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

Final Report

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

Michael J. C. Kearsley
Neil S. Cobb
Northern Arizona University

Helen K. Yard
Helen Yard Consulting

David C. Lightfoot
Sandra L. Brantley
University of New Mexico

Geoffrey C. Carpenter
Southwestern Biomes, Inc.

Jennifer K. 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

July 2005
revised and re-submitted February 2006
revised and re-submitted August 2006

TABLE OF CONTENTS

Part I
INTRODUCTION 4
M. J. C. Kearsley, D. C. Lightfoot, S. L. Brantley, J. K. Frey, H. K. Yard

Part II
INTEGRATED TERRESTRIAL ECOSYSTEM MONITORING

COMMON METHODS 32
M. J. C. Kearsley

VEGETATION STRUCTURE AND HABITAT MEASURES 46
M. J. C. Kearsley

ARTHROPODS 64
D. C. Lightfoot, S. L. Brantley, N. S. Cobb, R. J. Delph

HERPETOFAUNA 103
G. C. Carpenter

MAMMALS 120
J. K. Frey

INTEGRATION AND INTERPRETATION OF VEGETATION AND FAUNAL ABUNDANCE PATTERNS 144
M. J. C. Kearsley and D. C. Lightfoot

Part III
RELATED SURVEYS OF VEGETATION

VEGETATION DYNAMICS 177
M. J. C. Kearsley

Part IV
RECOMMENDATIONS FOR IMPROVED INVENTORY AND MONITORING METHODS 200
M. J. C. Kearsley, D. C. Lightfoot, S. L. Brantley

APPENDIX A
Lists of plant species encountered 213

APPENDIX B
Lists of arthropod taxa encountered 220

APPENDIX C
Lists of herpetofauna species encountered 246

APPENDIX D
Lists of bird species encountered 248

APPENDIX E
Lists of mammal species encountered 253

APPENDIX F
Mammal voucher specimens 255

APPENDIX G
Mammals of the Grand Canyon region 258

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

Part I
Introduction

Michael J. C. Kearsley[1], David C. Lightfoot[3],
Sandra L. Brantley[3], Jennifer K. Frey[2], and Helen K. Yard[4]
[1]Northern Arizona University, [2]New Mexico State University,
[3]University of New Mexico, [4]Helen Yard Consulting

Terrestrial riparian corridors along rivers of the semi-arid Southwest have been highly impacted by the presence of human constructed dams. Dams have altered river flows, ending natural flooding events, shoreline fluctuation, and sediment deposition. Dam effects on downstream ecosystems are complex, variable, often indirect, but generally result in negative impacts on native biodiversity and ecosystem function. Stabilization of annual peak floods allows the establishment of often non-native plant communities in areas previously scoured annually of most vegetation (Turner and Karpiscak 1980, Walker 1986). In contrast, the drying of habitats by flow reduction decreases the growth rates of and causes mortality in mature plants and prevents the germination seeds of many riparian species (Rood and Mahoney 1990, Smith et al. 1991, Stromberg 1993, Stromberg et al. 1996). Although higher river flows are generally associated with increased vigor and survival of plants in riparian habitats (Stromberg and Patten 1992, Smith et al. 1991, Auble et al. 1994) the effects of flow augmentation on riparian species are not always positive (Stromberg and Patten 1992). Further, the loss of nutrient-rich and moisture-retaining fine soils due to fluctuating flow levels can lead to a loss of species diversity through changes in germination sites (Nilsson et al. 1997).

Glen Canyon Dam operations have produced all these effects in Grand Canyon. Plant communities are separated into pre-dam old high water zone (OHWZ) and post-dam new high water zone (NHWZ) areas (Carothers and Aitchison 1976). The OHWZ dominated by native mesquite (*Prosopis glandulosa*), catclaw acacia (*Acacia greggii*), apache plume (*Fallugia paradoxa*), and hackberry (*Celtis reticulata*) is generally in decline due to dewatering and a lack of nutrient-laden sediment inputs (Anderson and Ruffner 1987, Bureau of Reclamation 1995). The NHWZ is composed mostly of exotic saltcedar (*Tamarix ramosissima*) with associated native species such as willow (*Salix exigua*), arrowweed (*Pluchea sericia*), and baccharis (*Baccharis* spp.) and is subject to dynamic changes based on dam operations for hydropower or management objectives (Stevens et al. 1995, Kearsley and Ayers 1996, 1999a,b,c).

