidae	*Monomorium*	*cyaneum*	OHWZ	9.2	0.030

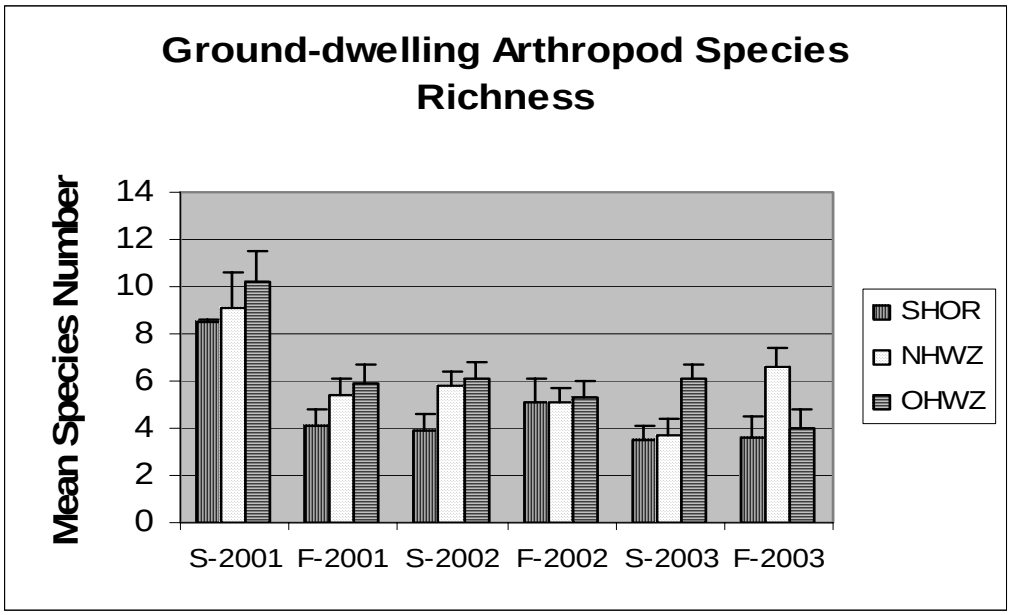


Figure 4. Species richness of all ground-dwelling arthropods by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

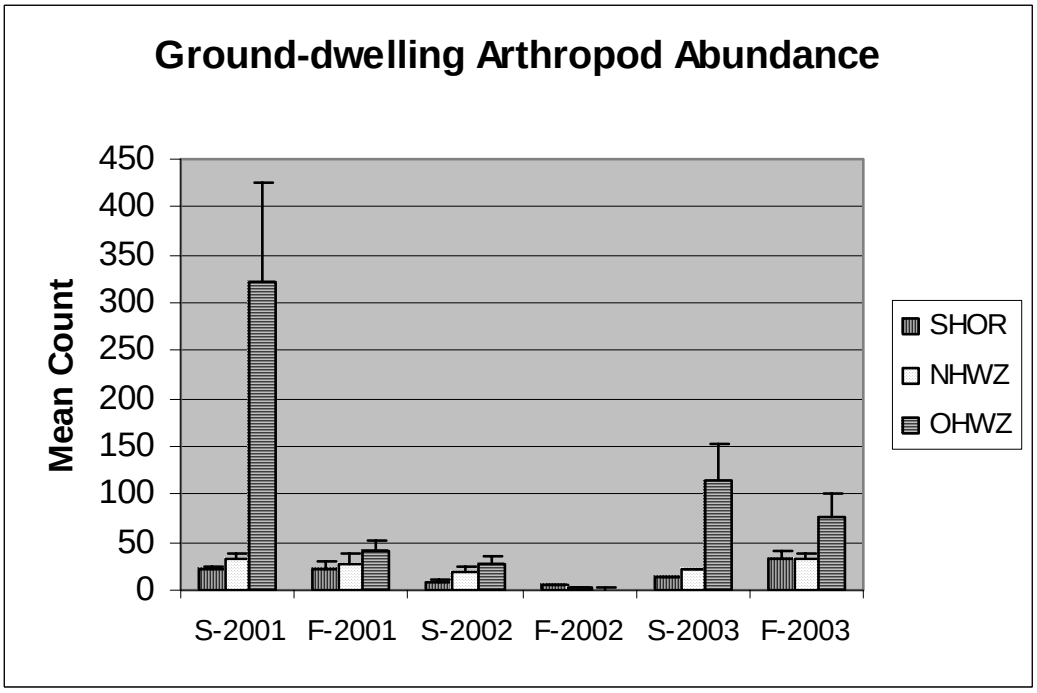


Figure 5. Counts of all individuals of all species of ground-dwelling arthropods by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

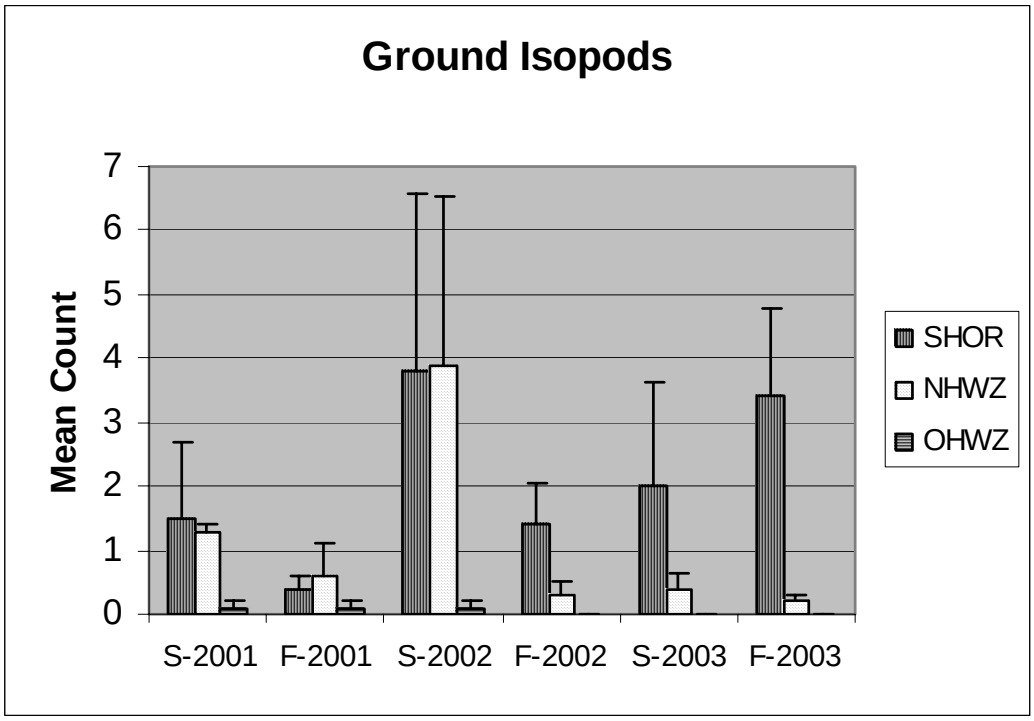


Figure 6. Counts of all individuals of all ground-dwelling isopods by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

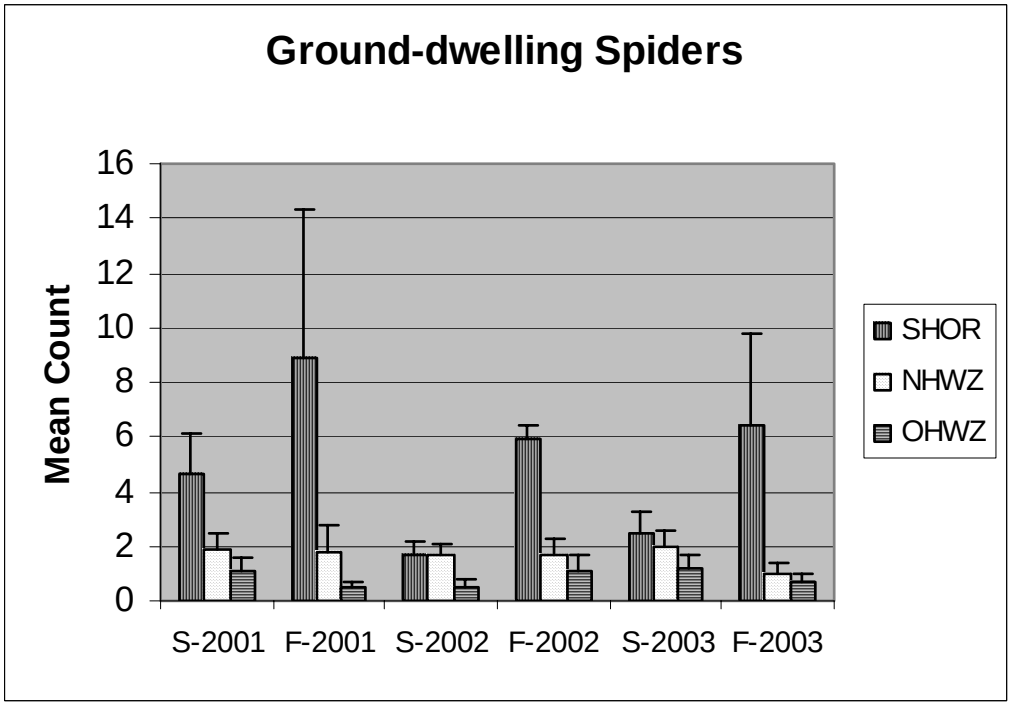


Figure 7. Counts of all individuals of all ground-dwelling spiders by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

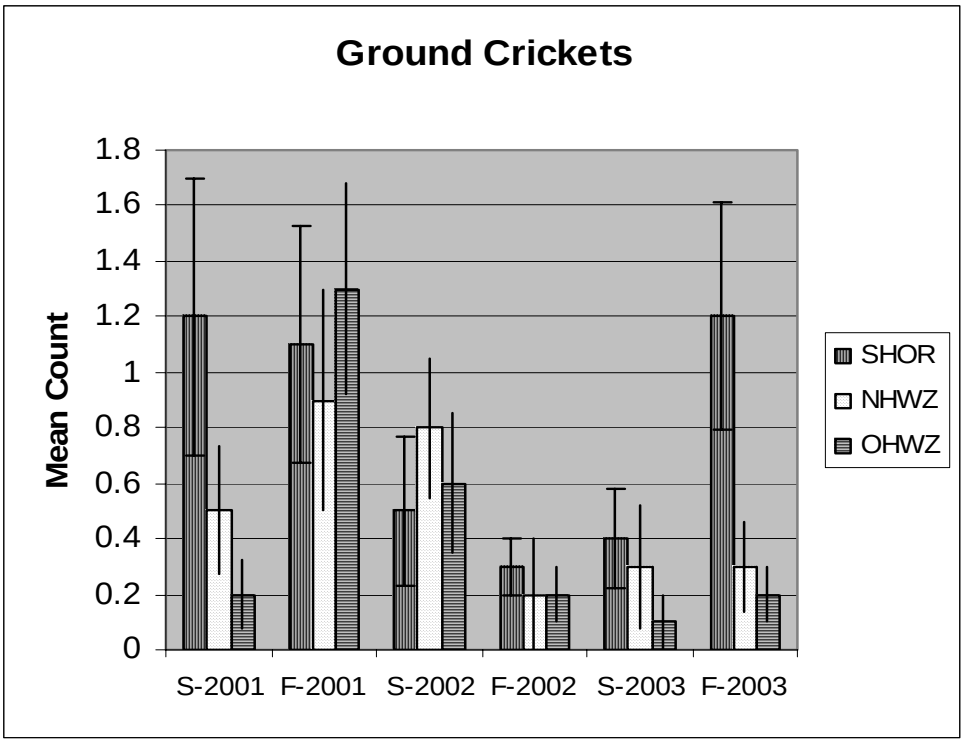


Figure 8. Counts of all individuals of all ground-dwelling crickets by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

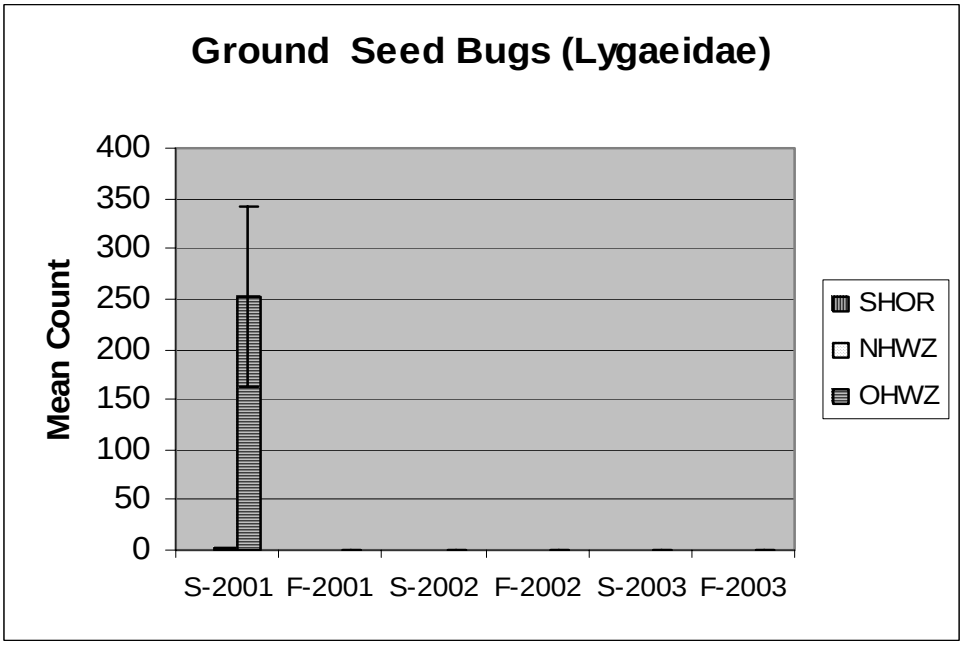


Figure 9. Counts of all individuals of all ground-dwelling seed bugs by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

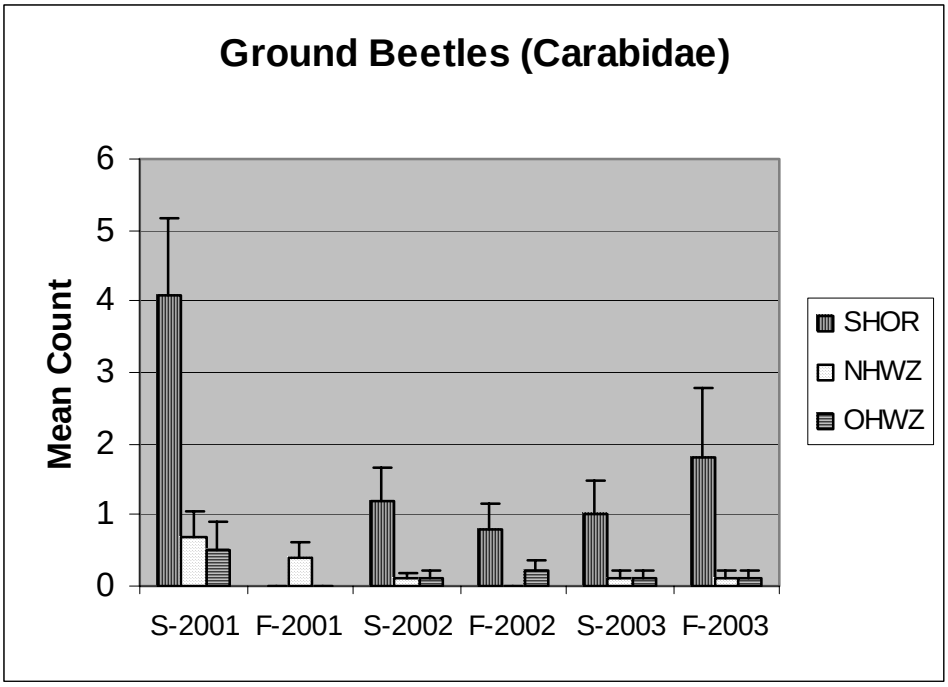


Figure 10. Counts of all individuals of all ground-dwelling ground beetles by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

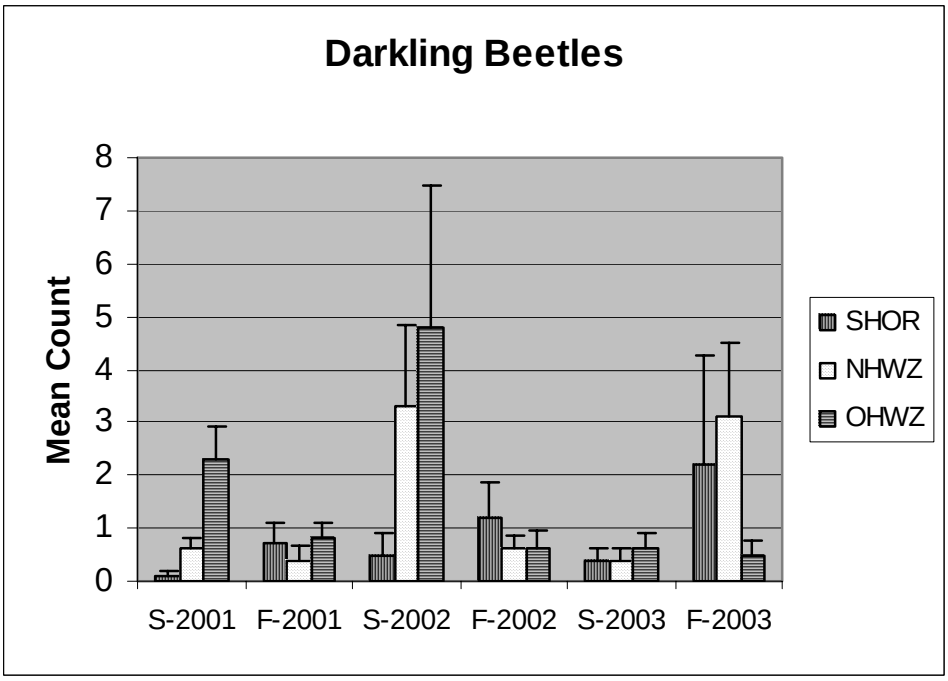


Figure 11. Counts of all individuals of all ground-dwelling darkling beetles by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

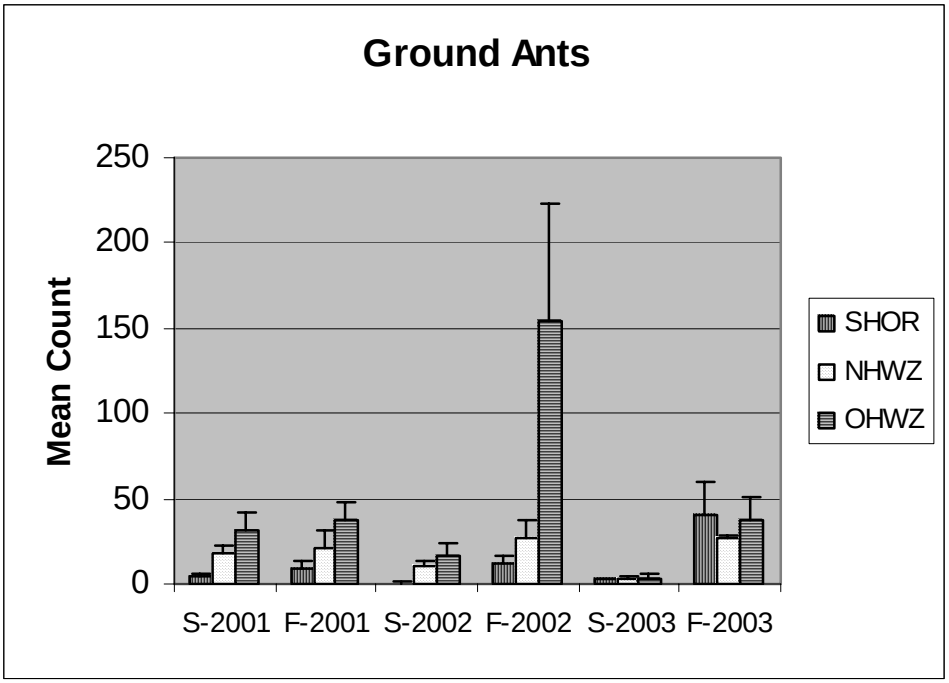


Figure 12. Counts of all individuals of all ground-dwelling ants by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

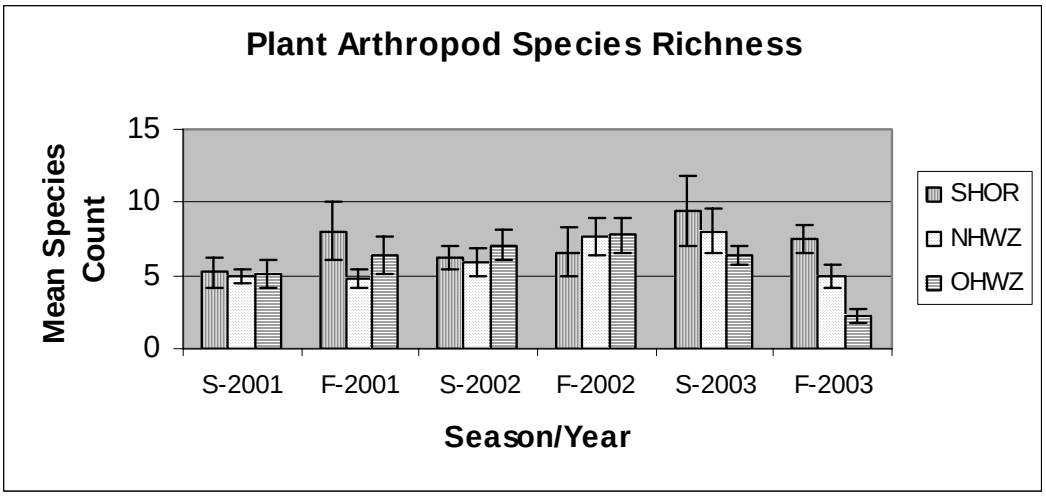


Figure 13. Species richness of all plant-dwelling arthropods by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

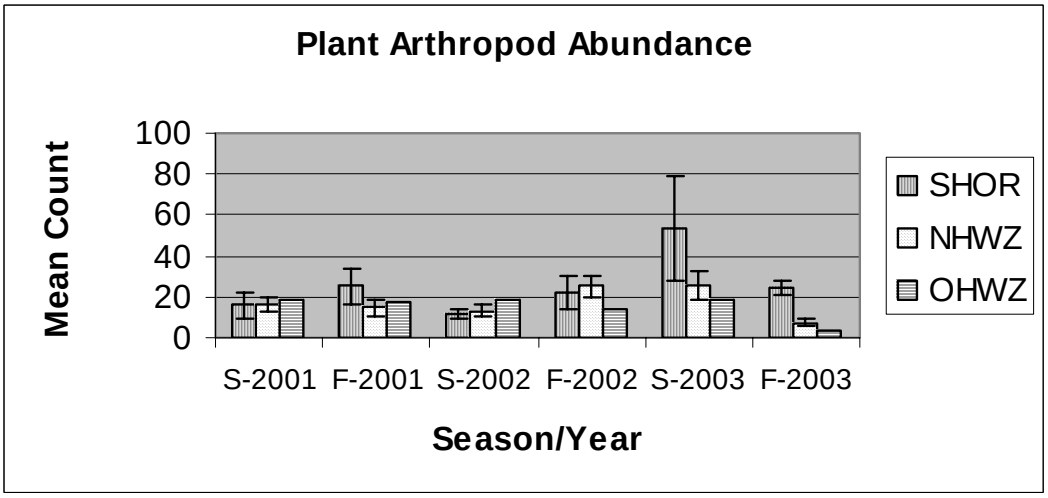


Figure 14. Counts of all individuals of all plant-dwelling arthropods by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

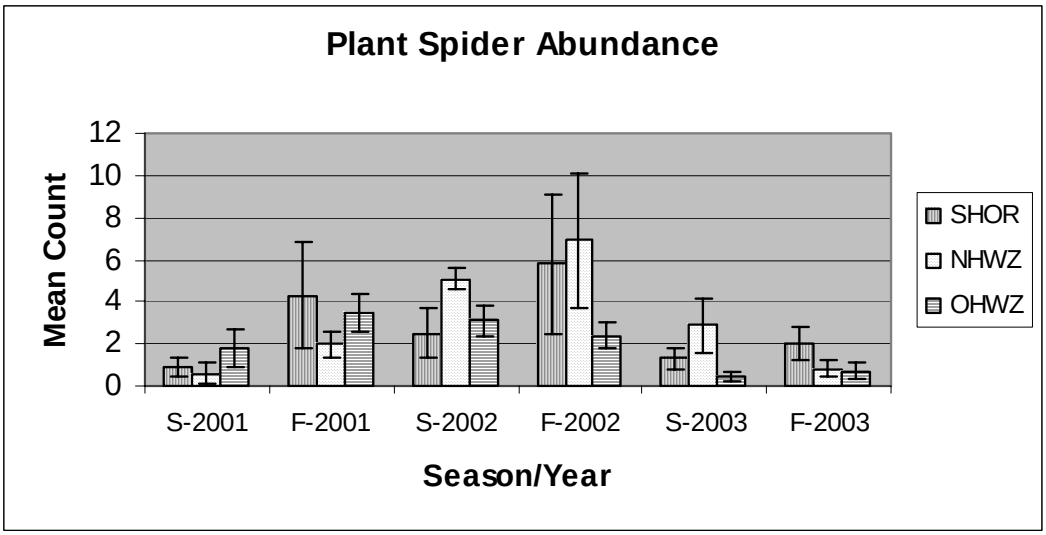


Figure 15. Counts of all individuals of all plant-dwelling spiders by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

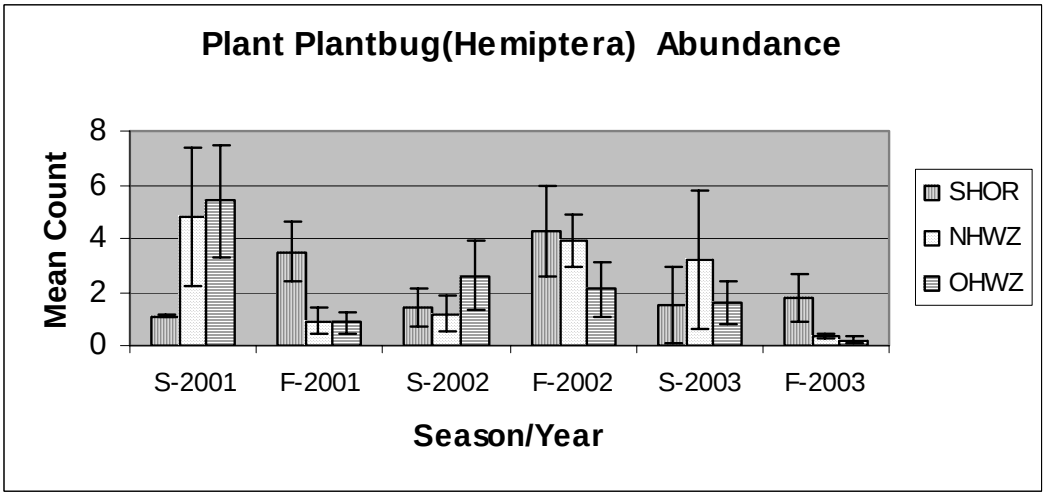


Figure 16. Counts of all individuals of all plant-dwelling plant bugs (Hemiptera) by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean

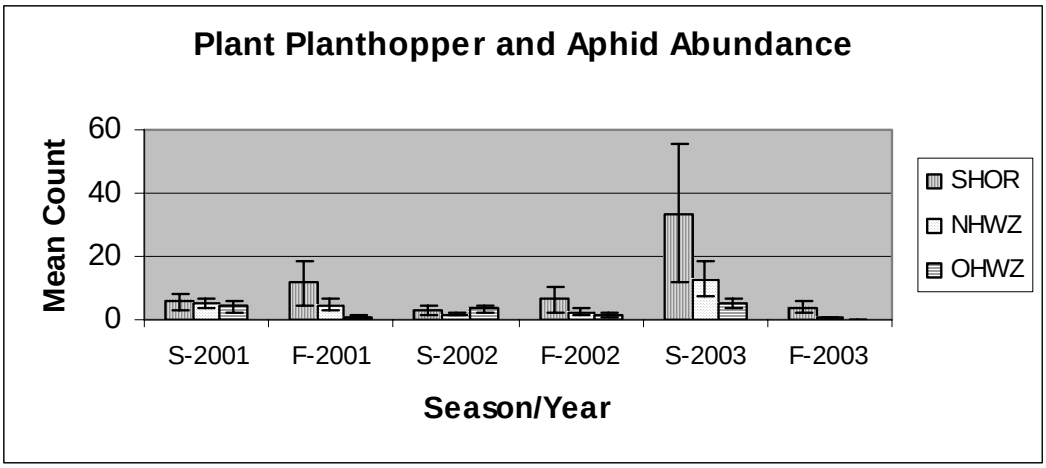


Figure 17. Counts of all individuals of all plant-dwelling planthoppers and aphids (Homoptera) by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

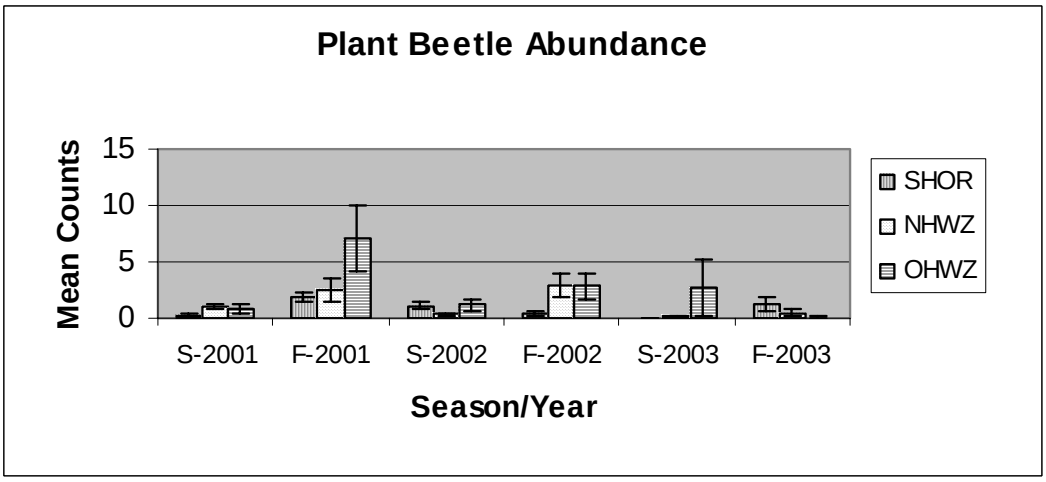


Figure 18. Counts of all individuals of all plant-dwelling beetles by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

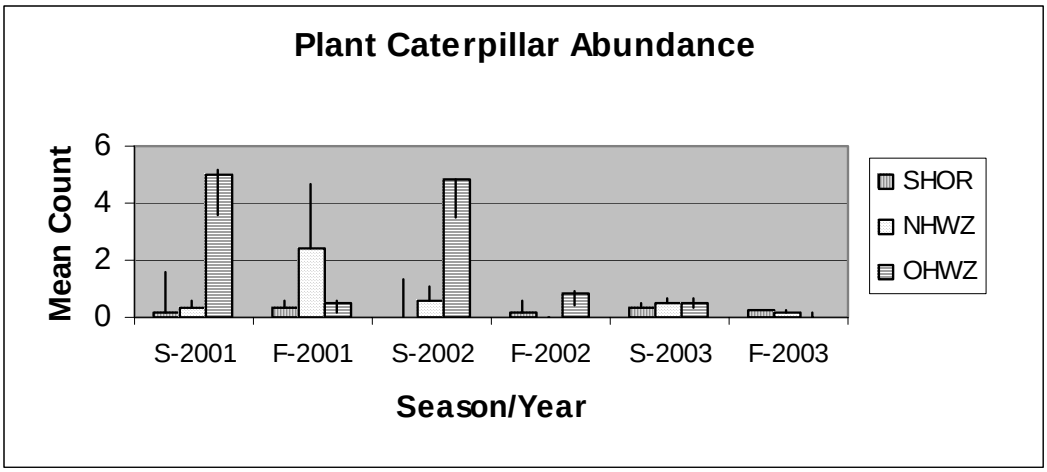


Figure 19. Counts of all individuals of all plant-dwelling caterpillars by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

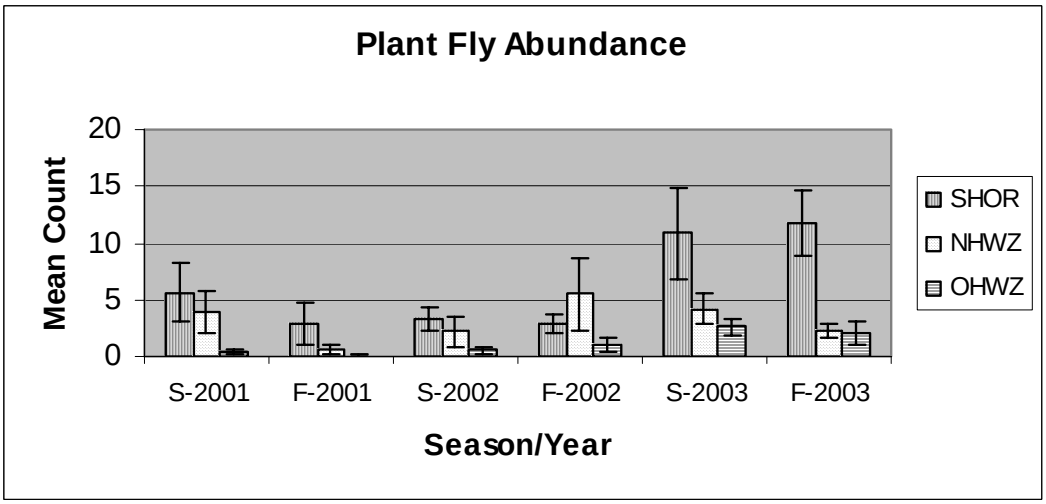


Figure 20. Counts of all individuals of all plant-dwelling flies by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

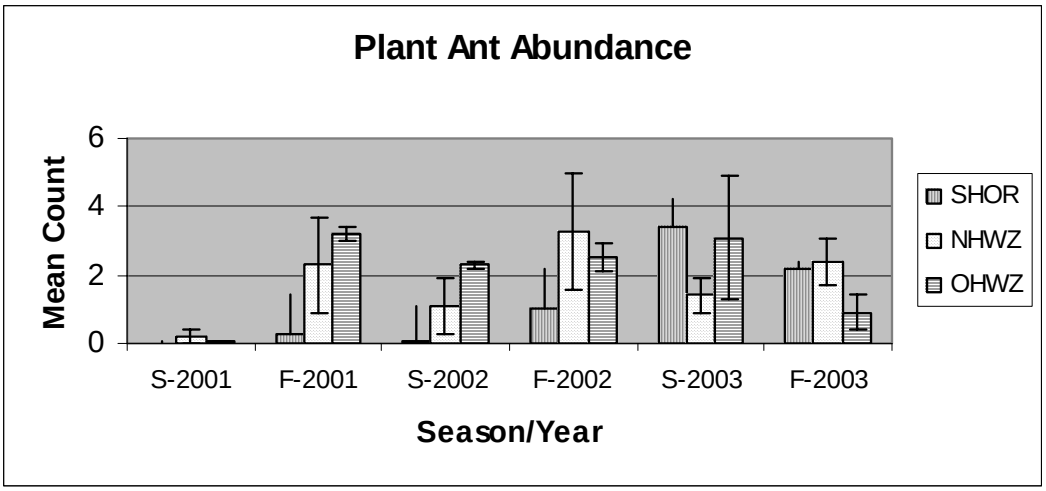


Figure 21. Counts of all individuals of all plant-dwelling ants by season and year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, +/- one standard error of the mean.

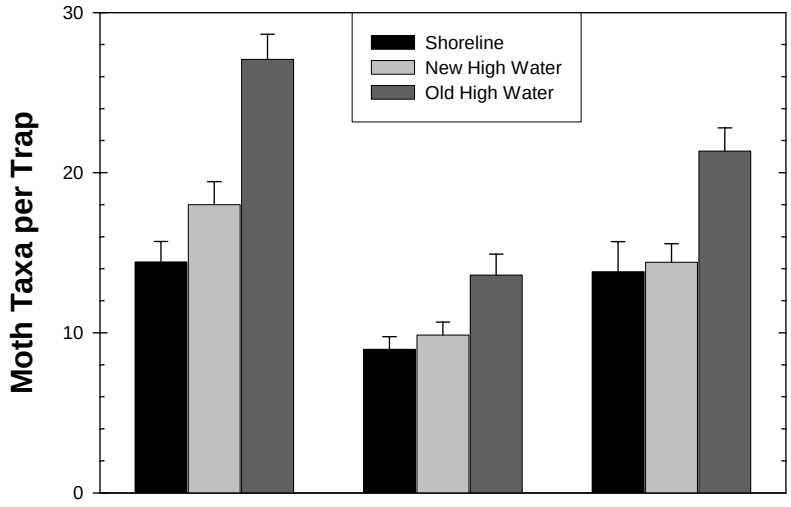


Figure 19. Overall species richness of moths collected in the TEM sits. Figures represent means per trap-night across years and sites. Vertical bars represent +/- 1 s.e

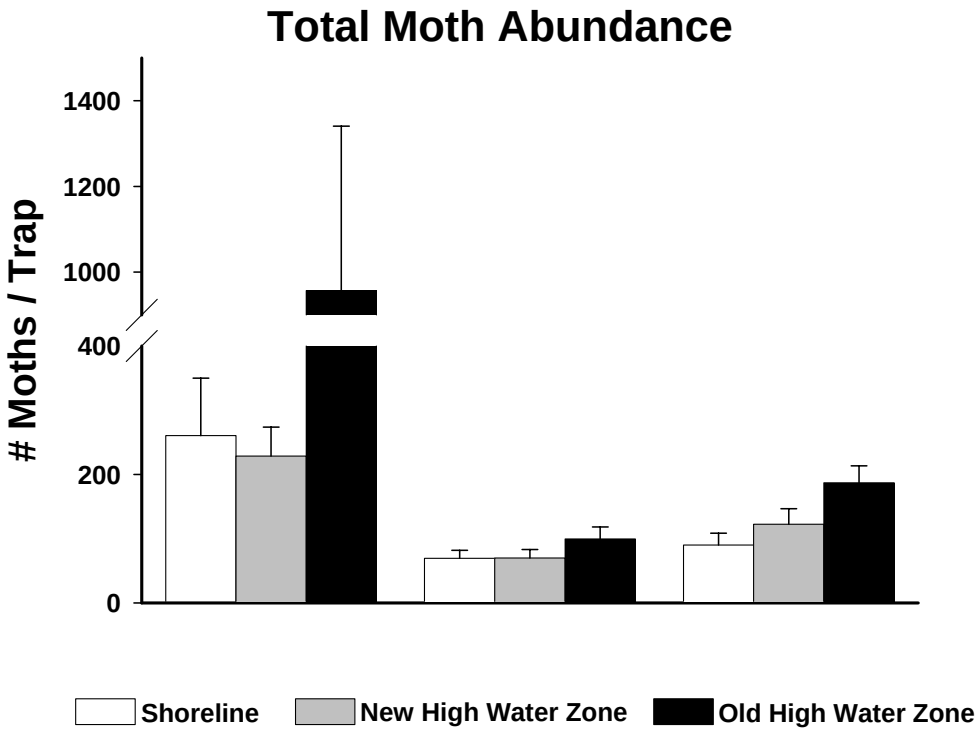


Figure 20. Overall moth abundance in the TEM sites. Figures represent means across sites and years; vertical bars represent +/- 1 s.e.

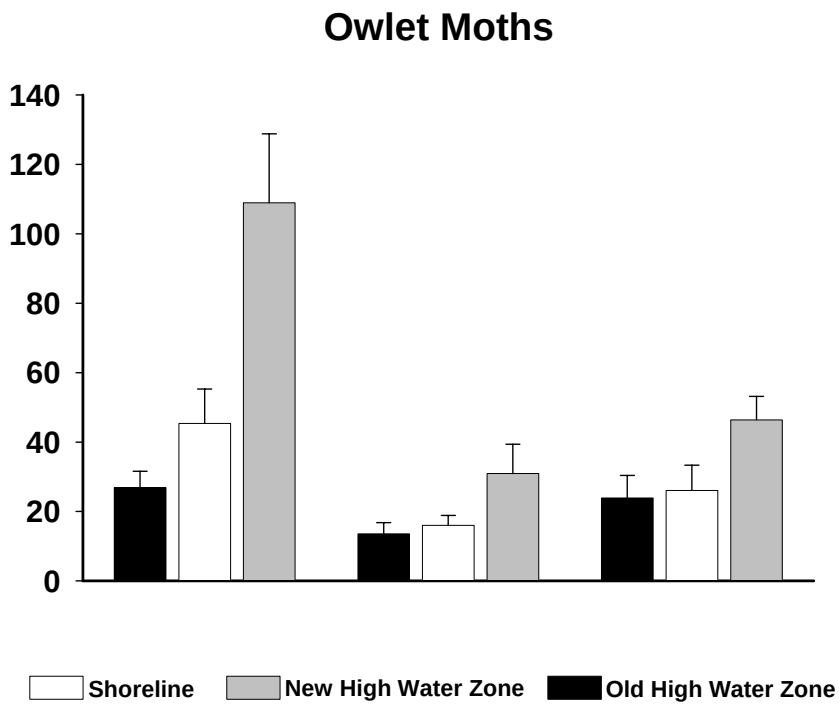


Figure 21. Abundance of owlet moths (Lepidoptera: Noctuidae) in the TEM sites. . Figures represent means across sites and years; vertical bars represent +/- 1 s.e.

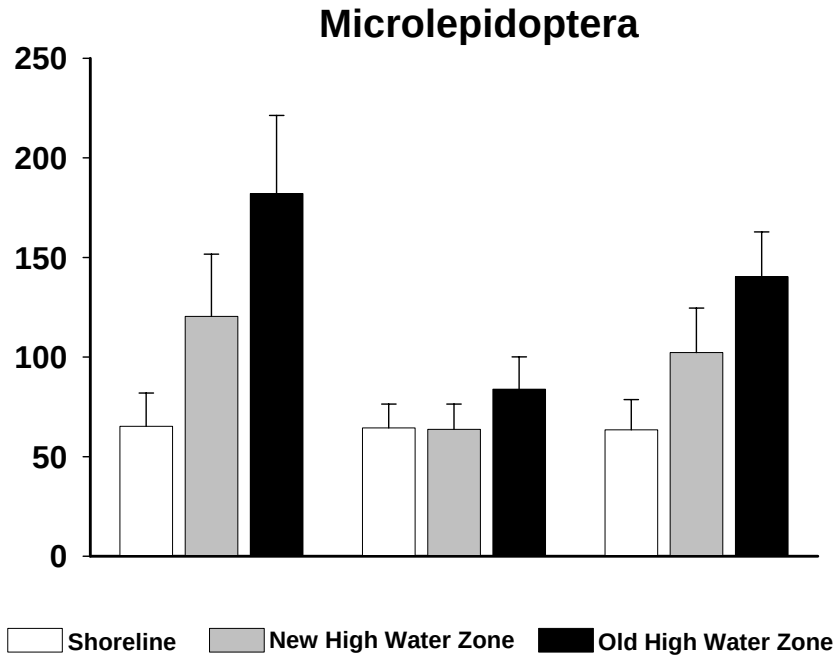


Figure 22. Abundance of Microlepidoptera (Lepidoptera: Frenatae) in the TEM sites. . Figures represent means across sites and years; vertical bars represent +/- 1 s.e.

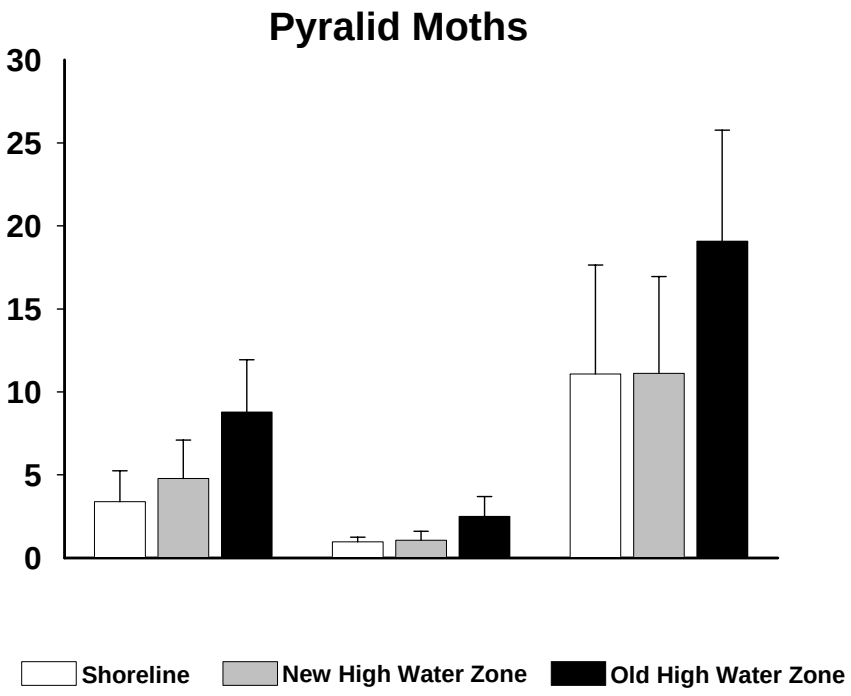


Figure 23. Abundance of pyralid moths (Lepidoptera: Pyralidae) in the TEM sites. . Figures represent means across sites and years; vertical bars represent +/- 1 s.e.

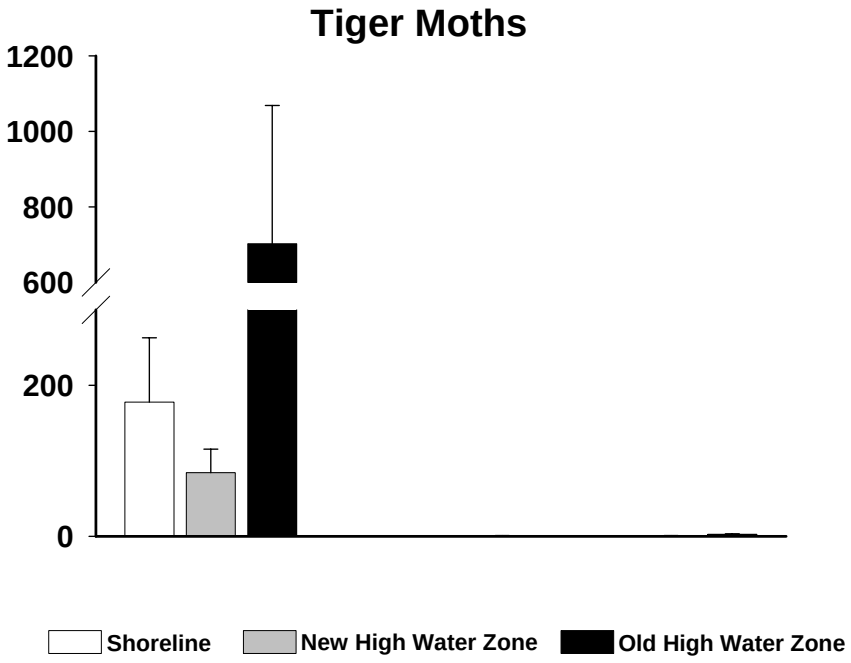


Figure 24. Abundance of tiger moths (Lepidoptera: Arctiidae) in the TEM sites. . Figures represent means across sites and years; vertical bars represent +/- 1 s.e.

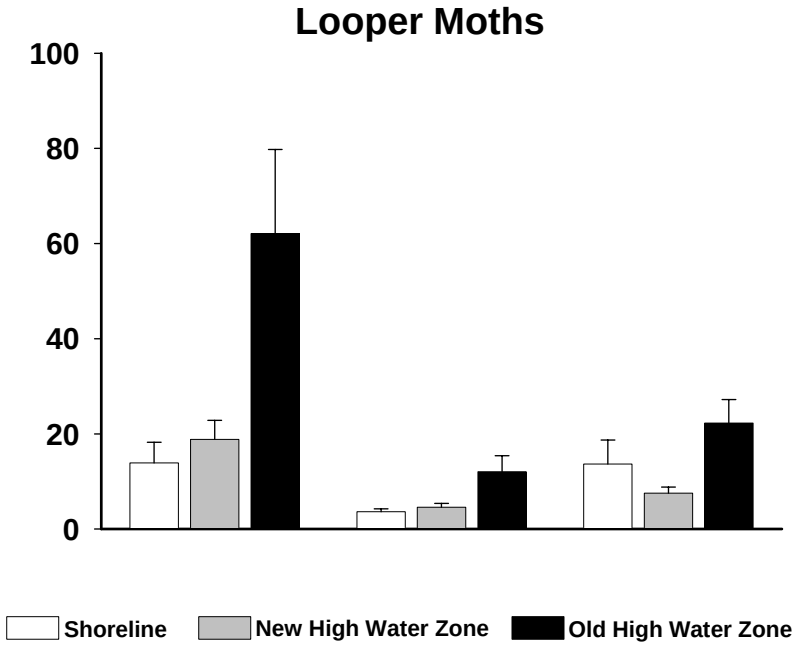


Figure 25. Abundance of looper moths (Lepidoptera: Geometridae) in the TEM sites. . Figures represent means across sites and years; vertical bars represent +/- 1 s.e

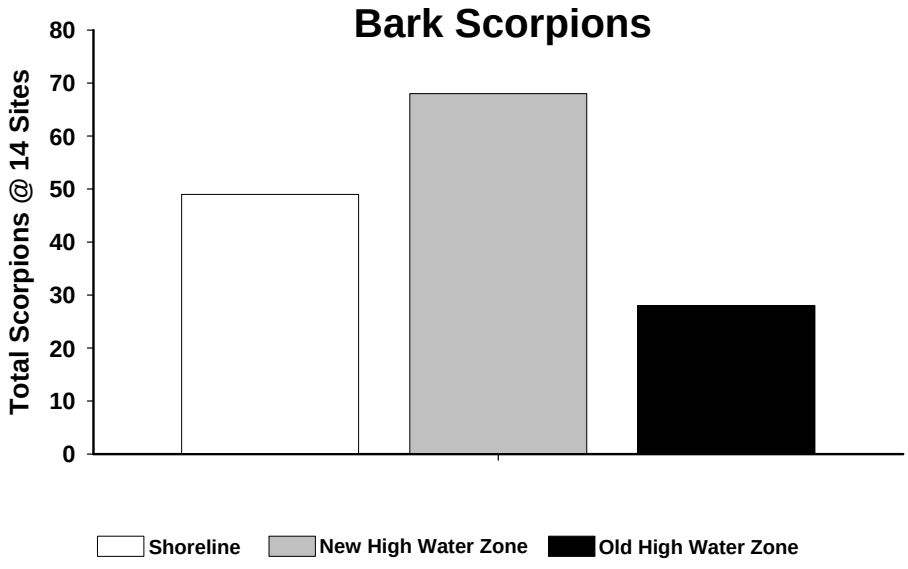


Figure 26. Abundance of bark scorpions collected in the TEM sites. Figures represent means across sites and years, vertical bars represent +/- 1 s.e.

Herpetofaunal Surveys

Geoffrey C. Carpenter
The University of New Mexico, Albuquerque, NM
& Southwestern Biomes, Inc., Bosque Farms, NM.

Purpose:

Herpetological surveys of riparian habitat along the Colorado River in the Grand Canyon were conducted during 2001-2003, as a component of The Grand Canyon Monitoring and Research Center's (GCMRC) integrated Terrestrial Ecosystem Monitoring (TEM) program. Herpetological survey and census data serve to: (1) provide baseline inventory records for the corridor, (2) provide insight into community dynamics among terrestrial lizards, snakes, and toads occupying habitat within three different river flow stage riparian environments; (3) glean information concerning community dynamics in relation to river level fluctuations resulting from Glen Canyon Dam operations; and (4) provide data with which to investigate community dynamics in relation to aspects of vegetation and trophic relationships with other faunal groups.

These data provide important information essential for exploring potential effects of dam operations on herpetological communities along the river corridor, and are integrated with corresponding data representing vegetation, other vertebrate animals, and invertebrates (arthropods) generated for the TEM research program, to explore potential effects of dam operations on riparian ecosystems in the corridor. These data are to be included in GCMRC's database so that they are available to GCMRC and other agencies, stakeholders and researchers.

Objectives:

Principal objectives for the herpetological components of TEM are to:

1) Determine herpetofaunal species composition and relative abundance associated with three distinct zones: the old high water zone, the new high water zone, and the fluctuation zone ("shore") environments.
2) Determine microhabitat associations for the common species of lizards, snakes, and toads, to include water zone and substrate (i.e. boulders, cobbles, vegetated beach) habitat utilized, and to record thermal and behavioral information that will help assess how different species are using these habitats differently.
3) Investigate herpetofaunal species composition in relation to vegetation, other vertebrate animals, and, to arthropod community structure, across the three hydrologic riparian zones.
4) Assess effectiveness of survey/monitoring techniques for characterizing herpetofaunal communities across the three riparian hydrologic zones over time (season, year). Monitoring data will be used to investigate the impacts of water level fluctuation resulting from the operation of Glen Canyon Dam.

5) Compare observed riparian herpetofaunal community patterns (e.g. reproductive success each year) to temporal variation in climate, across the three hydrologic zones, in relation to linear position along the river (river mile), and in relation to dam operations.

6) To accumulate distribution records of herpetofauna along the river corridor, to include photographic vouchers when possible.

Methods:

The 14 primary TEM sites were visited three times during 2003: the first sampling period was divided into lower-half (April 10-18) and upper-half (May 1-7) trips; the second sampling period was June 26-July 11; and the third was August 26-September 5. Early and late summer seasons support different species and age class compositions within the various riparian hydrologic zones and activity patterns of herps also vary seasonally. Spring, early summer, and late summer sampling periods were selected to capture the scope of potential seasonal variation in active herpetofauna, to assess reproductive activity (spring) and reproductive success (late-summer), and to coincide with integrated sampling on these same river trips.

TEM site surveys.

Daytime surveys were completed in each zone at each site during the best possible conditions available during a site visit (optimal cannot be used here, because not all sites reached optimal conditions for herpetofaunal activity during each visit). Lizards, toads, and snakes observed were recorded by a herpetologist walking a route along the transect lines. The walk consisted of a slow meander, with frequent stops (every few steps) to visually scan in all directions for herp movement and profiles/silhouettes. Nooks, crannies, and the undersides of rocks were checked. Sandy substrates were scanned for tracks, and substrates and boulder surfaces were examined for scats. Each individual observed was recorded to species, sex (when determinable), and age class. Notes and metadata concerning substrate, temperature, other microhabitat measures, and behaviors were also recorded (Figure 1). Transects and the habitat patches that contained them were thoroughly surveyed during peak daytime activity periods for diurnally active herps. Weather and terrain permitting, night operations to search for nocturnally active herps were undertaken (usually in concert with nighttime scorpion searches by members of the bug crew), but very few herps were ever found on these night walks.

The entire study site was searched, and while the amount of time spent surveying at each site was recorded, capture rate was not used, because the sites varied in size and habitat complexity, hence some sites could be thoroughly searched faster than others. Therefore, the capture rate co-varies with habitat complexity and size of the study area. For this reason, standardized timed searches were deemed unsuitable for this study. Rather, raw numbers observed were corrected for patch size (area) and densities were calculated. Although this technique allows for the comparison of repeated visits within on site, it is difficult to use raw capture data to make comparisons among different sites.

Vegetation / bird patch surveys. During the spring trip, in which vegetation/bird patches were sampled, a herpetologist went along with the vegetation sampling crew to survey for herps at these sites to acquire additional herpetological records along the corridor. Sampling at these sites consisted of a pedestrian survey for herps and herp sign in each zone.

Opportunistic encounters and accounts. Additionally, lizards were occasionally captured in the arthropod pitfalls (described in arthropod section of this report), and toads were often captured in Sherman live traps for small mammals. Data for these accidentally trapped herps were also recorded.

Collaboration. As part of ongoing genetic studies, blood was collected from the caudal vein of adult rattlesnakes encountered (under Arizona Game & Fish Department Scientific Collecting Permit SP762801), and sent to the laboratory of Dr. Michael Douglas at Colorado State University, where blood samples are being analyzed.

Data Analysis: To determine if the species composition of herp communities differed among the three hydrologic zones, MRPP analyses were run using Bray-Curtis dissimilarity (PC-ORD; McCune, B. and M. J. Mefford. 1999). This method compares dissimilarities between samples within groups from the data set to those calculated from randomly assembled groups (Mielke 1984, Zimmerman et al. 1985). A significant result indicates that group members are more similar to each other than would be expected by chance. Additionally, an Indicator Species Analysis was run to determine if there were particular species responsible for compositional differences among zones (Dufrene and Legendre 1997). This method uses information about species' abundances (mean abundance per sample in each zone, for example) and frequency within groups (proportion of samples containing the species) to determine if a species could be used as a bioindicator for a particular zone.

Results:

Eighteen species of herps were observed during 2003 at TEM (18) and VEG-BIRD (11) sites (Table 1, Figure 2): two toads (Woodhouse's toad, red-spotted toad), one frog (canyon treefrog), eight lizards (side-blotched lizard, western whiptail lizard, desert spiny lizard, tree lizard, collared lizard, chuckwalla, banded gecko, desert horned lizard [a single individual at Lee's Ferry, not included on graph]), and seven snakes (Grand Canyon pink rattlesnake, speckled rattlesnake, blacktail rattlesnake, gopher snake, coachwhip, lined whipsnake, kingsnake).

A graph of species richness (Figure 3) shows that during 2003 the greatest average number of species at TEM sites was found in the new high water zone, followed

by the old high water zone, with the shore yielding the poorest species richness. In 2001 richness was greatest in the old high water zone, followed by the new high water zone, while during 2002; richness was comparatively low in all three hydrologic zones.

As was true during 2001 and 2002, Figure 4 shows that the most commonly encountered herps during 2003 were four lizard species (side-blotched lizard, Western whiptail, desert spiny lizard, and tree lizard) and two toads (Woodhouse's toad, and the red-spotted toad), followed by the Grand Canyon pink rattlesnake. These patterns of abundance are consistent not only across years (Figure 4), but also between TEM and VEG-BIRD sites (Figure 2). For descriptive purposes, data that are not being specifically related to TEM sites were pooled to enhance sample sizes in some of the below analyses.

Among these seven common species, side-blotched and spiny lizards were most commonly observed in the old high water zone but were quite common in the new high water zone as well. Other species were found most frequently in the new high water zone (Figure 5). The two toads and the tree lizard exhibited the greatest use of the fluctuation/shore zone (Figure 6).

In terms of overall observations in each zone, we see that all seven common species are using all three of the zones (Figure 6). However, different species are using the zones in different proportions, and moving from zone to zone (i.e. not using a single zone exclusively). In the spring and fall observations of the two toads were most frequently in the new high water, but in the summer toads favored the shore zone. Toads were seldom encountered in the old high water zone. Tree lizards also were observed frequently along the shore, as they often occupy shoreline boulder and cobble habitats (reported by Warren and Schwalbe, 1988). Side-blotched and spiny lizards are common in both old and new high water zones, and whiptails are seen more frequently seen in new high water compared to the old high water zone.

Figure 7 presents numbers of the common species observed during 2003's spring, summer and fall trips. A few patterns are evident: (1) spring was the most active time for most species, (2) side-blotched lizard activity dropped off during the heat of the summer, (3) active whiptails decreased in numbers overall (this is not unexpected as whiptails (especially adults) are know to become inactive in by late summer (Etheridge and Wit, 1993; Pianka, 1970). Also, adult activity for most lizard species is generally slower during the fall trip, when the proportions of sub-adults, juveniles, and hatchlings are higher (Figure 8).

A MRPP analysis (PC-ORD, Version 4.10) revealed significant differences in the species composition of the three hydrologic zones ($A = 0.05667923$, $p = 0.00000000$) and significant differences between seasons ($A = 0.00947285$ $p = 0.00012582$). But no such trends were evident by year. The compositional and seasonal distinctions were most apparent between old high water and new high water and between old high water and shore zones. Shoreline did not appear to be different from the new high water zone in this test.

A univariate analysis of variance, General Linear Model (SPSS) Tests of Between-Subjects Effect, showed an effect of zone (F = 7.172, p = 0.00), but no influence from year, patch, or interactive effects among these variables.

An indicator species analysis yields seven herp species with signifiant indicator values (Table 2), five of which are among the seven most common species noted above.

The results from an Indicator Species Analysis (ISA: PC-ORD, Version 4.10) are presented in Table 2. The ISA uncovered several species which whose presence were connected with each zone. Both toad species (*B. woodhousei* and *B. punctatus*) and the Western whiptail (*C. tigris*) were significantly associated with the new high water zone. Side-blotched lizards (*U. stansburiana*), spiny lizards (*S. magister*), collared lizards (*C. collaris*) and chuckwallas (*S. obsusus*) are significantly associated with the old high water zone (OHWZ). Thus, these species can be considered "indicators" for these zones. These abundant and visually obvious species will provide the best data for integrated monitoring purposes, and form a suite of species that provide an indication of the role of ectothermic vertebrates in riparian ecosystems of the river corridor.

To investigate significant relationships among the herps, plant arthropods, and pitfall arthropods, a Spearman Rank Correlation Analyses was performed (see arthropod section for descriptions of arthropod functional groups). The following patterns between herps and arthropods were revealed:

I. PLANT ARTHROPODS and ALL HERPS

(1) In the new high water zone, there was a relationship between herps and plant-ants (R=-0.302; p=0.0022).

(2) In the old high water zone there was a relationship between herps and plant spiders (R= 0.23908, p = 0.0166) and herps and plant ants (R= 0.30312, p = 0.0022) herps and plant beetles (R= 0.26240, p = 0.0084) and herps and plant bugs (R= 0.25509, p = 0.0104).

(3) At the shore line there was a relationship between herps and plant spiders (R= 0.41707, p = 0.0114).

II. PITFALL ARTHROPODS and ALL HERPS

A relationship between herps and tenebrionid beetles (R=-0.17463; p=0.0420) in the old high water zone.

III. PITFALL ARTHROPODS and SIDE-BLOTCHED AND WHIPTAIL LIZARDS ONLY

(1) In the new high water zone, there was a relationship between the two lizards and carabid beetles (R=-0.26163 p=0.0473).

(2) In the old high water zone there was a relationship between the two lizards and tenebrionid beetles (R= 0.27469, p = 0.0307) and the two lizards and ants (

R= 0.24372, p = 0.0563) the two lizards and spiders (R= 0.46726, p = 0.0509).

(3) At the shore line there was a relationship between the two lizards and carabid beetles (R= 0.46726, p = 0.0246).

Discussion:

The most effective sampling technique to assess herpetological community structure at TEM sites, given logistical and monetary constraints, is to use pedestrian surveys to intensively survey entire patches of habitat during the best available times (temperature, sunlight, moon phase, precipitation) during site visits. This is generally from around four in the afternoon, when the crew arrives at a site, until late morning the following day, when it is time to get onto the boats and travel to the next site. The optimal time to conduct pedestrian surveys of TEM sites is generally in the morning, when sunshine first hits the site. This is problematic on south-facing beaches with steep north-side canyon walls, especially early and late in the season, and sometimes direct sunlight never hits certain sites during a visit. Additionally, cloud cover and other climatic events can obscure the sun for the entire duration of a visit to a beach. Hence, ideal survey conditions are not always available. Nevertheless, pedestrian surveys, consisting of a slow meandering walk, stopping frequently and remaining vigilant through each of the hydrologic zones is an effective means to document herp activity on a site at a particular time, and to collect reliable information for monitoring, inventory, and other purposes.

Patterns of microhabitat associations for the common species of lizards, snakes, and toads in the riparian environments within the corridor become clearer as more trips are taken, and more data are collected. Factors that drive distribution among these animals include temperature, food, moisture, and shelter requirements. These drivers vary seasonally within and among zones, making seasonal information particularly important when determining the effects that the hydrologic regime might have on herp communities in the corridor.

While it is tempting to associate certain species with the individual zones, most species do not utilize a single zone, rather species exhibit spatial and temporal variations in habitat use. For instance, over the span of a year, side-blotched and spiny lizards are found most frequently in the old high water zone. However, they also utilize the new high water zone quite a bit, but are infrequently observed along the shore. Seasonally side-blotched and spiny lizards are found more frequently in the new high water zone during the intense heat of mid summer than in either the spring or the fall, when temperatures are more moderate. Drawing strict generalizations is tenuous, however, as almost all species are observed, at least occasionally, in all zones and preferred microclimates change diurnally, tracking solar movement.

Use of a zone also may be attributed to foraging strategy and/or substrate affinities. Active foragers, such as whiptails (Vitt and Ohmart 1973), are usually found on the ground. Territorial sit-and-wait predators, such as tree, side-blotched, and spiny

lizards, are generally found on vertical surfaces (primarily tree lizards) or among rocks or more heterogeneous terrain (side-blotched, spiny, and tree lizards). That whiptails are most frequently observed in the new high water zone may reflect their active foraging mode as they meander among salt cedar and arrow weed rooting out arthropod prey. In fact, similar survey studies have reported that whiptails are really the only herp that utilizes dense tamarisk galleries along the Lower Colorado River (Vitt and Ohmart 1978), and this has been attributed to their active foraging mode. It is interesting, in this light, that the Indicator Species Analysis revealed that this species is associated with the new high water zone. Toads and tree lizards are the principal herp occupants of the shore (i.e. they use the shoreline proportionally more than any of the other species), and are observed more in the new, than in the old high water zones; but they are seen in all zones. However, toads were found to be indicator species for new high water zone, because they were abundantly observed in and around the new high water zone vegetation. Sit-and-wait spiny lizards are insect generalists and seem to prefer beetles and ants (Parker and Pianka 1973; Vitt and Ohmart 1974). Spiny lizards can be abundant in areas with trees (new high water salt cedar) or with rocks (old high water boulder fields), yet sometimes venture to the shoreline to forage. For the spiny lizard these patterns vary seasonally, due not only to varying micro-climatic regimes, but also because the food base (arthropods) varies by zone and season as well. So, while this species, along with the most abundant herp, the side-blotched lizard, are indicators of old high water zone, they certainly do not use this zone exclusively, and exhibit a pattern of shifting proportional zone usage from spring to summer to fall; using the cooler new high water zone more during the hot summer months, then retreating to the old high water zone in the fall, hibernating, then emerging in the old high water zone in the spring. The other significant indicators of the old high water zone, collared lizards and chuckwallas, prefer the hotter and drier habitat of the old high water zone, although they are considerably rarer than other lizard species. Thus the abundance and composition of herps varies at sites with different characteristics, which are in turn affected differently by the microclimate, substrate, and prey characteristics related to the hydrograph. Species associated with these zones serve as "indicators" of how ectothermic vertebrates are faring in these systems.

Statistical diagnostics to uncover relationships between herps and arthropods indicate that there is an association between the common herps and arthropods inhabiting the different hydrologic zones. While continued data collection and analyses are required to reveal the exact nature of these relationships, it is interesting that some of the arthropod groups that are associated with herps in the different zones in the correlation analysis are indicator species of arthropods for those same zones (see arthropod section). One way to garner supplementary data to address questions concerning food webs would be to analyze lizard diets. This would involve a three pronged approach using (1) behavioral (feeding) observations, (2) analysis of flushed stomach samples, and (3) analysis of fecal pellets, to draw stronger correlations, and attribute them directly to trophic relationships (rather than simply to similar habitat preferences, for instance).

The strongest potential for these data will likely involve the comparison of time-lagged population responses (measured seasonally, in terms of relative abundance or density at repeat sites, or sites with similar size/structure) to responses of vegetation and arthropod communities to climate and the hydrograph. For example, a spike in lizard reproduction might be expected during the year following high average spring flows, lush

vegetation, and abundant arthropod prey. In response to the prey base, lizards are able to garner energy reserves with which they can emerge from hibernation the following year having undergone gonadal recrudescence (re-growth after winter atrophy), ready to reproduce. Several sample periods a year will be necessary to provide data with which firm inferences can be drawn regarding reproduction and other life history parameters. Figure 8 shows the expected seasonal variation in presence of juveniles and hatchlings of the indicator species for old high water and new high water zones respectively, the side-blotched and whiptail lizards, with hatchling numbers peaking in the summer, and juvenile numbers peaking in the fall. While these patterns are evident with but three years of data, comparisons among years will likely yield stronger patterns with a greater potential for integrating with plant and arthropod data. For example, only by sampling herp communities in the corridor at least three times a year for several years can demographic trends be revealed, and subsequently tied to the arthropod food base. Another interesting pattern to be explored is the possible relationship between rattlesnake and small mammal populations in some of these habitat patches. While these analyses were run with three years' of data, the results were inconclusive, likely due to small sample sizes after only three years of sampling. Answers to these questions will come only with time, as continued data collection will be necessary to elucidate these patterns.

It has long been recognized that the ecology of desert lizards is highly variable both within and among populations. Vitt and Ohmart (1973) summarized it well:

"Although there are considerable amounts of data on reproduction and ecology of desert lizards, integration and comparisons of these studies are difficult due to the nature of desert habitats and methods of most studies. Yearly and seasonal fluctuations in rainfall on desert habitats undoubtedly has a great effect on resources and should (affect) reproductive cycles and ecologies of these lizards, thus rendering many studies…..not comparable. The differences in reproductive cycles and aspects of the ecology of lizards studied during different time periods may result from yearly or seasonal climatological changes alone and hence obscure interpretation of data collected out of synchrony. Long term studies on several sympatric species would help to clarify these relationships. The climatological variables could be monitored and thus interpretation of ecological variables could be facilitated. In addition, if a drought year followed a more typical year, any potential for food competition could be realized and data on intense species interactions and habitat and/or resource shifts could be evaluated."

Therefore, we cannot expect to acquire and understanding of herpetological community dynamics (lizards in particular) within the riparian corridor of the Grand Canyon based on studies in other systems, or based on the few short-term studies that have been performed within the system, which have only scratched the surface. A multidisciplinary, integrated understanding these riparian habitats within the corridor will require long-terms studies to capture the complexity of these dynamic systems.

In sum, data from three years of this study allow for an initial interpretation of herpetofaunal species composition and relative abundance in association with the three hydrologic zones, and possibly with year, season, canyon width, river reach, and linear location along the river (river mile). One conclusion that can be drawn is that the common species do not restrict themselves to a single zone, rather, each species is found, at least occasionally, in all three of the zones. However, different species appear to be

using the zones in different proportions, and in different ways, hence relative species abundance may be affected by impacts the hydrograph, climate, and other factors have on vegetation, arthropod abundance, and other aspects of habitat quality in the three zones. In spite of all of this variation, a substantial set of species, both herp and arthropod, emerge as zone indicators, and these data have a high potential for application, either alone or in tandem, for assessing effects of dam operations on the Grand Canyon riparian ecosystem.

Literature Cited:

Etheridge, K., and L.C. Wit. 1993. Factors affecting activity in *Cnemidophorus*. pp. 152-162 In.Wright, J.W. and L.J. Vitt (eds) Biology of Whiptail Lizards (Genus *Cnemidophorus*). Oklahoma Museum of Natural History, Norman, Oklahoma. 417 pp.

Parker, W.S. and E.R. Pianka. 1973. Notes on the ecology of the iguanid lizard, *Sceloporus magister*. Herpetologica, 29:143-152.

Pianka, E.R. 1970. Comparative autecology of the lizard *Cnemidophorus tigris* in different parts of its geographic range. Ecology 51:703-720.

Vitt, L.J. and R.D. Ohmart. 1974. Reproduction and ecology of a Colorado River population of *Sceloporus magister* (Sauria: Iguanidae). Herpetologica 30:410-417

Vitt, L.J. and R.D. Ohmart. 1978. fauna of the Lower Colorado River: Davis Dam to the Mexican border. Proc. Western Found.Vert. Zool. 2:35-72.

Warren, P.L. and C.R. Schwalbe. 1988. Lizards along the Colorado River in Grand Canyon National Park: Possible effects of fluctuating river flows. Glen Canyon Environmental Studies, Executive Summaries of Technical Reports, October, 1988.

Table 1. GRAND CANYON / COLORADO RIVER CORRIDOR HERPS 2003

Lizards

side-blotched lizard *(Uta Stansburiana*)
Western whiptail (*Cnemidophorus tigris)*
desert spiny lizard *(Sceloporus magister*)
tree lizard *(Urosaurus ornatus*)
collared lizard *(Crotaphytus collaris*)
desert horned lizard *(Phrynosoma platyrhinos)*
chuckwalla *(Sauromalus obesus*)
banded gecko (*Coleonyx variegatus*)

Snakes

Grand Canyon pink rattlesnake *(Crotalus viridis abyssus*)
speckled rattlesnake *(Crotalus mitchelli*)
black-tailed rattlesnake *(Crotalus molossus*)
king snake *(Lampropeltus getulus*)
red racer/coachwhip *(Masticophis flagellum*)
lined whipsnake (*Masticophis taeniatus*)
gopher snake *(Pituophis melanoleucus*)

Toads and Frogs

red-spotted toad *(Bufo punctatus*)
Woodhouse's toad *(Bufo woodhousei*)
canyon treefrog *(Hyla arenicolor*)

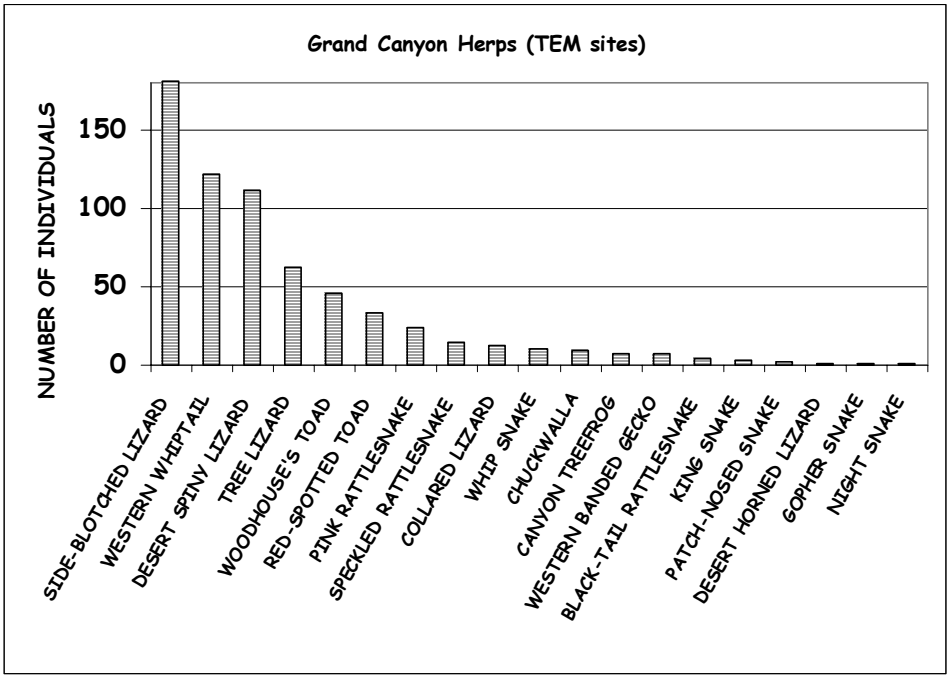
Table 2. Observed random indicator groups from Indicator Species Analysis for Grand Canyon river corridor herps, 2001-2002.

Species	Hydrologic Zone	Indicator Value	p
Red-spotted Toad	NHWZ	4.7	0.0180
Woodhouse's Toad	NHWZ	13.5	0.0010
Western Whiptail	NHWZ	21.5	0.0010
Collared Lizard	OHWZ	5.1	0.0220
Chuckwalla	OHWZ	4.8	0.0160
Spiny Lizard	OHWZ	19.7	0.0040
Side-blotched Lizard	OHWZ	34.1	0.0010

HERPER DATE

Site/RM	ZONE	SPP	AGE/CLASS	TIME	MICROHAB/SUBSTR	TEMP	SUN	BEHAV	COMMENTS

Figure 22. Sample data sheet for TEM herp surveys.



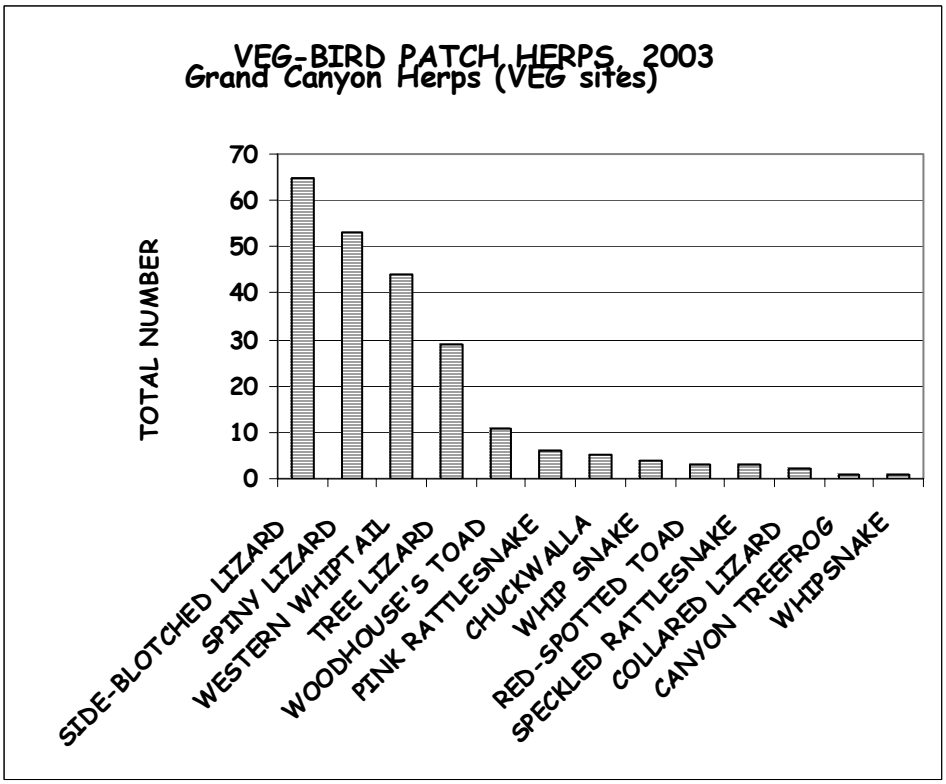


Figure 23. Herps encountered at TEM sites (above) and VEG-BIRD patches (below) during river trips in the Grand Canyon, 2003.

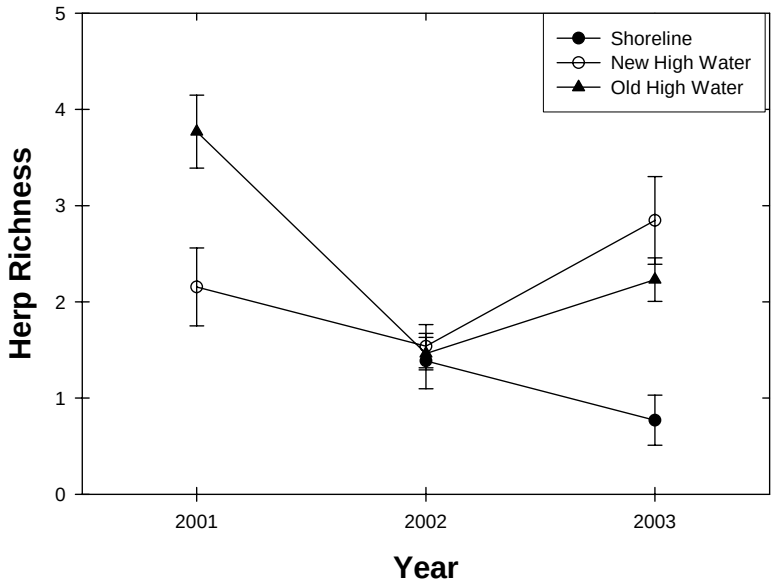


Figure 24. Species richness (number of species) of herps in the three hydrologic zones during 2001-2003.

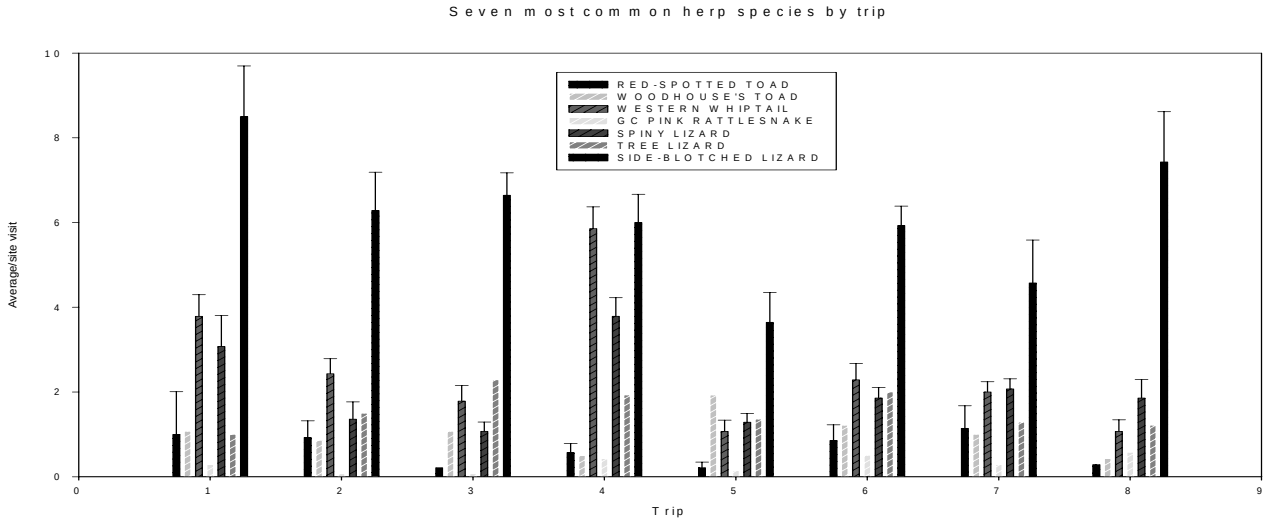


Figure 25. The seven most commonly encountered herps during TEM trips, 2001-2003.

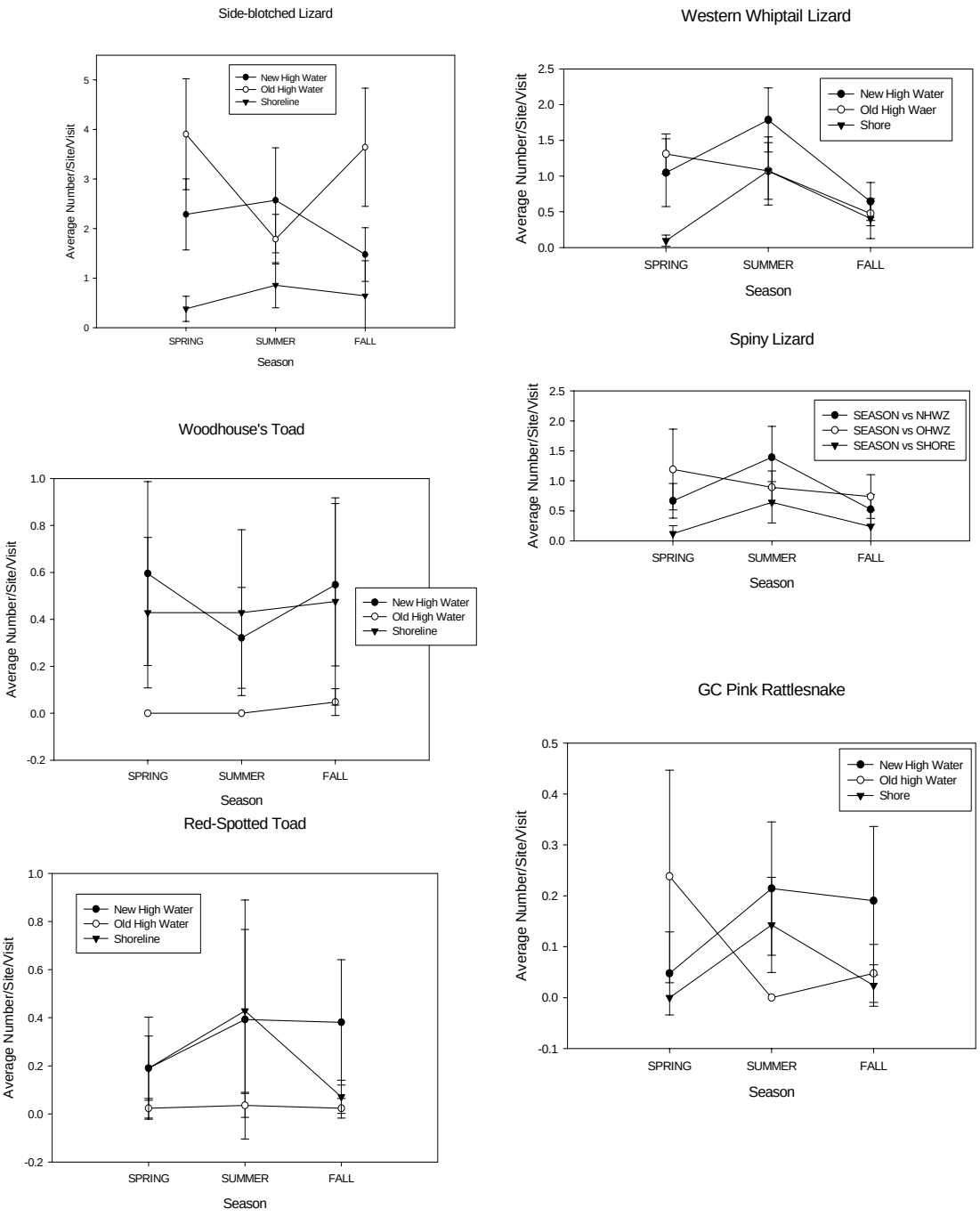


Figure 26. The seven most common herps in each of the three hydrologic zones.

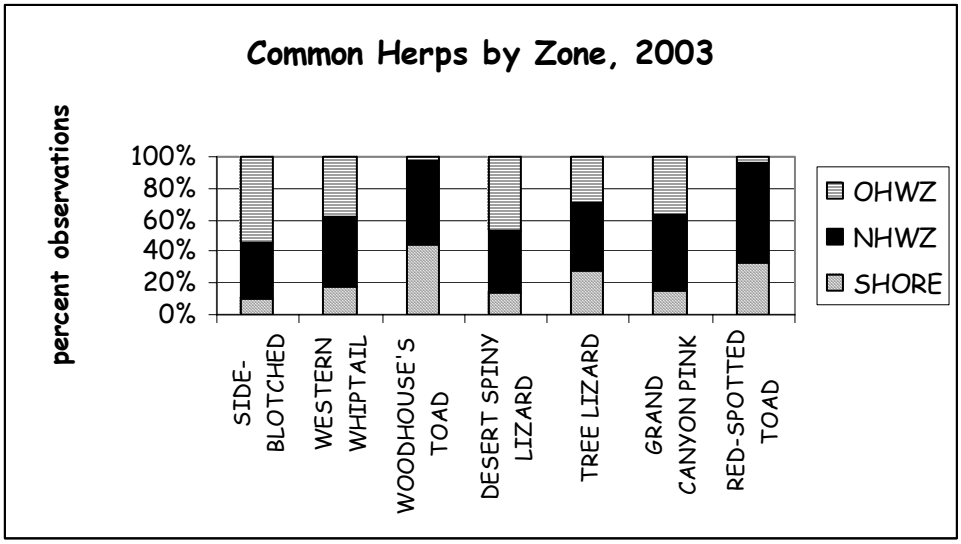


Figure 27. Percentage of observations of the seven most commonly encountered herps in each of the three hydrologic zones.

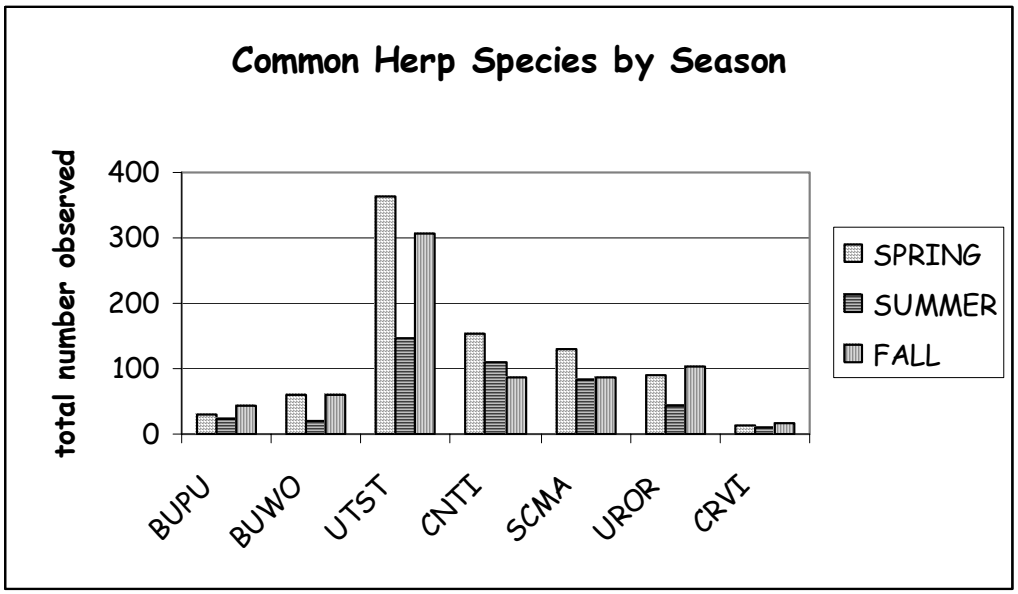


Figure 28. The seven most common herps observed, by season, on Grand Canyon TEM trips during 2003.

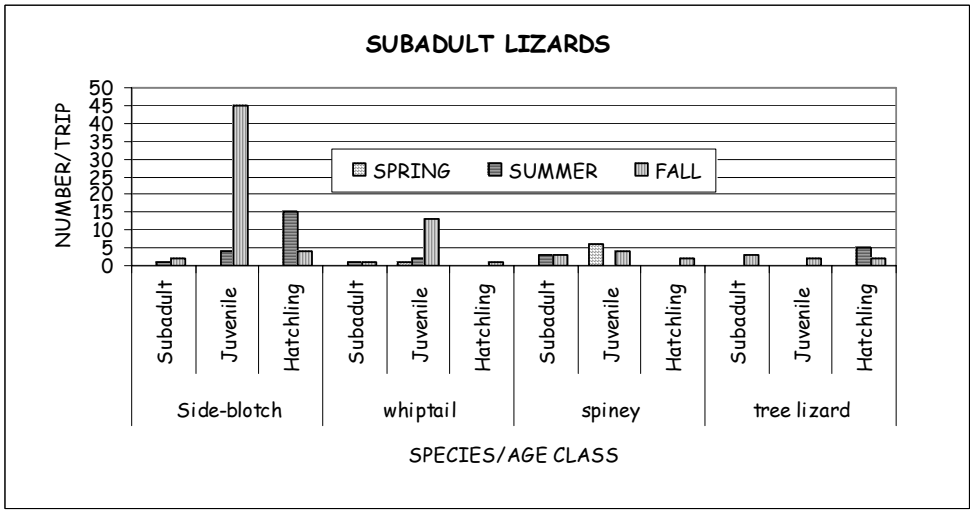


Figure 29. Sub-adult, juvenile, and hatchling lizards, by season, on Grand Canyon TEM trips during 2003.

BREEDING BIRD SURVEYS

Helen K. Yard and John G. Blake
Helen Yard Consulting

Aims of breeding bird assessments and surveys were to:
1) Estimate the number of breeding pairs in14 monitoring sites, 2) Document avian density, abundance, species richness and composition in different vegetation zones and seasons (April, May and June), 3) Test for differences in avian density, abundance and species composition between zones and seasons, 4) Determine if similarity in species composition of bird communities among sites along the Colorado River was related to distance among those sites, 5) Compare avian abundance and species between years and, 6) Provide tribes with information regarding birds of interest. In addition to tasks undertaken as required by the original proposal, we also compared survey methods (point count versus walking surveys).

Methods:

Site selection. Sites for breeding bird assessments and surveys were specified by the original Request for Proposals and by the Terrestrial Biologist from GCMRC. A total of 57 sites were chosen for avian surveys in 2001, 64 sites were chosen in 2002 with 17 sites being surveyed during both years. In 2003, 67 sites were chosen of which 61 were surveyed during all three trips. Fourteen sites were selected for monitoring (camp) sites where all terrestrial resources (mammals, invertebrates, herpetofauna and vegetation) were surveyed during 2001, 2002, and 2003. Five of the 14 sites were monitored for all three years of the study (see sites elsewhere in document).

Nest searches. **2001 only**. Nest searches for riparian breeding birds were conducted in and around the 14 camps specified by GCMRC on both field trips using standard methods (Brown 1989). Searches began in the afternoons upon arrival at camps, continued until dusk, then were resumed after the point counts and walking surveys the next morning. Equal time was not allocated in searching at each site due to variable travel times between sites. However, within sites, equal time was spent searching in each vegetation zone (a minimum of four hours per zone for a total of eight hours). Four biologists, and volunteers when available, spent a minimum of eight hours per site searching for nests.

Breeding Pair Assessment. No breeding bird assessments were conducted in 2001 because nest searching at monitoring sites was not feasible in the time allowed at each site. We then implemented riparian breeding bird assessments at the14 monitoring sites during three field trips in 2002 and 2003 (see dates elsewhere in document). Assessments began in the afternoons upon arrival at camps, continued until dusk, then resumed the following morning after point counts and walking surveys, and continued through the morning until all other terrestrial monitoring activities were concluded (approximately 11 AM). Assessments involved marking the locations, species, and sex of each bird observed within the patch (spot mapping) onto aerial photographs at each

site; a minimum of two observers plotted locations. Equal time was spent mapping singing males and pairs in each vegetation zone though breeding bird assessments are made for the entire patch. Numbers of singing males and confirmed pairs of birds were summarized before leaving each site. We counted singing males as a pair (Mills et al. 1991, Wiens 1992) and attempted to confirm the presence of a female in a territory where a male was detected singing. We also recorded breeding behavior (e.g, adult feeding young, food begging fledglings) according to Arizona Game and Fish and breeding bird atlas specifications (Corman 1994) to assist in documenting breeding pairs.

Walking Surveys. Surveyors spent up to 40 minutes walking at a consistent pace through each vegetation zone in each patch. OHWZ and NHWZ zones were surveyed independently (one observer walking each zone concurrently). Observers walked on established trails or chose a path of least resistance where no trails existed (repeated on each trip) to minimize impacts and multiple trailing. Surveyors recorded date, time, site, vegetation zone, species, age, sex, detection type (visual/auditory), estimated perpendicular distance from the observer to each bird (Buckland et al. 1992, 2001), plant or substrate where the bird was detected, activity (sing, call, perch, fly, forage, breeding bird behavior [Corman 1994]), and relevant notes. Walking survey data were used to compare bird abundance, density and species composition between the two vegetation zones.