The impacts of changes in river flow cascading through food webs are not well understood. The addition of highly productive wetland and riparian vegetation to areas formerly scoured by spring high flows creates habitat patch mosaics with novel characteristics which can be opportunistically exploited by biota (Carothers and Sharber 1976, Brown et al. 1983, Brown 1989, 1992). The removal of sediment and release of cold, clear water promotes aquatic productivity in near-shore habitats that attracts a variety of vertebrate consumers (Bureau of Reclamation 1995, Stevens et al. 1997). Changes in the timing and other characteristics of the floods caused by flow regulation (Thoms and Walker 1992, Walker et al. 1995, Puckridge et al. 1998) are likely to have impacts on avian and herpetofaunal nesting and other animal life history traits (Warren and Schwalbe 1985, 1986).

Computer models have been developed to predict the physical effects of dam operations on the Grand Canyon river corridor. An analytical model (STARS; Randle and Pemberton 1987) predicts stage-elevation information at 700 cross sections, and has been used to predict sediment transport under various flow scenarios (Wiele 1998). A conceptual model is under development (Korman and Walters 1998), which makes geomorphic reach-averaged predictions about sediment deposition and erosion. Until now, no terrestrial biological monitoring data has been collected in Grand Canyon in a way that allows its inclusion in either model.

Research Objectives

Six primary objectives motivated the research reported here. Objectives specific to individual elements followed directly from these. The results of our three-year biological inventory and monitoring program will serve as the basis for future fully integrated terrestrial riparian resource monitoring and the development of predictive models for terrestrial vegetation and indicator taxa. We measured breeding bird abundance and species richness in patches where five years of comparably collected data already existed. We also surveyed arthropods, amphibians and reptiles (herpetofauna), and mammals in those same patches to provide baseline data for integrated, long-term monitoring. We measured vegetation structure and composition in those same patches to address questions regarding the relationship between breeding bird communities and habitat variables. We also monitored vegetation throughout the river corridor at specific river stage elevations to determine whether vegetation changes were specifically associated with the hydrograph. We then addressed the primary question: Are there dam-related changes in vegetation whose effects cascade up through insect, bird, herpetofauna, and mammal communities? Our six primary research objectives were:

1) To create a powerful sampling design with probability-based site selection, which will allow system-wide inferences to be made from monitoring data.
2) To integrate sampling of terrestrial biotic resources in ways that are based on our understanding of how hydrographs of regulated rivers impact terrestrial resources.
    A. Water level impacts plant productivity through water table and flooding.
    B. Plant productivity determines food base and structure for primary consumers.
3) To monitor terrestrial resources in ways which allow their inclusion in current conceptual and analytic computer models relating dam operations to physical processes.
    A. Reach-based resource averages for conceptual models;
    B. Point-based resource estimates for analytic models.

4) To expand on integrated investigations currently underway regarding interactions among vegetation structure, arthropod abundance, and breeding bird populations in the Colorado River corridor. This includes consideration of:
    A. Vegetation structure vs. invertebrate abundance.
    B. Invertebrate abundance as “breeding currency” for riparian breeding birds.
5) To survey terrestrial faunal components about which little is known beyond scattered collection records, including:
    A. Terrestrial arthropods.
    B. Herpetofauna.
    C. Small mammals.
6) To incorporate Tribal perspectives and information in all phases of monitoring through consultation, shared sampling, training and reciprocal exchanges of information.

In summary, we attempted to develop a framework for a permanent inventory and monitoring program that will provide a bioassay of dam operation effects on the long-term integrity of riparian communities in the Grand Canyon corridor. The most important component of our inventory and monitoring research was to ensure a sound research campaign that would provide the most extensive biological inventory possible, and provide the basis for future monitoring of the impacts of river regulation on riparian communities. The key to all of this is the integration of research across all disciplines involved (plants, animals, edaphic habitat substrates, cultural resources, and dam operations).

This report presents the results of our 3-year project to inventory and monitor biotic resources of the terrestrial riparian ecosystem of the Colorado River corridor of Grand Canyon National Park. The strength of our study lies in its integrated design, that is, simultaneously sampling many different taxa at the same sites and times. We now have the opportunity to examine some predicted relationships among different groups (Figure Int-1). The primary aim of this project was to link patterns of change in riparian habitats and their associated fauna to the operations of Glen Canyon Dam. We experienced three study years with distinct patterns in both the weather and the dam-regulated flows during our study and therefore have been able to tease apart the effects of river flows and variation in the weather for some components in the riparian habitats.

An additional goal of this project was to include perspectives from the Tribes who participate in the adaptive management process. Rather than imposing a formal method for this goal, we have accomplished it by maintaining direct contacts with members of the Paiute, Hopi and Hualapai tribes. We have met while on the river when our separate trips have coincided, have included tribal representatives in our trips, and have participated in resource monitoring trips sponsored by the Tribes. We have also presented results of our first three years of work to the Tribes in a set of twice-yearly formal presentations at GCMRC during which we received feedback on how our work relates to Tribal concerns. We have also been advised on how to perform and report the work so that it bears directly on Tribal information needs and avoids conflicts with cultural values. We have endeavored to incorporate these points into the work described in this report.