Point Counts: Counts were conducted at the same patches as the walking surveys. Count lengths were 5 minutes divided into 0 - 3 and 3 - 5 minute intervals. Point counts were conducted at existing flagged stations established by Spence et al. (1998 – 2000) when patches were repeated in both studies. In new patches, stations were established by walking 50 meters into the patch at the transition zone between the OHW and NHW zones, conducting the 5 minute point count, and then proceeding 100 meters farther to conduct the next count until we reached the end of the patch as delineated by aerial photographs. Number of counts per patch was, thus, proportional to the size of the patch. Surveyors recorded the same information on the data sheets that were recorded during walking surveys. GPS readings were taken at point count stations in each patch where possible. For analyses, we used combined point count estimates for each patch to assess numbers of birds in the entire patch as recommended by the Peer Review Panel (2000). These data, based on estimates of bird numbers in the same sites surveyed in all three years, were used to assess among year differences in bird abundance, density and species composition.

Additional task: We also assumed an additional task that was not stated in the original proposal. We compared numbers of birds detected in the two survey methods in order to obtain information on which method revealed the highest number of birds. Comparisons of this nature made in past studies suggested that the number of birds detected in each method was similar but point counts were selected as being the most repeatable method that could be standardized.

Analyses

Breeding Bird Assessment: One-way ANOVA's were used to compare abundance of breeding pairs between trips (seasons), years, and sites. We ran statistical analyses only on five TEM sites assessed for breeding birds in both 2002 – 2003.

Abundance and Density: Students paired t-tests were used to examine differences in the abundance and density of birds found within NHWZ habitat to those found within OHWZ habitat within each year. This test examines avian use of each zone at the time of the survey and does not assume the data are independent. We also compared how abundance may differ within a given zone (NHWZ, OHWZ) from one trip to another to examine seasonal variation in abundance. When multiple comparisons were made on related data (e.g., using paired t-tests to compare results between pairs of trips), we used the Dunn-Šidák procedure to calculate an experimentwise error rate, where $\alpha' = 1 - (1 - \alpha)^{1/k}$ (k = number of intended tests) (Sokal and Rohlf 1995). We used an ANOVA with year being the factor, to compare abundance and density of birds among years.

Species Composition: We used analysis of similarity (ANOSIM; described in Clarke and Warwick 2001) to compare the level of similarity in species composition among a set of related sites (OHWZ, NHWZ) to the level of similarity across all sites (i.e., to determine if predefined groups differed in species composition). For example, ANOSIM allows us to determine if all NHWZ samples and all OHWZ samples are more similar within their respective zones than are samples taken at random from all samples (i.e., including comparisons across zones). ANOSIM is a nonparametric permutation procedure that is combined with a Monte Carlo test (i.e., a general randomization approach to the generation of significance levels) to determine if the level of similarity among samples within a group is greater than expected by chance when compared to the level of similarity among samples across all groups. When more than two groups are compared, ANOSIM first calculates a global test that indicates whether or not any difference exists among groups. This is followed by pairwise tests that evaluate levels of difference between all possible pairs of groups included in the analysis. (This procedure is conceptually similar to an analysis of variance followed by multiple comparisons of means tests.) The significance of the ANOSIM test statistics are determined by comparison with the value obtained by the randomization procedure.

We also used MRPP (multi-response permutation procedure) to test the hypothesis of no difference between or among groups (McCune and Grace 2002). As with ANOSIM, MRPP is a nonparametric produced that uses ranked differences to compare similarities of samples within and between groups. In most cases, results from ANOSIM and MRPP were in general agreement but in some cases MRPP indicated a significant difference between groups when ANOSIM did not. Thus, we take a more conservative approach and report only those results obtained with ANOSIM.

We used Mantel tests in 2003 to examine the correlation between sites based on species composition and on river-mile distance. Significance of the test statistic was based on a randomization test with 1,000 iterations.

Sample patches differ in area, which is likely to influence the number of individuals (and species) recorded. Thus, comparisons based on raw numbers

unstandardized by area (i.e., an estimate or index of density) may obscure differences in composition that are unrelated to area. We used a relativization procedure to partially account for any effects of area on numbers of individuals counted. Counts of individuals were standardized by using the maximum value recorded for a species. We first relativized species abundances within samples (across species) and then within species (across samples). This procedure has the effect of eliminating differences in total numbers of individuals among samples and tends to equalize the importance of common and uncommon species. Thus, it reduces the effect of total quantity (abundance) to focus more directly on relative quantities (McCune and Grace 2002).

We followed the ANOSIM analysis with an indicator species analysis (Dufrêne and Legendre 1997, McCune and Grace 2002) to determine which species (if any) were particularly characteristic (indicative) of different groups. Indicator species analysis combines data on the abundances of species within samples from different groups with the frequency of occurrence of that species in the different groups being compared. A species would be a perfect indicator of a particular group if it occurred in all samples from that groups and did not occur in samples from any other group. Indicator values are tested for significance with a Monte Carlo randomization procedure (McCune and Mefford 1999).

We used non-metric multidimensional scaling (NMDS) to graphically represent similarities (and differences) in species composition among sites (Clarke and Warwick 2001, McCune and Grace 2002). NMDS is an ordination procedure that uses ranked distances (i.e., levels of similarity or dissimilarity) between sample units to describe the relationships among all samples. The procedure extracts axes from the samples that describe variation in species composition among the samples and uses a Monte Carlo procedure to determine if the amount of variation described by the different axes was more or less than expected by chance (i.e., whether there was significant structure in the data).

All multivariate analyses (ANOSIM and NMDS) were run on PC-ORD, Version 4 (McCune and Mefford 1999) or PRIMER, Version 5 (Clarke and Gorley 2001). We used the Sørensen similarity measure (also called the Bray-Curtis coefficient) to calculate similarity matrices for the multivariate analyses (see descriptions of distance measures in McCune and Grace 2002). We omitted sites where no birds were recorded for all analyses that depended on calculation of a similarity matrix. Such sites typically were represented by very small areas of habitat (e.g., little if any OHW zone vegetation in a number of different sites). Other statistical tests were conducted using SPSS, Version 10.0.

Quality control on data sheets and files

At the end of each day, all data sheets and notebooks were stored in a waterproof ammo can. During the river trip, all data was entered into excel spreadsheets on a laptop computer giving us both hard and electronic copies. Excel spreadsheets with all data were saved onto PC hard drives and backed up on CD's in the office of Helen Yard Consulting then sent via electronic file to GCMRC.

Results

Nest Searches

2001 - A total of 33 nests of eight bird species were located during the May and June trips, 2001. During the May trip, 20 nests were found; 17 in the NHW, 3 in the OHW zone. In June, we found 13 nests; 9 in the NHW, and 4 in the OHW zone (Breeding Bird Table 1).

Breeding Pair Assessment

2002 - We detected a total of 24 breeding species at 14 monitoring sites during 2002 (Breeding Bird Table 2). The highest number and density of breeding birds was detected at RM 198. The highest number of breeding species was detected at 204 (Spring Canyon). Overall, mean numbers and density of breeding birds were highest at larger sites being consistent with findings from previous studies (Sogge et al. 1997, Spence et al 1998b).

2003 – 26 breeding species were detected at 14 monitoring sites (Breeding Bird Table 3). Again, highest abundance of breeding pairs were detected in largest sites. Density of breeding pairs was not calculated for 2003.

Between year comparisons:

No significant difference was detected between the number of breeding bird pairs when we compared their abundance within the same sites ($F = 0.2$, $p = 0.65$) or between trips (seasonal differences, $F = 1.4$, $p = 0.25$) during 2002 – 2003. There was a significant difference in numbers of breeding pairs between sites ($F = 5.1$, $p = 0.004$, Breeding Bird Fig. 1) with the highest number of pairs being detected at site RM 198, the largest of the five sites.

Walking Surveys.

2001 – We detected a total of 1787 birds, including 48 species, at 57 patches during two field trips, 2001. No sites above Lees Ferry were surveyed in 2001. On the May trip, 883 birds ($\bar{x}$ = 15.4/patch) representing 39 species were recorded. During June, 904 birds ($\bar{x}$ = 15.9/patch) representing 34 species were detected.

2002 - Walking surveys were conducted at 64 patches during three trips in 2002. Four sites were surveyed upriver of Lees Ferry, 60 sites were surveyed below Lees Ferry. A total of 2627 passerines of 66 species were detected during surveys on three field trips in 2002. Detection numbers of birds and bird species on each trip were as follows: April - 736 birds ($\bar{x}$ = 11.5/patch), 32 species; May - 1209 birds ($\bar{x}$ = 19.0/patch), 52 species, and June - 682 birds ($\bar{x}$ = 10.6/patch), 32 species. The highest numbers of birds and bird species were detected in May.

2003 - We detected 2427passerines of 67 species at 61 patches during three breeding season trips, 2003. Four sites were surveyed upriver of Lees Ferry, 57 below Lees Ferry. Detection numbers of birds and bird species on each trip were as follows: April – 473 birds ($\bar{x}$ = 7.8 birds/patch), May – 984 birds ($\bar{x}$ 16.1 birds/patch) of 42 species, June – 970 birds ($\bar{x}$ = 15.9 birds/patch) of 29 species.

Point Counts.

2001 - A total of 672 birds of 37 species were detected during point counts in 57 patches in May and June combined. A higher number of birds (383, $\bar{x}$ = 6.7 birds/patch)

and bird species (31) were detected during the May trip. During June, a total of 293 ($\bar{x}$ = 5.1 birds/patch) birds of 25 species were recorded

2002 - A total of 1016 birds of 48 species were detected during point counts at 64 patches during the 2002 breeding season. A higher number of birds (410, $\bar{x}$ = 6.4 birds/patch) and bird species (39) were detected during May than in April (310 birds, $\bar{x}$ = 4.8 birds/patch, 27 species) or in June (296 birds, $\bar{x}$ = 4.6 birds/patch, 24 species).

2003 - A total of 1247 birds of 47 species were detected during point counts at 64 patches during the 2003 breeding season. A higher number of birds (537, $\bar{x}$ = 8.8 birds/patch) and bird species (41) were detected during May than in April (277 birds, $\bar{x}$ = 4.5 birds/patch, 20species) or in June (394 birds, $\bar{x}$ = 6.5birds/patch, 23 species).

Abundance and density: For statistical analyses, we included migratory species, permanent, winter and summer resident species, excluding Common Raven, White-throated Swifts and Violet-green Swallows. Density was not calculated for 2003.

2001 - Bird abundance was significantly higher in the old high water zone than in the new high water zone (mean = 19.84 ± 2.55 vs. 16.11 ± 1.78) when both trips were combined ($t = 7.1$, $p < 0.05$). When the two survey periods (May and June) were considered separately (Breeding Bird Fig. 2), a significantly higher abundance of birds was found in the old high water zone in May (11.53 ± 1.87) vs. the new high water zone (7.18, SE ± .88) ($t = 3.0$, $p < .005$). In June, no significant difference was shown between bird abundance in the new high water zone (8.93 ± 1.03) and old high water zone (8.3 ± 1.11) ($t = -0.61$, n.s.). No significant difference was detected in bird densities between zones.

2002 - We found an overall higher abundance of birds in the NHWZ when compared with the OHWZ during the 2002 breeding season ($t = 3.4$, $P = 0.001$) (Breeding Bird Fig. 3b). Density did not differ significantly among seasons or trips though higher densities corresponded with abundance data, being higher in the NHWZ and in May (Breeding Bird Fig. 3a).

2003 – No difference was detected in overall bird abundance between zones during 2003 ($F = 1.4$, $p = 0.24$). Trip 1 had a significantly higher number of birds in the OHWZ but Trips 2 and 3 showed no significant difference in bird abundance between zones. Seasonal differences between trips were significant with Trips 2 and 3 having a higher abundance of birds than Trip 1 (Breeding Bird Figure 4).

Species richness and composition:

2001 – Species richness (number of species) was significantly higher in the new high water zone than in the old high water zone (9.13 ± 0.83 vs. 7.20 ± 0.58) when both trips' data were combined (Breeding Bird Fig. 5; $t = 3.44$, $p < 0.001$). The same results were true for May (new 4.62 ± 0.42, old = 3.67 = ± 0.38; $t = 2.8$, $p< 0.007$), and June (new 4.5 ± 0.44, old 3.5 ± 0.33; $t = 3.0$, $p < .005$. No ANOSIM analyses were preformed on 2001 data.

No significant seasonal differences were found in the old high water zone between May and June (11.5 ± 1.9 vs. 8.3 ± 1.1; $t = 1.9$, n.s.) due to large variances (May = 157.2, June = 55.1). Species richness was not significantly different within the new high water zone (May 4.6 ± 0.42; June 4.5 ± 0.45; $t = .34$, n.s.) or the old high water zone (May 3.6 ± 0.38; June 3.5 ± .33; $t = 0.3$, n.s.) between May and June.

2002 – Species richness was higher in the NHWZ throughout the season and on each trip (season - $F = 9.5$, $P = 0.002$, zone - $t = 3.6$, $P < 0.05$, Breeding Bird Fig. 6). Species richness was higher in the NHWZ throughout the season and on each trip (season - $F = 9.5$, $P = 0.002$, zone - $t = 3.6$, $P < 0.05$).

We first used a two-way ANOSIM to compare species composition across all trips and between the two high water zones. Results indicated that species composition differed across trips (Global $R = 0.063$, $P < 0.001$; all pairwise comparisons between trips were significant at $P < 0.002$ or better) and between zones ($R = 0.026$, $P < 0.01$). We next compared species composition of NHW and OHW habitats separately for each trip. This was done to examine how use of the different habitats might change from one trip to the next. If species shift in their patterns of habitat use we might expect to find changes in the distinctiveness of the different groups and changes in which species were (or were not) selected as indicators of a particular habitat.

We included 104 site/zone combinations and 35 species in the analysis for the first trip. Although a series of species were more characteristic of one zone over the other (e.g., Blue-gray Gnatcatcher was characteristic of OHW; see previous year's report for appropriate tables and figures), the two zones did not differ substantially in overall species composition (ANOSIM $R = 0.019$, $P < 0.119$). Consequently, samples representing the different habitat zones overlapped substantially in space defined by a NMDS analysis. In contrast, new and old high water zones differed in overall species composition during the second trip ($R = 0.026$, $P < 0.05$); more species were selected as indicators of NHW than OHW. Species composition again did not differ between zones during the third trip ($R = -0.02$, $P > 0.50$), although two species still were selected as indicators of the NHWZ.

To further analyze seasonal shifts in use of the two habitats, we compared how species composition of each zone changed from one trip to the next (i.e., comparisons were made across trips within a zone rather than between zones). Species composition of NHW differed among trips (ANOSIM Global $R = 0.061$, $P < 0.001$; Trip 1 - Trip 2, $R = 0.074$, $P < 0.002$; Trip 2 - Trip 3, $R = 0.052$, $P < 0.003$; Trip 1 - Trip 3, $R = 0.056$, $P < 0.002$). A variety of species contributed to the differences in overall species composition within zones among trips, with many more species selected as indicators of the second trip. In contrast to the NHW, differences among trips were much less pronounced within OHW (Global $R = 0.008$, $P < 0.24$; no paired comparisons significant). Nonetheless, several species were selected as indicators of a particular trip (Table C). Thus, these comparisons suggest greater change in species composition within NHW than within OHW.

Using ANOVA, we compared the abundance of 15 common bird species between zones to examine distribution. Results showed four species were found in significantly higher abundance in the NHWZ: Common Yellowthroat, Yellow Warbler, Say's Phoebe, and Song Sparrow. None of the other 15 common species were shown to have significantly higher abundances in the OHWZ during 2002.

<u>Species composition above and below the Little Colorado River:</u> 2002 only

We based our comparisons of species composition of sites above and below the LCR on data from NHWZ only; sites were omitted from analyses if no birds were recorded during a particular trip. Trip 1 had 31 species distributed across 25 sites above

and 34 sites below the LCR; trip 2 had 48 species across 26 sites above and 34 below; trip 3 had 40 species across 24 sites above and 34 below. Composition of bird communities above the LCR differed from those below the LCR during all three trips (ANOSIM: trip 1 - $R = 0.221$, $P < 0.001$; trip 2 - $R = 0.113$, $P < 0.002$; trip 3 - $R = 0.0.66$, $P < 0.05$). During each trip, a limited set of species was selected as indicators of sites above or below the LCR. For example, during the first trip, Canyon Wrens were restricted to sites above the LCR whereas Bell's Vireo and Lucy's Warbler were more characteristic of sites below. As the season progressed, Lucy's Warbler spread farther upriver and was not selected as an indicator species during the second or third trips. In contrast, Bell's Vireo remained downriver and was selected as an indicator species for all trips.

2003 - **When bird species richness was compared between the OHWZ and NHWZ and between seasons, we found marginally higher numbers of species in the NHWZ (Breeding Bird Fig. 7). Species richness was highest during the second (May) trip.**

We used a two-way ANOSIM to compare species composition across all trips and between the two high water zones. Results indicated that species composition differed across trips (Global $R = 0.025$, $P < 0.004$; trip 1 vs. trip 2, $P < 0.083$, trip 1 vs. trip 3, $P < 0.015$, trip 2 vs. trip 3, $P < 0.023$) and between zones ($R= 0.037$, $P < 0.001$). We next compared species composition of NHWZ and OHWZ habitats separately for each trip. This was done to examine how use of the different habitats might change from one trip to the next. If species shift in their patterns of habitat use we might expect to find changes in the distinctiveness of the different groups and changes in which species were (or were not) selected as indicators of a particular habitat. During the first trip, the two zones did not differ substantially in overall species composition ($R = 0.023$, $P < 0.066$). Consequently, samples representing the different habitat zones overlapped substantially in space defined by a NMDS analysis. In contrast, new and old high water zones differed in overall species composition during the second trip ($R= 0.042$, $P < 0.02$) (Breeding Bird Fig. 8); more species were selected as indicators of NHW than OHW (Breeding Bird Table 4). Species composition again did not differ between zones during the third trip ($R= 0.04$, $P > 0.16$), although six species still were selected as indicators of one zone or the other.

To further analyze seasonal shifts in use of the two habitats, we compared how species composition of each zone changed from one trip to the next (i.e., comparisons were made across trips within a zone rather than between zones). Species composition of NHWZ was not substantially different across trips (Global $R = 0.028$, $P < 0.012$; Trip 1 - Trip 2, $R = 0.027$, $P < 0.083$; Trip 2 - Trip 3, $R = 0.029$, $P < 0.091$; Trip 1 - Trip 3, $R = 0.027$, $P < 0.023$). Several species contributed to the differences in overall species composition within zones among trips. Black-chinned Hummingbird was an indicator for Trip 1; Blue-gray Gnatcatcher and Yellow Warbler for Trip 2; and Ash-throated Flycatcher, Yellow-breasted Chat, and Blue Grosbeak for Trip 3. Differences among trips were even less pronounced within OHWZ (Global $R = 0.021$, $P < 0.53$; only the comparison between Trip 1 and Trip 3 was significant, $P < 0.022$). Nonetheless, several species were selected as indicators of a particular trip (Lucy's Warbler, Trip 1; Black-chinned Hummingbird, Trip 2; and Say's Phoebe, Rock Wren, and Blue Grosbeak for

Trip 3). Thus, these comparisons suggest greater change in species composition within NHWZ than within OHWZ.

Similarity in species composition was significantly correlated with distance between sites during the first trip (Mantel test, $r = 0.438$, $P < 0.001$) (i.e., the closer sites were along the river, the more similar the bird communities). In contrast, during the second and third trips, similarity was not related to distance ($r = -0.011$ and $r = 0.022$, $P > 0.30$, respectively).

Among year comparisons of bird abundance and species: No significant difference was found in the abundance of birds or bird species among years 2001 – 2003 ($F = 2.15$, $p = 0.20$).

When we compared the abundance of 15 common species between 2001 and 2003, we found that three species showed significant trends among years (Breeding Bird Table5). No distinct pattern was detected.

Census Methods Comparison: When the number of birds detected in walking surveys was compared with numbers detected during 50-meter bounded point counts, we found a significantly higher number of birds were detected in walking surveys (paired-t, $t = 8.985$, $p < .001$).

Discussion

Breeding bird assessment

In the limited time allowed at each TEM site, we are confident that qualified observers are estimating number of breeding bird pairs accurately using our techniques. Spot-mapping and census data are used to estimate breeding bird population trends elsewhere (Holmes and Sherry 2001). No difference was detected in abundance of breeding birds between years but it must be remembered that two years of data are not sufficient to determine meaningful trends. Our finding that more breeding pairs and higher species diversity were detected at larger sites is consistent with past studies in Grand Canyon (Sogge 1997, Spence 1998b).

Abundance and density of birds

Overall, riparian bird abundance or density does not appear to be directly related to Glen Canyon Dam operations. Factors totally unrelated to dam operations, such as weather patterns, may directly affect migration and breeding behavior and are probably responsible for minor differences in avian abundance and species composition among years in Grand Canyon. Our data, however, showed no difference in abundance of birds after three years of study. Long-term avian monitoring studies such as those by Holmes and Sherry (30 years, 2001), and Means and Finch (17 years, 1999) have detected fluctuations in avian populations. With only three years of data, we cannot make any conclusions regarding fluctuations in bird populations in Grand Canyon. Long-term examinations of breeding bird abundance may be warranted to detect changes over time.

One goal of the study was to attempt to link terrestrial avifauna to vegetation

zones and dam regulations. TVV measurements correlated with breeding birds were conducted for that purpose. Results are presented elsewhere in this document. No direct link of terrestrial birds to dam flow releases was established in this study, but indirect links may have been established. Two bird species, Lucy's and Yellow warblers, were found in high abundances throughout our study. Both bird species have been linked to anthropomorphic changes created by the dam. In a recent diet study (Yard et al. 2004) these two species were shown to have consumed high proportions of prey items found in greatest abundance in the tamarisk-dominated vegetation zone that has been established since the construction of Glen Canyon Dam. Non-native leafhoppers (*Opsius stactagolus*) specific to non-native tamarisk substantially augmented Lucy's Warbler diets (49%), while Yellow Warbler diets were composed of 45% aquatic midges. Aquatic midges emerge from clear cold water from the Colorado River and were not likely present in high abundance prior to the construction of the dam (Shannon 1993) These two species appeared to exhibit ecological plasticity in response to an anthropogenic increase in prey resources and are among the most common bird species we detected in our censuses.

It was also noted that diets of all bird species had high overlap values (Pianka 1974) with arthropods collected in the OHWZ. Our findings that higher bird abundance was detected in the OHWZ for one of three years of this study may be due to a higher incidence of foraging in the native vegetation of that zone. Results of the arthropod studies may reveal a clearer pattern regarding arthropod abundance and species diversity in the New and Old High Water Zones. Tamarisk, though low in arthropod diversity, offers two new and abundant prey resources as well as cover for nesting birds (Brown and Trosset 1989). The salty exudates from tamarisk leaves has been reported as a deterrent to arthropod diversity, while native vegetation has been suggested to exhibit a more diverse arthropod assemblage and better bird food (i.e., large, soft bodied insects) for foraging birds (Anderson and Ohmart 1977). Management decisions for riparian vegetation should consider the importance of both vegetation zones to foraging Neotropical migratory birds.

Song Sparrows have increased their breeding range upstream from Lake Meade along the Colorado River in the past 20 year, though these data are not quantified and will need verification. It is known that Bell's Vireo has expanded its breeding range upstream from Lake Meade along the Colorado River since the dam was constructed (Brown et al. 1983). This range expansion was due to an increase in vegetation along the river's edge. Examination of four years of unpublished census data (B.Brown 1984 – 1987, pers. com. B.Brown) indicated that few if any Song Sparrows were detected along the river corridor from Lees Ferry to Diamond Creek. Currently, Song Sparrows are found distributed upstream as far as RM –10.0 and are one of the 15 most common species detected in our surveys during this study. As with Bell's Vireo, this range expansion is most likely related directly to the increase of vegetation along the river since the construction of the dam. Verification of Song Sparrow range expansion would include nest searching in addition to census data to compare with historical records.

Our comparison of two census methods, unbounded 5-minute point counts and walking surveys, clearly showed a significant difference between the two. Walking surveys revealed a significantly higher number of birds. In results of previous studies in

Grand Canyon that compared these two methods, no difference was shown between the two. If comparisons between two vegetation zones are a goal in future studies, walking surveys may be the preferred method. Sample sizes of birds in our study are low compared to other riparian areas in the southwest (Means and Finch 1999). Maximizing the number of birds counted in surveys along the Colorado River may be essential to detect distinct patterns on a regional level. In future studies, GCMRC may wish to re-examine these two methods.

The distance estimation sampling technique (Buckland et al. 1992, 2001) was not used to estimate avian densities in our study as we had originally intended. All densities in this study were calculated by dividing the number of birds by the patch and vegetation zone areas digitized from aerial photographs, a method we considered to be more accurate. We found several short- comings in the distance sampling technique when applied to our data. First, one of the major assumptions of the method was violated. Walking a straight line in dense and/or thorny vegetation is not possible without crashing through the vegetation that will induce flight responses from bird. Second, estimating distances from the observer to a bird in thick vegetation when birds are detected by song or call is extremely difficult. Auditory detections of birds comprised 37 – 39% of our data depending on the year. Finally, the distance sampling technique is not accurate in estimating densities with small sample sizes of birds such as in the Grand Canyon. As stated above, point counts revealed significantly fewer birds than line transects (walking surveys), though the distance sampling method when surveying difficult terrain such as in Grand Canyon recommends point counts. If using line transects (walking surveys), transects should be randomly chosen and perpendicular to the river according to distance sample recommendations. Randomly chosen transects could be difficult if not impossible to walk in some patches due to thick vegetation. Here again, the noise made by an observer crashing through the vegetation would elicit a response from birds causing them to fly away before being counted. In most sites we survey along the river there are no trails and in Grand Canyon National Park we cannot cut vegetation to create them. The patches along the river are generally small and very narrow making multiple perpendicular, systematic, or full random transects not feasible in some sites. We recorded estimated distances to birds however, and if future studies wish to incorporate these data, it will be available.

Literature Cited

Anderson, B. W., and R. D. Ohmart. 1977. Vegetation structure and bird use in the lower Colorado River Valley, p. 23–33. *In* R. R. Johnson and D. A. Jones [tech. coords.], Importance, preservation and management of riparian habitat: a symposium. USDA Forest Service General Technical Report RM-GTR-43.

Brown, B.T., S.W. Carothers and R.R. Johnson. 1983. Breeding range expansion of Bell's Vireo in Grand Canyon, Arizona. Condor 85: 499-500.

Brown, B.T. 1989. Breeding ecology of riparian birds along the Colorado River in Grand Canyon, Arizona. University of Arizona Cooperative National Park Resources Studies Unit Tech. Rep., No. 25. 42pp.

Brown, B. T., and M.W. Trosset. 1989. Nesting-habitat relationships of riparian birds along the Colorado River in Grand Canyon, Arizona. Southwestern Naturalist 34(2):260-270.

Buckland, S.T., D.R. Anderson, K.P. Burnham and J. L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, New York. 446 pp.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J. L. Laake, D.L. Borchers and L. Thomas. 2001. Introduction to Distance Sampling. Oxford University Press, Oxford, UK.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology **18**:117-143.

Clarke, K.R., and R.N. Gorley. 2001. PRIMER v5: Use manual/tutorial. PRIMER-E, Ltd., Plymouth, UK.

Clarke, K.R., and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E Ltd., Plymouth, UK.

Corman, T. 1994. Arizona Breeding Bird Atlas. Arizona Game and Fish Department, NonGame Branch Phoenix, AZ.

Douglas, M.E. and Endler, J.A. (1982): Quantitative matrix comparisons in ecological and evolutionary investigations. J. Theor. Biol. 99, 777-795.

Dufrêne, M., and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67:345-366.

Ehrlich, Paul R., David S. Dobkin, and Darryl Wheye. 1988. The Birders Handbook. Simon and Schuster, New York, NY.

Fancy, S. G. 1997. A new approach for analyzing bird densities from variable circular plot counts. Pacific Science 51:107-114.

Finch, D.M., and S.H. Stoleson. 2000. Status, ecology, and conservation of the southwestern willow flycatcher. Gen. Tech. Rep. RMRS-GTR-60. Odgen, UT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 131pp.

Finch, D.M., J.C. Whitney, J.F. Kelly, S.R. Loften. 1999. Rio Grande ecosystems: linking land, water, and people. Toward a sustainable future for the Middle Rio Grande Basin. 1998 June 2-5. Albuquerque, NM. Proc. RMRS-P-7. den, UT: US Department of Agriculture, Forest Service, Rock Mountain Research Station, 245 p.

Holmes, Richard T. and Thomas W. Sherry. 2001. Thirty-year bird population

trends in an unfragmented temperate deciduous forest: Importance of habitat change. Auk 118(3):589-609.
Interpretive Staff. 1937. Check-list of birds of Grand Canyon National Park. Bulletin No. 8, Grand Canyon Natural History Association. Grand Canyon, Arizona. 55pp.
Kearsley, M.K., H.K. Yard, N. Cobb, D. Lightfoot, G. Carpenter, S. Brantley, J. Frey. 2001. Inventory and Montoring of Terrestrail Resources in the Colorado River Corridor of Grand Canyon: An Integrative Approach. Annual report submitted to Grand Canyon Monitoring and Research Center, USGS. Pp. 77.
McCune, B., and J.B. Grace. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon.
McCune,B; Allen,TFH (1985): Will similar forests develop on similar sites?
Can. J. Bot. 63, 367-376.
Mills, G.S., J.B. Dunning and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin. 103:468-479.
Pianka, E. R. 1974. Niche overlap and diffuse competition. Proceedings of the National Academy of Sciences 71:2141–2145.
Shannon, J. P. 1993. Aquatic ecology of the Colorado River through Grand Canyon National Park, Arizona. M.Sc. thesis, Northern Arizona University, Flagstaff, AZ.
Sillett, T. S. 1994. Foraging ecology of epiphyte-searching insectivorous birds in Costa Rica. Condor 96:863–877.
Sogge, M.K., D. Felley, and M. Wotawa. 1998. Riparian bird community ecology in the Grand Canyon. Final Report. U.S. Geological Survey, Colorado Plateau Field Station, Flagstaff, AZ.
Sogge, M., R. Marshall, S. Sferra, and T. Tibbetts. 1997. A Southwestern Willow Flycatcher Natural History Summary and Survey Protocol. Technical Report NPS/NAUCPRS/NRTR-97/12. Colorado Plateau Research Station at Northern Arizona University. U.S. Fish and Wildlife Service, Arizona Department of Game and Fish, National Park Service.
Spence, J.R., C.T LaRue, J.R. Muller and N.L. Brown. 1998a. 1997 avian community monitoring along the Colorado River from Lees Ferry to Lake Mead. Unpublished report submitted to Grand Canyon Monitoring and Research Center. National Park Service, Resource Management Division, Glen Canyon NRA. Pp 17.
Spence, J.R., C.T LaRue, and N.L. Brown. 1998b. Monitoring of Southwestern Willow Flycatcher, riparian breeding avifauna and overwintering avifauna along the Colorado River ecosystem. Quarterly report, Winter 1998. Unpublished report submitted to Grand Canyon Monitoring and Research Center. National Park Service, Resource Management Division, Glen Canyon NRA. Pp 17.
Spence, J.R. 2000. Summary of the 1996-1999 Avian monitoring program along the Colorado River from Glen Canyon Dam to Upper Lake Meade. Unpublished report submitted to Grand Canyon Monitoring and Research Center. National Park Service, Resource Management Division, Glen Canyon NRA. Pp 20.
Stevens, L. E., J. P. Shannon, and D. W. Blinn. 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: dam, tributary and

geomorphological influences. Regulated Rivers: Research and Management **13**:129-149.

Turner, R.M. and M.M. Karpiscak. 1980. Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. U.S. Geological Survey Professional Paper 1132, U.S. Government Printing Office, Washington, D.C. Pp. 125.

Weins, J.A. 1992. The Ecology of Bird Communities: Vol.1, Foundations and Patterns. Cambridge Univ. Press, Cambridge, UK.

Yard, H.K. , C. van Riper, B. T. Brown, and M.J. Kearsley. 2004. Diets of insectivorous birds along the Colorado River in Grand Canyon, Arizona. Condor 106: 107-116 (in press).

Breeding Bird Table 1. Nests searching results, 2001 Breeding Season

site	trip	bird sp	zone	tree sp	eggs	young
43.1	1	BCHU	n	tach	0	0
43.1	1	BGGN	n	tach	0	0
43.1	2	LUWA	n	tach	0	2
43.1	2	BCHU	n	tach	3	0
46.7	1	BCHU	n	tach	0	2
46.7	1	BCHU	n	tach	unk	unk
46.7	1	BCHU	n	tach	unk	unk
46.7	1	BCHU	n	tach	0	3
46.7	2	LUWA	n	tach	0	1
46.7	2	ATFL	o	dead acgr	unk	unk
50.4	1	BCHU	n	tach	0	2
50.4	1	BCHU	n	tach	unk	unk
50.4	1	BCHU	n	tach	0	2
50.4	1	BCHU	n	tach	unk	unk
50.4	1	YEWA	n	tach	unk	unk
50.4	1	UNK	o	prgl	unk	unk
50.4	1	LUWA	n	tach	0	2
50.4	1	SUTA	n	tach	0	0
50.4	1	LUWA	o	prgl	0	0
50.4	2	BCHU	n	tach	0	2
50.4	2	HOFI	n	tach	0	0
50.4	2	ATFL	o	acgr	unk	unk
122.7	1	BGGN	n	tach	5	0
171.1	1	BEVI	n	tach	unk	unk
174.5	1	LUWA	o	acgr	unk	unk
198	1	SUTA	n	tach	unk	unk
198	1	BEVI	n	tach	1	0
122.8	2	LUWA	n	tach	0	2
171.1	2	BEVI	o	prgl	1	3
194	2	BCHU	n	tach	0	3
194	2	BCHU	n	tach	0	1
194	2	SUTA	o	prgl	unk	unk
198	2	BEVI	n	prgl	0	0

Breeding Bird Table 2. Number of breeding birds in 14 TEM sites, 2002.

Number of Breeding Pairs, 2002

Site (River Mile)	Trip 1	Trip 2	Trip 3	Mean	Density	# of Species
0.4	1	4	3	2.67	3.31	8
8	1	2	4	2.33	1.21	5
22	1	5	7	4.33	7.45	6
37.5	1	2	7	3.33	12.73	9
46.7	8	13	38	19.67	5.54	10
65.3	4	11	18	11.00	3.69	12
92.3	1	1	1	1.00	1.27	4
122.8	13	12	7	10.67	6.29	12
133	6	1	4	3.67	4.10	8
164.5	5	3	4	4.00	2.46	6
186.5	14	12	14	13.33	3.77	10
198	30	37	14	27.00	14.09	17
204	39	23	18	26.67	8.82	18
211	10	2	5	5.67	4.96	7

Breeding Bird Table 3. Number of breeding pairs, 2003

Trip	1		2		3		TOTAL	
Site	# of species	breeding pairs	# of species	breeding pairs	# of species	breeding pairs		
23	1	1	3	6	1	1	13	
40.1	3	2	5	12	5	12	39	
46.7	6	17	11	22	8	24	88	
51.5	4	14	8	25	11	18	80	
65.3	5	10	10	30	8	17	80	
71.1	no data		9	18	6	18	51	
92.3	3	5	4	4	4	4	24	
104	2	4	6	7	5	6	30	
122.8	5	5	11.0	17	4	5	47	*bhco
140.4	8	10	7.0	12	5	10	52	
166.5	4	5	6.0	6	3	3	27	
180.5	5	5	14.0	27	7	10	68	*bhco
198	8	21	13.0	65	16	36	159	
202.5	6	10.0	6.0	27	4	8	61	
TOTAL	60	109	113	278	87	172	819	

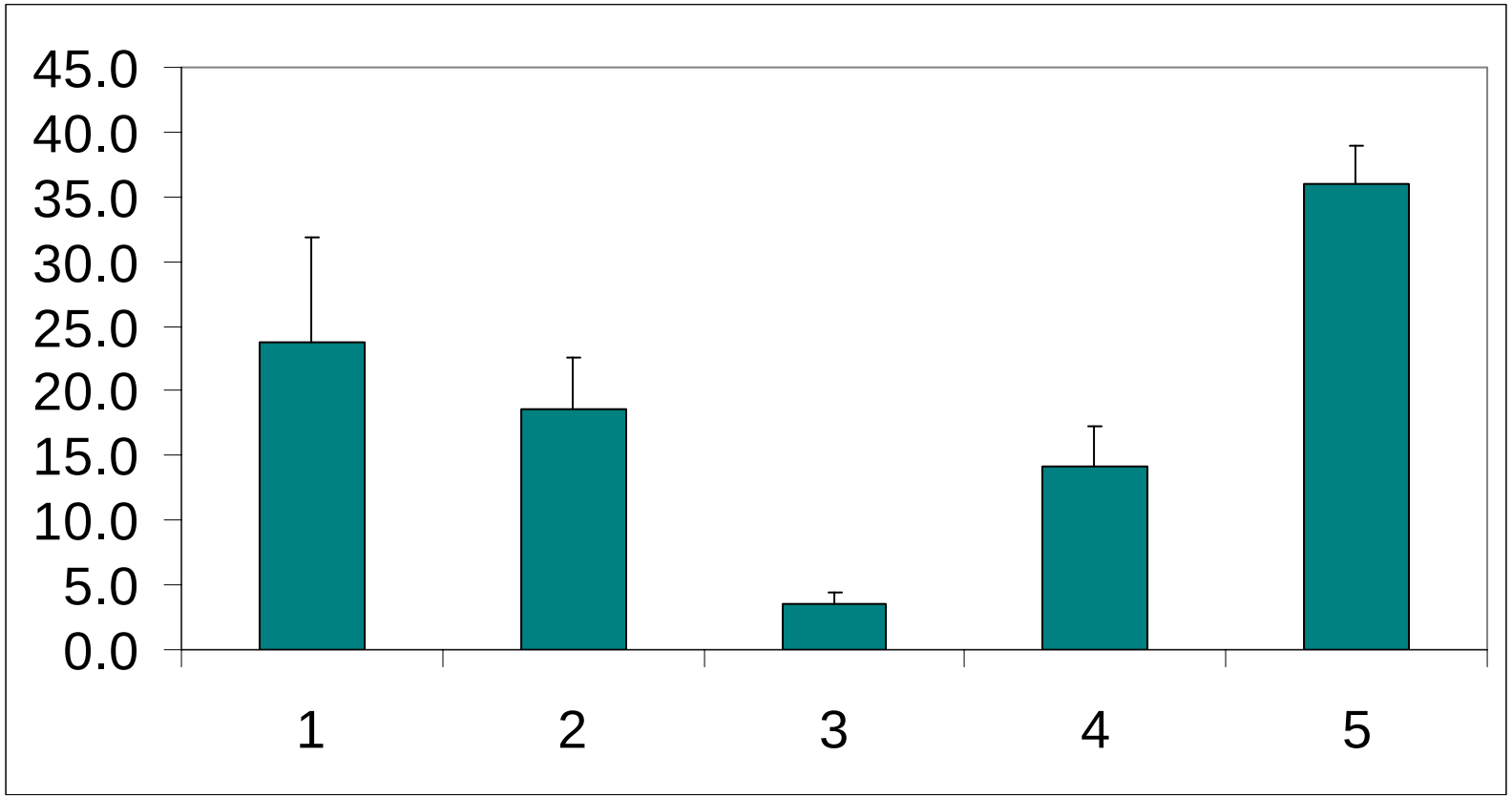
Breeding Bird Table 4. Species selected as indicators of NHWZ or OHWZ within each trip during 2003. Significance of the species as an indicator is based on a randomization test (all species with a probability level of $P < 0.10$ are given).

	NHWZ	P <	OHWZ	P <
Trip 1	Black-chinned Hummingbird	0.016	Ash-throated Flycatcher	0.092
Trip 2	Yellow Warbler	0.005	Canyon Wren	0.004
	Say's Phoebe	0.062	Rock Wren	0.005
	Song Sparrow	0.003		
	Common Yellowthroat	0.021		
Trip 3	Black-chinned Hummingbird	0.005	Rock Wren	0.009
	Lucy's Warbler	0.091		
	Yellow-breasted Chat	0.019		
	Black Phoebe	0.064		
	Common Yellowthroat	0.004		

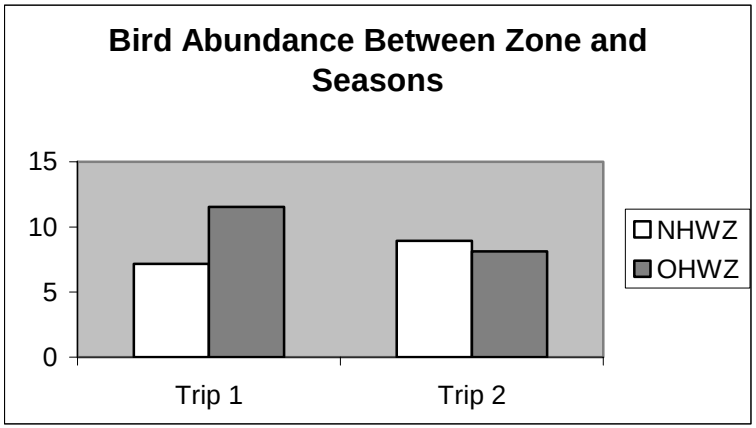
Breeding Bird Table 5. Rank in abundance over three years, and mean number of birds ± SE counted during point counts at the same sites in May and June, 2001 – 03. Bird species in bold indicates significant trends.

Rank	Bird Species	2001	2002	2003	Trend	F-Value	P-Value
1	Lucy's Warbler	1.5 ± 0.30	1.1 ± 0.20	1.8 ± 0.30	01>02<03	1.82	0.16
2	House Finch	0.34 ± 0.14	0.30 ± 0.10	0.07 ± 0.24	01>02>03	1.82	0.16
3	Blue-gray Gnatcatcher	0.23 ± 0.008	0.35 ± 0.09	0.37 ± 0.1	01<02<03	0.61	0.54
4	Black-chinned Hummingbird	0.12 ± 0.004	0.24 ± 0.006	0.007 ± 0.003	01<02>03	2.40	0.09
5	Bell's Vireo	0.30 ± 0.008	0.40 ± 0.0	0.40 ± 0.10	01<02=03	0.40	0.63
6	Ash-throated Flycatcher	0.19 ± 0.005	0.23 ± 0.006	0.32 ± 0.008	01<02<03	1.10	0.30
7	Yellow Warbler	0.19 ± 0.006	0.15 ± 0.007	0.22 ± 0.008	01>02<03	0.27	0.77
8	Bewick's Wren	0.009 ± 0.003	0.006 ± 0.003	0.21± 0.003	01>02<03	2.40	0.09
9	Common Yellowthroat	0.10 ± 0.004	0.2 ± 0.007	0.14 ± 0.005	01<02>03	0.64	0.52
10	Song Sparrow	0.003 ± 0.002	0.2 ± 0.006	0.007 ± 0.006	01<02>03	2.58	0.08
11	Black-throated Sparrow	0.003 ± 0.003	0.006 ± 0.03	0.006 ± 0.005	01<02=03	0.05	0.94
12	Mourning Dove	0.007 ± 0.005	0 ± 0.0	0.001 ± 0.0	01>02<03	2.31	0.10
13	**Canyon Wren**	0.001 ± 0.0	**0.006 ± 0.003**	0.001 ± 0.0	**01<02>03**	**4.18**	**0.02**
14	**Say's Phoebe**	0.001 ± 0.001	0.003 ± 0.002	**0.13 ± 0.005**	**01<02<03**	**3.81**	**0.02**
15	**Yellow-breasted Chat**	0.21 ± 0.006	0.003 ± 0.002	**0.28 ± 0.009**	**01>02<03**	**3.98**	**0.02**

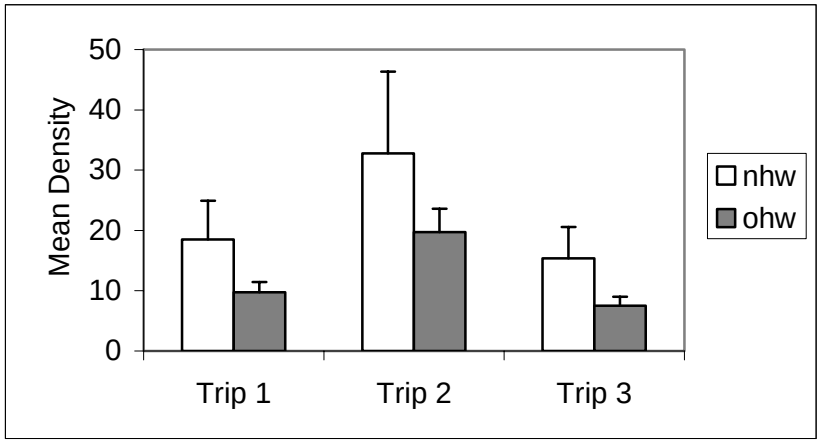
Breeding Bird Figure 1. Number of breeding bird pairs detected at five TEM sites assessed for breeding birds, 2002 - 2003

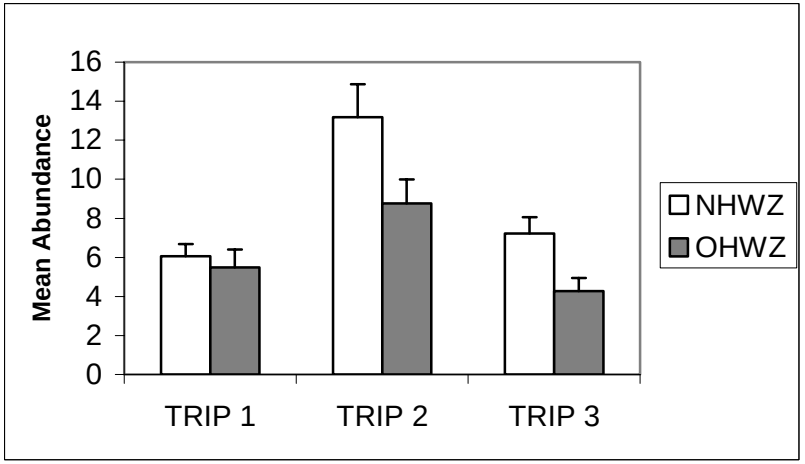


Breeding Bird Figure 2. Breeding bird abundance per patch by hydrologic zone in Marble Canyon and Grand Canyon in 2001.

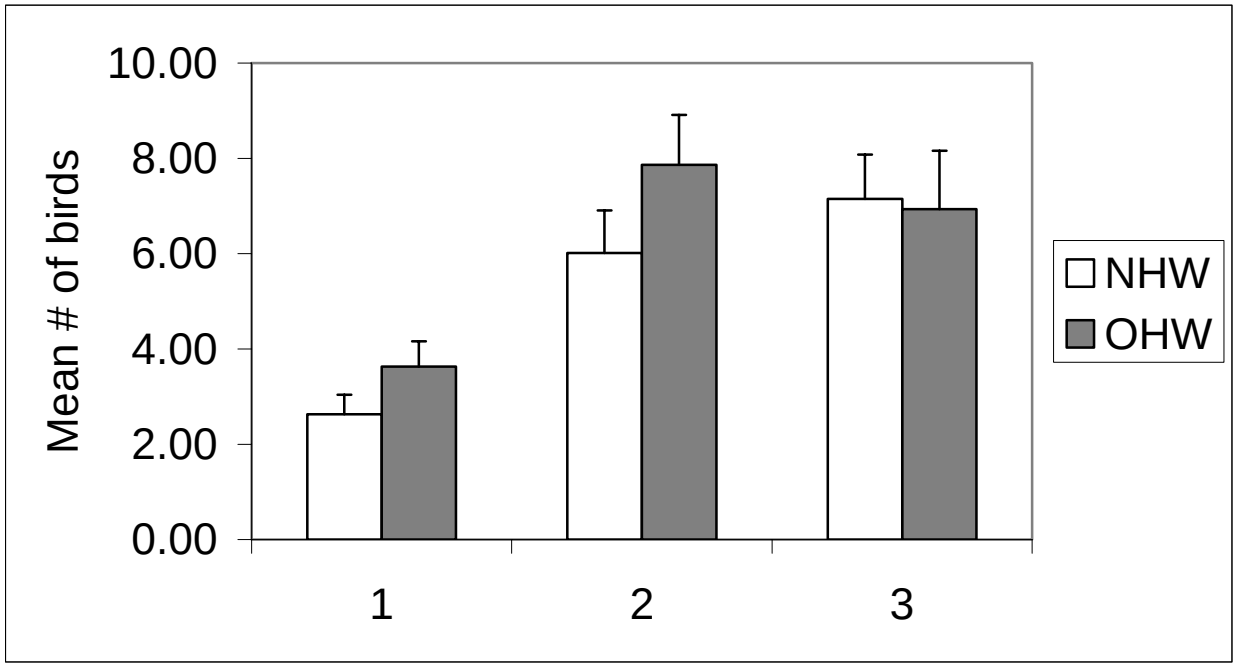


Breeding Bird Figure 3a and 3b . Mean density and abundance of passerines in each zone and trip along the Colorado River, Grand Canyon, 2002.

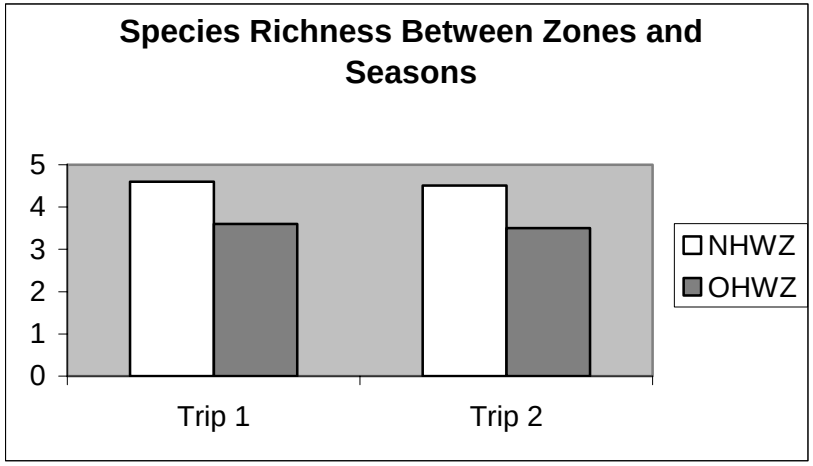




Breeding Bird Figure 4. Mean abundance of passerines in each zone and trip along the Colorado River, Grand Canyon, 2003



Breeding Bird Figure 5. Bird species richness per patch by hydrologic zone in Marble Canyon and Grand Canyon in 2001.



Breeding Bird Figure 6. Species richness (number of species) between zones and seasons, 2002.

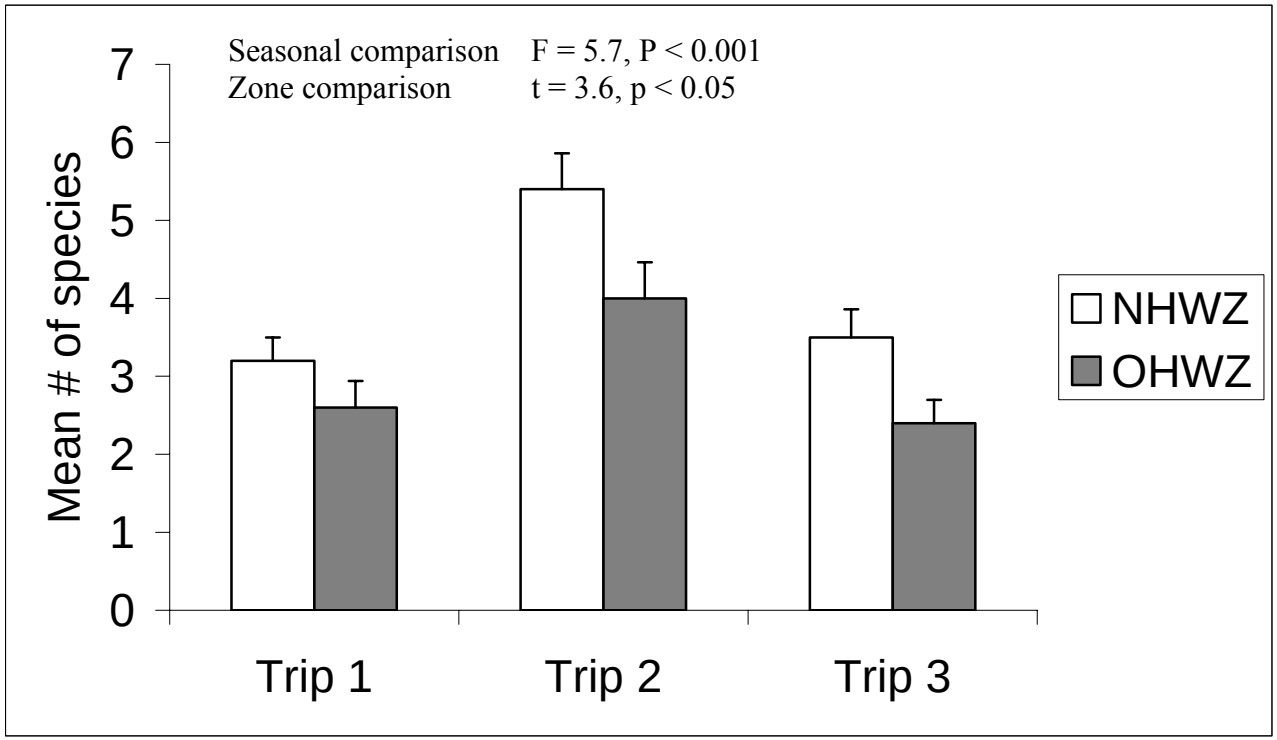
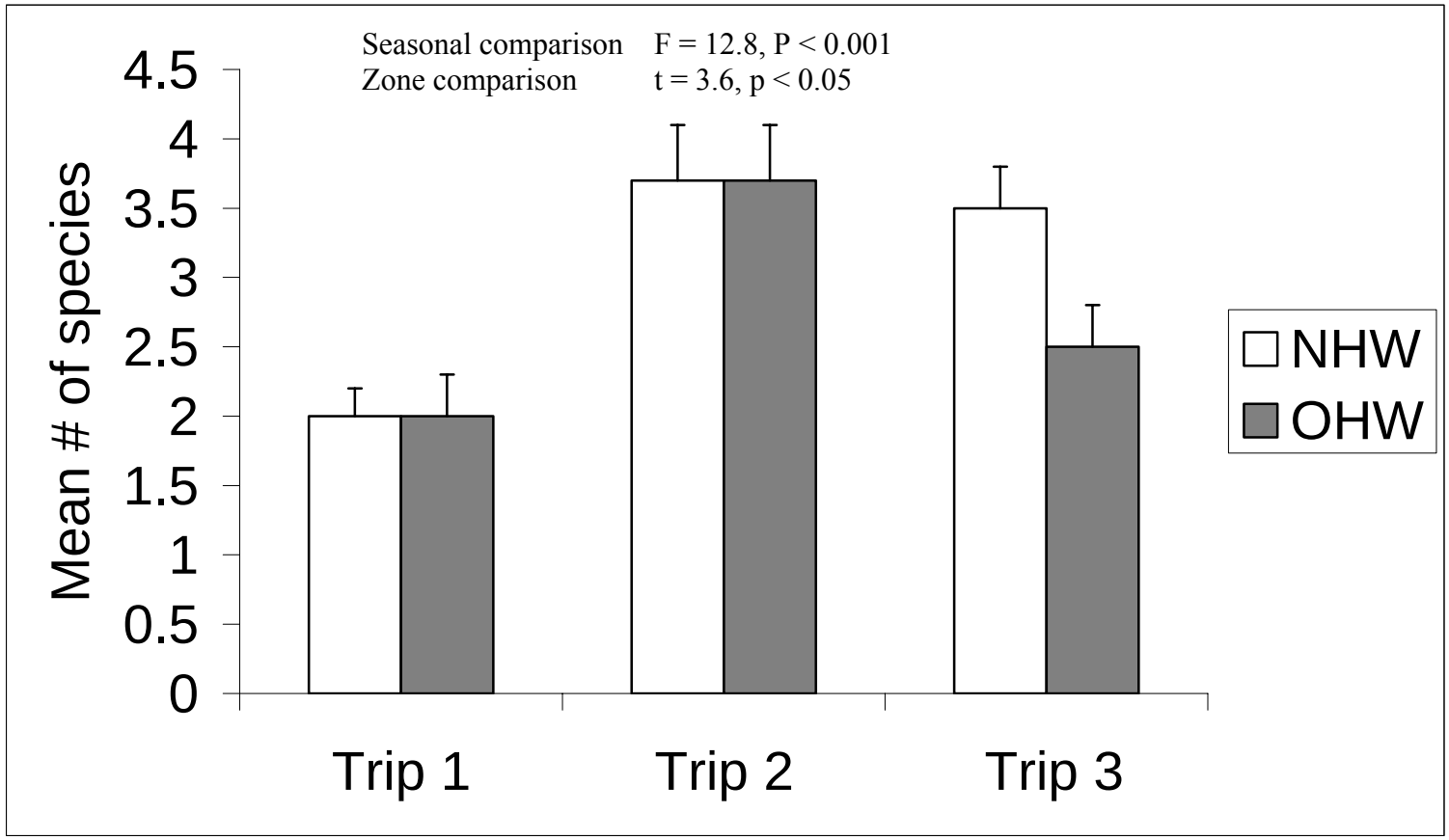
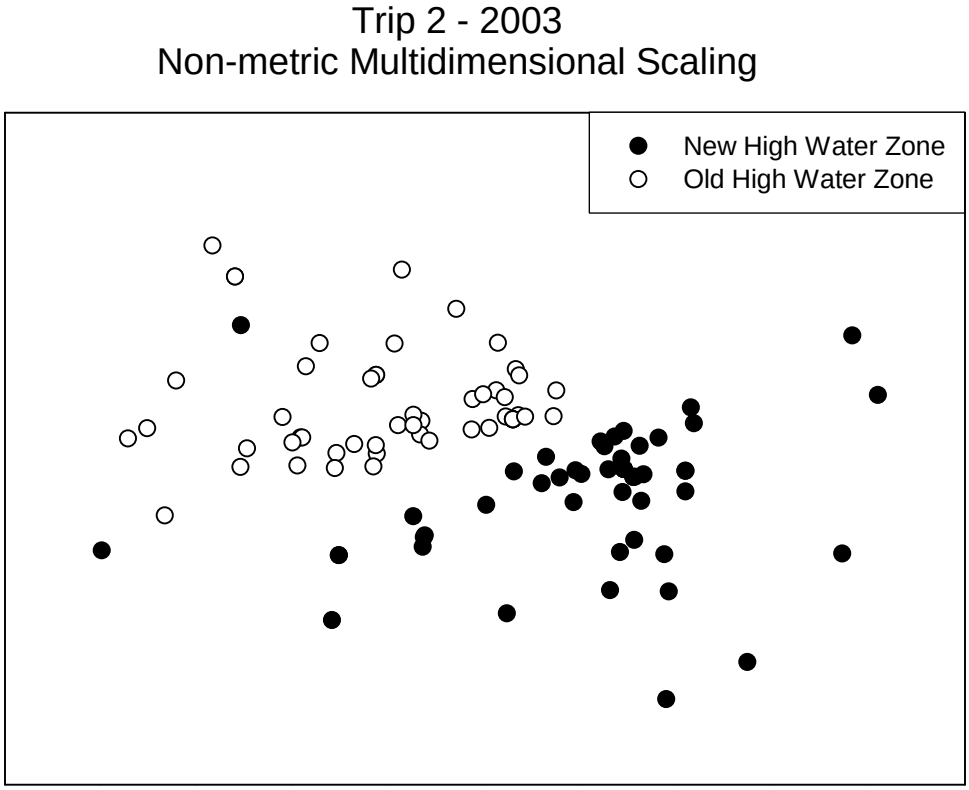


Figure 7. Species richness (number of species) between zones and seasons, 2003.



Breeding Bird Figure 8. Similarity in species composition among New and Old High Water Zones for sites sampled during the June trip during 2003.



Grand Canyon Inventory and Monitoring
2003 Mammal Report

Prepared by J.K. Frey

Purpose: The purpose is to inventory and monitor the mammalian fauna of the Grand Canyon riparian zone in relation to water stage elevation.

Objectives: The objectives were to 1) generate a complete inventory of the mammal resources in the river corridor; 2) monitor spatial trends in the mammal community in relation to site, water stage elevation, and other factors; and 3) monitor temporal trends in the mammal communities, particularly in relation to dam-related factors.

Methods: As with previous years, during 2003 mammal sampling was conducted during Spring (9-17 April, 1-7 May) and Fall (21 August - 4 September). In addition, a supplemental mammal sampling occurred during summer (26 June – 10 July).

Small Terrestrial Mammals.—Small mammals were sampled with Sherman live traps baited with oatmeal and peanut butter. The trapping design consisted of 3 parallel 100 m transects of 50 traps set at 2 m increments. Each transect was located within a water level zone and located 4 m upslope from the corresponding arthropod transect. Traps were set in the evening and removed the following morning. Captured animals were tentatively identified based on external characteristics, sexed, measured, and either released or euthanized and prepared as a standard museum voucher specimen. Total trapping effort was 150 trap-nights/site-visit, for a total of 6,300 trap-nights during 2003.

Medium and Large Mammals.—Medium and large mammals were sampled through observation of individuals or their sign. The nature and locality of all observations were recorded.

Statistical Analyses.—Refer to the vegetation section for a description of methods for determining patch area, river flow and precipitation variables. Normality was tested using one-sample Kolmogorov-Smirnov tests; all variables were significantly ($P < 0.001$) non-normal. Small mammal species richness and abundance were the dependent variables in all analyses. I used the SPSS univariate general linear model to perform regression analysis and analysis of variance for each of these dependent variables and one or more independent factors or variables. Separate ANOVAs were run for richness and abundance. In these analyses, year, zone, and season were considered fixed factors while site was considered a random factor. Simple spearman correlations and analysis of covariance were used to identify relationships between environmental variables and each of the dependent variables. Stepwise multiple regressions were used to determine the most important predictors of small mammal richness and abundance. Although observational data on medium and large mammals were used for the inventory, these data were not deemed appropriate for statistical analysis due to the sampling method and small sample sizes.

Results:

Small Mammal Abundance. — During 2002, small mammal abundance had declined relative to 2001 (7.53 per 100 trap-nights in 2001, 5.44 per 100 trap-nights in 2002; Figure 1). However, during 2003 mean small mammal abundance (7.35 per 100 trap-nights) had rebounded and was nearly back to 2001 levels (Figure 1). Relative abundance by year was significantly different (ANOVA: d.f. = 2, 410; F = 3.792; P = 0.023). The annual difference in total numbers of small mammals captured from 2001 to 2003 was primarily due to annual variation in recruitment during the growing season. Spring abundance of small mammals was relatively constant (Figure 2) and was not significantly different across years (ANOVA: d.f. = 2, 157; F = 1.714, P = 0.184). In contrast fall relative abundance across the three years were significantly different (ANOVA: d.f. = 2, 250; F = 4.565; P = 0.011) and all were higher than the preceding spring (Figure 2). As in 2001 and 2002 most (44% in 2001, 50% in 2002, 44% in 2003) small mammals were captured in the old (highest) water zone (Figure 1). This zone is often associated with the steeper sides of the canyons that afford more structure for small mammals. In addition, two rare species (*Perognathus formosus, Dipodomys ordii*) have only been captured in this zone. With the exception of *Reithrodontomys megalotis,* which was not caught in the old high water zone, each of the other species was captured in all three zones.

Based on ANOVA (fixed factors: year, zone, and season; random factor: site), significant influences on small mammal abundance across the three study years included water zone (F=19.398, P = 0.000), season (F = 58.240, P = 0.000), and site (F = 2.5465, P = 0.011). Further, although year was not a significant influence on abundance (F = 0.244, P = 0.788), there was a significant interaction between year and season (F = 9.016, P = 0.009) as well as between zone and season (F = 9.933, P = 0.000). Consequently, an ANOVA was run for each season separately. During spring, only water zone exhibited a significant influence on small mammal abundance (F = 6.234, P = 0.003). However, during fall zone (F = 23.183, P = 0.000), year (F = 5.943, P = 0.023), and site (F = 8.405, P = 0.001) were significant influences on small mammal abundance.

Based on simple Spearman correlations, small mammal abundance was significantly correlated with several independent variables including patch area (r_s = 0.209, P = 0.001; Figure 3), percent cliff at shoreline (r_s = -0.174, P = 0.006; Figure 4), minimum river flow (r_s = 0.261, P = 0.000; Figure 5), mean river flow (r_s = 0.207, P = 0.001; Figure 6), and precipitation deviation (r_s = -0.223, P = 0.000; Figure 7). However, due to the nature of the data these relationships had low r-square values. Analysis of covariance (fixed factor: zone, random factor: site) provided similar results for some variables. An ANCOVA that included minimum river flow and precipitation deviation as covariates was significant for all variables including minimum river flow (F = 41.399, P = 0.000) and precipitation deviation (F= 24.580, P = 0.000). Unlike the spearman correlation, an ANCOVA that included patch area as the covariate was not significant (F = 0.340, P = 0.560). Total catchment area was not significantly related to small mammal abundance in either a Spearman correlation (r_s = -010, P = 0.878) or an ANCOVA (F = 3.367, P = 0.068; Figures 6 and 7). Finally, small mammal abundance was significantly greater in wide versus narrow reaches (one-way ANOVA: F = 9.010, P = 0.003; Figure 8).

Stepwise multiple regressions were used to asses the most important independent predictors of abundance within each season and water zone. During spring, the most significant predictors of abundance included minimum river flow in the shore zone (Figure 8) and patch area in the new high water zone (Figure 9). No independent variables were significant predictors

of abundance in the old high water zone. During fall, minimum river flow was the most significant predictor of small mammal abundance in all zones (Figure 10).

Small Mammal Richness. — Overall richness has remained low and relatively constant. Overall richness was 7 in 2001, 8 in 2002, and 8 in 2003 (see Figure 12 for the total captures by species across all three years). With the exception of Ord's kangaroo rat (*Dipodomys ordii*), all species captured in 2002 were also captured in 2003. In addition, the white-throated woodrat (*Neotoma albigula*) was captured during 2003. This species had not been captured during 2002. In summary, during 2003 a total of 507 individuals of 8 species were captured including (in order of decreasing abundance; reported as number per 100 trap-nights): *Peromyscus eremicus* (7.548), *Peromyscus boylii* (1.690), *Neotoma lepida* (0.762), *Peromyscus crinitus* (0.714), *Chaetodipus intermedius* (0.500), Neotoma albigula (0.452), *Perognathus formosus* (0.381), and *Reithrodontomys megalotis* (0.024). *Dipodomys ordii*, which was captured in 2002, was not captured in 2003. This was likely due to sampling design because it was captured at Lees Ferry (-0.4R), which was not sampled during 2001 or 2003. The species was previously reported from this area. The reason for our failure to capture *N. albigula* during 2002 remains unknown. This species was captured at two sites in 2003 (65.3L and 71.3L). Neither of these sites had been sampled during previous years. The three sites where this species was captured in 2001 were not sampled during either 2002 or 2003. Thus, it is possible that sampling error accounts for the absence of *N. albigula* during 2002. No new species of mammals were observed during 2003.

Small mammal abundance and richness were highly correlated (Spearman correlation: r_s = 0.824, P = 0.000; Figure 13). Significant factors related to species richness were similar to those related to abundance (Figures 1 and 2). Based on ANOVA (fixed factors: year, zone, and season; random factor: site), significant influences on small mammal richness across the three study years included water zone (F = 16.849, P = 0.000), season (F = 60.766, P = 0.000), and site (F = 2.308, P = 0.015). Further, although year was not a significant influence on richness (F = 1.721, P = 0.233; Figure 2) there was a significant interaction between year*season (F = 6.730, P = 0.019). Consequently, ANOVA was run for each season separately. During spring, water zone (F = 8.361, P = 0.001), as well as site (F = 2.600, P = 0.025), exhibited a significant influence on small mammal richness. However, during fall, water zone (F = 15.641, P = 0.000), as well as year (F = 7.853, P = 0.011), exhibited a significant influence on small mammal richness.

Based on simple Spearman correlations, small mammal richness was significantly correlated with the same independent variables as was abundance including: patch area (r_s = 0.251, P = 0.000), percent cliff at shoreline (r_s = -0.203, P = 0.001), minimum river flow (rs = 0.192, P = 0.002), mean river flow (r_s = 0.142, P = 0.025), and precipitation deviation (r_s = -0.152, P = 0.017). Again, due to the nature of the data these relationships had low r-square values. Analysis of covariance (fixed factor: zone, random factor: site) provided different results for some variables. For example, an ANCOVA that included minimum river flow and precipitation deviation as covariates was significant for both variables (minimum river flow: F = 31.075, P = 0.000; precipitation deviation: F = 7.478, P = 0.007). Other significant covariates in ANCOVA models included: mean river flow (F = 22.747, P = 0.000), patch area (F = 5.473, P = 0.020), and percent cliff shoreline (F = 9.880, P = 0.002). In contrast to the correlations, total catchment area was a significant covariate in an ANCOVA (F = 6.541, P = 0.011). Finally, small mammal richness was significantly greater in wide versus narrow reaches (one-way ANOVA: F = 4.989, P = 0.026; Figure 19).

Stepwise multiple regressions were used to asses the most important independent predictors of richness within each season and water zone. During spring, the most significant predictors of richness included river flow fluctuation in the shore zone (Figure 20) and patch area

in the new high water zone (Figure 21). No independent variables were significant predictors of richness in the old high water zone. During fall, the most significant predictors of richness included minimum river flow in the shore zone (Figure 22), patch area in the new high water zone (Figure 23), and total catchment area in the old high water zone (Figure 24). The relationship between total catchment area and specie richness in the old high water zone was largely driven by site 198.0R. This site is unusual in that it has an extremely large total catchment area but a small local catchment area (Figure 25).

Voucher Specimens.—A total of 2 individuals were preserved as standard museum voucher specimens (including tissue samples) during 2003. These specimens were *Peromyscus eremicus* that had died in the trap. Additional collection is needed in order to verify study results. For most species, field identification based on gross external morphology is not sufficient to *verify* species because diagnostic characters are based on cranial, dental or other internal structures. Consequently, the accuracy of most of the mammal data can never be assured; GCNP permit limitations on numbers of specimens allowed is in opposition with standard methods in mammalogy.

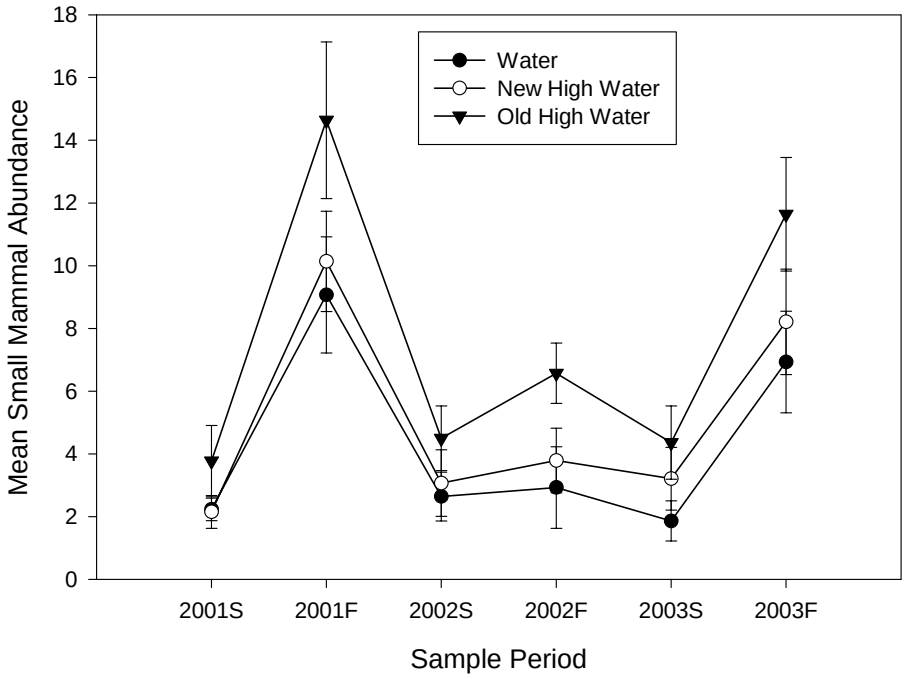
Summary: Small mammal abundance was higher in 2003 as compared to 2002. This was due to good recruitment during the growing season. Of the 9 species captured during 2001-2003, only one rare species (D. *ordii*) was not captured during 2003. No new species were captured or observed during 2003. From 2001-2003, a total of 26 species of mammal have been identified as occurring in the river corridor of the Grand Canyon.

Small mammal abundance is strongly influenced by season, water zone, and specific site characteristics. Small mammal abundance is low and relatively consistent in spring, but high and highly variable in fall. Further, abundance is virtually always highest in the old high water zone and lowest in the water zone. During spring, water zone is the most important influence on abundance while during fall, year, site and zone are important. Thus, spring abundance may represent zone-specific carrying capacities maintained through over-winter compensatory mortality. In contrast, fall abundance may represent a response to prevailing environmental conditions at each site. Reasons for this pattern are not understood but likely result from a variety of biotic and abiotic factors, including specific site characteristics. Important site-specific factors include the percent cliff at shoreline and to a lesser extent patch area. Important environmental factors include precipitation and river flow, especially minimum flow.

Like abundance, small mammal richness is strongly influenced by season, water zone, and specific site characteristics. Small mammal richness is higher when abundance is higher. This is probably due to the greater likelihood of sampling rare species during peaks in population. Water zone may be the most important factor determining species richness in small mammals. During spring, water zone and site are the most important influence on richness, while during fall, water zone and year are important. Important site-specific characteristics, which are important in determining spring richness, are mostly related to area effects, including patch area and total catchment area. The influence of area may be most important in the new high water zone. The percent of cliff at shoreline is also a significant determinant of species richness, which probably relates to availability of different habitat types. As for abundance, both precipitation and river flow are important in determining species richness patterns. The impacts of river flow seem to be most important in determining richness in the water zone.

Figure 1: Small Mammal Response to Water Zone and Sample Period

Figure 1: Relationship between small mammal abundance (top) and richness (bottom) by water zone during each sampling period from 2001 through 2003.



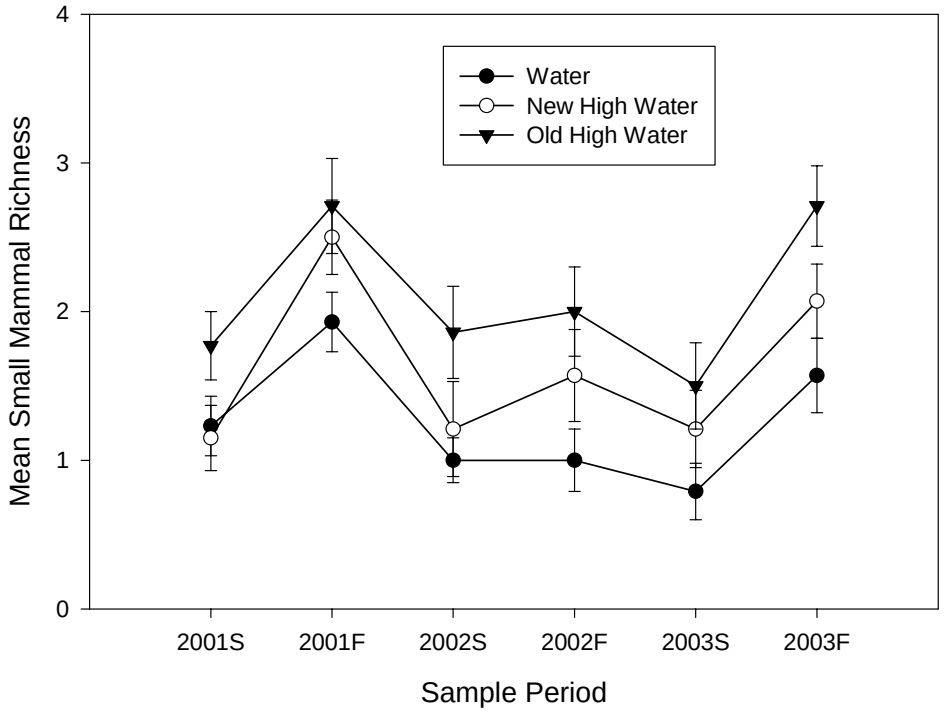
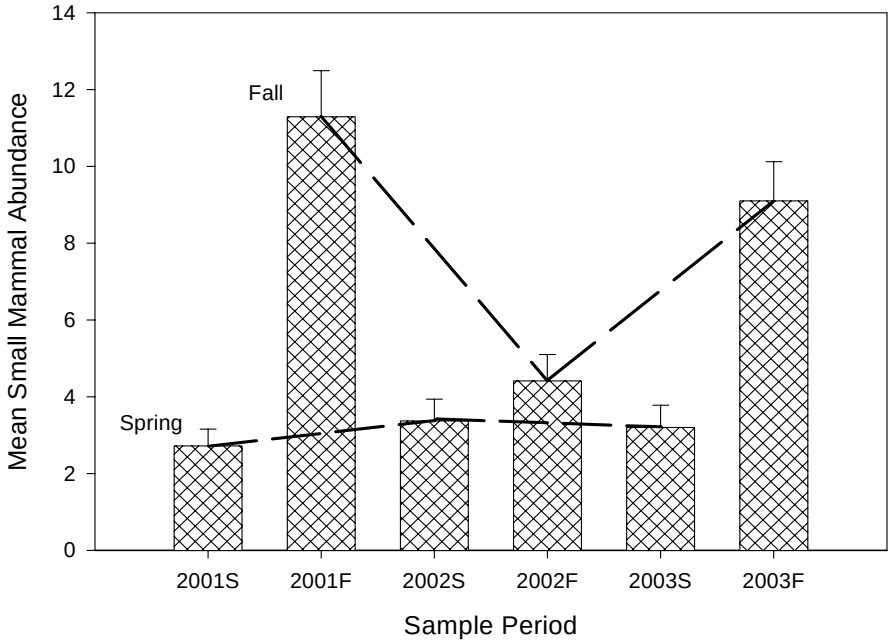

Water
New High Water
Old High Water
Mean Small Mammal Richness
0
1
2
3
4
2001S
2001F
2002S
2002F
2003S
2003F
Sample Period

Figure 2: Small Mammal Response to Sample Period

Figure 3: Relationship between mean small mammal abundance (top) and mean richness (bottom) during each sampling period from 2001 through 2003. Dashed lines connect samples taken during the same season illustrating the relative stability of abundance and richness in spring.



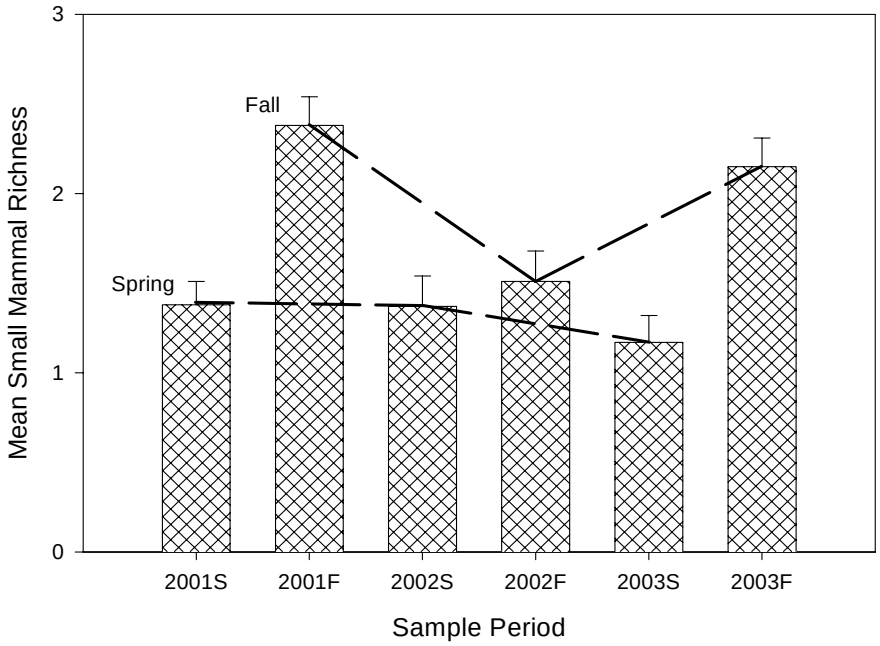


Figure 3: Small Mammal Abundance and Patch Area

Figure 3: Significant relationship between patch area and small mammal abundance.

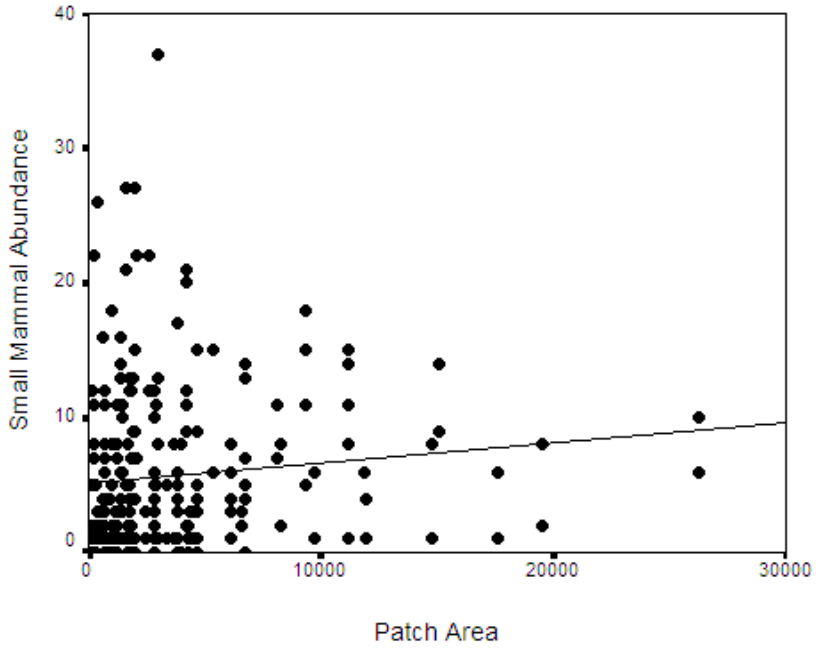


Figure 4: Small Mammal Abundance and Percent Cliff at Shore

Figure 4: Significant relationship between percent cliff at shore and small mammal abundance.

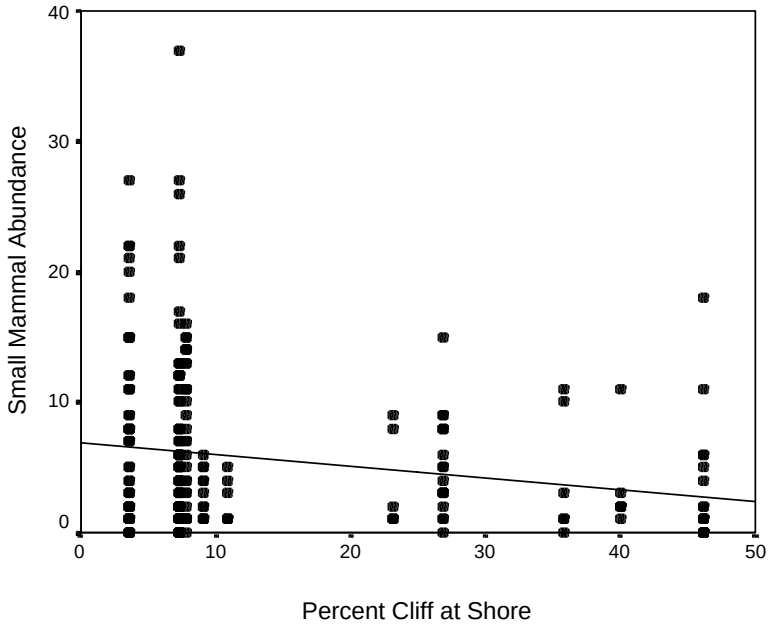


Figure 5: Small Mammal Abundance and Minimum River Flow

Figure 5: Significant relationship between minimum river flow and small mammal abundance.

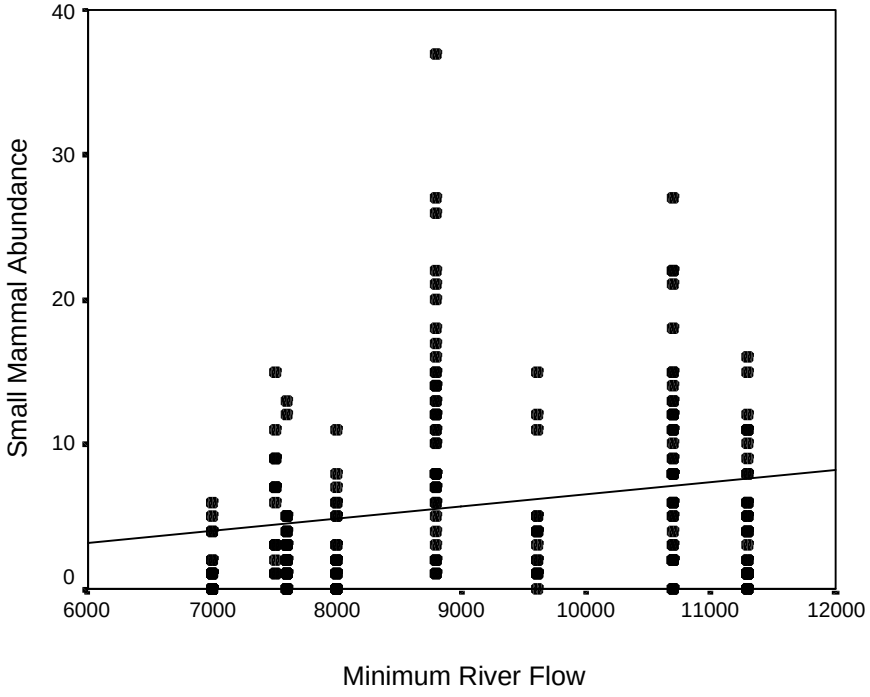


Figure 6: Small Mammal Abundance and Mean River Flow

Figure 6: Significant relationship between mean river flow and small mammal abundance.

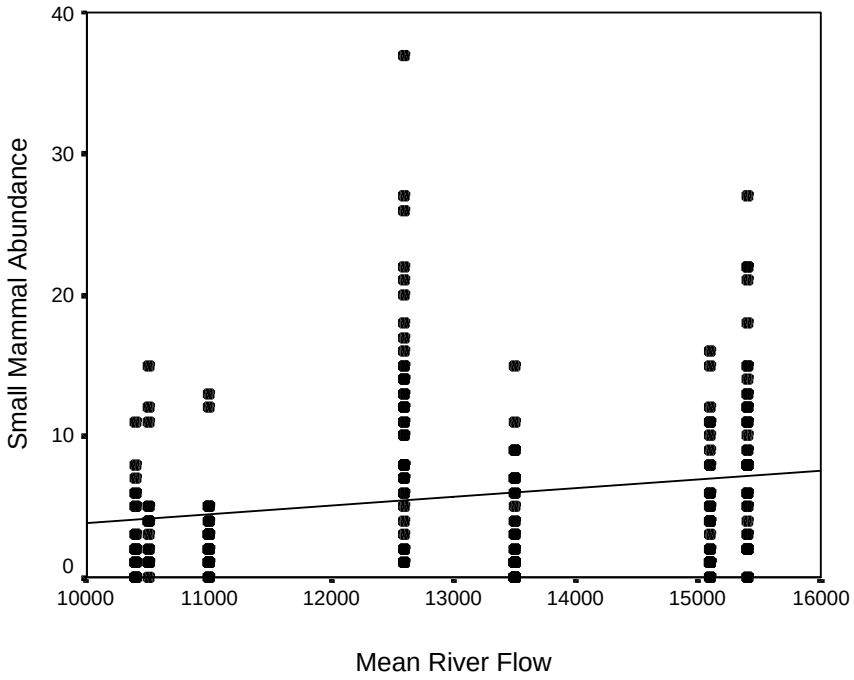

Small Mammal Abundance
40
30
20
10
0
10000
11000
12000
13000
14000
15000
16000
Mean River Flow

Figure 7: Small Mammal Abundance and Precipitation

Figure 7: Significant relationship between precipitation deviation and small mammal abundance.

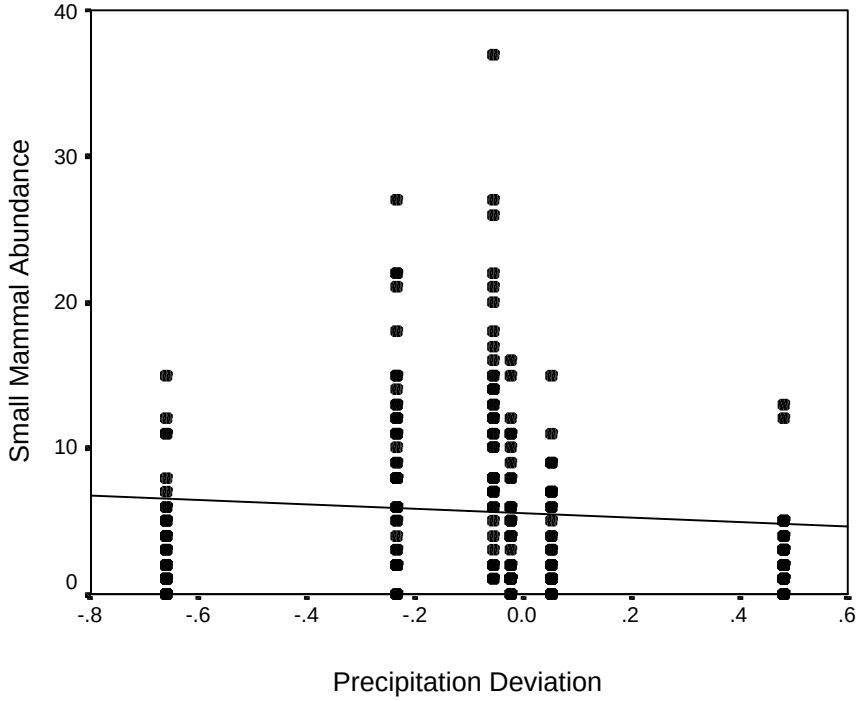


Figure 8: Small Mammal Abundance by Reach Type

Figure 19: Relationship between reach type and small mammal richness.

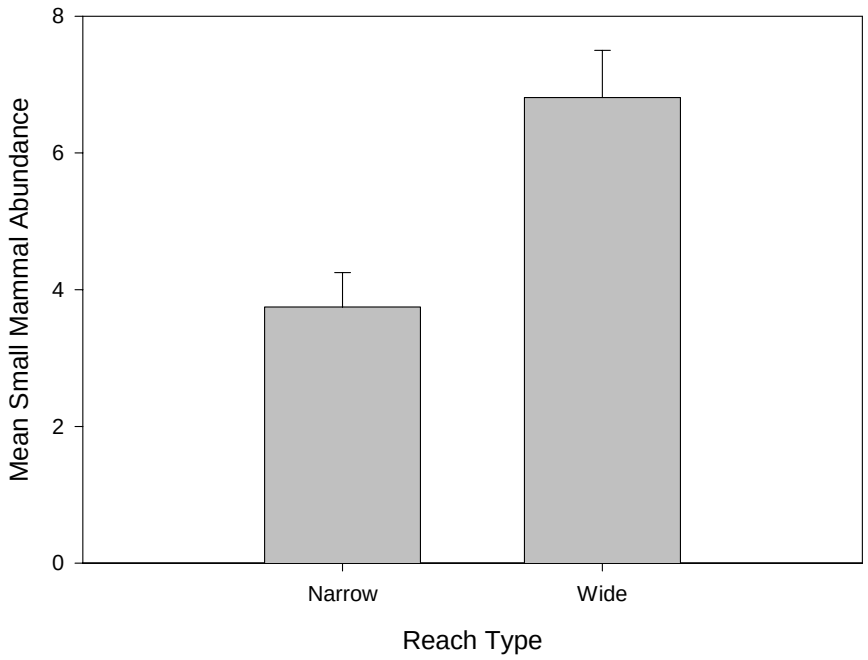

8
6
4
2
0
Mean Small Mammal Abundance
Narrow
Wide
Reach Type

Figure 9: Spring Small Mammal Abundance in Shore Zone

Figure 9: Relationship between minimum river flow and small mammal abundance during spring in the shore zone.

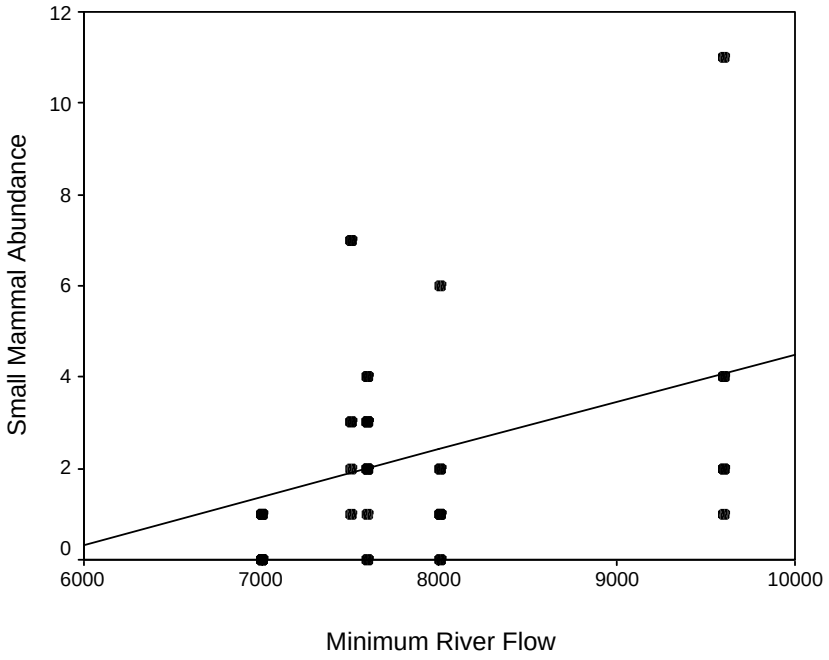


Figure 10: Spring Small Mammal Abundance in New High Water Zone

Figure 10: Relationship between patch area and small mammal abundance during spring in the hew high water zone.

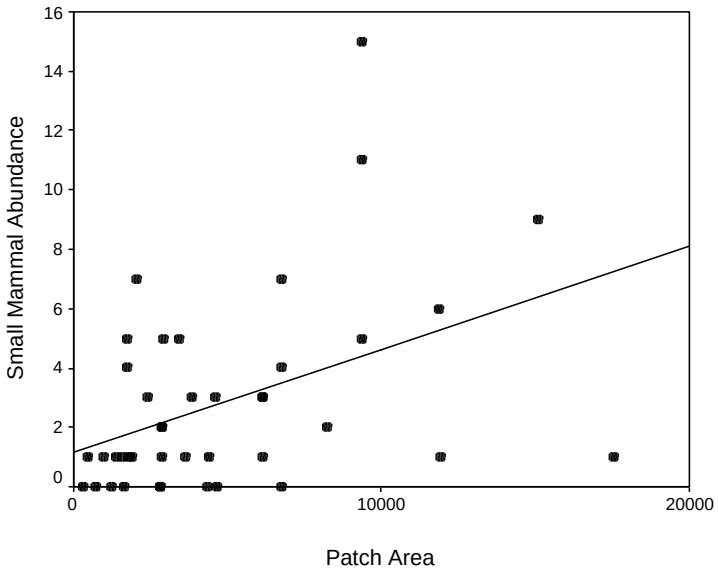


Figure 11: Spring Small Mammal Abundance in New High Water Zone

Figure 11: Relationship between minimum river flow and small mammal abundance during fall in each water zone.

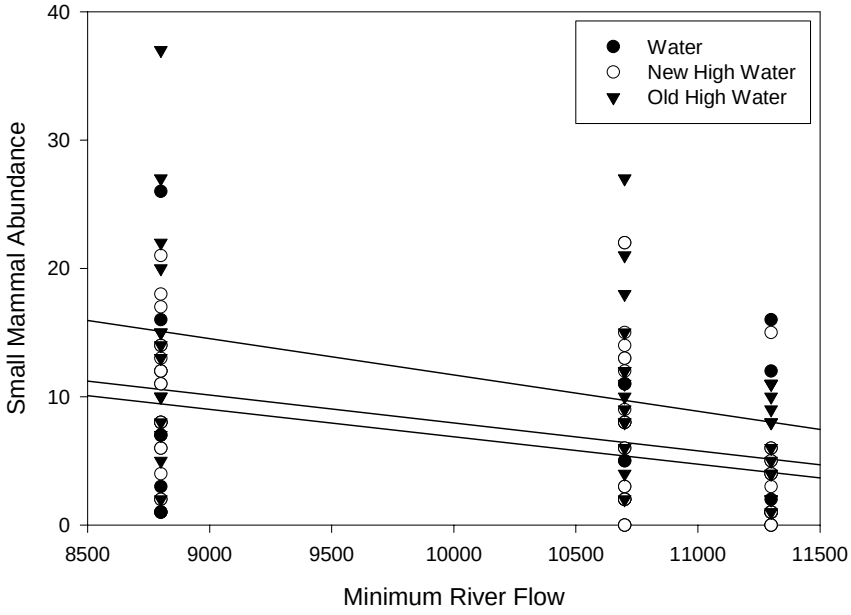


Figure 12: Small Mammal Species

Figure 12: Total number of each species of small mammal captured in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

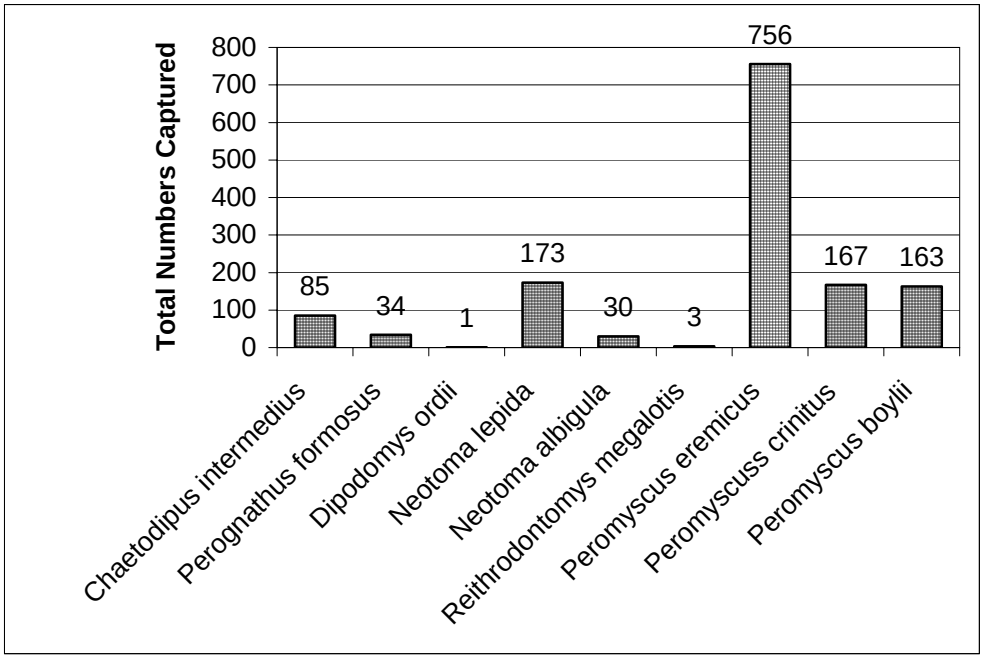


Figure 13: Small Mammal Richness and Abundance

Figure 13: Significant relationship between small mammal richness and abundance in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

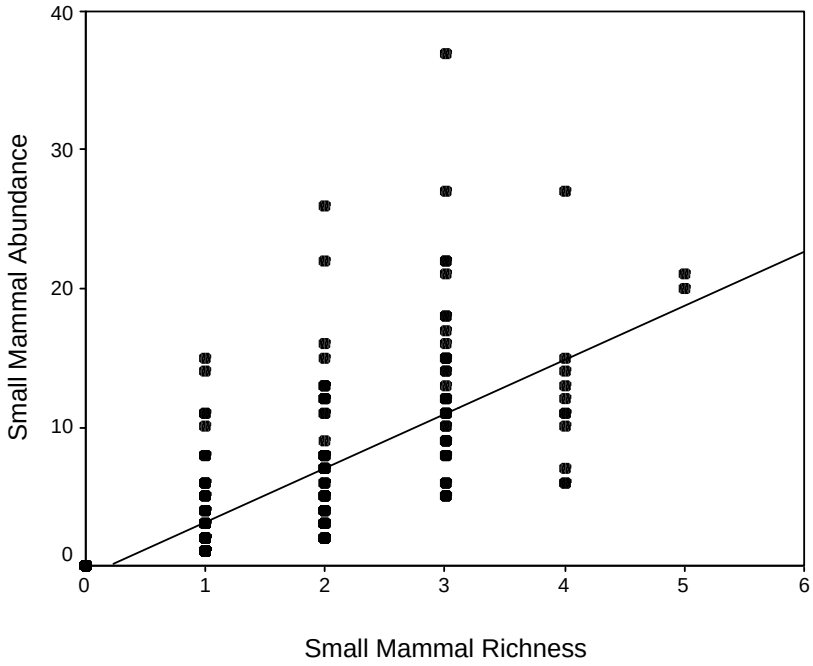


Figure 14: Small Mammal Richness and Patch Area

Figure 14: Significant relationship between patch area and small mammal richness in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

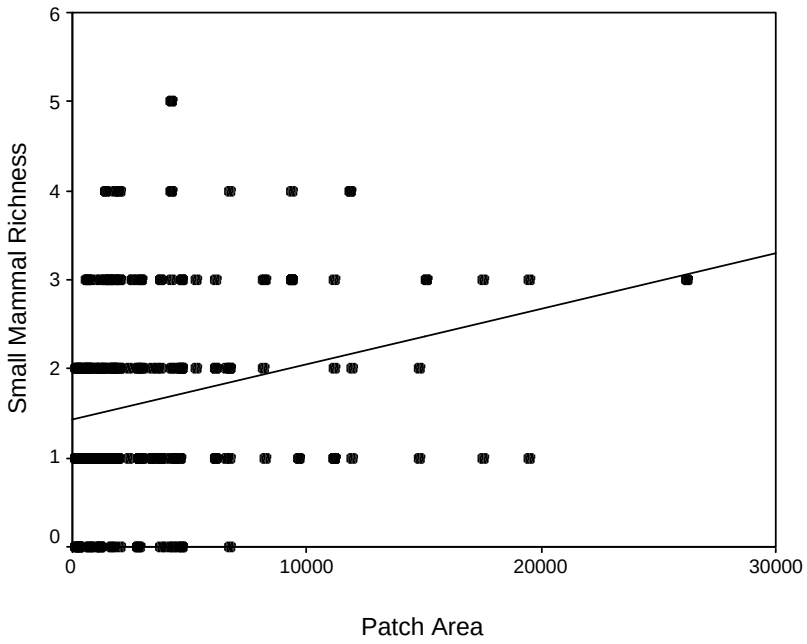

Small Mammal Richness
6
5
4
3
2
1
0
0
10000
20000
30000
Patch Area

Figure 15: Small Mammal Richness and Percent Cliff at Shoreline

Figure 15: Significant relationship between percent cliff at shoreline and small mammal richness in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

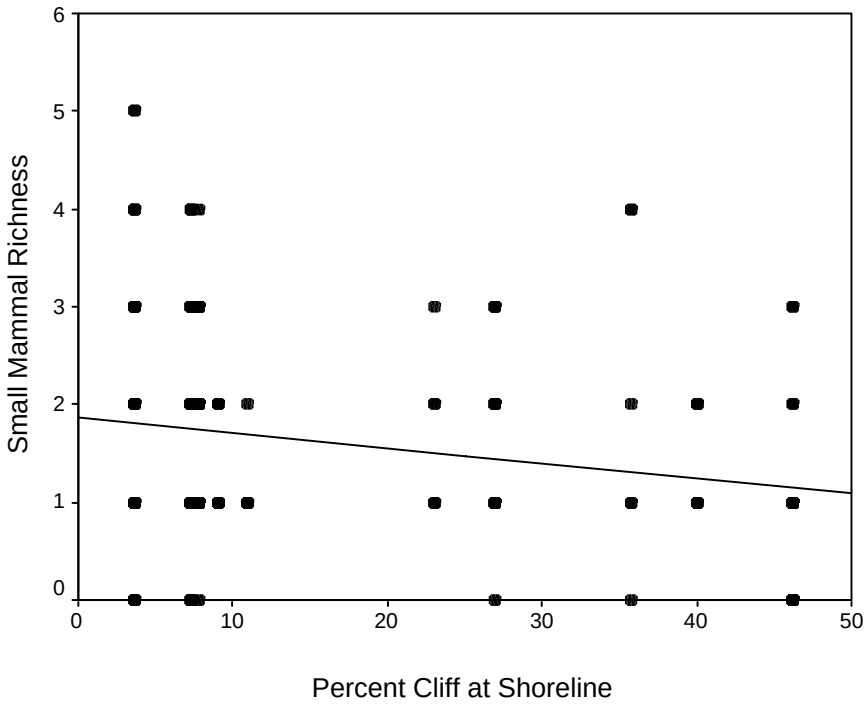


Figure 16: Small Mammal Richness and Minimum River Flow

Figure 16: Significant relationship between minimum river flow and small mammal richness in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

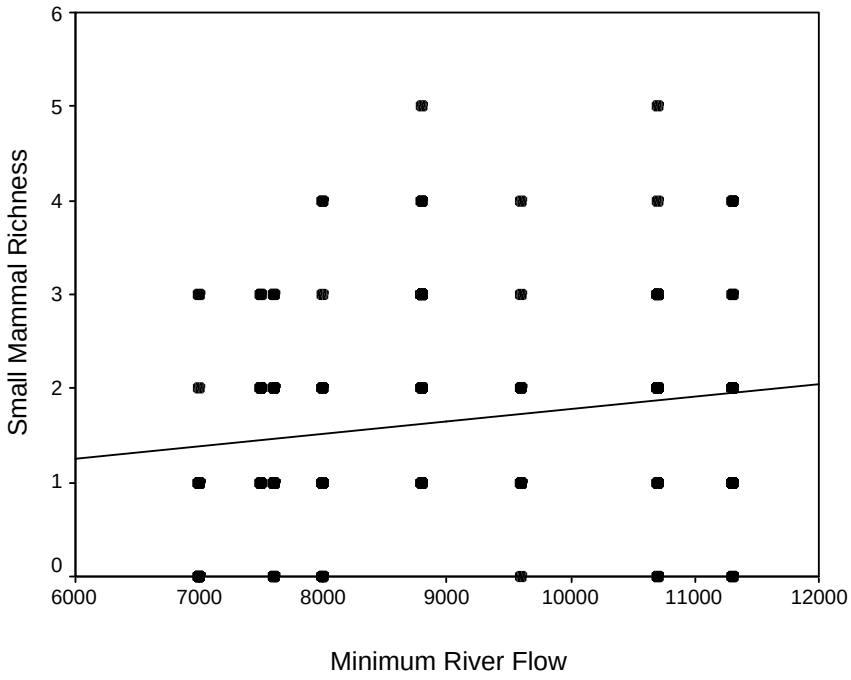

Small Mammal Richness
0
1
2
3
4
5
6
6000
7000
8000
9000
10000
11000
12000
Minimum River Flow

Figure 17: Small Mammal Richness and Mean River Flow

Figure 17: Significant relationship between mean river flow and small mammal richness in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

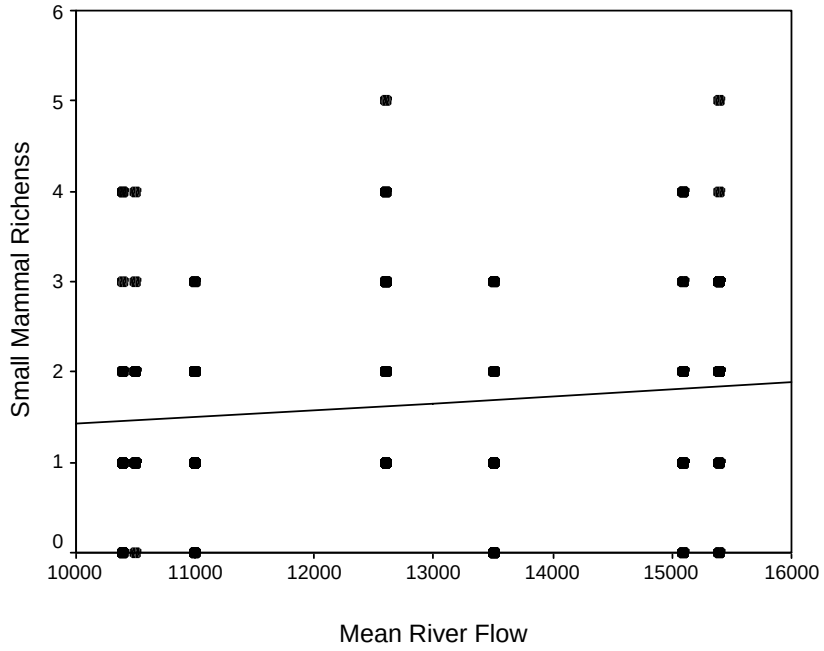


Figure 18: Small Mammal Richness and Precipitation Deviation

Figure 18: Significant relationship between precipitation deviation and small mammal richness in the Colorado River corridor of the Grand Canyon from 2001 to 2003.

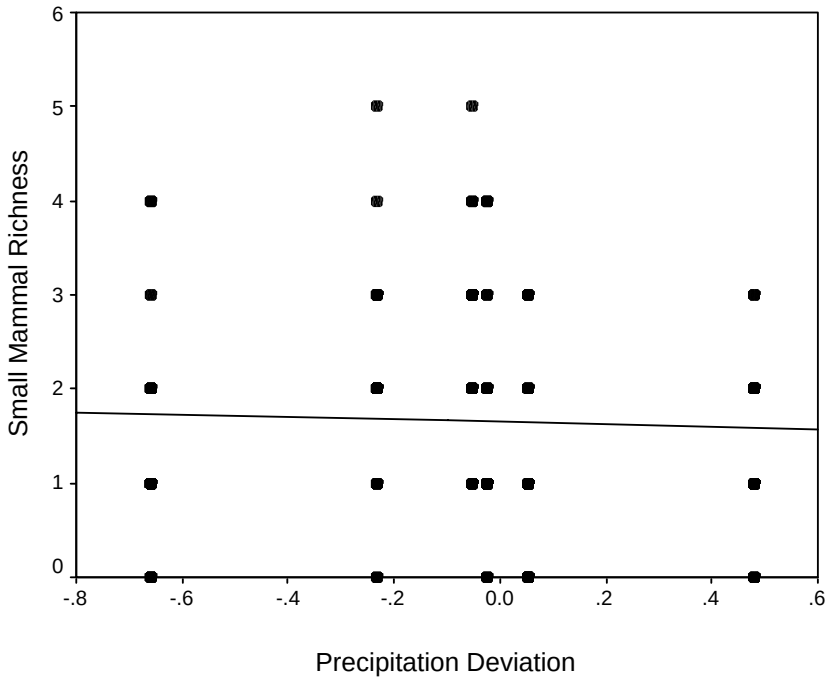

Small Mammal Richness
6
5
4
3
2
1
0
-.8
-.6
-.4
-.2
0.0
.2
.4
.6
Precipitation Deviation

Figure 19: Small Mammal Richness by Reach Type

Figure 19: Relationship between reach type and small mammal richness.

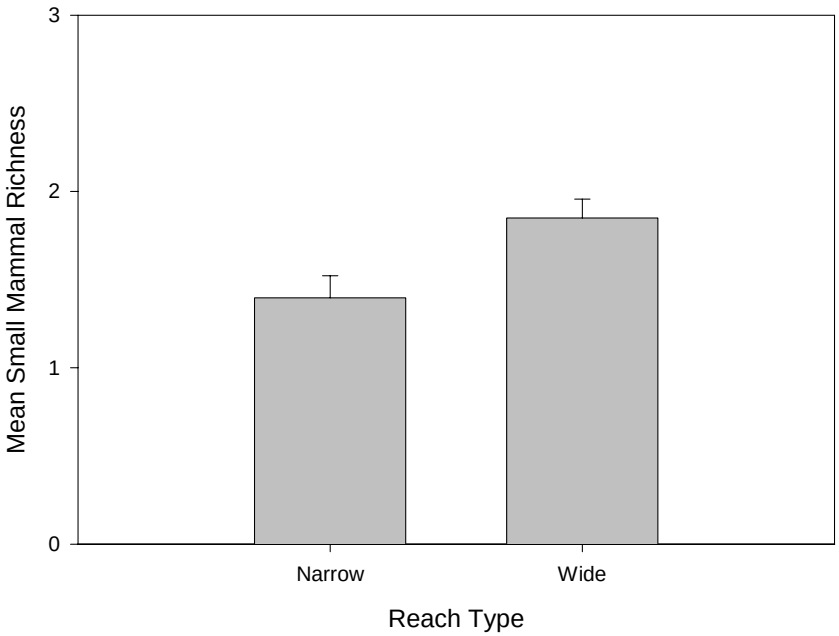


Figure 20: Spring Small Mammal Richness in Shore Zone

Figure 20: Relationship between river flow fluctuation and small mammal richness during spring in the shore zone.

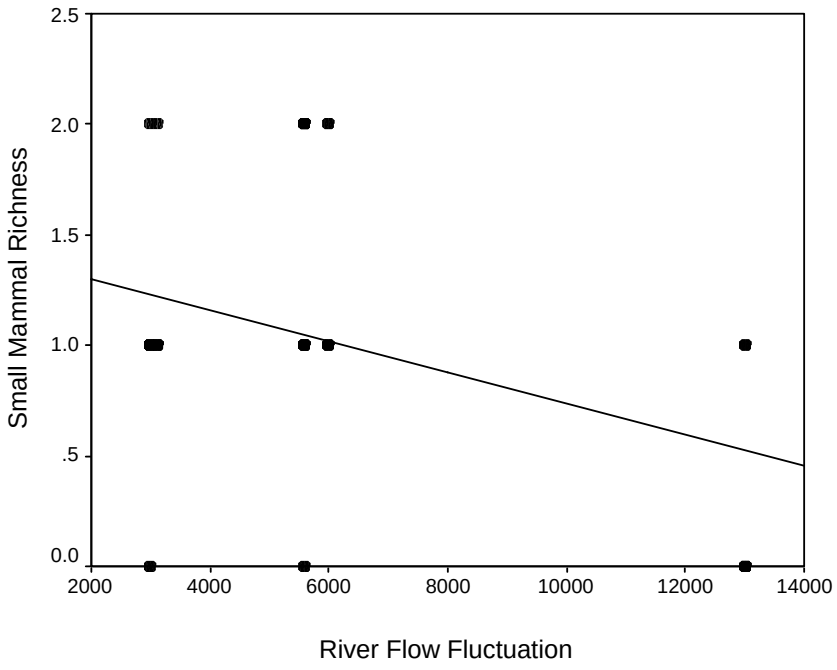

2.5
2.0
1.5
1.0
.5
0.0
Small Mammal Richness
2000
4000
6000
8000
10000
12000
14000
River Flow Fluctuation

Figure 21: Spring Small Mammal Richness in New High Water Zone

Figure 21: Relationship between patch area and small mammal richness during spring in the new high water zone.

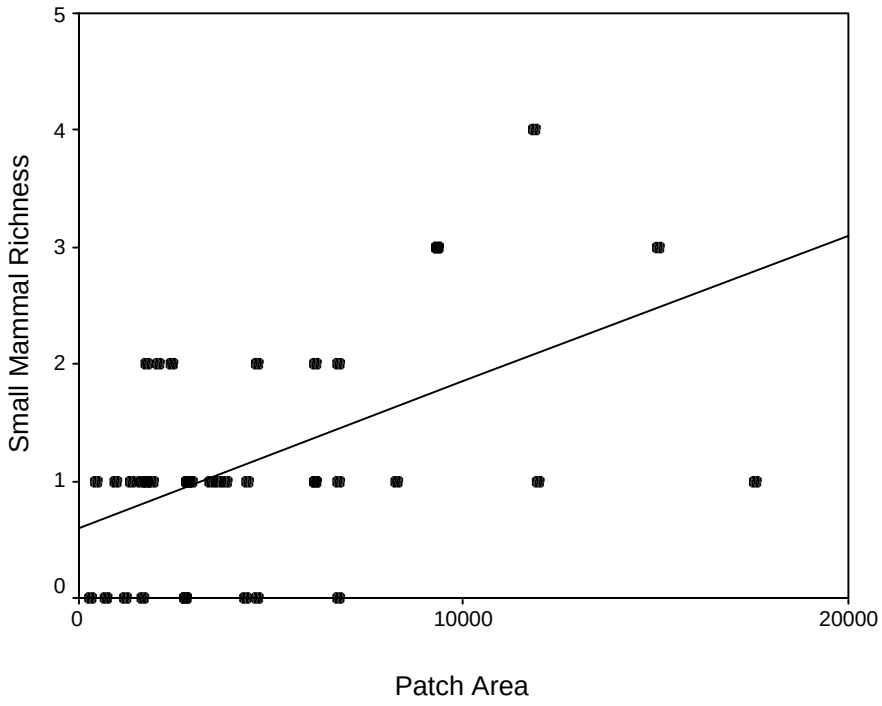


Figure 22: Fall Small Mammal Richness in Shore Zone

Figure 22: Relationship between minimum river flow and small mammal richness during fall in the shore zone.

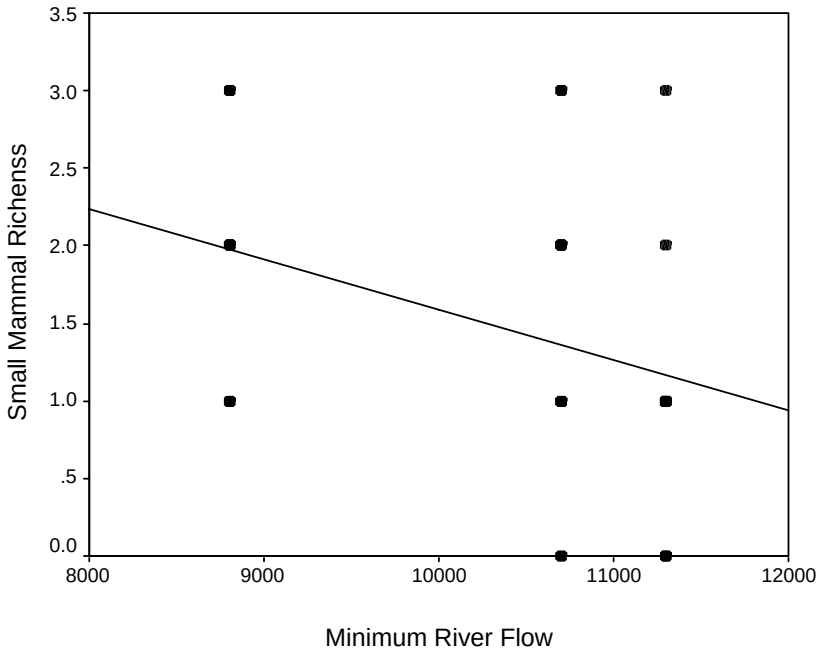

Small Mammal Richenss
3.5
3.0
2.5
2.0
1.5
1.0
.5
0.0
8000
9000
10000
11000
12000
Minimum River Flow

Figure 23: Fall Small Mammal Richness in New High Water Zone

Figure 23: Relationship between patch area and small mammal richness during fall in the new high water zone.

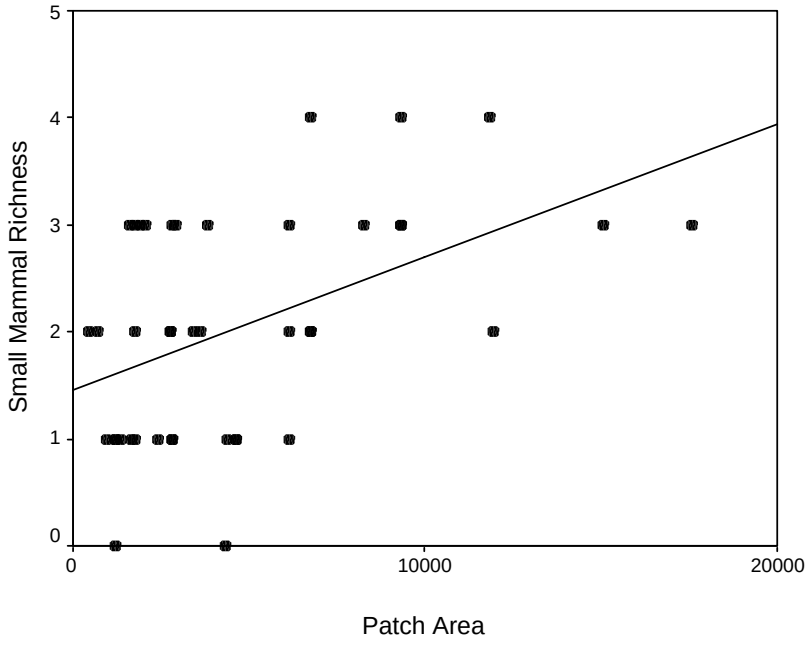


Figure 24: Fall Small Mammal Richness in Old High Water Zone

Figure 24: Relationship between total catchment area and small mammal richness during fall in the old high water zone.

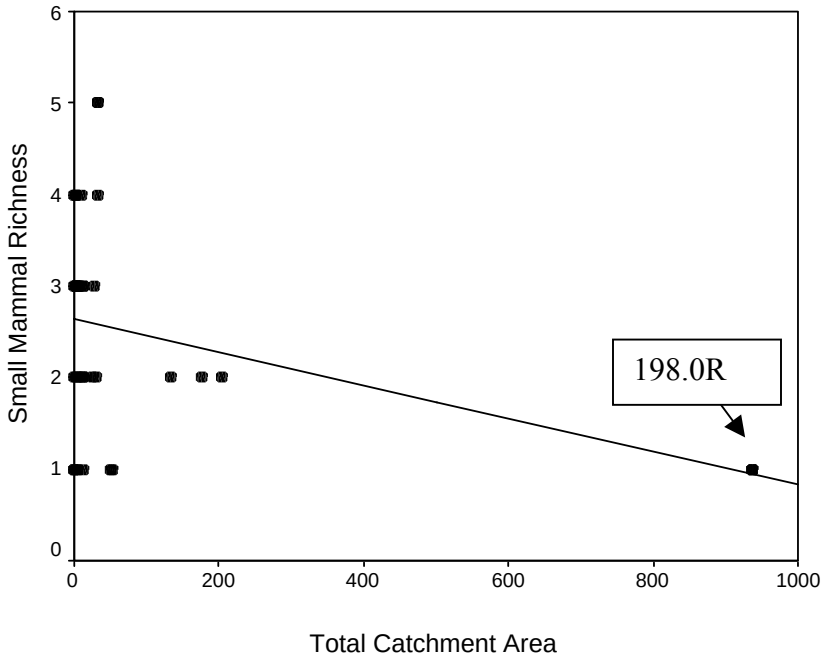
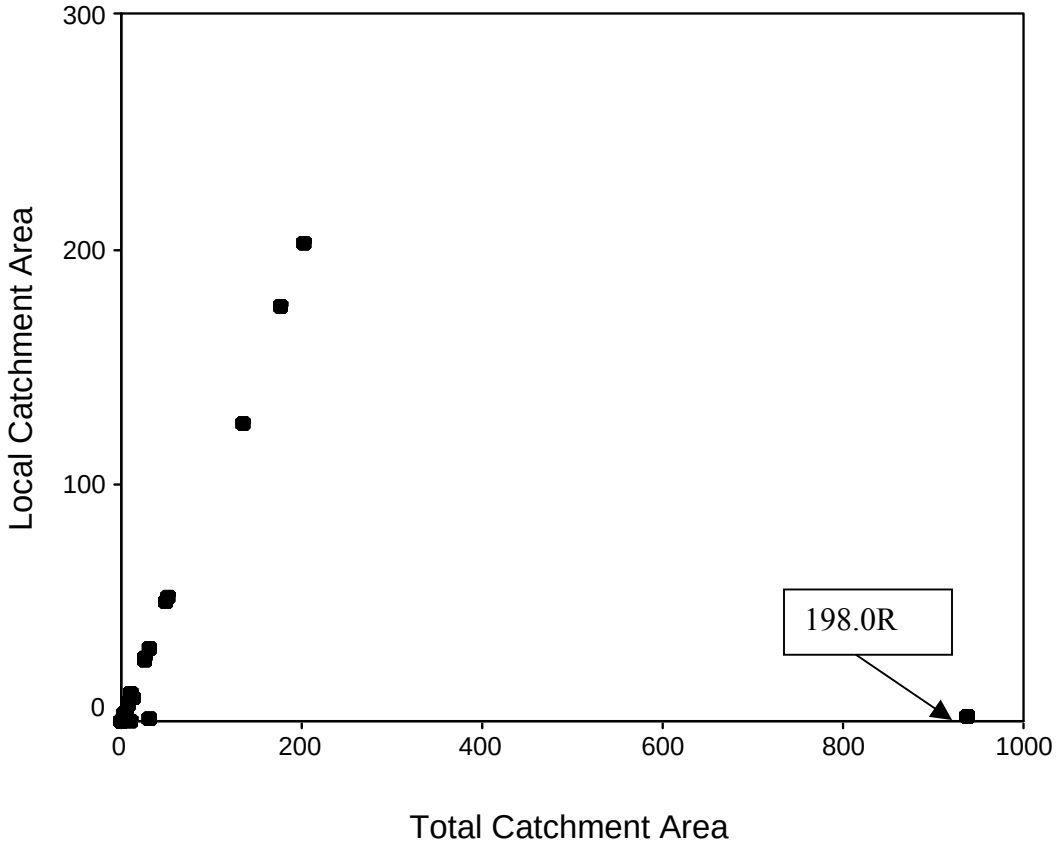


Figure 25: Relationship Between Total and Local Catchment Area

Figure 25: Relationship between total catchment area and local catchment area indicating that 198 mile (pre-Parashant) site is unusual..


300
200
100
0
Local Catchment Area
198.0R
0
200
400
600
800
1000
Total Catchment Area

Integration and Interpretation

Michael Kearsley
Northern Arizona University

Purpose:

The purpose of the work described in this section is to combine information on vegetation and the faunal components of the terrestrial riparian ecosystem to better understand their interrelationships in the river corridor.

Objectives:

Because a much larger document devoted to integration and synthesis of patterns seen during three years of vegetation and faunal surveys is to be completed in early 2004, we have limited the scope of this section to avoid redundancy. Here we have limited the integration section to a single objective.

1) To relate vegetation structure data to breeding bird abundance in patches where birds have been censused in previous years as part of other projects.

Methods:

The data for this section were collected for inventory and monitoring purposes the previous sections in which the site selection and data collection methods have been described. This section is concerned with the relationships among those data sets, so the methods described are for the numerical examination of the relationships.

Bird community / vegetation relationships. Data on breeding bird abundance in patches were taken from the avian monitoring data from May 2001 through May 2003. Although several surveys were conducted each year, only those data from the trips on which both bird and vegetation work were collected simultaneously are included here. The vegetation structure data was collected during the integrated terrestrial riparian sampling trips in May 2001, April and May 2002, and April and May 2003 and on upstream day trips to sites in Glen Canyon in each year. Patch area data were generated by B. Ralston and T. Gushue of the GCMRC with input from H. Yard and M. Kearsley, using ESRI ARC-Map v 8.3 software to manipulate digital aerial orthophotos taken in June of 2002.

To determine whether vegetation structure, measured as total vegetation volume (TVV: Mills et al. 1991) influenced bird abundance, the bird data had to be converted via a number of steps from abundance to density to avoid site area effects. First, breeding bird density, measured as per Mills et al. (1991), concerns only those species which are known to breed in the area being studied. Therefore, all migrants, "tourists" and non-breeding species were excluded from the bird abundance data set. Second, records of territorial species were adjusted to reflect the territorial behavior; males and females within a patch were counted by male / female pairs and each single-gender record left was counted as two individuals. Non-territorial species were simply counted as the number of records in a patch. Finally, the total number of breeding birds thus calculated in a patch was divided by the patch area from the GIS work to produce a bird density (number per hectare).

A visual examination of the graph of breeding bird density versus patch area (Figure 1) revealed two important facts. First, there was an extremely strong negative and non-linear dependence of density on area. This may have resulted from less efficient searching in larger patches by surveyors, over utilization of patch edges by birds such that interior portions of the

larger patches are not occupied, or a spatial split between nesting (inside the patch) and foraging (outside the patch) behaviors (e.g., Estades 2001). And second, the variation of densities in small patches made the assumption of equal variances across all patches untenable. This likely resulted from the fact that each record of a bird in a small patch had a disproportionately large effect on density estimates. For example, a single sighting of a territorial species in a patch of 500 square meters (0.05 ha) would increase the density estimate of that patch by 40 birds per hectare, which was roughly twice the average density across all plots. To minimize the effects of this variability on our analyses, we excluded all plots less than 0.25 hectares.

We analyzed the relationship between breeding bird density and vegetation density in two ways. First, we performed a standard linear least-squares analysis of covariance (ANCOVA) of the breeding bird density for all usable patches. In the model we included, as predictors, total vegetation volume and patch area as a covariates, year (2001, 2002, 2003), canyon width (per Schmidt and Graf 1990; narrow, wide), and zone (new high water, old high water) as fixed effects. Because there was a statistical interaction between year and zone (zones behaved differently over the three year period), we analyzed each zone in separate ANCOVAs.

The second analysis involved the use of quantile regression to determine the upper limit of bird density for a given patch density. Quantile regression is a method useful in situations where not all potential limiting factors are measured at each site. The limiting factor(s) which are measured can then be used to predict an upper bound on potential population sizes (Cade and Noon 2003). For this analysis, we used an upper bound by regressing the 99th quantile against total vegetation volume.

Results:

There was a strong, positive relationship between breeding bird density and vegetation density as measured by TVV (Figure 2) In the new high water zone bird patches, TVV explained 10% of the variability in bird density ($F_{(1,96)} = 11.363$, $p < 0.005$). In the old high water zone patches, TVV explained roughly 8% of the variation in bird density (Figure 3; $F_{(1,81)} = 6.201$, $p < 0.001$).

The relationship was also seen in the quantile regressions. The upper bound on new high water zone bird densities increased with total vegetation volume (Figure 2; $Q_{99} = 23.276 + 0.2285*TVV$; $p = 0.0078$). In old high water zone patches, patches with more dense vegetation also had higher breeding bird densities (Figure 3; $Q_{99} = 27.602 + 0..1561*TVV$; $p = 0.0428$).

Interestingly, the density of breeding birds in all patches declined slightly, though not significantly, across all three years in both habitats. In new high water zone plots, the decline was approximately 3 birds / ha / year (Figure 4; $F_{(2,96)} = 2.053$, $p = 0.134$). In old high water zone plots, the decline was approximately 1 bird/ ha / year in 2002, then a drop of 5.5 birds / ha / year in 2003 (Figure 4; $F_{(2,81)} = 2.501$, $p = 0..088$). This may, in part, be due to our sampling a set of patches with a slightly greater mean area in the three years (Figure 5).

Summary;

It is clear that the density of vegetation is an important component of habitat quality for riparian breeding birds in the river corridor of Grand Canyon. Breeding birds are found most often where the vegetation is densest. This is likely a function of the high productivity of these patches which is reflected in more seeds, flowers, leaf material and associated arthropods which serve as “breeding currency”. It may also be that the density of woody vegetation in these patches provides a cooler, shadier nesting site which can be used while foraging activities take

place outside the patch itself. In either case, vegetation density is a useful predictor of breeding bird habitat quality.

The relationship between bird density and vegetation density in Grand Canyon riparian habitats appears to be more complex than was indicated by Mills et al. (1991) for other Arizona riparian habitats. In the latter, there was a tight linear fit of breeding bird density to total vegetation volume, even though the TVV and breeding bird densities surveyed were in the same range as in this study (TVV = 16 to 236; bird densities = 3 to 30 per ha). In our data, the relationship is decidedly "wedge" shaped, indicating that at higher densities of vegetation there is a broad range of possible bird densities. There are several possible sources of this variability. First, Mills and his colleagues developed the model in riparian habitats of an alluvial river in the Tucson Valley which were, perhaps, more continuous and homogeneous than the isolated patches in the deeply incised Grand Canyon. Second, factors outside the breeding patches, such as mortality and habitat loss in the overwintering grounds of these migratory species may have become higher in the 15 years since Mills performed his field work. Individuals would then not reliably return to patches in Grand Canyon. Third, food resources not measured by woody production may be limiting the numbers of birds in some of our patches. For example, the density of bird species which feed on arthropods with aquatic juvenile stages or seeds and flowers of herbaceous plants would not necessarily be related to woody plant density. Finally, high densities of exotic species, specifically tamarisk, in our study sites may not support the same density of birds supported by native species.

Literature Cited

Cade, B.S. and Noon, B.R. 2003. A gentle introduction to quantile regression for ecologists. Frontiers in Ecology and the Environment. 1: 412-420.

Estades, C.F. 2001. The effect of breeding-habitat patch size on bird density. Landscape Ecology. 16: 161-173.

Mills, G.S, Dunning, J.B. and Bates, J.M. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin. 103: 468-479.

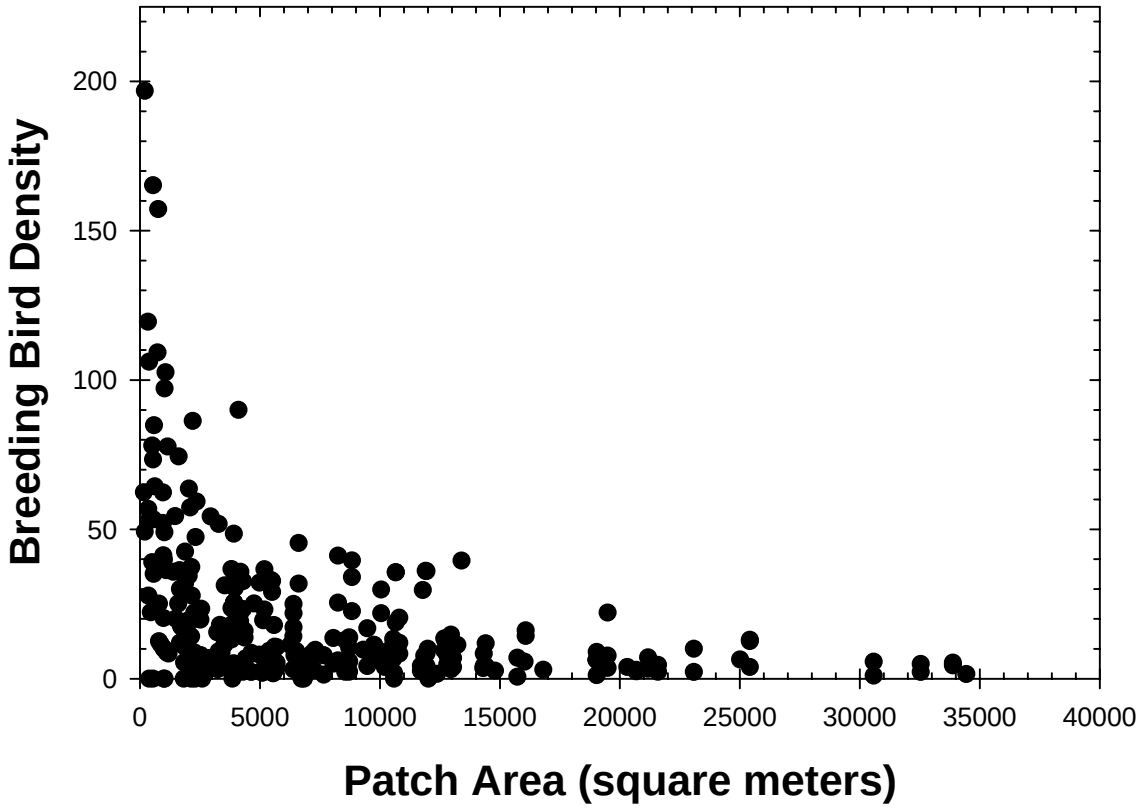


Figure 30. Breeding bird density decreases with increasing patch area, as does the variance in breeding bird density in both new high water zone and old high water zone plots. Data are taken from all three years of surveying.

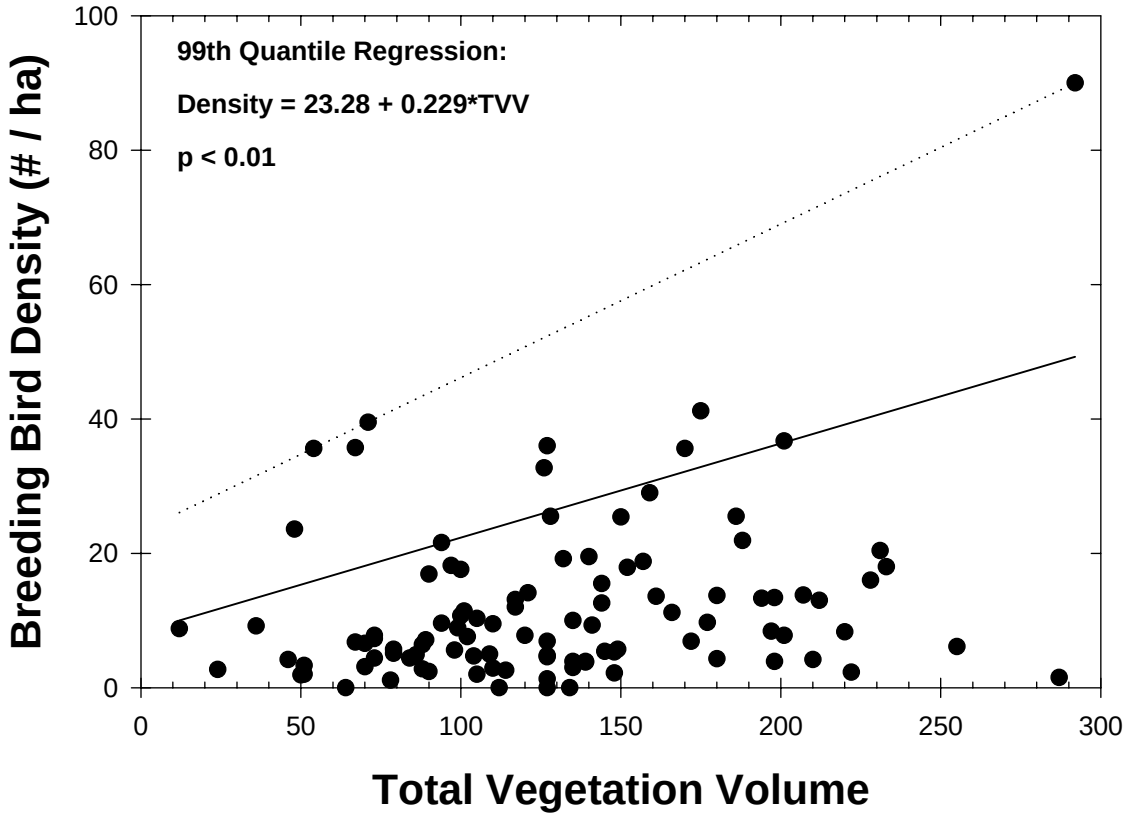


Figure 31. Breeding bird density and total vegetation volume in new high water zone bird patches. Solid line is least squares regression line. Dotted line shows the 99th quantile regression line.

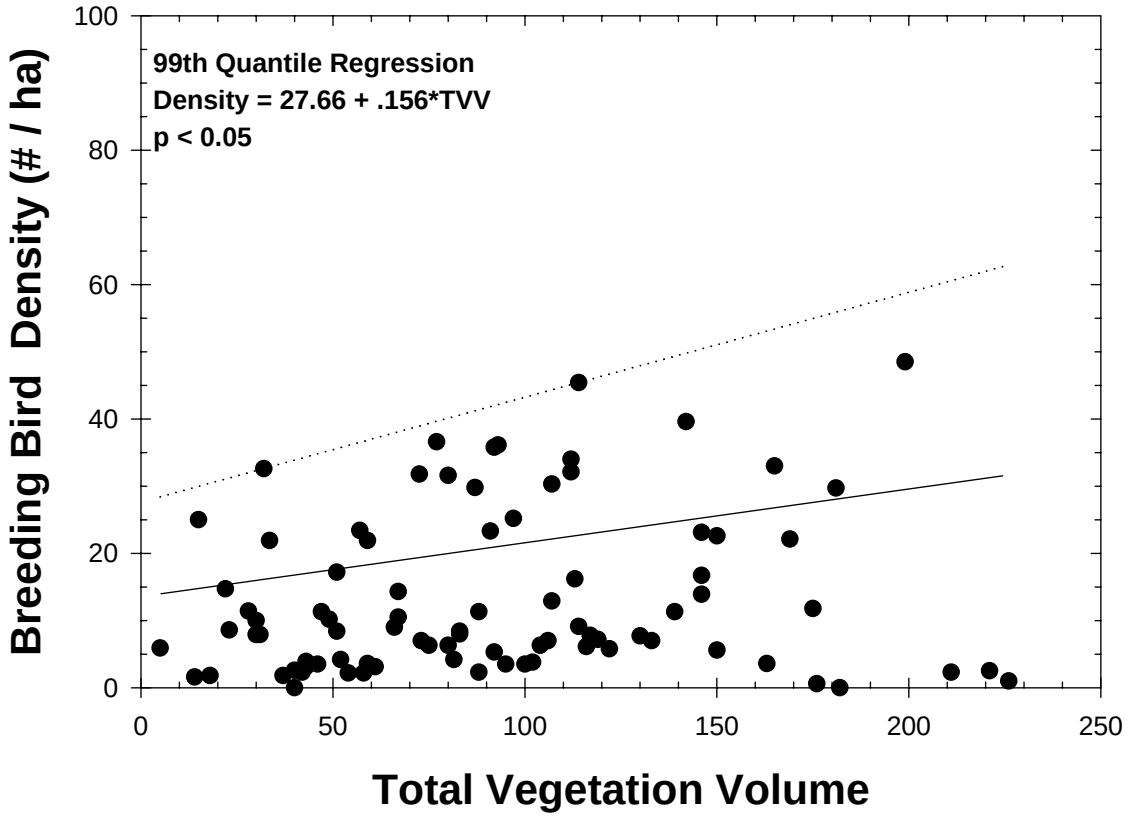


Figure 32. Breeding bird density and total vegetation volume in old high water zone bird patches. Solid line is least squares regression line. Dotted line shows the 99th quantile regression line.

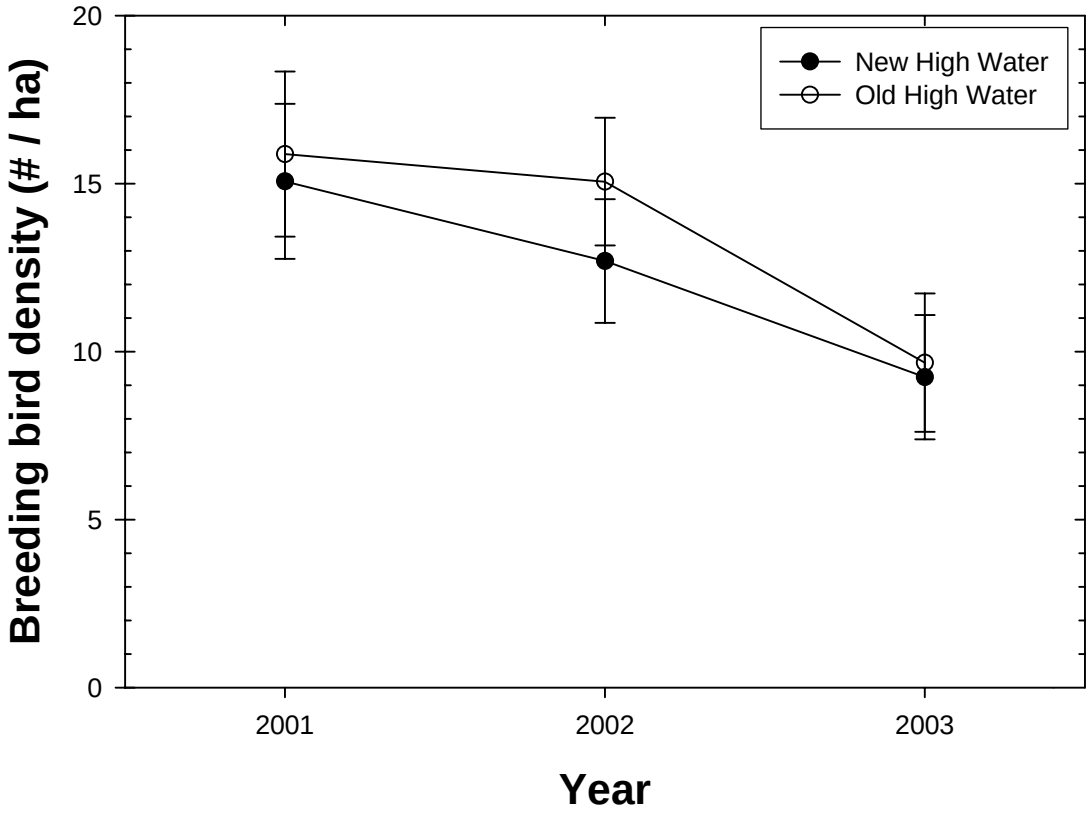


Figure 33. Mean breeding bird densities decreased in both new high water zone and old high water zone patches between 2001 and 2003. Vertical bars represent +/- 1 standard error.

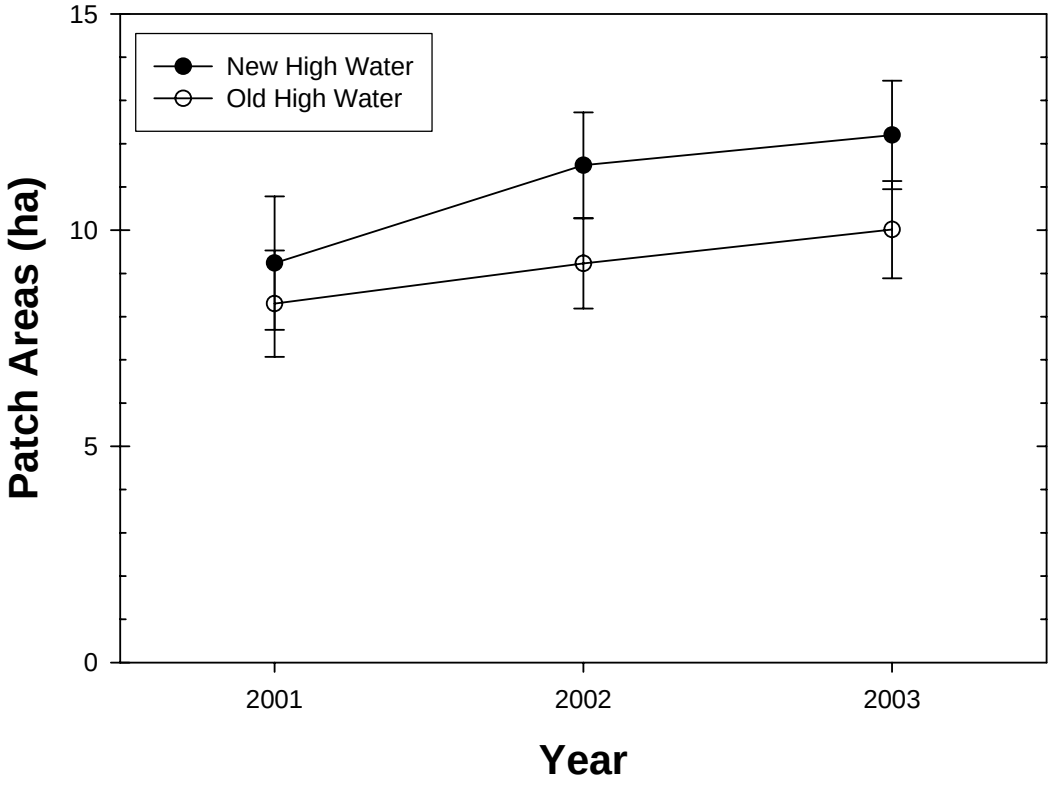


Figure 34 Areas of bird patches surveyed increased between 2001 and 2003, potentially leading to decreases seen in breeding bird densities in the patches. Vertical bars represent +/- 1 standard error.

Vegetation Dynamics

Michael Kearsley
Northern Arizona University

Purpose:
The purpose of the vegetation dynamics work is to generate information on the status of and trends in the distribution, abundance, diversity and composition of riparian vegetation in relation to stage elevation along the Colorado River between Glen Canyon Dam and Diamond Creek.

Objectives:
In 2002 there were five primary objectives for the vegetation dynamics work. 1) To determine vegetation cover, species richness, diversity (Shannon H') and wetland indicator status at elevations above the river corresponding to flows of 15, 25, 35, 45, and 60 thousand cubic feet per second (kcfs). 2) To compare these measures of vegetation to others taken in 2001 and 2002 to determine trends within stage zones. 3) To compare trends in each year's measures to indices of water availability in the form of seasonal precipitation indices and elements of the river hydrograph. 4) To compare yearly trends in vegetation in low and high zones to differentiate between impacts of dam operations and climatic variability. 5) To determine the average substrate texture (percent of surface with sand or finer sediment) at each of the stage elevations, and to compare that with 2001 levels to test for flow-related changes.

Methods:
Selection of Sample Sites and Transects: As in described in the 2001 and 202 Annual Reports, site selection was based on a probabilistic sampling of river segments. Between Lees Ferry and Diamond Creek, 703 segments were defined by using pairs of adjacent river cross sections. These cross sections were developed and used by Randle and Pemberton (1987) and later investigators (Korman and Walters 1998) to predict elevation rise from discharge data at these cross sections. We treated the river as a drop-and-pool model in which the downstream cross section in each segment controlled that segments elevation rise.

Of the 60 sites sampled in 2002, 40 were replaced by new sites in 2003 and 20 were scheduled to be repeated. Table 1 shows the general layout of the augmented rotating panel design used for vegetation dynamics sampling. In addition, we added two randomly selected sites from the Glen Canyon reach above Lees Ferry. In 2003, the 40 replacement sites were derived from a set of 60 potential sites visited during the January winter birds / vegetation transect layout trip. On the trip, we first had to determine which of the sites were usable and which would not be usable. Potential sites could be rejected as unusable for several reasons: "cliff" sites were too vertical to support vegetation and thus would not contribute to our understanding of dynamics, others were inaccessible or logistically unsafe (in the middle of rapids) or administratively off-limits (Kanab ambersnail sites at Vaseys Paradise and Deer Creek, culturally significant sites near the confluence with the Little Colorado River).

At each usable replacement site, transects were established and documented using the same protocol employed in 2001 and 2002. Transect top and elevation control points were installed (see Figure 1). The transect top point consisted of a single mark of nail polish on a rock above our estimate of the 60 kcfs elevation if possible. If the transect ended in a cliff before the 60 kcfs elevation, we placed the mark as high as possible. In cases where the entire transect could not be seen easily from the transect top point, a separate elevation control point was

marked above the 60 kcfs point with nail polish from which all could be seen. Written descriptions of the points relative to nearby landmarks and the drop from the elevation control point to the previous day's high water, measured with an Abney level and a telescoping survey rod were recorded. Given that drop, and an estimate of the previous day's high river stage derived by routing discharges from Glen Canyon dam through the CRFSSGUI model (Korman and Walters 1998), we could then use elevation rise per stage rise data from the STARS model (Randle and Pemberton 1987) to calculate the drop from the elevation point to the sample points at 15, 25, 35, 45, and 60 kcfs. Site location photographs were taken of the points and the transect itself. At least one transect photograph was a shot down slope from the top point with a survey rod at the transect bottom showing a cross-river point to be used for reestablishing the transect in the fall.

Vegetation Sampling. Vegetation sampling was conducted in the fall of 2003. Transects between Lees Ferry and Diamond Creek were sampled during a downriver trip between August 21st and September 5th. Upriver sites were sampled on a day trip on September 30th. Due to logistical constraints involving a few very long mileage days on the water, two of the 60 planned downriver sites were missed in 2002.

Sampling of each transect consisted of three steps: reoccupation, frame placement, and survey. First, the transect itself and the elevation control points were reoccupied using cues from site photographs and descriptions. The transect line was then reestablished by having one crew member sighting from the transect top point to the cross-river point and directing the placement of a tape down the transect to the water's edge.

Points on the transect corresponding to five stage elevations (15, 25, 35, 45, and 60 kcfs) were located using elevation values calculated from data collected on transect establishment trips. The elevation drop to each of these points was measured with an Abney level at the control point and an extendable survey rod on the transect. Pin flags were placed at points along the transect. At each elevation point, a 1 x 1m sighting frame (per Floyd and Anderson, 1982) with 100 crosshair intersections was placed and leveled with one side along the transect and the riverward corner of the transect side directly over the pin flag. Once a frame was surveyed, the frame was moved upstream or downstream at the same level so that four 1 x 1 meter areas were sampled (two frames upstream of the transect and two downstream).

Vegetation data were recorded in the following way. First, all species present in the 1 x 1 m areas were recorded. Those individuals whose identity was in doubt and for which individuals could be found nearby which had enough material for identification (leaves, flowers, fruits, etc.) were assigned a temporary name, and a nearby example was collected for identification later. Specimens were discarded after identification. Very small seedlings and plants which could not be identified and which had no useful parts for identification were recorded with an "unknown" label (e.g., "unknown grass" or "unknown dicot seedling"). These data were included in the univariate measures (cover, richness, diversity), but were excluded from the multivariate analyses.

To estimate percent vegetative cover in each frame, the number of sighting points which intercepted each species was counted. Only the first contact with a given species under the sighting point was counted, so that no species could have more than 100% cover individually. However, if multiple species were present under a single sighting point, all were recorded once, so that the total cover of all species could collectively sum to more than 100%. For tall shrubs and trees whose canopies were above the sampling frame, cover was visually estimated by consensus of the data readers. Species which were encountered in at least one of the frames but

which were not seen beneath any of the 400 sighting points were assigned an arbitrary "trace" cover value of 0.001 percent.

Surface Texture Sampling: In order to document the characteristics of the soil surface at the shore of different flow levels, the substrate texture was recorded 40 points per stage elevation. A measuring tape or survey rod was laid on the ground perpendicular to the transect at each stage point. Every 10 centimeters for two meters upstream and two meters downstream of the transect, the size of the surface particle below that point was recorded on a 7 point scale (Table 2).

Vegetation Analysis: To avoid problems with independence, data on each species' cover were averaged across all four frames within each stage level at each transect before analyses. Cover data, as percent total vegetative cover, richness and diversity (Shannon H'), were therefore based on the four meter squared totals. Several univariate descriptive measures were derived from each transect's pooled data at each stage level. Total vegetative cover was calculated as the sum of average foliar cover values of all species at the stage level. Species richness was the number of unique species encountered per four meters squared. Plant species diversity was calculated as the Shannon (H') index with untransformed mean cover values.

Because dam operations can have a profound effect on plant water relations by altering ground water levels, mean wetland indicator scores were calculated within each stage zone for all transects. Each species has a characteristic wetland indicator score, ranging from 1 for obligate upland species to 5 for obligate wetland species (Reed, 1988; plus 1996 update available at http://www.nwi.fws.gov/bha/). Each plot's mean wetland score was calculated by simply averaging the indicator scores of all species recorded in the 4 meter squared frames at a given stage level.

To test for changes in vegetation measures across all three years of sampling, we compared total cover, richness, and diversity and wetland indicator scores within each stage elevation separately. Because the rotating panel sampling design resulted in an unbalanced data set (not all plots were surveyed in all years), we used an unbalanced, mixed-effects analysis of variance which included year (2001, 2002, 2003), and canyon width (per Schmidt and Graf 1990; narrow, wide) as fixed effects, and site as a random effect nested within canyon width. We also included terms to determine if there were interactions between year and width. The presence of a random effects factor required us to use a restricted maximum likelihood method to fit the model (SAS Institute Inc., 2001).

To determine the contributions of changes in water relations to the patterns of vegetation change, we also analyzed for precipitation and hydrograph effects. In those cases in which we detected significant year effects on cover and richness, we substituted a relative precipitation index from the pre-trip monsoon months (July and August) as well as elements of the hydrograph for the month preceding launch. These latter terms included the minimum, maximum, and mean flow, as well as the top end of daily fluctuations (see VEGETATION STRUCTURE section above for a complete description of how these measures were derived).

Compositional Analysis. Because univariate analyses often miss important, but subtle, shifts in communities (Gray et al, 1990; Warwick and Clarke, 1991), we used two approaches to test for compositional changes between years. First, an analysis of similarity (ANOSIM; Clarke, 1993) was used to contrast data in each stage level. ANOSIM calculates the difference between the mean rank of between-group dissimilarity with the mean rank of within-group dissimilarity from field data. This number is compared to differences generated after samples have been randomly assigned to groups. Cover values for each species were relativized to a proportion of

that species' maximum at that stage level and the Bray-Curtis index was used to calculate dissimilarities (Faith et al, 1987). We analyzed each stage zone separately for among-year changes. When an ANOSIM analysis detected a statistical difference among years, we made pairwise comparisons (2001 vs. 2002, 2001 vs. 2003 and 2002 vs. 2003) to determine which years were driving the results. Because these were not independent tests, we used the Bonferroni adjustment to keep the overall alpha level at 0.05 (Sokol and Rolf 1995; page 240). In cases where the ANOSIM analysis detected a significant compositional change, we used indicator species analysis (Dufrêne and Legendre, 1997) to determine whether species turnover was taking place without being manifested in species richness or total cover comparisons. Indicator species uses information on the abundance (mean abundance per sample within each group vs. mean abundance in all groups) and frequency (proportion of samples in a group with that species) to discern which species "indicate" a particular group. Data sets from each stage level were analyzed separately. Species were considered good indicators only if their indicator value was greater than 25 and Monte Carlo simulations showed that their indicator value was larger than those found in 90% of simulated random samples.

Surface texture analysis. Data on substrates at stage levels at the transects were reduced to simplify analyses. We collapsed all readings into a proportion of sand and silt points because that class of sediment would have the greatest impact on plants. Because the rotating panel sampling design resulted in an unbalanced data set (not all plots were surveyed in all years), we used an unbalanced, mixed-effects analysis of variance which included year (2001, 2002, and 2003), zone (15, 25, 35, 45, and 60 kcfs) and width (per Schmidt and Graf 1990: narrow and wide) as fixed effects, transect site as a random effect nested within canyon width, and the year by zone interaction and year by width interaction. The presence of a random effects factor required us to use a restricted maximum likelihood method to fit the model (SAS Institute Inc., 2001). In cases where there was a significant difference among years, we substituted measures of the pre-trip hydrograph (minimum, maximum, mean and fluctuation top) and an index of pre-trip monsoon precipitation (see VEGETATION STRUCTURE section above for a full description of how these were calculated) as continuous variables for the "year" term to determine what effects changes in water availability from different sources had on substrate texture.

Results:

Univariate Vegetation Measures. At all stage levels, the analysis showed a loss of total vegetative cover in 2002 and 2003 (Figure 2, Table 3). Although we expected cover change to be negatively correlated with flow parameters in the lowest zones due to scour and flooding, coefficients were negative for all zones where significant changes were found (Table 3). There was no relationship, even at the higher zones, between relative precipitation and cover change.

Species richness also changed significantly between 2001 and 2003, but in a slightly different way (Figure 3, Table 3). There was a significant drop in richness between 2001 and 2002, and a recovery of richness in 2003. However, within individual flow levels, only richness at the 15, 45, and 60 kcfs zones changed to a degree that was statistically detectable (Table 4). Richness decreased at the 15 kcfs level and dropped much more sharply in 2003. This pattern was related to scouring by higher flows, and not to precipitation patterns. At the 45 and 60 kcfs levels, there were strong year effects which were related to precipitation and not to flow patterns (Table 4). There were no statistically detectable changes in richness at the 25 and 35 kcfs elevations between 2001 and 2003. However, even though years were not statistically different,

when flow and precipitation parameters were substituted for the "year" effect in the analysis both coefficients were positive which we would expect, based on results from the Vegetation Structure analysis.

Although based on calculations which use abundance and richness, the Shannon diversity (H') indices behaved differently that either of them in our plots (Figure 4, Table 5). There was no difference among years at the 15 kcfs stage elevation. At the 25 and 35 kcfs elevations, there were large differences among years, and these were related primarily to flow means and, to a lesser extent, relative precipitation. At the 45 and 60 kcfs stage elevation, there were also significant year-to-year differences in H', but these were driven more by precipitation patterns than by river stage.

The wetland scores of plots changed across years as well ($F_{(2, 616)} = 5.01$, $p < 0.05$; Figure 5). The overall difference however did not manifest itself in any of the individual stage elevations where smaller sample size decreased our power to detect change. Because there was no interaction between year and zone ($F_{(8,616)} = 0.515$, n.s.), we substituted relative precipitation and flow mean for year in the overall analysis. Both had small, but significant, negative effects on wetland score indicating that as flow levels and precipitation increased, plants in the plots tended to have more upland characteristics.

Compositional analysis. The analysis of similarity analyses showed that higher elevation plots changed more in terms of species composition than the low elevation plots. There was a slight shift in the 15 kcfs plots ($R = 0.028$, $p = 0.022$), but none of the pairwise comparisons among years was less likely than the Bonferroni-adjusted alpha level. There were no differences among plots' composition in any of the years at the 25 kcfs stage level ($R = 0.006$, n.s.). At the 35 kcfs level, the overall difference among all three years ($R = 0.032$, $p = 0.0022$) reflected a strong difference between 2002 and the other two years. At both the 45 kcfs and 60 kcfs stage level, there were strong differences among all years at both levels.

Much of the differences between years, where they appeared, can be attributed to the loss of annuals, especially the Bromes, in 2002, and the lack of a complete recovery in 2003. Indicator species analysis showed that the lack of Bromes (*Bromus rubens and Bromus tectorum*) in 2002 and 2003 was the only consistent change among years at the 15, 35, 45, and 65 kcfs stage elevation. Three-awn (*Aristida purpurea*) was more abundant in 2003 than in the other years at the three highest stage elevations. There were no species which set the 2002 plots apart at any stage elevation.

Substrate texture. The surface texture of soils in the plots changed only in the lowest plots (Figure 6). Fines were lost both between 2001 and 2002 and between 2002 and 2003 ($F_{(2, 29)} = 5.61$, $p < 0.05$). This pattern primarily was related to the negative effects of higher fluctuation top ends ($F_{(1,31)} = 7.51$, $p < 0.05$) and, marginally, to relative monsoonal precipitation ($F_{(1, 31)} = 3.27$, $0.05 < p < 0.10$).

Summary:

Below average precipitation in both 2002 and 2003 and higher flows and flow fluctuations in 2003 led to a series of changes in the riparian zone vegetation in Grand Canyon. Increasing mean flows were correlated with higher species diversity and richness, and lower levels of vegetative cover in the plots. The latter result does not make sense to us and is likely the result of one or more factors. First, the use of flow parameters from only the 30 days prior to launch may have not been an appropriate lead time. The flows from the spring and mid-summer may have had more of an effect on plant establishment and growth, and would have yielded

different results. Second, the data represent only three years – one baseline year and two years of change in the system. The correlations we showed may simply be spurious and will disappear with more diversity of conditions in the data set.

Flow fluctuations were also correlated with the loss of fine sediments in the lowest zone. This was expected for two reasons. First, we predicted a major change in substrate texture, a drop of 20% of silt and sand in the 15 kcfs zone in a year when that zone was regularly inundated and flows could remove the finer sediments. These results were obtained in a year when our statistical power was reduced because many of the plots were underwater at the time of the survey. And second, we expected to see no change in the texture of substrates in the upper elevation plots where no inundation occurred and no change would be expected.

Precipitation effects were detected in species richness and diversity measures in the upper elevations of the riparian zone. Precipitation, relative to seasonal norms, was responsible for increases in species richness in both the 45 and 60 kcfs plots, most likely due to the increase in the establishment of annuals in wetter years. Increases in the H' diversity across all but the lowest plots likely results from the increases in abundances of these same rare species.

The negative affects of precipitation (and to a lesser extent, flows) on wetland scores of the plots results from the same phenomenon, but requires some further explanation. The species which germinate and grow during wetter years are those annuals which are categorized as either upland or facultative upland species, such as annual bromes and mustards. When moisture conditions allow them to establish in the lower elevation plots, they shift the mean value for the entire plot lower (towards less wetland-ishness). The drought of 2002 had the effect of removing these species from the lower plots and thus, paradoxically increasing the wetland scores there. In other systems, and over longer time span (e.g., Stromberg et al. 1996) drought and dewatering may produce more intuitive results in which drier conditions produce a more xeric flora. Here, over such a short period, there is no adjustment in the major species.

Most of the conclusions drawn in this section will remain tenuous at best until more time has elapsed. The greatest allies of trend detection are time and consistently applied methods (Urquhart et al. 1993). We expect that some of our conclusions, especially those relating high flows to low cover, will change. If the cover decreases in 2002 and 2003 are actually the result of below average precipitation first killing many plants and then not allowing new establishment to follow, then two years with above average precipitation and higher flows will change the relationship entirely. In contrast, we expect that other results, such as the correlation between flows and diversity and richness in the mid-elevation plots will be strengthened as more years of data are added.

Literature Cited

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology. 18:117-143.

Dufrêne, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecological Monographs. 67:345-366.

Faith, D.P., P.R. Minchin and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio. 69:57-68.

Floyd, D.A. and J.L. Anderson. 1982. A new point interception frame for estimating cover of vegetation. Vegetatio. 50:185-186.

Gray, J.S., K.R. Clarke, R.M. Warwick and G. Hobbs. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series. 66:285-299.

Korman, J. and Walters, C. 1998. Users guide to the Grand Canyon Ecosystem Model. G.C.M.R.C. anonymous FTP site. http://ftp.gcmrc.gov/model/. 49 pages.

Randle, T.J. and E.L. Pemberton. 1987. Results and analysis of STARS modeling efforts of the Colorado River in Grand Canyon. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center, Flagstaff, AZ. NTIS report no. PB88-183421.

Reed, P.B. 1988. National list of plant species that occur in wetlands: southwest (region 7). United States Fish and Wildlife Service Biological Report 88 (26.7). 71 pages.

SAS Institute Inc. 2001. JMP Statistics and Graphics Guide, Version 4. SAS Institute, Inc., Cary, N.C., 634 pp.

Stromberg, J.C., Tiller, R. and Richter, B. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications. 6, 113-131.

Urquhart, N.S., Overton, W.S. and Birkes, D.S. 1993. Comparing sampling designs for monitoring ecological status and trends: impact of temporal patterns. *In* Barnett, V. and Turkman K.F. eds., Statistics for the environment. John Wiley and Sons, New York. pages 71-85.

Warwick, R.M. and K.R. Clarke. 1991. A comparison of some methods for analysing changes in benthic community structure. Journal of the Marine Biology Association of the United Kingdom. 71:225-244.

Table 1. Temporal sampling pattern design for vegetation transects surveyed for vegetation dynamics studies.

	2001	2002	2003	2004	2005	…
Repeat Panel	20	20	20	20	20	…
Rotate Panel 1	40			40		…
Rotate Panel 2		40			40	…
Rotate Panel 3			40			…
Total Sampled:	60	60	60	60	60	…

Table 2. Sediment classes used in substrate texture assessments.

Silt / Clay	Fine sediment with no detectible grittiness. May roll easily when moistened.
Sand	Gritty fine sediment, particles less than 2mm diameter.
< 1cm	Fine gravel between 2mm and 1cm along longest axis.
< 10 cm	Coarse gravel between 1 cm and 10 cm along longest axis.
< 1m	Cobbles, rocks and small boulders between 10 cm and 1m along longest axis.
< 10m	Boulders between 1 and 10 meters along longest axis.
Bedrock	Solid rock or cliff face more than 10 meters along longest axis.

Table 3. Results of ANOVA analyses of cover changes between 2001 and 2003. Only significant results are presented (n.s. = no statistical effect)				
Zone	Year Effect	Flow Minimum	Flow Coeff.	Precip
15 kcfs	$F_{(2,42)} = 3.301$ $p < 0.05$	$F_{(1,43)} = 6.651$ $p < 0.05$	-0.003687	n.s.
25 kcfs	$F_{(2,46)} = 5.287$ $p < 0.05$	$F_{(1,47)} = 4.744$ $p < 0.05$	-0.003037	n.s.
35 kcfs	$F_{(2,44)} = 6.604$ $p < 0.05$	$F_{(1,45)} = 10.140$ $p < 0.05$	-0.003282	n.s.
45 kcfs	$F_{(2,42)} = 3.816$ $P < 0.05$	n.s.	n.s.	n.s.
60 kcfs	$F_{(2,40)} = 9.450$ $p < 0.05$	$F_{(1,41)} = 3.301$ $p < 0.05$	-0.004553	n.s.
Flow Coeff. = coefficient of flow effect in model with flow and relative precipitation				

Table 4. Results of ANOVA analyses of richness changes between 2001 and 2003. Only significant results are presented (n.s. = no statistical effect)				
Zone	Year Effect	Flow Minimum	Flow Coeff.	Precip
15 kcfs	$F_{(2,42)} = 3.780$ $p < 0.05$	$F_{(1,43)} = 12.221$ $p < 0.05$	-0.000687	n.s.
25 kcfs	n.s.	n.s.	n.s.	n.s.
35 kcfs	n.s.	n.s.	n.s.	n.s.
45 kcfs	$F_{(2,42)} = 6.745$ $P < 0.05$	n.s.	n.s.	$F_{(1,43)} = 8.142$ $P < 0.05$
60 kcfs	$F_{(2,40)} = 9.450$ $p < 0.05$	n.s.	n.s.	$F_{(1,41)} = 6.720$ $P < 0.05$
Flow Coeff. = coefficient of flow effect in model with flow and relative precipitation				

Table 5. Results of ANOVA analyses of diversity (H') changes between 2001 and 2003. Only significant results are presented (n.s. = no statistical effect)				
Zone	Year Effect	Flow Minimum	Flow Coeff.	Precip
15 kcfs	n.s.	n.s.	n.s.	n.s.
25 kcfs	$F_{(2,44)} = 28.6331$ $P < 0.05$	$F_{(1,46)} = 64.840$ $p < 0.05$	0.0001642	$F_{(1,46)} = 24.085$ $P < 0.05$
35 kcfs	$F_{(2,44)} = 33.457$ $P < 0.05$	$F_{(1,46)} = 75.093$ $p < 0.05$	0.0001612	$F_{(1,46)} = 26.889$ $P < 0.05$
45 kcfs	$F_{(2,44)} = 11.982$ $P < 0.05$	$F_{(1,46)} = 17.012$ $p < 0.05$	0.0000772	$F_{(1,46)} = 28.144$ $P < 0.05$
60 kcfs	$F_{(2,44)} = 7.974$ $P < 0.05$	$F_{(1,46)} = 7.030$ $p < 0.05$	0.0000809	$F_{(1,46)} = 21.537$ $P < 0.05$
Flow Coeff. = coefficient of flow effect in model with flow and relative precipitation				

Figure 1. Diagram of sampling scheme in plan view. Transect (thick line) is perpendicular to river flow, running from documented top point (Circle X) to the water's edge. Meter-squared survey plots (shaded boxes) are placed up- and downstream of the transect at estimated stage elevation points. Elevation control point (Circle Cross) is positioned so as to allow a view of the entire transect.

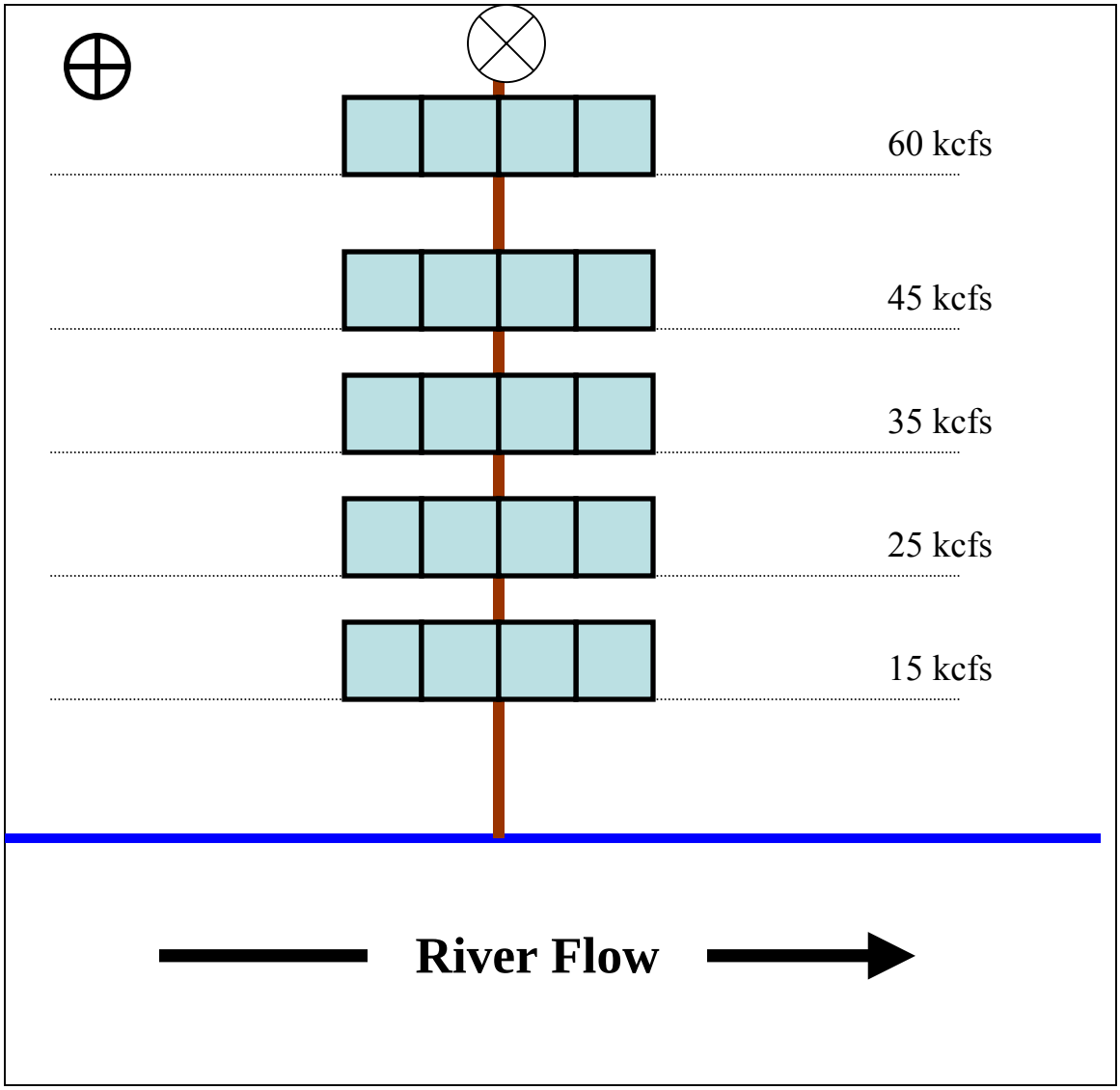


Figure 2. Percent vegetative cover at five stage elevation zones between 2001 and 2003. Vertical bars represent +/- 1 standard error.

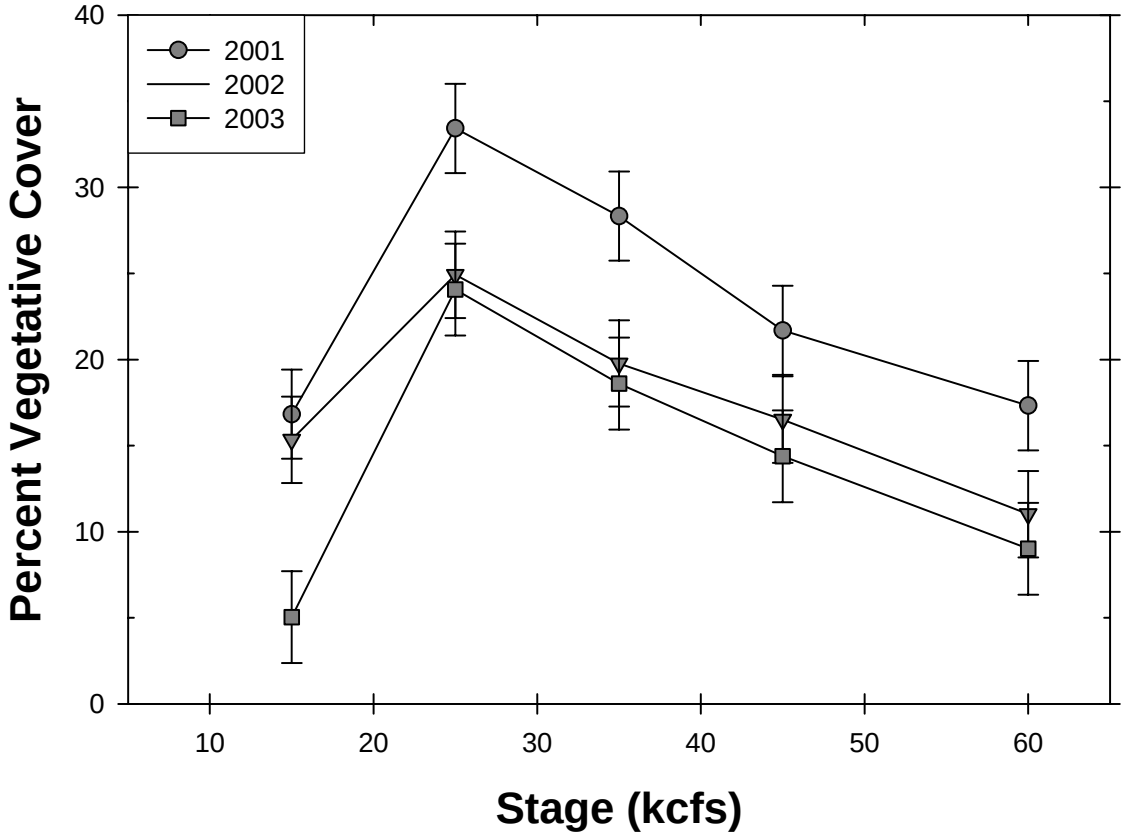


Figure 3. Species richness in five stage zones in 2001 and 2002, and change between year. Vertical bars represent +/- 1 s.e.

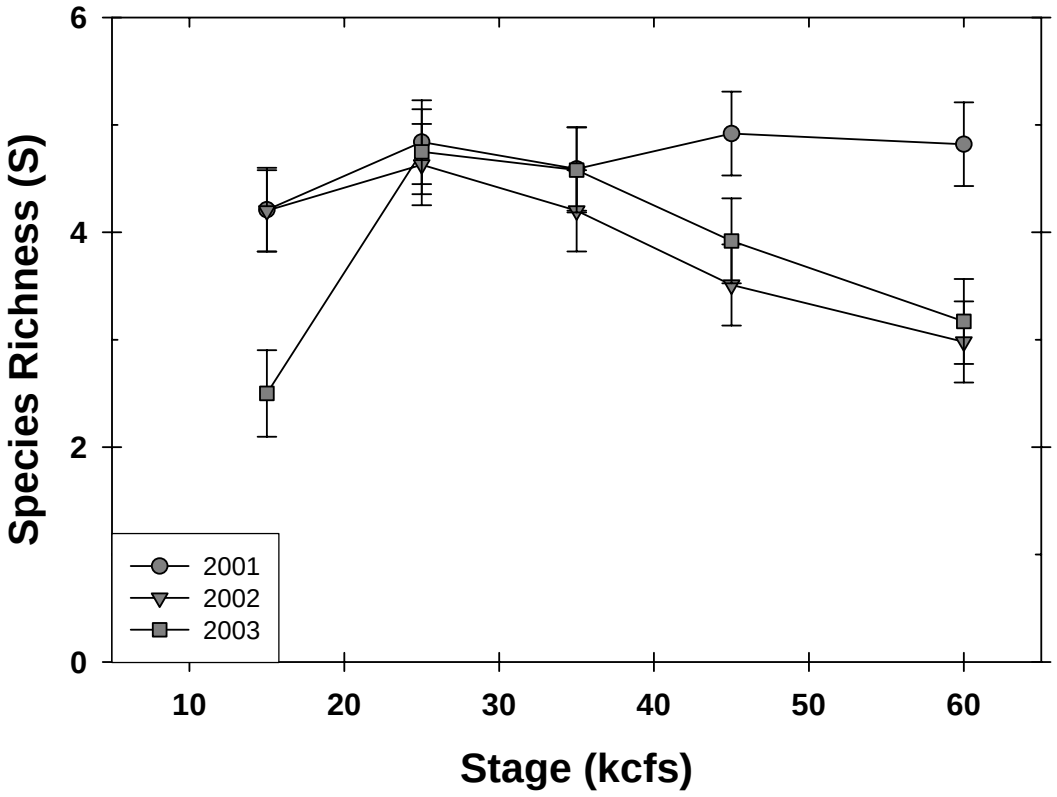


Figure 4. Shannon diversity (H') in five elevation zones between 2001 and 2003. Vertical bars represent +/- 1 s.e.

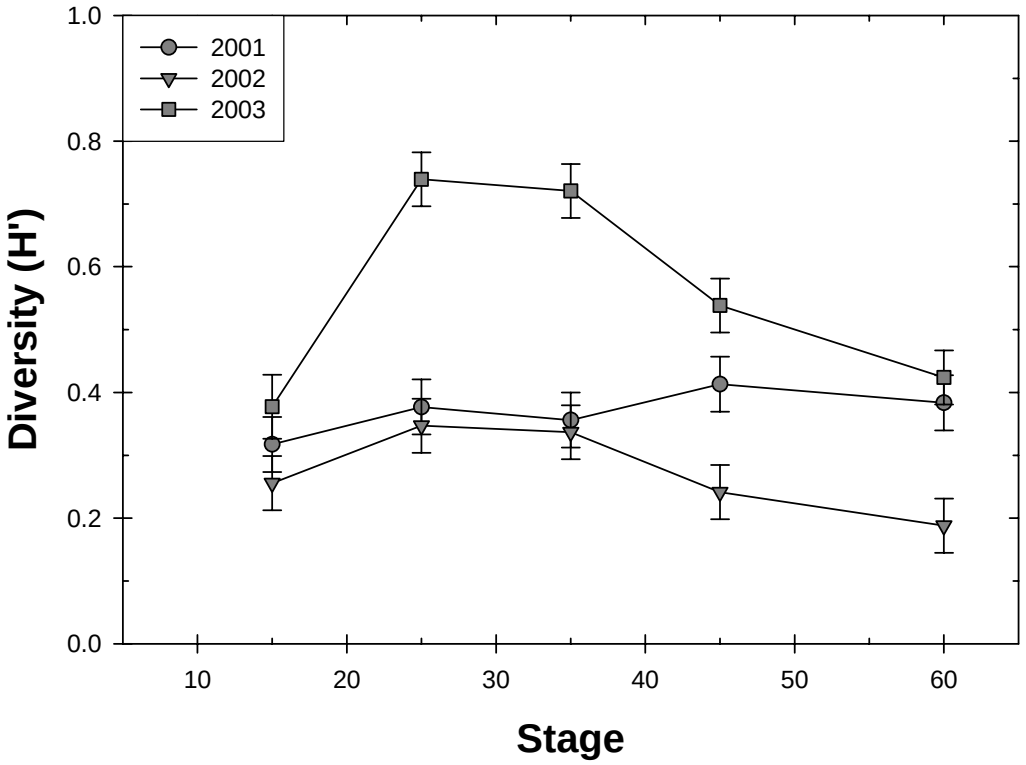


Figure 5. Wetland indicator scores in five elevation zones between 2001 and 2003. Higher scores represent more wetland affiliation. Vertical bars represent +/- 1 s.e.

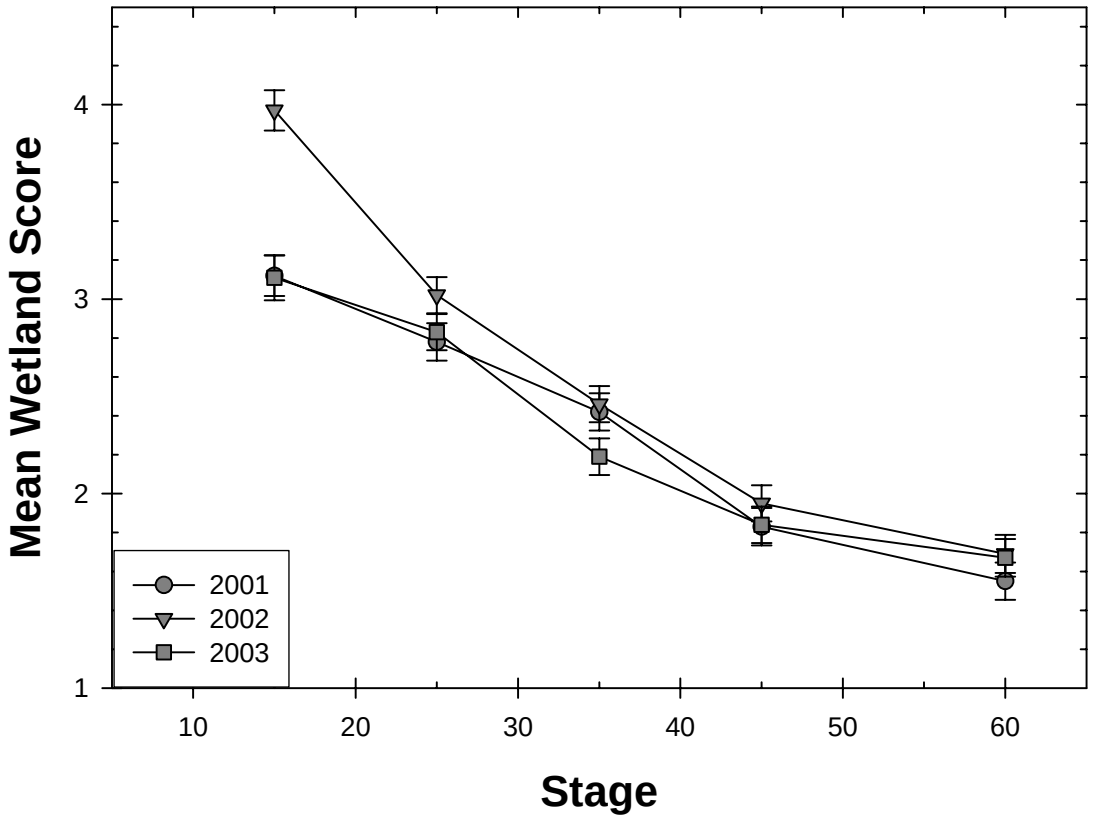
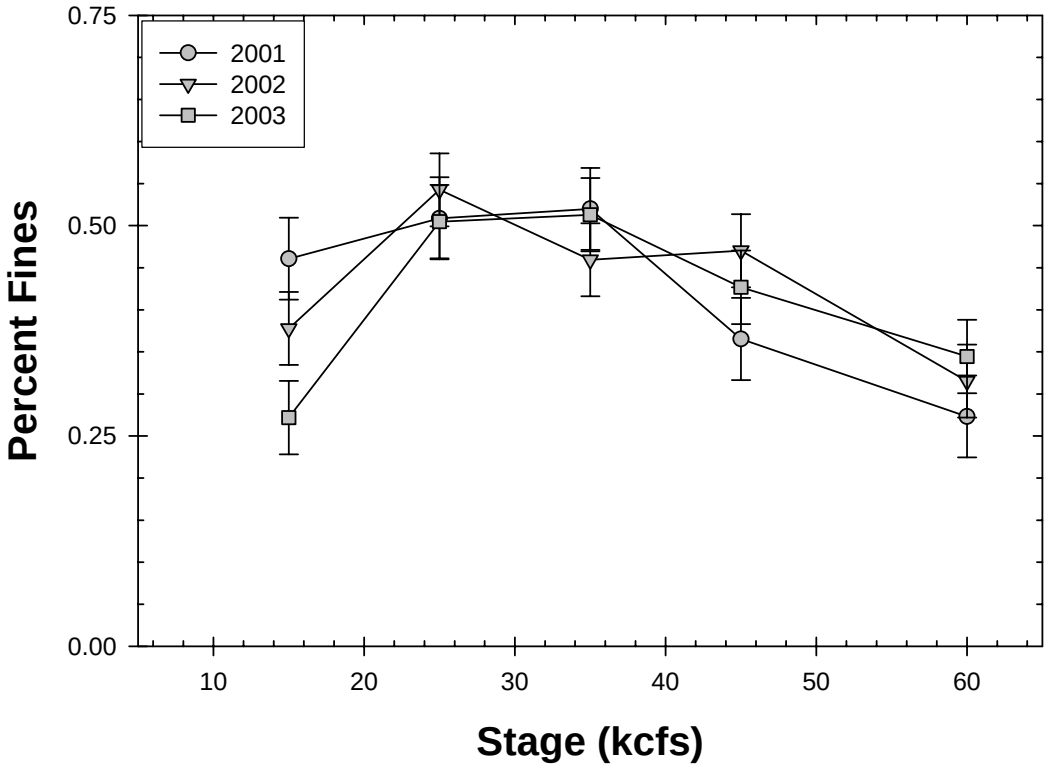


Figure 6. Soil texture changes between 2001 and 2003 in five elevation zones. Data represent the percent of points at the stage zone covered by sand or finer sediments. Vertical bars represent +/- 1 s.e.



OVERWINTERING RIPARIAN BIRDS, WATERFOWL AND RAPTORS

Helen Yard
Helen Yard Consulting

Aims of surveys:

1. Continue to document the abundance, spatial distribution and composition of over wintering aquatic birds, raptors and riparian birds in the river corridor by using boat-based surveys and area searches (walking surveys).
2. To determine trends in abundance and distribution of over wintering aquatic birds and raptors as related to river productivity which is known to decrease exponentially downstream from Glen Canyon Dam, and to determine trends in the abundance and distribution of winter riparian bird species in the vegetation along the river corridor.

Methods:

Trip Dates: January 26 - Feb 5, 2002 (11 days); January 18 – 29, 2003 (11 days). No winter trip was conducted in 2001. One motorized snout boat was used for winter bird surveys both years to be consistent with winter bird counts conducted since 1993 (Sogge et al. 1998, Spence 1998b). Use of motorized rafts maximized the number of patches we were able to survey for riparian birds between one hour after sunrise and dusk each day.

Locality: Surveys for aquatic birds and raptors were conducted from Glen Canyon Dam to Lake Meade. Over-wintering riparian bird surveys were conducted at pre-selected sites from Lees Ferry – Lake Meade.

Recording methods for aquatic birds and raptors: Waterfowl and raptor abundance were estimated using methods consistent with Stevens et al. (1997). In summary, aquatic birds (ducks, geese, wading birds, and shorebirds) and raptors were counted and identified by one to three observers from a motorized raft moving slowly downstream. Only birds that passed by the boat or flew upstream were counted, providing a conservative estimate of abundance. Criteria recorded for surveys included start and stop times, species, number of birds, river mile and geomorphic reach as defined by Schmidt and Graf (1990; Winter Birds Table 1).

Recording methods for riparian birds: Abundance and density of riparian birds was estimated using walking surveys (area searches), consistent with methods in past winter-bird studies (Sogge 1997, Spence 1998b, 2000. Two surveyors walking concurrently in each vegetation zone conducted searches. Recorded criteria included site (river mile and side of river), zone, species and number of birds, activity (sing, call, perch, fly, forage), and substrate where birds were detected. Surveys began ~1 hour after dawn and continued until dusk when necessary.

Quality control on data sheets and files: One individual recorded waterfowl and raptor data in a waterproof notebook as we proceeded downstream from Glen Canyon Dam to Lake Meade. Riparian bird counts were recorded onto data sheets made in advance of the trip. At the end of each day, all data was stored in a waterproof ammo can. During the river trip, the data was entered into excel spreadsheets on a laptop computer giving us both hard and electronic copies. Excel spreadsheets with all winter data were saved onto computer hard drives and backed up on CD's in the office of Helen Yard Consulting then sent via electronic file to GCMRC.

Statistical methods: Waterfowl counts were standardized for species/area effects (each reach being a different length and width) using the formula for Adjusted Rate of Encounter

[AARE = (Number of birds)/ (Reach Area)/ (Duration of observation)] described by Stevens et al. (1997). No adjustments or statistical analyses were necessary for reporting raptor abundance by reach. Abundance and density of riparian birds was compared between zones by Students paired-t tests. Yearly comparisons of abundance and density were assessed with Analysis of Variance (ANOVA; Sokal and Rolf 1995) in only those sites surveyed both years of the study. Density was calculated by dividing the number of birds by the site area in hectares (ha). GCMRC GIS personnel digitized hectares of each vegetation zone and total area of avian survey sites from aerial photographs.

Results:

Aquatic birds: Three surveyors counted waterfowl by geomorphic reach from a motorized boat from Glen Canyon Dam to Lake Meade during the winter field trips.

2002 - We counted 2365 individuals of 18 species of waterfowl between reaches 1 – 13. The highest number of aquatic birds was counted in Reach 1 (Glen Canyon Dam [RM –15.0]) to Paria Creek [RM 0.6]) through Reach 2 (from Paria Creek [RM 0.6]to around Soap Creek [RM 10]) (Winter Birds Table 2). Numbers dropped dramatically from Reach 2 through 4, rose slightly in Reach 5 (above the Little Colorado River), then dropped as we went downstream (Winter Birds Fig. 1). These findings are consistent with past waterfowl studies (Stevens et al. 1997, Spence 1996 - 2000) and with river productivity and sediment data collected by M. Yard (Ph.D. dissertation).

2003 – A total of 3698 aquatic birds of 17 species were counted between Reaches 1 – 13 (Winter Birds Table 3). Again, the highest numbers of aquatic birds were counted in Reaches 1 –2, dropping through Reaches 3-4, rising in numbers through Reach 5, and dropping exponentially until Reach 13 (Lake Meade; Winter Birds Fig. 1). These data exemplified the drop in aquatic bird abundance related to the exponential increase in sediment and decrease of productivity going downstream from Glen Canyon Dam to Lake Meade.

During 2002 and 2003, the abundance of aquatic birds was similar (Winter Birds Table 2), though in the graph showing both years for area adjustment rate of encounter, it appeared that Reach 1 in 2002 had fewer birds. This was an artifact of the AARE; abundance of aquatic birds was actually higher in Reach 1.

Raptors:

2002 - A total of 21 raptors of six different species were counted from Glen Canyon Dam to Lake Meade. The highest number of raptors was counted in Reach 2. Bald Eagle was the most common raptor seen (Winter Birds Table 2).

2003 – At total of 18 raptors of five species were counted during the winter trip 2003. Bald Eagle was the most common raptor seen, consistent with the 2002 data and raptor counts from previous studies (Spence 1998b, 2000; Stevens et al. 1997). Higher numbers of raptors, primarily Bald Eagles, were detected in Reaches 3 –5 (Winter Birds Table 3).

Riparian Birds:

2002 - Of the 56 patches surveyed during the 2001 breeding season, 37 were surveyed for winter riparian birds (Winter Birds Table 3). Shorter trip and day lengths restricted the number of surveys we were able to conduct. We counted 184 individuals of 20 species of birds in the riparian vegetation from Lees Ferry to Lake Meade during the winter trip, 2002. Concurrent surveys in both vegetation zones revealed 115 birds of 16 species in the NHWZ and 67 birds of 15 species in the OHWZ. No difference was found in the distribution ($t = 0.7$, $p = 0.5$; Winter

Birds Fig. 2) or density of winter riparian birds between vegetation zones ($t = -0.4$, $p = 0.7$; NHWZ mean density = 3.7 ± 1.5, OHWZ mean density = 5.2 ± 3.3).

2003 – Of the 61 patches we surveyed during the 2002 breeding season, 37 were surveyed during the winter trip, 2003 (Winter Bird Table 3). We counted 101 individuals of 16 species of birds in the riparian vegetation from Lees Ferry to Lake Meade during the winter trip, 2003. Concurrent surveys in both vegetation zones revealed 61 birds of 15 species in the NHWZ, and 43 birds of 13 species in the OHWZ. No difference was found in the distribution ($t = 0.9$, $p = 0.4$; Figure 3) or density of birds between vegetation zones ($t = 0.5$, $p = 0.7$; NHWZ mean density = 3.1 ± 1.1, OHWZ mean density 2.9 ± 1.8).

Between-year Comparisons

Sixteen sites were surveyed for riparian birds in both 2002 and 2003 (Winter Bird Table 3). No difference was detected in riparian bird abundance (ANOVA: $F_{1,62}$ 2.0, $p = 0.16$) or density (ANOVA: $F_{1,54}$ 0.67, $p = 0.42$) at sites surveyed both years. The ranks of the 10 most common species in order of abundance are shown in Winter Birds Table 4. Sites surveyed both 2002-2003 are listed in Winter Birds Table 5.

Summary/Discussion:

1. Waterfowl abundance drops longitudinally as you move downstream from Glen Canyon Dam to Lake Meade which is clearly related to sediment input and dropping river productivity as you move downstream. These findings are consistent with previous studies on aquatic birds and current studies on light attenuation and sediment input into the river.
2. Raptors are distributed throughout the canyon with Bald Eagle being the most common raptor detected during both 2002 and 2003 winter bird surveys.
3. Ruby-crowned kinglet was the most common winter riparian species during both years of winter riparian bird surveys. No difference in density or abundance of winter riparian birds was found between zones or between years.

Aquatic Birds

Prior to the construction of Glen Canyon Dam, large populations of aquatic birds were rare or non-existent. Presently, large aggregations of aquatic birds are seen along the Colorado River during winter months due to high productivity in the clear, cold water being released from the Dam (Stevens et al. 1997). These aquatic bird communities on the Colorado River show fluctuations in species composition and abundance between years (Winter Bird Tables 2 and 3). The resources available to waterfowl in the study area are relatively stable given similar flows, with primary productivity greatest near the dam with a rapid drop downstream as the river becomes more turbid. Hence, year-to-year fluctuations detected in aquatic bird numbers and composition during two years of study were probably related to factors that extend beyond the study area and which are not directly related to dam operations. Factors likely to affect winter bird numbers along the Colorado River may include conditions on breeding grounds to the north, and fall and winter weather patterns in association with migration patterns.

Riparian Birds

We found no difference in the composition, distribution or density of winter riparian birds between zones or between years. The vegetation in both zones, being deciduous, was without leaves in the winter and birds appeared to be using both zones equally. The most common riparian bird species, Ruby-crowned Kinglet, is a small insectivore that forages on vegetation by gleaning and hovering. We speculate that this bird is well suited to take advantage of small insect prey found in high abundance along the river in the winter (Chironomidae midges, results reported elsewhere in this report).

As with aquatic birds, species composition and abundance of winter riparian birds are most likely to be affected by fall and winter weather patterns and do not appear to be directly affected by dam operations. Minor changes in bird species composition between years (Winter Bird Table 4) were probably related to precipitation and food availability. Our intent is to continue monitoring aquatic birds, raptors and riparian birds in 2004. With three years of data, we will present a more thorough trend analysis on winter birds at the end of 2004.

Winter Birds Table 1. Geomorphic reaches described by Schmidt and Graff (1990). Reaches were modified by Stevens et al. (1997).

Reach #	Reach name	River Miles	River Kilometers
1	Glen Canyon	-15.0 – 0.6	-24.6 – 1.0
2	Permian Gorge	0.6 - 10.8	1.0 – 17.7
3	Supai Gorge	10.8 - 2.1	17.7 – 36.2
4	Redwall Gorge	22.1 - 39.3	36.2 – 64.4
5	Marble Canyon	39.3 – 60.1	64.4 – 98.6
6	Furnace Flats	60.1 – 75.9	98.6 – 124.5
7	Upper Granite Gorge	75.9 – 115.6	124.5 – 189.5
8	The Isles	115.6 – 123.2	189.5 – 201.9
9	Middle Granite Gorge	123.2 – 137.4	201.9 – 225.3
10	Muav Gorge	137.4 – 157.0	225.3 – 257.4
11	Lower Canyon	157.0 – 209.9	257.4 – 344.1
12	Lower Granite Gorge	209.9 – 235.6	344.1 – 386.2
13	Upper Lake Mead	235.6 – 273.8	386.2 – 448.9

Winter Birds Table 2. Number of raptors and aquatic birds counted by reach, 2002.

		Reach													
		1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	Species														
Raptors	Bald Eagle	0	1	1	2	2	0	0	2	0	0	0	0	0	8
	California Condor	0	5	1	0	0	0	0	0	0	0	0	0	0	6
	Sharp-shinned Hawk	0	0	0	0	0	0	0	0	0	0	0	0	3	3
	Northern Harrier	2	0	0	0	0	0	0	0	0	0	0	0	0	2
	Golden Eagle	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	Peregrine Falcon	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	Total species = 6	2	6	3	3	2	0	0	2	0	0	0	0	3	21
Aquatic birds	Common Goldeneye	209	200	5	19	73	21	0	0	0	0	1	0	0	528
	Lesser Scaup	362	28	0	0	0	0	0	0	0	0	0	0	0	390
	American Widgeon	266	37	0	0	0	0	0	0	0	0	0	0	1	304
	Mallard	56	149	10	14	0	5	0	1	0	0	0	0	0	235
	American Coot	84	167	0	0	0	2	0	0	2	0	2	1	5	263
	Bufflehead	144	53	4	0	0	0	0	0	0	0	0	0	0	201
	Common Merganser	34	22	38	0	49	7	3	0	0	0	0	0	1	154
	Gadwall	26	13	0	0	0	0	0	0	0	0	0	0	12	51
	Canada Goose	2	1	0	0	0	11	0	0	0	0	0	0	0	14
	Double-crested Cormorant	36	0	0	0	0	0	0	0	0	0	0	0	0	36
	Redheaded Duck	29	5	0	0	0	0	0	0	0	0	1	0	0	35
	Great Blue Heron	5	3	1	0	5	2	2	2	0	0	1	1	0	22
	Green-winged Teal	0	0	0	0	0	0	0	0	0	1	14	0	0	15
	Cinnamon Teal	7	0	0	0	0	0	0	0	0	0	0	0	4	11
	unidentified ducks	12	0	0	0	0	0	0	0	0	0	0	0	0	12
	Ring-necked Duck	4	0	0	0	0	0	0	0	0	0	0	0	0	4
	Ruddy Duck	3	0	0	0	0	0	0	0	0	0	0	0	0	3
	Belted Kingfisher	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	American Dipper	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	Total species = 18	1279	678	58	34	127	48	5	3	2	1	19	2	25	2281

Winter Birds Table 3. Number of raptors and aquatic birds counted by reach, 2003.

		Reach													
		1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	Species														
Raptors	Bald Eagle	0	2	3	4	3	0	0	0	0	0	0	0	0	12
	Sharp-shinned Hawk	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Golden Eagle	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Coopers Hawk	0	0	0	0	0	1	0	0	0	0	0	1	0	2
	Red-tailed Hawk	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Total Species = 5	0	2	3	4	3	1	0	0	0	0	0	2	2	17
Aquatic birds	Common Goldeneye	873	218	0	32	261	77	0	0	0	0	0	0	0	1461
	Lesser Scaup	605	0	112	0	0	0	0	0	0	0	0	0	0	717
	American Widgeon	207	109	3	0	8	4	0	0	0	0	0	0	0	331
	Mallard	53	82	9	0	73	0	0	0	0	0	0	0	47	264
	American Coot	144	84	0	0	0	0	0	0	0	0	0	0	3	231
	Bufflehead	247	29	1	0	0	0	0	0	0	0	0	0	0	277
	Common Merganser	34	14	2	12	1	0	4	0	0	9	1	0	0	77
	Gadwall	17	0	0	0	0	0	0	0	0	0	0	0	11	28
	Canada Goose	0	0	0	0	9	10	0	0	0	0	0	0	22	41
	Double-crested Cormorant	27	0	0	0	0	0	0	0	0	0	0	0	8	35
	Redheaded Duck	18	0	0	0	0	0	0	0	0	0	0	0	0	18
	Great Blue Heron	4	4	1	1	1	0	3	1	1	0	0	1	11	28
	Green-winged Teal	0	0	0	0	5	0	3	0	0	10	0	0	133	151
	unidentified ducks	0	0	1	5	0	0	0	0	0	0	0	0	2	8
	Ruddy Duck	26	0	0	0	0	0	0	0	0	0	0	0	0	26
	Belted Kingfisher	0	0	0	0	0	0	0	0	1	0	0	0	0	1
	Spotted Sandpiper	0	0	0	0	1	0	0	0	0	0	0	0	2	3
	Surf Scoter	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	Total Species = 17	2255	540	129	50	360	91	10	1	2	19	1	1	239	3698

Winter Birds Table 4. Ranks of most common winter riparian birds counted in 2002 – 2003.

2002	Rank	2003
Ruby-crowned Kinglet	1	Ruby-crowned Kinglet
Horned Lark	2	Canyon Wren
White-crowned Sparrow	3	House Finch
Western Bluebird	4	*Western Bluebird
		*Song Sparrow
*Song Sparrow	5	Dark-eyed Junco
*Bewick's Wren	5	
Pinon Jay	6	*Mountain Chickadee
	6	*Bewick's Wren
*Phainopepla	7	*Say's Phoebe
*Dark-eyed Junco	7	*American Robin
*Canyon Wren	7	
Red-naped Sapsucker	8	Red-naped Sapsucker
Common Raven	8	*Common Raven
		*Rock Wren
*Rock Wren	9	Orange-crowned Warbler
*Say's Phoebe	9	
*American Robin	10	*Golden-crowned Kinglet
*Northern Flicker	10	*Hairy Woodpecker

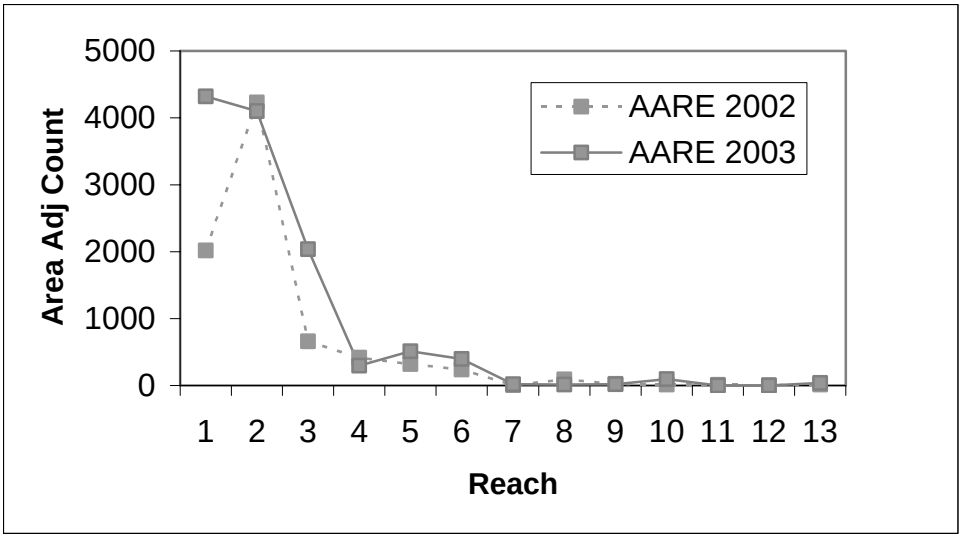
* Indicates tied ranks

Winter Bird Table 5. Sites surveyed for winter riparian birds, 2002 and 2003

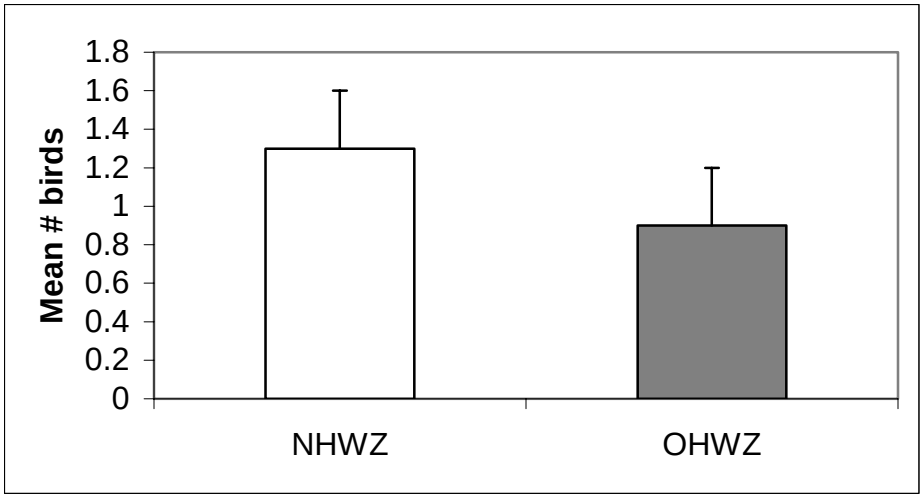
River Mile	Side	2002	2003
1.0	r	x	
1.6	r	x	
3.7	l	x	
5.1	r	x	x
5.8	r		x
8.0	l		x
22.0	r		x
22.3	r		x
25.0	l		x
37.3	l		x
38.6	l		x
40.6	r		x
40.8	r		x
41.5	r		x
43.1	l		
45.5	l		
46.7	r	x	x
47.5	l		
49.1	l	x	x
49.2	r		
50.0	r		x
50.4	l	x	x
65.3	l	x	x
74.4	r		x
92.3	l		
97.4	r		x
97.4	l		x
95.7	l		x
97.5	l	x	x
122.8	l	x	x
123.0	r		x
125.0	l	x	x
133.0	l		x
133.5	l		x
134.2	r		x
138.0	r		x
164.5	r		x
166.5	l	x	x

Winter sites cont.		2002	2003
168.8	r	x	
171.1	r	x	x
172.2	l	x	
174.2	r	x	
186.5	l	x	
189.0	r	x	
193.8	r	x	
194.0	l	x	
196.0	r	x	
197.6	r	x	
198.0	r	x	x
198.2	r	x	x
200.5	r	x	
202.0	r	x	
202.5	r	x	x
204.5	r	x	x
205.0	l	x	
206.5	r	x	
209.0	l		x
211.5	r	x	
213.6	l	x	
214.0	l	x	
214.2	l	x	
243.0	l	x	x
247.0	l	x	x
260.0	l	x	
Total sites surveyed		37	37

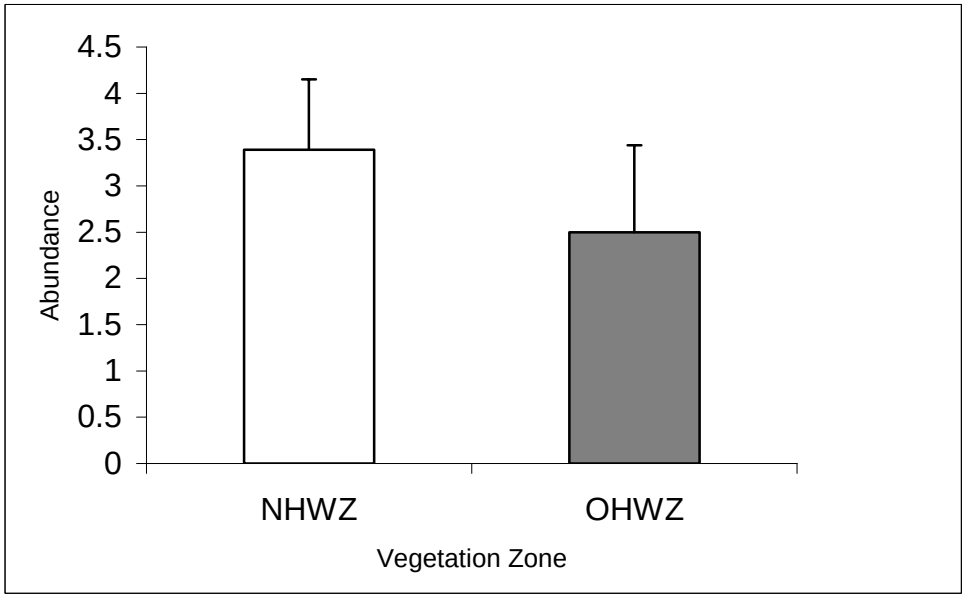
Figure 1. Area Adjusted Rate of Encounter (AARE) for years 2002 and 2003.



Winter Birds Figure 2. Mean number of birds counted in the New (NHWZ) and Old High Water Zone (OHWZ) vegetation, 2002.



Winter Birds Figure 3. Mean number of birds counted in the New (NHWZ) and Old High Water vegetation (OHWZ), 2003.



Southwestern Willow Flycatcher Surveys

Helen Yard
Helen Yard Consulting

Aims:
Surveys and nest searches for the endangered southwestern willow flycatchers are in compliance with Management Objective (MO) 11 essentially stating to "protect, restore, enhance survival of native and special status species" and MO 13 which reiterates MO 11 ("to protect, restore and enhance the survival" of specific species such as bald eagles, peregrine falcons and southwestern willow flycatchers"). Presence/absence surveys are also in compliance with U.S. Fish and Wildlife Service (USFWS) regulations.

Conduct surveys to determine presence/absence of Southwestern Willow Flycatchers at historically surveyed sites from Lees Ferry to Diamond Creek and 2) to document rates of nesting success of southwestern willow flycatchers when possible.

History:
Pre-dam information on the number of wifls along the river is sparse. During avian monitoring along the river beginning the 1980's, Brown (1988) found as many as 11singing males and two flycatcher nests during any one breeding season. Since then, the breeding population has fluctuated between one and four breeding pairs (Brown 1991, Sogge and Tibbitts 1992, Sogge et al. 1993, Sogge and Tibbitts 1994, Sogge et al. 1995, Petterson and Sogge 1996). From 1992 – 1996, cowbird parasitism was documented at high levels in flycatcher nests and nest productivity was low (Sogge 1998).

Methods:
Willow Flycatcher Surveys. Southwestern willow flycatcher surveys were conducted during the three USFWS required periods in 2001 and 2002. In 2003, two required surveys were conducted. Verbal permission was obtained to omit the first survey (May) period due to lack of logistical and financial support (per com Greg Beatty, USFWS). In past years, flycatchers detected during May surveys were most likely northbound migrants not detected in the June 15-21 and June 22-July10 surveys. GCMRC expressed interest in finding breeding flycatchers, therefore the May survey appeared less likely to reveal breeding pairs of birds. We surveyed most sites listed in historically accounts from Lees Ferry to Diamond Creek (Spence et al. 1998a). All surveys were conducted as per the official multi-agency protocol (Sogge, et al. 1997). In summary, these methods require the surveyor to walk through the site playing a tape or CD of the song and calls of the southwestern willow flycatcher every ~100 yards to induce a response from the birds. Survey forms issued by Arizona Game and Fish Department (AGF) were filled out at each site by biologists conducting the survey and returned to AGF by the required date.

Willow Flycatcher Nest Searches. Nest searches were conducted according to the official protocol (Rourke et al. 1999) where pairs of southwestern willow flycatchers were identified.

Results:

Willow Flycatcher Surveys.

2001: Ten of 16 historically surveyed sites were formally examined for willow flycatchers during the 2001breeding season (Table WIFL 1). As many as five willow flycatchers were detected at four different sites along the river corridor between Lees Ferry and Diamond Creek during 2001. One willow flycatcher was detected at RM 5.1-2R during May, two were detected during the early June survey, and two were detected during the last survey period. We cannot assume that the willow flycatcher observed during the second survey was the same bird found during the last survey without positive identification such as colored leg bands however we suspect the flycatcher at 50.4L in early June was one of a pair found in late June. Brown-headed cowbirds, nest parasites correlated with willow flycatcher declines throughout the southwest, were not detected during surveys at any of the sites where flycatchers were found.

2002: We surveyed 16 sites historically surveyed for southwestern willow flycatchers from Lees Ferry to Diamond Creek during the three required survey periods (Table WIFL 1). As many as four willow flycatchers were detected during formal surveys at three different sites along the river between Lees Ferry and Diamond Creek. During the May survey period, one flycatcher responded to the tape playback at RM 191.2R. During the second survey period, one willow flycatcher was detected singing at RM 50.4L and two (a breeding pair) of willow flycatchers was detected at RM 50.4L during the third survey period. The flycatcher found at 191.R during the second survey period was not detected in two later surveys strongly suggesting that the bird was a northbound migrant. The flycatcher at 50.4L was probably one of the pair found in the last survey however, none of the observed flycatchers were color banded therefore individuals could not be distinguished from one survey to the next. Brown-headed cowbirds were not detected during surveys at any of the sites where flycatchers were found.

2003: As many as eight willow flycatchers were detected in two surveys during June-July (WIFL Table 1). During the June 1 – 21 period, three willow flycatchers (a pair with one fledged young) were found at RM 28.3L during a general bird survey. Two flycatchers (a pair) were detected at RM 50.4L. This pair was determined to be in the nest building phase, though a nest was not located at that time. The pair with one young was most likely the same pair with a nestling during both the early and late June surveys. The three birds were not detected at the site in mid-July. No willow flycatchers were detected at RM 50.4L during the last required survey (see discussion). We speculate that a total of seven flycatchers were actually present at two sites (three at RM 28.3L and four at RM 50.4L) during the 2003 breeding season. Brown-headed cowbirds were not detected during surveys at any of the sites where flycatchers were found.

Willow Flycatcher Nest Search Results.

2001: We located a southwestern willow flycatcher nest at RM 50.4L on June 30. The nest was approximately 2 m high in a tamarisk tree 4 m from the river. The nest

contained two flycatcher eggs and one brown-headed cowbird egg. The completed Willow Flycatcher Nest Site Data Form was returned to AGF. Nest outcome was not determined.

2002: From territorial behavior exhibited by the willow flycatcher pair at 50.4L by the Arizona Game and Fish biologist, a nest was most likely present at the site. The biologist conducted a nest search according to the official protocol, but did not locate the nest. We were unable to access the site again during the breeding season to determine if there was a nest and the result of nesting if it had occurred at the site.

2003: Two pairs of willow flycatchers fledged a total of three flycatcher young in 2003. Both nests were constructed approximately 2-3 m high in tamarisk within 5 m of the water's edge. One pair fledged one flycatcher at the newly discovered nesting site at RM 28.3L. Two flycatcher young were fledged at RM 50.4L. This finding occurred during an additional river trip taken by the observer during mid-July, not during the required presence/absence surveys. The two completed Willow Flycatcher Nest Site Data Forms were returned to AGF and the finding of a new flycatcher pair at 28.3L was reported to Grand Canyon National Park biologists.

Summary/Discussion

Surveys during 2001- 03 revealed a low number of Southwestern Willow Flycatchers with a detection average of 3.5 birds along the Colorado River from Lees Ferry to Diamond Creek. These findings are consistent with past willow flycatcher surveys along the river in Grand Canyon (Brown 1991, Sogge and Tibbitts 1992, Sogge et al. 1993, Sogge and Tibbitts 1994, Sogge et al. 1995, Petterson and Sogge 1996). During May surveys conducted in 2001 and 2002, and in previous years of surveys (Sogge et al. 1993), flycatchers were detected at various large patches along the river between Lees Ferry and Diamond Creek. The river corridor as well as side canyon tributaries may play an important role in migrating willow flycatchers. NPS is presently removing tamarisk in selected side canyons. We recommend immediate replacement with native, woody vegetation in interest of migrating willow flycatchers and all migratory riparian birds. The experimental native re-vegetation project at Lees Ferry is an excellent example of rapid native vegetation replacement.

One speculation on why so few willow flycatchers have been found breeding between Lees Ferry and Diamond Creek may include lack or few areas with slow or still water along the river (marshes and permanent backwaters). Other important habitat criteria appear to include dense vegetation in the interior of the patch and saturated soil (Sogge and Marshall 2000). Southwestern willow flycatchers are known to occupy breeding habitat throughout the Southwest typically associated with these factors (Finch and Stoleson 2000). Other speculations of why there are so few willow flycatchers are in Grand Canyon may include small patch sizes compared with sites where numerous flycatchers are known to breed and perhaps the lack of preferred food resources. Brown (1991) found two to three nesting pairs along the river at sites containing marshes and standing water (Kwagunt [RM 56L] and Cardenas [RM 71.1L] marshes). Marshes at these sites have since dried up due to dam regimes and no willow flycatchers have been detected at these sites in several years (Sogge et al. 1995, Petterson and Sogge 1996,

Spence et al. 1998b, this report). Perhaps the lack of large marsh habitats is a limiting habitat factor for breeding flycatchers.

During 2001 and 2002, nest outcomes were not determined due to lack of trips available during that time period. Nest outcomes were assessed only during 2003 due to an additional trip not included in the scope of work. We suggest that if agencies (Grand Canyon Nation Park, USFWS, GCRMC) are primarily interested in breeding flycatchers along the river, a late-July, early-August visit to nest site(s) should be included if nest(s) are found during any of three required presence/absence surveys. This nest outcome visit and presence/absence surveys could be in coordination with other research trips in order to reduce logistics costs.

Cowbirds were not detected during surveys at breeding sites during flycatcher surveys, 2001 – 2003. During 2001, one cowbird egg was found with two flycatcher eggs in the nest at RM 50.4L but unfortunately we could not assess nest outcome. No cowbird fledglings were detected with the two nesting pairs that fledged young in 2003 (RMs 28.3 and 50.4). Brown-headed cowbirds are considered to be a problem in nesting success of willow flycatchers throughout the Southwest (Finch and Stoleson 2000). From our findings, we can only report that they appeared not to have an affect on nesting success in 2003. A personal observation during five years of bird surveys along the Colorado River is that cowbirds are not vocal during the breeding season and are therefore not often detected during surveys. During July, 2003, I observed numerous flocks of fledged cowbirds along the river from Lees Ferry to Phantom Ranch. Perhaps a better assessment of cowbird fledging success could be made in mid to late July.

A noteworthy incident which occurred this past season was that a biologist certified through the multi-agency training offered in Arizona (year 2000) did not detect willow flycatchers at the RM 50.4 site in June. No "fitz-bew" (classic flycatcher song) response was detected though the tape was played numerous times for a two hour period. The biologist admitted not being familiar with the full repertoire of flycatchers. Personally visiting the site in mid-July, I found a willow flycatcher nest, and a pair of flycatchers (presumably the same pair found in early June) feeding two fledged willow flycatchers at the site. Fortunately no information was lost due to an extra trip for assessing nesting status. In areas where there are very few willow flycatchers and solitary pairs may exist such as in Grand Canyon, there is a possibility of missing breeding birds unless surveyors are trained to recognize all songs and calls. I recommend that persons certified to conduct willow flycatcher surveys be familiar with all flycatcher songs and calls and not completely reliant on a "fitz-bew" response to the CD or tape playback.

In support of that recommendation, one pair of breeding southwestern willow flycatchers discovered in a new location in Grand Canyon (RM 28.3L) was found by auditory detection of other calls (creet, weoo, interactions) made by willow flycatchers. This site had never been surveyed for birds in the past and the finding was coincidental with a general bird survey showing the importance of surveying randomly selected sites. An interesting observation was that as in the case of the willow flycatchers at RM 50.4L,

this pair did not respond to the "fitz-bew" tape. The pair was detected solely upon other vocalizations and visual identification by me and two other experts (USFWS – Robert Mesta, Smithsonian Institute avian ecologist Peter Bichier Garrido). A hypothesis regarding this matter is that solitary pairs, not breeding in the usual "semi-colonial" fashion typical of this species, was not responsive to the tape due to lack of intra-specific interactions. Another factor may have been that the birds had already fledged young and were being very secretive. This reinforces the importance of surveyors being trained to identify all the songs and calls.

WIFL Table 1. Southwestern Willow Flycatcher Survey Results Years 2001, 2002, 2003

Dates	Survey 1 (May 15 - 31)			Survey 2 (June 1 - 21)			Survey 3 (June 22 - July 10)		
Site	2001	2002	2003	2001	2002	2003	2001	2002	2003
5.2R	ns	0	ns	1	0	0	0	0	0
28.3L*	ns	ns	ns	ns	ns	3	0	0	3
43.1 - 43.8L	ns	0	ns	0	0	0	0	0	0
46.5R	ns	0	ns	0	0	0	0	0	0
50.4L	0	0	ns	1	1	2	2**	2***	0****
51.4L	0	0	ns	0	0	0	0	0	0
56.0R	ns	0	ns	0	0	0	0	0	0
65.3L	ns	0	ns	0	0	0	0	0	0
71.1L	0	0	ns	0	0	0	0	0	0
143R	ns	0	ns	0	0	0	ns	0	0
191.1R	ns	0	ns	ns	0	0	0	0	0
191.2L - 196L	0	1	ns	ns	0	0	0	0	0
196 - 198L	ns	0	ns	0	0	0	0	0	0
196-198R	ns	0	ns	0	0	0	0	0	0
198R	ns	0	ns	0	0	0	0	0	0
198.3R	ns	0	ns	0	0	0	0	0	0
204.5R	0	0	ns	0	0	0	0	0	0
Total	0	1	0	2	1	5	2	2	3

ns - no survey

* A pair of swwfs with one fledged young were found during a general bird survey. No previous bird surveys at this site.

** pair of swwfs, nest with 2 swwf eggs, one bhco egg, outcome not determined

*** A pair of swfls was detected. The AGF observer suspected a nest from behavioral observation, but the nest was not found.

**** The pair of swwfs found in June was probably present at the site though did not respond to the fitz-bew tape. See text in report
The pair was located with two fledged swwfs in July.

Problematic issues in 2003

There were several problems with field work , analytic approaches, and overall sampling strategy which arose during 2003 and in earlier years. Many of these have been mentioned in the individual sections above and in previous reports. Below we bring up several which we felt bore repeating and further elaboration.

Mammal vouchering. The severe restrictions placed on our ability to voucher small mammals are still making it difficult to properly inventory this group and to collect useful monitoring data. Field identification, based on gross external morphology, cannot verify species identification. During last year's first river trip, two individuals of *Chaetodipus penicillatus* were identified in the field using standard field measurement techniques. When the professionally acceptable skull measurements were taken in the lab, however, they appeared to be closer to *C. intermedius*, although some ambiguity remains because the specimens' measurements are near the dividing line between the two species. This is an important question because the *C. penicillatus* identification represents a new record for the Park and a range extension for the species. Without a more extensive collection, the results will continue to be inconclusive.

Herpetofaunal surveys: logistics. Several factors interacted to produce constraints on effective sampling and create logisitic complications. As ectotherms, herps' activities are largely driven by climatic factors, and are primarily constrained by temperatures. Lack of sunshine (e.g. late shade or cloudy conditions), combined with the necessity to rig boats and make river time so as to arrive at the next camp at the appropriate time to initiate late afternoon set-up and sampling, resulted in a narrow window of time to effectively survey for herps at many camps. In fact, on certain occasions, favorable conditions were lacking during our entire stay at a camp, and no herps were observed. Likewise, herp surveyors who accompanied vegetation structure crews often found absolutely no herps in sites because the timing of the surveys was far too early in the day Wind, clouds, and rain often precluded herp activity for substantial periods at sites during 2002 trips. For instance, low numbers recorded for the Salt Creek (RM 92.3L) site (Figure 5) are largely a reflection of cool and overcast conditions plus limited sunlight due to the canyon's structure at that point. While every effort was made to sample at each of the 14 primary sites during peak morning activity hours, this was not always possible at non-primary sites, which were sometimes visited either very early in the morning, late in the afternoon, or when shaded during mid-day.

Herpetofaunal surveys: zonation. An additional concern, for herps, is that they are quite often observed at the interface between two of the riparian hydrologic zones (where the NHWZ and OHWZ meet), often moving from one habitat type to another. This trend is strong enough to warrant the inclusion of zone-interface categories (SHORE-NHWZ and NHWZ-OHWZ) in next year's herpetological TEM component.

Logistics: shared logistics. When research trips combine several objectives, it can be difficult to satisfy all the parties' needs. In the case of the fall trip, vegetation surveys and faunal surveys take place at different sites whose locations are determined by separate random processes. It is, at times, difficult for the vegetation crews to complete their work and get to the next camp where the faunal surveys were to take place. At other times, there were only one or two sites for the vegetation crew between the faunal sites. Rather than launch a single, large trip, it might make more sense to launch two separate trips, each with a single focus.

Logistics: faunal sampling schedule. The question of the representativeness of data collected in a single night from each of the sites in the spring and fall has arisen many times in discussions among the investigators in this project during the past year. When the weather is windy, rainy, or cold, the success at trapping arthropods and small mammals is much reduced and the activity of lizards and snakes is minimal. Furthermore, it is uncertain what proportion of the species of arthropods, mammals and herpetofauna are encountered in a single night of sampling. Rather than a single large trip which samples all the sites, better data might be collected if a number of smaller crews were dropped off at different sites where they would take samples for several nights. Crews could be shifted to a second set of sites by a resupply-style trip and picked up by a third trip. We would like to undertake a pilot project in which two or three sites are sampled repeatedly in series of nights to address questions regarding the accumulation of species over time in a single site.

APPENDIX

Lists of species encountered during monitoring activities in 2003

Plant Species Encountered

Agavaceae	Agave utahensis Engelm.
Apocynaceae	Apocynum cannabinum L.
Asclepiadaceae	Funastrum cynanchoides (Dcne.) Schlechter ssp. cynanchoides
Asteraceae	Acourtia wrightii (Gray) Reveal & King
	Ambrosia acanthicarpa Hook.
	Artemisia dracunculus L.
	Artemisia ludoviciana Nutt.
	Baccharis brachyphylla Gray
	Baccharis emoryi Gray
	Baccharis salicifolia (Ruiz & Pav≤n) Pers.
	Baccharis sarothroides Gray
	Baccharis sergiloides Gray
	Bebbia juncea (Benth.) Greene
	Brickellia atractyloides Gray
	Brickellia californica (Torr. & Gray) Gray var. californica
	Brickellia longifolia S. Wats.
	Chloracantha spinosa (Benth.) Nesom
	Cirsium L.
	Conyza canadensis (L.) Cronq. var. pusilla (Nutt.) Cronq.
	Dicoria canescens Gray ssp. brandegeei (Gray) Kartesz, comb. nov. ined.
	Encelia farinosa Gray ex Torr.
	Encelia frutescens (Gray) Gray
	Eriastrum Woot. & Standl
	Erigeron divergens Torr. & Gray
	Erigeron L.
	Erigeron lobatus A. Nels.
	Euthamia occidentalis Nutt.
	Gutierrezia Lag.
	Gutierrezia sarothrae (Pursh) Britt. & Rusby
	Hymenopappus L'Her.
	Isocoma acradenia (Greene) Greene
	Lactuca L.
	Machaeranthera canescens (Pursh) Gray ssp. Canescens var. incana (Lindl.) Gray
	Machaeranthera pinnatifida (Hook.) Shinners
	Machaeranthera pinnatifida (Hook.) Shinners ssp. gooddingii (A. Nels.) B.L. Turner & Hartman var. paradoxa B.L. Turner & Hartman
	Pluchea sericea (Nutt.) Coville
	Porophyllum gracile Benth.
	Pseudognaphalium stramineum (Kunth) W.A. Weber
	Sonchus asper (L.) Hill
	Sonchus oleraceus L.
	Stephanomeria parryi Gray
	Symphotrichium subulatum (Michx.) Nesom
	Taraxacum officinale G.H. Weber ex Wiggers ssp. officinale
	Thymophylla pentachaeta (DC.) Small var. pentachaeta
	Trixis californica Kellogg
	Xanthium strumarium L.
	Xylorhiza tortifolia (Torr. & Gray) Greene

Boraginaceae	Boraginaceae
	Cryptantha Lehm ex G. Don
	Lappula occidentalis (S. Wats.) Greene var. cupulata (Gray) Higgins
	Tiquilia latior (I.M. Johnston) A. Richards.
Brassicaceae	Descurainia pinnata (Walt.) Britt.
	Lepidium fremontii S. Wats.
	Lepidium latifolium L.
	Rorippa nasturtium-aquaticum (L.) Hayek
	Stanleya pinnata (Pursh) Britt.
Cactaceae	Echinocereus triglochidiatus Engelm.
	Ferocactus cylindraceus (Engelm.) Orcutt var. cylindraceus
	Mammillaria grahamii Engelm. var. grahamii
	Opuntia basilaris Engelm. & Bigelow
	Opuntia erinacea Engelm. & Bigelow ex Engelm. var. utahensis (Engelm.) L. Benson
	Opuntia phaeacantha Engelm.
	Mortonia scabrella Gray
Chenopodiaceae	Atriplex canescens (Pursh) Nutt.
	Atriplex confertifolia (Torr. & FrΘm.) S. Wats.
	Salsola tragus L.
Crossosomataceae	Glossopetalon spinescens Gray var. aridum M.E. Jones
Cyperaceae	Carex aquatilis Wahlenb.
Elaeagnaceae	Elaeagnus angustifolia L.
Ephedraceae	Ephedra nevadensis S. Wats.
	Ephedra torreyana S. Wats.
Equisetaceae	Equisetum arvense L.
	Equisetum ferrissii Clute (pro sp.)
Ericaceae	Arctostaphylos pungens Kunth
Euphorbiaceae	Euphorbia L.
Fabaceae	Acacia greggii Gray
	Alhagi maurorum Medik.
	Astragalus L
	Medicago sativa L.
	Melilotus P. Mill
	Parryella filifolia Torr. & Gray ex Gray
	Prosopis glandulosa Torr.
	Psoralidium lanceolatum (Pursh) Rydb.
	Psorothamnus fremontii (Torr. Ex Grey) Barnaby var. fremontii
	Quercus turbinella Greene
Gentianaceae	Centaurium calycosum (Buckl.) Fern.
	Centaurium exaltatum (Griseb.) W. Wight ex Piper
Juncaceae	Juncus articulatus L.
	Juncus balticus Willd.
	Juncus L.
	Juncus torreyi Coville
	Schoenoplectus pungens (Vahl) Palla
Lamiaceae	Hedeoma oblongifolia (Gray) Heller
	Mentha arvensis L.
Liliaceae	Nolina microcarpa S. Wats.
Malvaceae	Sphaeralcea ambigua Gray
	Sphaeralcea grossulariifolia (Hook. & Arn.) Rydb.

Nyctaginaceae	Abronia elliptica A. Nels.
	Mirabilis multiflora (Torr.) Gray
Onagraceae	Epilobium ciliatum Raf. ssp. ciliatum
	Oenothera elata Kunth
	Oenothera pallida Lindl.
Plantaginaceae	Plantago lanceolata L.
	Plantago major L.
	Plantago ovata Forsk.
	Plantago patagonica Jacq.
Poaceae	Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth
	Achnatherum speciosum (Trin. & Rupr.) Barkworth
	Agropyron Gaertn.
	Agrostis stolonifera L.
	Andropogon gerardii Vitman
	Andropogon glomeratus (Walt.) B.S.P.
	Aristida purpurea Nutt. var. nealleyi (Vasey) Allred
	Bothriochloa barbinodis (Lag.) Herter
	Bothriochloa saccharoides (Sw.) Rydb.
	Bouteloua curtipendula (Michx.) Torr.
	Bouteloua trifida Thurb.
	Bromus catharticus Vahl
	Bromus diandrus Roth
	Bromus japonicus Thunb. ex Murr.
	Bromus L
	Bromus rigidus Roth
	Bromus rubens L.
	Bromus tectorum L.
	Cynodon dactylon (L.) Pers.
	Dasyochloa pulchella (Kunth) Willd. ex Rydb.
	Distichlis spicata (L.) Greene
	Elymus canadensis L.
	Elymus elymoides (Raf.) Swezey ssp. elymoides
	Elymus trachycaulus (Link) Gould ex Shinners ssp. trachycaulus
	Eragrostis cilianensis (All.) Vign. ex Janchen
	Eragrostis von Wolf
	Hesperostipa comata (Trin. & Rupr.) Barkworth ssp. comata
	Hordeum jubatum L.
	Lollium arundinaceum (Schreb) S.J. Darbyshire
	Muhlenbergia asperifolia (Nees & Meyen ex Trin.) Parodi
	Panicum capillare L.
	Panicum obtusum Kunth
	Pascopyrum smithii (Rydb.) A. L÷ve
	Phragmites australis (Cav.) Trin. ex Steud.
	Piptatherum miliaceum (L.) Coss.
	Pleuraphis jamesii Torr.
	Pleuraphis rigida Thurb.
	Poa fendleriana (Steud.) Vasey
	Poa L.
	Polypogon monspeliensis (L.) Desf.
	Polypogon viridis (Gouan) Breistr.

	Saccharum ravennae (L.) L.
	Schizachyrium scoparium (Michx.) Nash var. scoparium
	Sporobolus airoides (Torr.) Torr.
	Sporobolus contractus A.S. Hitchc.
	Sporobolus cryptandrus (Torr.) Gray
	Sporobolus flexuosus (Thurb. ex Vasey) Rydb.
	Sporobolus R. Br.
	Tridens muticus (Torr.) Nash
	Vulpia octoflora (Walt.) Rydb.
Polemonaceae	Phlox L.
	Ipomopsis aggregata (Pursh) V. Grant
Polygonaceae	Eriogonum deflexum Torr.
	Eriogonum inflatum Torr. & FrΘm.
	Polygonom L.
Pteridaceae	Cheilanthes eatonii Baker
Rosaceae	Fallugia paradoxa (D. Don) Endl. ex Torr.
Rubiaceae	Galium stellatum Kellogg
Salicaceae	Populus fremontii S. Wats.
	Salix exigua Nutt.
Scrophulariaceae	Castilleja linariifolia Benth.
	Veronica americana Schwein. ex Benth.
Solanaceae	Datura wrightii Regel
	Lycium andersonii Gray
	Solanum americanum P. Mill.
Tamaricaceae	Tamarix ramosissima Ledeb.
Typhaceae	Typha domingensis Pers.
Ulmaceae	Celtis laevigata Willd. var. reticulata (Torr.) L. Benson
Unknown	Unknown Dicot Seedling
Verbenaceae	Aloysia wrightii Heller ex Abrams
Viscaceae	Phoradendron californicum Nutt.

Plant dwelling arthropod taxa encountered

TAXA CODE	ORDER	FAMILY	GENUS	SPECIES
ARAANY001001	Araneae	Anyphaenidae	001	001
ARAANY001IMM	Araneae	Anyphaenidae	001	IMM
ARAARA001001	Araneae	Araneidae	001	001
ARAARA001IMM	Araneae	Araneidae	001	IMM
ARAARALAR001	Araneae	Araneidae	Larinia	001
ARAARAMET001	Araneae	Araneidae	Metepeira	001
ARAARAMETARI	Araneae	Araneidae	Metepeira	arizonica
ARADIC001001	Araneae	Dictynidae	001	001
ARADIC001IMM	Araneae	Dictynidae	001	IMM
ARADICDICIMM	Araneae	Dictynidae	001	IMM
ARADICMALPAL	Araneae	Dictynidae	Mallos	pallidus
ARALIN001001	Araneae	Linyphidae	001	001
ARALYCARCLIT	Araneae	Lycosidae	Arctosa	littoralis
ARAMIMMIM001	Araneae	Mimetidae	Mimetus	001
ARAOECOEC001	Araneae	Oecobiidae	Oecoius	001
ARAOXYOXYSCA	Araneae	Oxyopidae	Oxyopes	scalaris
ARAPHIAPOTEX	Araneae	Philodromidae	Apollophanes	texanus
ARAPHIEBO001	Araneae	Philodromidae	Ebo	001
ARAPHIEBOIMM	Araneae	Philodromidae	Ebo	IMM
ARASAL001001	Araneae	Salticidae	001	001
ARASAL001IMM	Araneae	Salticidae	001	IMM
ARASALPSE001	Araneae	Salticidae	Pseudicius	001
ARASALSAS001	Araneae	Salticidae	Sassacus	001
ARASALSIT001	Araneae	Salticidae	Sitticus	001
ARATETTET001	Araneae	Tetragnathidae	Tetragnatha	001
ARATETTETVER	Araneae	Tetragnathidae	Tetragnatha	
ARATHE001001	Araneae	Theridiidae	001	001
ARATHE001IMM	Araneae	Theridiidae	001	IMM
ARATHELATHES	Araneae	Theridiidae	Latrodectus	hesperus
ARATHO001IMM	Araneae	Thomisidae	001	IMM
ARATHOMIS001	Araneae	Thomisidae	Misumenops	001
ARATHOMISCAL	Araneae	Thomisidae	Misumenops	
ARATHOMISIMM	Araneae	Thomisidae	Misumenops	IMM
ARATHOTMA001	Araneae	Thomisidae	001	001
ARATHOTMAANG	Araneae	Thomisidae	001	001
CLLSMI001001	Collembola	Sminthuridae	001	001
COL001001001	Coleoptera	001	001	001
COL001001002	Coleoptera	001	001	002

COL001001003	Coleoptera	001	001	003
COL001001004	Coleoptera	001	001	004
COL001001005	Coleoptera	001	001	005
COL001001006	Coleoptera	001	001	006
COL001001007	Coleoptera	001	001	007
COLANTNOTCAL	Coleoptera	Anthicidae	Notoxus	calcaratus
COLCHR001002	Coleoptera	Chrysomelidae	001	002
COLCHR001004	Coleoptera	Chrysomelidae	001	004
COLCHR001006	Coleoptera	Chrysomelidae	001	006
COLCHR001007	Coleoptera	Chrysomelidae	001	007
COLCHR001008	Coleoptera	Chrysomelidae	001	008
COLCHR001009	Coleoptera	Chrysomelidae	001	009
COLCHR001010	Coleoptera	Chrysomelidae	001	010
COLCHR001011	Coleoptera	Chrysomelidae	001	011
COLCHR001012	Coleoptera	Chrysomelidae	001	012
COLCHR001013	Coleoptera	Chrysomelidae	001	013
COLCHR001014	Coleoptera	Chrysomelidae	001	014
COLCHR001015	Coleoptera	Chrysomelidae	001	015
COLCHR001017	Coleoptera	Chrysomelidae	001	017
COLCHR001018	Coleoptera	Chrysomelidae	001	018
COLCHR001019	Coleoptera	Chrysomelidae	001	019
COLCHR001IMM	Coleoptera	Chrysomelidae	001	IMM
COLCHRBRU001	Coleoptera	Chrysomelidae	bruchine	001
COLCHRCRY001	Coleoptera	Chrysomelidae	cryptocephaline	001
COLCHRCRY003	Coleoptera	Chrysomelidae	cryptocephaline	003
COLCHRCRY004	Coleoptera	Chrysomelidae	cryptocephaline	004
COLCLE001001	Coleoptera	Cleridae	001	001
COLCLE001002	Coleoptera	Cleridae	001	002
COLCOC001001	Coleoptera	Coccinellidae	001	001
COLCOC001002	Coleoptera	Coccinellidae	001	002
COLCOC001004	Coleoptera	Coccinellidae	001	004
COLCOCCHISTI	Coleoptera	Coccinellidae	Chilocorus	stigma
COLCOCHIPCON	Coleoptera	Coccinellidae	Hippodamia	convergens
COLCOCHYP002	Coleoptera	Coccinellidae	Hyperaspidius	002
COLCUR001001	Coleoptera	Curculionidae	001	001
COLCUR001002	Coleoptera	Curculionidae	001	002
COLCUR001003	Coleoptera	Curculionidae	001	003
COLCUR001004	Coleoptera	Curculionidae	001	004
COLCUR001005	Coleoptera	Curculionidae	001	005
COLCUR001006	Coleoptera	Curculionidae	001	006
COLCUR001007	Coleoptera	Curculionidae	001	007

COLCUR001008	Coleoptera	Curculionidae	001	008
COLCUR001011	Coleoptera	Curculionidae	001	011
COLCUR001012	Coleoptera	Curculionidae	001	012
COLCUR001016	Coleoptera	Curculionidae	001	016
COLELA001001	Coleoptera	Elataridae	001	001
COLMEL001001	Coleoptera	Melyridae	001	001
COLMEL001004	Coleoptera	Melyridae	001	004
COLMELCOL001	Coleoptera	Melyridae	Colops	001
COLMELCOL003	Coleoptera	Melyridae	Colops	003
COLMELTRI001	Coleoptera	Melyridae	Trichochrous	001
COLSCRANARUF	Coleoptera	Scraptiidae	Anapsis	rufa
COLSTA001003	Coleoptera	Staphylinidae	001	003
COLTENMETCON	Coleoptera	Tenebrionidae	Metaponium	convexicolle
DIP001001001	Diptera	001	001	001
DIP001001002	Diptera	001	001	002
DIP001001003	Diptera	001	001	003
DIP001001004	Diptera	001	001	004
DIP001001005	Diptera	001	001	005
DIP001001006	Diptera	001	001	006
DIP001001007	Diptera	001	001	007
DIP001001008	Diptera	001	001	008
DIP001001009	Diptera	001	001	009
DIP001001010	Diptera	001	001	010
DIP001001011	Diptera	001	001	011
DIP001001012	Diptera	001	001	012
DIP001001013	Diptera	001	001	013
DIP001001014	Diptera	001	001	014
DIP001001015	Diptera	001	001	015
DIP001001016	Diptera	001	001	016
DIP001001017	Diptera	001	001	017
DIP001001018	Diptera	001	001	018
DIP001001019	Diptera	001	001	019
DIP001001020	Diptera	001	001	020
DIP001001021	Diptera	001	001	021
DIP001001022	Diptera	001	001	022
DIP001001023	Diptera	001	001	023
DIP001001024	Diptera	001	001	024
DIP001001025	Diptera	001	001	025
DIP001001026	Diptera	001	001	026
DIP001001027	Diptera	001	001	027
DIP001001028	Diptera	001	001	028

DIP001001029	Diptera	001	001	029
DIP001001030	Diptera	001	001	030
DIP001001031	Diptera	001	001	031
DIP001001032	Diptera	001	001	032
DIPBIM001001	Diptera	Bibionidae	001	001
DIPBOM001001	Diptera	Bombyliidae	001	001
DIPBOM001002	Diptera	Bombyliidae	001	002
DIPBOM001003	Diptera	Bombyliidae	001	003
DIPBOM001004	Diptera	Bombyliidae	001	004
DIPBOM001005	Diptera	Bombyliidae	001	005
DIPBOM001006	Diptera	Bombyliidae	001	006
DIPBOM001007	Diptera	Bombyliidae	001	007
DIPCAL001001	Diptera	Calliphoridae	001	001
DIPCEC001001	Diptera	Cecidomyiidae	001	001
DIPCER001001	Diptera	Ceratopogonidae	001	001
DIPCHI001001	Diptera	Chironomidae	001	001
DIPCHL001001	Diptera	Chloropidae	001	001
DIPCHL001002	Diptera	Chloropidae	001	002
DIPCHL001003	Diptera	Chloropidae	001	003
DIPCON001001	Diptera	Conopidae	001	001
DIPCUL001001	Diptera	Culicidae	001	001
DIPDOL001001	Diptera	Dolichopodidae	001	001
DIPDOL001002	Diptera	Dolichopodidae	001	002
DIPDOL001003	Diptera	Dolichopodidae	001	003
DIPMUS001001	Diptera	muscoid	001	001
DIPMUS001002	Diptera	muscoid	001	002
DIPMUS001003	Diptera	muscoid	001	003
DIPMUS001004	Diptera	muscoid	001	004
DIPMUS001005	Diptera	muscoid	001	005
DIPMUS001006	Diptera	muscoid	001	006
DIPMUS001007	Diptera	muscoid	001	007
DIPMUS001008	Diptera	muscoid	001	008
DIPMUS001010	Diptera	muscoid	001	010
DIPMUS001011	Diptera	muscoid	001	011
DIPMUS001012	Diptera	muscoid	001	012
DIPMUS001013	Diptera	muscoid	001	013
DIPMUS001014	Diptera	muscoid	001	014
DIPMUS001015	Diptera	muscoid	001	015
DIPMUS001016	Diptera	muscoid	001	016
DIPMUS001017	Diptera	muscoid	001	017
DIPMUS001018	Diptera	muscoid	001	018

DIPMUS001019	Diptera	muscoid	001	019
DIPMUS001020	Diptera	muscoid	001	020
DIPMUS001021	Diptera	muscoid	001	021
DIPMUS001022	Diptera	muscoid	001	022
DIPMUS001025	Diptera	muscoid	001	025
DIPPIP001001	Diptera	Pipunculidae	001	001
DIPSAR001001	Diptera	Sarcophagidae	001	001
DIPSAR001002	Diptera	Sarcophagidae	001	002
DIPSAR001003	Diptera	Sarcophagidae	001	003
DIPSAR001004	Diptera	Sarcophagidae	001	004
DIPSAR001005	Diptera	Sarcophagidae	001	005
DIPSAR001006	Diptera	Sarcophagidae	001	006
DIPSEP001001	Diptera	Sepsidae	001	001
DIPSIM001001	Diptera	Simulidae	001	001
DIPSYR001001	Diptera	Syrphidae	001	001
DIPSYR001002	Diptera	Syrphidae	001	002
DIPTAC001001	Diptera	Tachinidae	001	001
DIPTEP001001	Diptera	Tephritidae	001	001
DIPTEP001002	Diptera	Tephritidae	001	002
DIPTEP001003	Diptera	Tephritidae	001	003
DIPTEP001004	Diptera	Tephritidae	001	004
DIPTEP001005	Diptera	Tephritidae	001	005
DIPTIP001001	Diptera	Tipulidae	001	001
HEMANT001001	Hemiptera	Anthocoridae	001	001
HEMANTORI001	Hemiptera	Anthocoridae	Orius	001
HEMBERPROANN	Hemiptera	Berytidae	Pronotacanthus	annulata
HEMLYG001002	Hemiptera	Lygaeidae	001	002
HEMLYG001004	Hemiptera	Lygaeidae	001	004
HEMLYGNYS001	Hemiptera	Lygaeidae	Nysius	001
HEMLYGNYS002	Hemiptera	Lygaeidae	001	002
HEMLYGOCH001	Hemiptera	Lygaeidae	Ochrimnus	001
HEMMIR001001	Hemiptera	Miridae	001	001
HEMMIR001005	Hemiptera	Miridae	001	005
HEMMIR001006	Hemiptera	Miridae	001	006
HEMMIR001009	Hemiptera	Miridae	001	009
HEMMIR001010	Hemiptera	Miridae	001	010
HEMMIR001011	Hemiptera	Miridae	001	011
HEMMIR001012	Hemiptera	Miridae	001	012
HEMMIR001013	Hemiptera	Miridae	001	013
HEMMIR001014	Hemiptera	Miridae	001	014
HEMMIR001015	Hemiptera	Miridae	001	015

HEMMIR001016	Hemiptera	Miridae	001	016
HEMMIR001017	Hemiptera	Miridae	001	017
HEMMIR001019	Hemiptera	Miridae	001	019
HEMMIR001020	Hemiptera	Miridae	001	020
HEMMIR001021	Hemiptera	Miridae	001	021
HEMMIR001022	Hemiptera	Miridae	001	022
HEMMIR001IMM	Hemiptera	Miridae	001	IMM
HEMMIRPHY001	Hemiptera	Miridae	Phytocoris	001
HEMNABDOL001	Hemiptera	Nabidae	Dolichonabis	001
HEMPENTHY001	Hemiptera	Pentatomidae	Thyanta	001
HEMPENTHY003	Hemiptera	Pentatomidae	Thyanta	003
HEMPHY001001	Hemiptera	Phymatidae	001	001
HEMPHYPHY001	Hemiptera	Phymatidae	Phymatus	001
HEMRED001001	Hemiptera	Reduviidae	001	001
HEMRED001002	Hemiptera	Reduviidae	001	002
HEMRED001003	Hemiptera	Reduviidae	001	003
HEMRED001IMM	Hemiptera	Reduviidae	001	IMM
HEMREDZEL001	Hemiptera	Reduviidae	Zelus	001
HEMREDZEL002	Hemiptera	Reduviidae	Zelus	002
HEMRHO001001	Hemiptera	Rhopalidae	001	001
HEMRHO001IMM	Hemiptera	Rhopalidae	001	IMM
HEMRHOARH001	Hemiptera	Rhopalidae	Arhyssus	001
HEMTIN001001	Hemiptera	Tingidae	001	001
HEMTIN001002	Hemiptera	Tingidae	001	002
HOMACA001001	Homoptera	Acanaloniidae	001	001
HOMAPH001001	Homoptera	Aphididae	001	001
HOMAPH001003	Homoptera	Aphididae	001	003
HOMAPH001005	Homoptera	Aphididae	001	005
HOMAPH001006	Homoptera	Aphididae	001	006
HOMCER001001	Homoptera	Cercopidae	001	001
HOMCIC001001	Homoptera	Cicadellidae	001	001
HOMCIC001002	Homoptera	Cicadellidae	001	002
HOMCIC001003	Homoptera	Cicadellidae	001	003
HOMCIC001004	Homoptera	Cicadellidae	001	004
HOMCIC001005	Homoptera	Cicadellidae	001	005
HOMCIC001006	Homoptera	Cicadellidae	001	006
HOMCIC001007	Homoptera	Cicadellidae	001	007
HOMCIC001008	Homoptera	Cicadellidae	001	008
HOMCIC001009	Homoptera	Cicadellidae	001	009
HOMCIC001010	Homoptera	Cicadellidae	001	010
HOMCIC001011	Homoptera	Cicadellidae	001	011

HOMCIC001012	Homoptera	Cicadellidae	001	012
HOMCIC001014	Homoptera	Cicadellidae	001	014
HOMCIC001015	Homoptera	Cicadellidae	001	015
HOMCIC001017	Homoptera	Cicadellidae	001	017
HOMCIC001018	Homoptera	Cicadellidae	001	018
HOMCIC001019	Homoptera	Cicadellidae	001	019
HOMCIC001023	Homoptera	Cicadellidae	001	023
HOMCIC001024	Homoptera	Cicadellidae	001	024
HOMCIC001027	Homoptera	Cicadellidae	001	027
HOMCIC001029	Homoptera	Cicadellidae	001	029
HOMCIC001030	Homoptera	Cicadellidae	001	030
HOMCIC001031	Homoptera	Cicadellidae	001	031
HOMCIC001032	Homoptera	Cicadellidae	001	032
HOMCIC001034	Homoptera	Cicadellidae	001	034
HOMCIC001035	Homoptera	Cicadellidae	001	035
HOMCIC001036	Homoptera	Cicadellidae	001	036
HOMCIC001037	Homoptera	Cicadellidae	001	037
HOMCIC001038	Homoptera	Cicadellidae	001	038
HOMCIC001040	Homoptera	Cicadellidae	001	040
HOMCIC001041	Homoptera	Cicadellidae	001	041
HOMCIC001042	Homoptera	Cicadellidae	001	042
HOMCIC001043	Homoptera	Cicadellidae	001	043
HOMCIC001044	Homoptera	Cicadellidae	001	044
HOMCIC001045	Homoptera	Cicadellidae	001	045
HOMCIC001047	Homoptera	Cicadellidae	001	047
HOMCIC001048	Homoptera	Cicadellidae	001	048
HOMCIC001049	Homoptera	Cicadellidae	001	049
HOMCIC001050	Homoptera	Cicadellidae	001	050
HOMCIC001051	Homoptera	Cicadellidae	001	051
HOMCIC001052	Homoptera	Cicadellidae	001	052
HOMCIC001IMM	Homoptera	Cicadellidae	001	IMM
HOMCICOPS001	Homoptera	Cicadellidae	Opsius	001
HOMCIX001002	Homoptera	Cixiidae	001	002
HOMCIX001003	Homoptera	Cixiidae	001	003
HOMCIX001004	Homoptera	Cixiidae	001	004
HOMCIX001005	Homoptera	Cixiidae	001	005
HOMCIX001006	Homoptera	Cixiidae	001	006
HOMCIX001017	Homoptera	Cixiidae	001	017
HOMCOC001001	Homoptera	coccoidae	001	001
HOMCOC001003	Homoptera	coccoidae	001	003
HOMDEL001001	Homoptera	Delphacidae	001	001

HOMDEL001002	Homoptera	Delphacidae	001	002
HOMPSY001001	Homoptera	Psyllidae	001	001
HOMPSY001002	Homoptera	Psyllidae	001	002
HOMPSY001003	Homoptera	Psyllidae	001	003
HOMPSY001004	Homoptera	Psyllidae	001	004
HOMPSY001006	Homoptera	Psyllidae	001	006
HOMPSY001007	Homoptera	Psyllidae	001	007
HYM001001002	Hymenoptera	001	001	002
HYMAND001001	Hymenoptera	Andrenidae	001	001
HYMAND001002	Hymenoptera	Andrenidae	001	002
HYMAND001003	Hymenoptera	Andrenidae	001	003
HYMAND001004	Hymenoptera	Andrenidae	001	004
HYMAND001005	Hymenoptera	Andrenidae	001	005
HYMAND001006	Hymenoptera	Andrenidae	001	006
HYMANT001001	Hymenoptera	Andrenidae	001	001
HYMBRA001001	Hymenoptera	Braconidae	001	001
HYMBRA001002	Hymenoptera	Braconidae	001	002
HYMBRA001003	Hymenoptera	Braconidae	001	003
HYMBRA001004	Hymenoptera	Braconidae	001	004
HYMBRA001005	Hymenoptera	Braconidae	001	005
HYMBRA001006	Hymenoptera	Braconidae	001	006
HYMBRA001007	Hymenoptera	Braconidae	001	007
HYMBRA001008	Hymenoptera	Braconidae	001	008
HYMCHA001001	Hymenoptera	chalcidoidea	001	001
HYMCHA001002	Hymenoptera	chalcidoidea	001	002
HYMCHA001004	Hymenoptera	chalcidoidea	001	004
HYMCHA001006	Hymenoptera	chalcidoidea	001	006
HYMFOR001001	Hymenoptera	Formicidae	001	001
HYMFOR001002	Hymenoptera	Formicidae	001	002
HYMFOR001003	Hymenoptera	Formicidae	001	003
HYMFOR001004	Hymenoptera	Formicidae	001	004
HYMFORCAM001	Hymenoptera	Formicidae	Camponotus	001
HYMFORCREDEP	Hymenoptera	Formicidae	Crematogaster	depilis
HYMFORDORINS	Hymenoptera	Formicidae	Dorymyrmex	insana
HYMFORFORINT	Hymenoptera	Formicidae	Formica	integroides
HYMFORFORPRU	Hymenoptera	Formicidae	Forelius	pruinosus
HYMFORMON002	Hymenoptera	Formicidae	Monomorium	002
HYMFORMONCYA	Hymenoptera	Formicidae	Monomorium	cyanus
HYMFORMYR001	Hymenoptera	Formicidae	Myrmecosystus	001
HYMFORPAR001	Hymenoptera	Formicidae	Paratrechina	001
HYMFORPHE001	Hymenoptera	Formicidae	Pheidole	001

HYMFORPHE003	Hymenoptera	Formicidae	Pheidole	003
HYMFORPOGMAR	Hymenoptera	Formicidae	Pogonomyrmex	maricopa
HYMFORSOLXYL	Hymenoptera	Formicidae	Solenopsis	xyloni
HYMHAL001001	Hymenoptera	Halictidae	001	001
HYMHAL001002	Hymenoptera	Halictidae	001	002
HYMHAL001003	Hymenoptera	Halictidae	001	003
HYMICH001001	Hymenoptera	Ichneumonidae	001	001
HYMICH001002	Hymenoptera	Ichneumonidae	001	002
HYMMEG001001	Hymenoptera	Megachilidae	001	001
HYMMUT001001	Hymenoptera	Mutillidae	001	001
HYMPOM001001	Hymenoptera	Pompilidae	001	001
HYMSPH001001	Hymenoptera	Sphecidae	001	001
HYMTEN001001	Hymenoptera	Tenthredinidae	001	001
IXOIXODERVAR	Ixodida	Ixodidae	Dermacentor	variabilis
LEP001001001	Lepidoptera	001	001	001
LEP001001005	Lepidoptera	001	001	005
LEP001001IMM	Lepidoptera	001	001	IMM
LEPARC001001	Lepidoptera	Arctiidae	001	001
LEPARC001003	Lepidoptera	Arctiidae	001	003
LEPARCTEN001	Lepidoptera	Arctiidae	ctenuchine	001
LEPGEL001001	Lepidoptera	Gelechiidae	001	001
LEPGEO001001	Lepidoptera	Geometridae	001	001
LEPGEO001IMM	Lepidoptera	Geometridae	001	IMM
LEPGEOSEM001	Lepidoptera	Geometridae	Semiothesia	001
LEPGEOSEMIMM	Lepidoptera	Geometridae	001	IMM
LEPMIC001001	Lepidoptera	microlep	001	001
NEUCHR001001	Neuroptera	Chrysopidae	001	001
NEUCHR001002	Neuroptera	Chrysopidae	001	002
NEUCHR001IMM	Neuroptera	Chrysopidae	001	IMM
NEUMYR001001	Neuroptera	Myrmeleontidae	001	001
ODOCOE001001	Odonata	Coenagrionidae	001	001
ORTACRAEOTEN	Orthoptera	Acrididae	Aeoloplides	tenuipennis
ORTACRORPPEL	Orthoptera	Acrididae	Orphuella	pelidna
ORTACRSCHAUL	Orthoptera	Acrididae	Schistocerca	alutacea
ORTACRSCHNIT	Orthoptera	Acrididae	Schistocerca	nitens
ORTACRTRIPAL	Orthoptera	Acrididae	Trimerotropis	pallidipennis
ORTGRYOEC001	Orthoptera	Gryllidae	Oecanthus	001
ORTTRIELLMIN	Orthoptera	Tridactylidae	Ellipes	minuta
PROANY001001	Prostigmata	Anystidae	001	001
PROERY001001	Prostigmata	Erythraeidae	001	001
PSECHEHYSPRO	Pseudoscorpiones	Cheliferidae	Hysterochelifer	proprius

THYPHL001001	Thysanoptera	Phloeothripidae	001	001
THYTHRFRA001	Thysanoptera	Thripidae	Frankliniella	001

Moth taxa encountered

Family	Subfamily	Genus/Species or Taxon
Noctuidae	Acontiinae	Acontia arida
Noctuidae	Acontiinae	Acontia areloides
Noctuidae	Acontiinae	Acontia sp.
Noctuidae	Acontiinae	Acontia cretata
Noctuidae	Acontiinae	Acontia lanceolata
Noctuidae	Acontiinae	LEPI NOCT 001 112
Noctuidae	Acontiinae	LEPI NOCT 001 113
Noctuidae	Acontiinae	LEPI NOCT 001 114
Noctuidae	Acontiinae	LEPI NOCT 001 115
Noctuidae	Acontiinae	Acontia semiatra ?
Noctuidae	Acontiinae	Aleptina inca
Noctuidae	Acontiinae	Conochares arizonae ?
Noctuidae	Acontiinae	Conochares sp.
Noctuidae	Acontiinae	Homolagoa grotelliformis
Noctuidae	Acontiinae	Bagisara buxea
Noctuidae	Acontiinae	Ozarba propera
Noctuidae	Acontiinae	Tarachidia semiflava
Noctuidae	Acontiinae	Tarachidia venustula
Noctuidae	Acontiinae	Tripudia dimidiata
Noctuidae	Acontiinae	LEPI NOCT 001 165
Noctuidae	Acontiinae	LEPI NOCT 001 166
Noctuidae	Acronictinae	Acronicta lithospila
Noctuidae	Acronictinae	Hoplolythra discistriga
Noctuidae	Amphipyrinae	Draudtia leucorena ?
Noctuidae	Amphipyrinae	LEPI NOCT 001 057
Noctuidae	Amphipyrinae	LEPI NOCT 001 058
Noctuidae	Amphipyrinae	Draudtia revelata ?
Noctuidae	Amphipyrinae	Emarginea percara
Noctuidae	Amphipyrinae	Lythrodes venatus
Noctuidae	Amphipyrinae	Nocloa aliaga ?
Noctuidae	Amphipyrinae	Platyperigea extima ??
Noctuidae	Amphipyrinae	Allerastria albicilaiata chacoensis ?
Noctuidae	Amphipyrinae	LEPI NOCT 001 093
Noctuidae	Amphipyrinae	LEPI NOCT 001 167
Noctuidae	Amphipyrinae	Pseudohadena vulnerea
Noctuidae	Amphipyrinae	Pseudanarta sp.
Noctuidae	Amphipyrinae	Spodoptera exigua ?
Noctuidae	Amphipyrinae	Walterella ocellata ??
Noctuidae	Catocalinae	Heteranassa mima ???
Noctuidae	Catocalinae	LEPI NOCT 001 035
Noctuidae	Catocalinae	LEPI NOCT 001 036
Noctuidae	Catocalinae	Heteranassa fraterna ??

Noctuidae	Catocalinae	LEPI NOCT 001 038
Noctuidae	Catocalinae	Heteranassa mima ??
Noctuidae	Catocalinae	Heteranassa mima ?
Noctuidae	Catocalinae	Heteranassa sp.
Noctuidae	Catocalinae	Bulia deducta ??
Noctuidae	Catocalinae	Bulia deducta ?
Noctuidae	Catocalinae	Bulia similaris californica
Noctuidae	Catocalinae	Cataocala babayaga
Noctuidae	Catocalinae	Catocala palaeogama ?
Noctuidae	Catocalinae	Melipotis indomita
Noctuidae	Catocalinae	Melipotis jucunda
Noctuidae	Catocalinae	Synedoida pallescens
Noctuidae	Catocalinae	Synedoida tejonica
Noctuidae	Catocalinae	Synedoida pulchra
Noctuidae	Catocalinae	Toxonprucha volucris ?
Noctuidae	Catocalinae	Toxonprucha sp.
Noctuidae	Catocalinae	Toxonprucha repentis
Noctuidae	Catocalinae	Zaleops umbrina
Noctuidae	Catocalinae	Zale rubiata
Noctuidae	Catocalinae	Zale sp.
Noctuidae	Cuculliinae	Polia sp.
Noctuidae	Cuculliinae	Polia nipana ?
Noctuidae	Cuculliinae	Polia sp. 2
Noctuidae	Cuculliinae	LEPI NOCT 001 159
Noctuidae	Cuculliinae	LEPI NOCT 001 047
Noctuidae	Cuculliinae	Catabena vitrina
Noctuidae	Cuculliinae	LEPI NOCT 001 150
Noctuidae	Cuculliinae	LEPI NOCT 001 153
Noctuidae	Cuculliinae	LEPI NOCT 217
Noctuidae	Cuculliinae	LEPI NOCT 218
Noctuidae	Cuculliinae	LEPI NOCT 001 078
Noctuidae	Cuculliinae	LEPI NOCT 001 154
Noctuidae	Cuculliinae	LEPI NOCT 001 096
Noctuidae	Cuculliinae	LEPI NOCT 001 097
Noctuidae	Cuculliinae	Oxycnemis gracillima
Noctuidae	Cuculliinae	Oncocnemis rosea
Noctuidae	Hadeninae	Lacinipolia illaudabilis ?
Noctuidae	Hadeninae	LEPI NOCT 001 031
Noctuidae	Hadeninae	LEPI NOCT 001 026
Noctuidae	Hadeninae	LEPI NOCT 001 027
Noctuidae	Hadeninae	LEPI NOCT 001 029
Noctuidae	Hadeninae	Lacinipolia marinitincta ?
Noctuidae	Hadeninae	LEPI NOCT 208
Noctuidae	Hadeninae	Scotogramma orida ??
Noctuidae	Hadeninae	Ulolonche dilecta
Noctuidae	Hadeninae	LEPI NOCT 001 048

Noctuidae	Hadeninae	LEPI NOCT 001 051
Noctuidae	Hadeninae	Leucania farcta
Noctuidae	Hadeninae	Faronta tetera ?
Noctuidae	Hadeninae	Pseudazetia unipuncta ?
Noctuidae	Hadeninae	Homorthodes fractura ???
Noctuidae	Hadeninae	Protorthodes alfkeni
Noctuidae	Heliothinae	Heliothis phloxiphagus
Noctuidae	Heliothinae	LEPI NOCT 209
Noctuidae	Heliothinae	Heliothis zea
Noctuidae	Heliothinae	Heliothis sp.
Noctuidae	Heliothinae	Schinia fertia ?
Noctuidae	Heliothinae	Schinia hulstia ?
Noctuidae	Heliothinae	Schinia intrabilis
Noctuidae	Heliothinae	Schinia lynx
Noctuidae	Heliothinae	Schinia sp.
Noctuidae	Heliothinae	Schinia miniana
Noctuidae	Heliothinae	LEPI NOCT 001 118
Noctuidae	Hypeninae	Hemeroplanis historialis
Noctuidae	Hypeninae	Hemeroplanis incusalis ?
Noctuidae	Hypeninae	Tathorhynchus exsiccatus
Noctuidae	Noctuinae	Abagrotis orbis
Noctuidae	Noctuinae	Abagrotis sp.
Noctuidae	Noctuinae	Agrotis ipsilon ?
Noctuidae	Noctuinae	LEPI NOCT 001 009
Noctuidae	Noctuinae	LEPI NOCT 001 016
Noctuidae	Noctuinae	Agrotis malefida ?
Noctuidae	Noctuinae	Euxoa auxiliaris
Noctuidae	Noctuinae	Euxoa medialis ?
Noctuidae	Noctuinae	Euxoa sp. 2
Noctuidae	Noctuinae	LEPI NOCT 001 019
Noctuidae	Noctuinae	Euxoa sp.
Noctuidae	Noctuinae	Peridroma saucia
Noctuidae	Plusiinae	Trichoplusia ni ?
Noctuidae	Plusiinae	Rachiplusia ou
Noctuidae	Stiriinae	Stiria consuela
Noctuidae		LEPI NOCT 001 157
Noctuidae		LEPI NOCT 001 143
Noctuidae		LEPI NOCT 001 144
Noctuidae		LEPI NOCT 001 119
Pyralidae		LEPI PYRA 016
Noctuidae		LEPI 0047
Pyralidae		LEPI PYRA 013
Noctuidae		LEPI NOCT 001 084
Noctuidae		LEPI NOCT 001 127
Noctuidae		LEPI NOCT 001 135
Noctuidae		LEPI NOCT 001 136

Noctuidae		LEPI NOCT 001 137
Noctuidae		LEPI NOCT 001 138
Noctuidae		LEPI NOCT 001 139
Noctuidae		LEPI NOCT 001 140
Noctuidae		LEPI NOCT 001 141
Noctuidae		LEPI 0002
Noctuidae		LEPI 0003
Noctuidae		LEPI 0006
Noctuidae		LEPI 0010
Noctuidae		LEPI 0013
Noctuidae		LEPI 0019
Noctuidae		LEPI NOCT 200
Noctuidae		LEPI NOCT 201
Noctuidae		LEPI NOCT 202
Noctuidae		LEPI NOCT 203
Noctuidae		LEPI NOCT 204
Noctuidae		LEPI NOCT 205
Noctuidae		LEPI NOCT 206
Noctuidae		LEPI NOCT 210
Noctuidae		LEPI NOCT 211
Noctuidae		LEPI NOCT 212
Noctuidae		LEPI NOCT 215
Noctuidae		LEPI NOCT 222
Noctuidae		LEPI NOCT 223
Noctuidae		LEPI NOCT 225
Noctuidae		LEPI NOCT 226
Noctuidae		LEPI NOCT 227
Noctuidae		LEPI NOCT 228
Noctuidae		LEPI NOCT 229
Noctuidae		LEPI NOCT 230
Noctuidae		LEPI NOCT 232
Noctuidae		LEPI NOCT 233
Noctuidae		LEPI NOCT 236
Noctuidae		LEPI NOCT 237
Noctuidae		LEPI NOCT 238
Noctuidae		LEPI NOCT 239
Noctuidae		LEPI NOCT 240
Noctuidae		LEPI NOCT 241
Noctuidae		LEPI NOCT 244
Noctuidae		LEPI NOCT 245
Noctuidae		LEPI NOCT 246
Noctuidae		LEPI NOCT 247
Geometridae	Geometrinae	Dichorda sp. ?
Geometridae	Geometrinae	Synchlora sp.
Geometridae	Geometrinae	Chlorochlamys phyllinaria
Geometridae	Sterrhinae	Euacidalia sp.

Geometridae	Sterrhinae	Pigia multilineata
Geometridae	Ennominae	Anacamptodes sancta ?
Geometridae	Ennominae	Chloraspilates bicoloraria
Geometridae	Ennominae	Chloraspilates minima ?
Geometridae	Ennominae	Elpiste metanemaria
Geometridae	Ennominae	LEPI GEOM 001 034
Geometridae	Ennominae	Eusarca sp.
Geometridae	Ennominae	Eusarca sp. 2
Geometridae	Ennominae	Eusarca tibiaria
Geometridae	Ennominae	Lambdina flavilinearia
Geometridae	Ennominae	Glaucina ochrofuscaria
Geometridae	Ennominae	Glaucina sp.
Geometridae	Ennominae	Narraga fimetaria
Geometridae	Ennominae	Pero modesta
Geometridae	Ennominae	Semiothisa s-signata
Geometridae	Ennominae	Semiothisa pallidata
Geometridae	Ennominae	Semiothisa sp. 1
Geometridae	Ennominae	Semiothisa sp. 2
Geometridae	Ennominae	Semiothisa sp. 3
Geometridae	Ennominae	Semiothisa sp. 4
Geometridae	Ennominae	Semiothisa sp. 5
Geometridae	Ennominae	Semiothisa nigrocomma ?
Geometridae	Ennominae	LEPI GEOM 001 019
Geometridae	Ennominae	LEPI GEOM 001 012
Geometridae	Ennominae	Stenoporpia pulchella ?
Geometridae	Larentiinae	Archirhoe neomexicana ?
Geometridae	Larentiinae	Dysstroma brunneata ?
Geometridae	Larentiinae	Eupithecia annulata
Geometridae	Larentiinae	Eupithecia sp.
Geometridae	Larentiinae	Lithostege rotundata
Geometridae	Larentiinae	Perizoma custodiata
Geometridae	Larentiinae	Zenophleps obscurata
Geometridae		LEPI GEOM 107
Geometridae		LEPI GEOM 108
Geometridae		LEPI GEOM 109
Geometridae		LEPI GEOM 001 013
Geometridae		LEPI GEOM 001 016
Geometridae		LEPI GEOM 001 027
Geometridae		LEPI GEOM 001 028
Geometridae		LEPI GEOM 001 029
Geometridae		LEPI GEOM 001 030
Geometridae		LEPI GEOM 110
Geometridae		LEPI GEOM 001 024
Geometridae		LEPI GEOM 100
Geometridae		LEPI GEOM 101
Geometridae		LEPI GEOM 102

Geometridae		LEPI GEOM 103
Geometridae		LEPI GEOM 105
Geometridae		LEPI GEOM 110
Geometridae		LEPI GEOM 111
Geometridae		LEPI GEOM 113
Geometridae		LEPI GEOM 115
Geometridae		LEPI GEOM 116
Geometridae		LEPI GEOM 117
Geometridae		LEPI GEOM 120
Geometridae		LEPI GEOM 121
Geometridae		LEPI GEOM 122
Geometridae		LEPI GEOM 124
Geometridae		LEPI GEOM 125
Geometridae		LEPI GEOM 126
Arctiidae	Lithosiinae	Cisthene angelus
Arctiidae	Lithosiinae	Cisthene juanita
Arctiidae	Lithosiinae	Cisthene sp.
Arctiidae	Lithosiinae	Crambidia myrlosea
Arctiidae	Lithosiinae	Lycomorpha sp. ?
Arctiidae	Arctiinae	Ectypia clio
Arctiidae	Arctiinae	Euchaetes perlevis
Arctiidae	Arctiinae	Euchaetes zella
Pyralidae	Crambinae	Euchromius ocelleus
Pyralidae	Crambinae	Fissicrambus sp.
Pyralidae	Epipaschiinae	Jacara trabalis
Pyralidae	Glaphyriinae	Hellula regatalis
Pyralidae	Nymphulinae	Petrophila jaliscalis
Pyralidae	Nymphulinae	Petrophila longipennis ?
Pyralidae	Nymphulinae	Paragyractis sp.
Pyralidae	Pyraustinae	Blepharomastix ranalis ?
Pyralidae	Pyraustinae	Diastictis fracturalis
Pyralidae	Pyraustinae	Diathrausta reconditalis
Pyralidae	Pyraustinae	Helvibotys helvialis
Pyralidae	Pyraustinae	Pyrausta onythesalis ?
Pyralidae	Pyraustinae	LEPI 0035
Pyralidae	Pyraustinae	Loxostege albiceralis
Pyralidae	Pyraustinae	Loxostege sp.
Pyralidae	Pyraustinae	Loxostege allectalis
Pyralidae	Pyraustinae	Lygropia octonalis
Pyralidae	Pyraustinae	Mimorista subcostalis
Pyralidae	Pyraustinae	Nomophila nearctia ?
Pyralidae	Pyraustinae	Palpita quadristigmalis
Pyralidae	Pyraustinae	Spoladea recurvalis
Pyralidae		Stegea sp.?
Pyralidae		Stega salutalis grisealis
Pyralidae		LEPI 0038

Pyralidae		LEPI 0040
Pyralidae		LEPI 0041
Pyralidae		LEPI 0037
Pyralidae		LEPI PYRA 001
Pyralidae		LEPI PYRA 002
Pyralidae		LEPI PYRA 003
Pyralidae		LEPI PYRA 004
Pyralidae		LEPI PYRA 005
Pyralidae		LEPI PYRA 007
Pyralidae		LEPI PYRA 009
Pyralidae		LEPI PYRA 010
Pyralidae		LEPI PYRA 011
Pyralidae		LEPI PYRA 012
Pyralidae		LEPI PYRA 015
Pyralidae		LEPI PYRA 017
Pyralidae		LEPI PYRA 018
Pyralidae		LEPI PYRA 019
Pyralidae		LEPI PYRA 020
Pyralidae		LEPI PYRA 021
Pyralidae		LEPI PYRA 022
Pyralidae		LEPI PYRA 023
Pyralidae		LEPI PYRA 025
Pyralidae		LEPI PYRA 027
Pyralidae		LEPI 100
Pyralidae		LEPI 101
Pyralidae		LEPI 102
Pyralidae		LEPI 103
Pyralidae		LEPI 104
Pyralidae		LEPI 105
Pyralidae		LEPI 106
Pyralidae		LEPI 107
Pyralidae		LEPI 108
Pyralidae		LEPI 109
Pyralidae		LEPI 110
Pyralidae		LEPI 111
Pyralidae		LEPI 112
Sphingidae	Macroglossinae	Hyles lineata
Sphingidae	Sphinginae	Sphinx chersis
Sphingidae	Sphinginae	Manduca quinquemaculata
Sphingidae	Sphinginae	Pachysphinx modesta
Saturniidae	Citheroniinae	Sphingicampa hubbardi
Saturniidae	Hemilevcinae	Hemileuca neumoegeni
Lasiocampidae		LASI 001
Notodontidae		NOTO 001
Pterophoridae	Platyptiliinae	Stenoptilodes grandis
Pterophoridae		LEPI PTER 001

Pterophoridae	LEPI PTER 002
Microleps	MICRO LEPI
Hesperidae	Copaeodes aurantica

Herpetofaunal species encountered

CODE, Species	(common name)
	LIZARDS
COVA, *Coleonyx variegatus*	(banded gecko)
CNTI, *Cnemidophorus tigris*	(western whiptail)
CRCO, *Crotaphytus collaris*	(collared lizard)
PHPL, *Phrynosoma platyrhinos*	(desert horned lizard)
SAOB, *Sauromalus obesus*	(chuckwalla)
SCMA, *Sceloporus magister*	(desert spiny lizard)
UROR, *Urosaurus ornatus*	(tree lizard)
UTST, *Uta Stansburiana*	(side-blotched lizard)
	SNAKES
CRMI, *Crotalus mitchelli*	(speckled rattlesnake)
CRMO, *Crotalus molossus*	(black-tailed rattlesnake)
CRVI, *Crotalus viridis abyssus*	(Grand Canyon pink rattlesnake)
LAGE, *Lampropeltus getulus*	(king snake)
MAFL, *Masticophis flagellum*	(red racer)
MATA, *Masticophis taeniatus*	(lined whipsnake)
SAGR, *Salvadora grahami*	(patch-nosed snake)
	TOADS AND FROGS
BUPU, *Bufo punctatus*	(red-spotted toad)
BUWO, *Bufo woodhousei*	(Woodhouse's toad)
HYAR, *Hyla arenicolor*	(canyon treefrog)

Bird species encountered

Species	2001	2002	2003
American Avocet		x	x
American Coot			x
American Crow	x		x
American Kestrel		x	x
American Pipit		x	
American Robin		x	
American Widgeon		x	
Ash-throated Flycatcher	x	x	x
Bald Eagle		x	
Bell's Vireo	x	x	x
Belted Kingfisher		x	x
Bewick's Wren	x	x	x
Black-billed Magpie			x
Black-chinned Hummingbird	x	x	x
Black-chinned Sparrow		x	
Black-crowned Night Heron			x
Black-throated Gray Warbler	x	x	x
Black-headed Grosbeak	x	x	x
Black Phoebe	x	x	x
Black-throated Sparrow	x	x	x
Blue-gray Gnatcatcher	x	x	x
Blue Grosbeak	x	x	x
Blue-throated Grey Warbler	x		
Blue-throated Hummingbird			x
Species List Cont.	2001	2002	2003
Blue-wing Teal		x	
Brewer's Sparrow		x	x
Broad-tailed Hummingbird		x	x
Brown-crested Flycatcher	x	x	x
Brown-headed Cowbird	x	x	x
Bullock's Oriole			x
Bufflehead		x	
California Condor		x	x
California Gull		x	x
Canada Goose		x	x
Canyon Wren	x	x	x
Chipping Sparrow		x	x

Cinnamon Teal		x	x
Clark's Nutcracker		x	
Cliff Swallow			x
Common Goldeneye		x	x
Common Grackle	x	x	x
Common Merganser		x	x
Common Poorwill		x	
Common Raven	x	x	x
Common Yellowthroat	x	x	x
Coopers Hawk		x	x
Cordilleran Flycatcher		x	x
Costas Hummingbird	x	x	x
Crissel Thrasher			x
Dark-eyed Junco	x	x	x
Eared Grebe		x	
Eastern Kingbird			x
Empidonax sp.	x	x	x
Gadwall		x	x
Gambles Quail	x	x	x
Golden Eagle		x	x
Golden-crowned Kinglet	x		x
Great Blue Heron		x	x
Great Horned Owl		x	x
Great-tailed Grackle	x	x	x
Green Heron			x
Green-tailed Towhee		x	x
Green-wing Teal			x
Hammonds Flycatcher		x	
Hooded Oriole	x	x	x
House Finch	x	x	x
House Sparrow			x
House Wren		x	x
Indgo Bunting		x	
Killdeer			x
Lark Sparrow	x		x
Lazuli Bunting	x	x	x
Lesser Goldfinch	x	x	x
Lesser Scaup		x	x
Loggerheaded Shrike	x	x	
Louisiana Waterthrush	x		

Lucy's Warbler	x	x	x
MacGillivray's Warbler		x	x
Mallard		x	x
Marsh Wren		x	x
Mexican Spotted Owl			x
Mourning Dove	x	x	x
Northern Flicker		x	
Northern Mockingbird	x	x	x
Northern Pintail			x
Northern Rough-wing Swallow		x	x
Orange-crowned Warbler			x
Osprey			x
Painted Bunting			x
Painted Redstart			x
Peregrine Falcon	x	x	x
Phainopepla	x	x	x
Pinon Jay	x		
Plumbeous Vireo			x
Red-breasted Merganser		x	x
Redhead Duck		x	x
Red-tailed Hawk		x	x
Red-winged Blackbird		x	x
Ring-billed gull			x
Ring-necked Duck		x	x
Rock Wren	x	x	x
Rose-breasted Grosbeak		x	x
Ross's Goose		x	
Ruby-crowned Kinglet		x	x
Rufus-crowned Sparrow			x
Rufus Hummingbird		x	
Says Phoebe	x	x	x
Scott'sOriole		x	x
Scrub Jay	x	x	x
Sharp-shinned Hawk			x
Snowy Egret			x
Song Sparrow	x	x	x
Southwestern Willow Flycatcher	x	x	x
Spotted Sandpiper	x	x	x
Spotted Towhee	x	x	x
Summer Tanager	x	x	x

Townsend's Solitare		x	x
Turkey Vulture	x	x	x
Vesper Sparrow			x
Violet-green Swallow	x	x	x
Voux Swallow		x	x
Virginia Warbler		x	x
Voux Swallow			x
Warbling Vireo	x		x
Western Kingbird		x	x
Western Tanager		x	x
Western Wood Peewee	x	x	
White-crowned Sparrow	x	x	x
White-faced Ibis			x
White-throated Swift		x	x
Willet			x
Wilson's warbler	x	x	x
Wood Duck			x
Yellow Warbler	x	x	x
Yellow-breasted Chat	x	x	x
Yellow-rumped Warbler	x	x	x
Total species	54	101	116

Mammal species encountered

Abbreviation	Latin Binomial	Common name
PEER	Peromyscus eremicus	Cactus Mouse
NELE	Neotoma lepida	Desert Woodrat
PECR	Peromyscus crinitus	Canyon Mouse
PEBO	Peromyscus boylii	Brush Mouse
CHIN	Chaetodipus intermedius	Rock Pocket Mouse
NEAL	Neotoma albigula	White-throated Woodrat
PEFO	Perognathus formosus	Long-tailed Pocket Mouse
DIOR	Dipodomys ordii	Ord’s Kangaroo Rat
REME	Reithrodontomys megalotis	Western Harvest Mouse