Part I of the report introduces our sampling and monitoring aims, a brief description of the physical setting of Grand Canyon, and a review of previous studies on plants and animals. Two of the taxonomic groups covered by this study, plants and birds, have received significant research attention in the past, but the other groups (arthropods, herpetofauna and small mammals), have been far less studied. Part II describes our sampling and monitoring methods, followed by results for each group of plants and animals, and ending with a synthesis of the interactions among the groups. Part III contains additional information about vegetation dynamics, overwintering bird species, and a survey of southwestern willow flycatcher occurrence in Grand Canyon. In Part IV we address current management issues with recommendations for continued monitoring efforts. The appendices at the end of the report list the species we encountered or collected.

Sampling and Monitoring Aims

Monitoring is often described as the repeated measurement of a resource in a geographically defined area (Noon et al. 1999), but we enlarge the definition to include those measurements used to evaluate changes in the condition of a resource relative to some defined management goal (Hollings 1978, Elzinga et al. 1998) or that can be used to determine subsequent management actions (Walters 1986, Bormann 1994).

The aims of our monitoring project included several elements. First, we wanted to sample multiple taxonomic groups simultaneously. Although earlier surveys and monitoring projects had included many taxa, the Terrestrial Protocol Review panel recommended that this project combine efforts on taxa which had previously been studied in depth (i.e., vegetation and avifauna) along with those which had received much less attention (i.e., invertebrates, herpetofauna, and small mammals) (Urquhart et al. 2000). By doing so we could not only gain more information on understudied groups, but could also document potential linkages among different parts of the riparian community. Second, we wanted a sampling regime that would let us link changes in biological resources with changes in the hydrograph, which is regulated by Glen Canyon Dam. By sampling in three hydrologic zones with different relationships to river flows, we could partition changes due to altered moisture relations into components driven by the hydrograph and those driven by climate. Third, we wanted to minimize investigator impacts, which are often the result of repeatedly returning to the same sites. For example, transects in a fluvial marsh near Kwagunt Canyon, which were surveyed twice-yearly between 1992 and 1996 (Stevens and Ayers 1995, Kearsley et al. 1996), were clearly visible in 1:1200 scale aerial photographs for several years after surveying had ceased (M. Kearsley, *personal observation*). We were present at sites for less than a day and left no permanent evidence of our sampling methods. Fourth, in addition to integrating information across multiple taxa, we wanted to make valid generalizations about each taxonomic group. In some monitoring programs, the selection of representative sites has proved to be difficult and has led to erroneous conclusions about the status of, or trends in, policy-relevant resource measures (Urquhart et al. 1998, Peterman et al. 1999). What we developed was a probability-based sampling design in which sampling units were well defined and organized into geographically meaningful groups so that random sampling could capture the natural variability of the riparian system. Fifth, we wanted to include the perspectives of members of the Hopi, Paiute and Hualapai tribes who have strong historical and cultural ties to Grand Canyon (Stevens 1994, Austin et al. 1996, Ferguson 1998). These groups are stakeholders in the adaptive management of Glen Canyon Dam, and many of these tribes' cultural properties are biological in nature and are heavily represented in the post-dam riparian zone (Stoffle et al. 1995). We therefore determined which elements of our project could supplement the information needs of the cultural programs of the tribes beyond those provided by their own ethnobotanical and cultural monitoring (e.g., Stoffle et al. 1995, Phillips and Jackson 1996, Huisinga and Yeatts 2003).

Colorado River Riparian Habitats

Physical setting. The Grand Canyon of the Colorado River occupies a critical area in the southwestern U.S., both physically and biogeographically. The canyon intersects three of the four major U.S. deserts (Brown 1994 p. 13) and therefore has elements from each which combine to enhance diversity and create a unique flora and fauna. The rims of Glen Canyon and Marble Canyon are in the cold high Great Basin Deserts, while at the lower end of Grand Canyon, the Colorado River flows into the hotter Mojave Desert. Many species of the Sonoran desert are also found in the lower end of Grand Canyon, having moved there using the riparian areas as a corridor (Phillips 1975, Phillips et al. 1987, Brown 1994).

Within this regional setting, the river is entrenched in a constrained canyon where the nature of the bedrock layers strongly influences the morphology of the corridor and biotic habitat features. Where the river flows through harder bedrock layers such as granites and limestones, the canyon narrows; where it flows through more erodible sandstones and shales it is much wider (Table Int-1; Schmidt and Graf 1990). The width of a reach is important in determining, to a large extent, the potential biotic productivity in both aquatic and terrestrial habitats (Blinn and Yard 1999, Kearsley and Ayers 2000, 2001, Shannon et al. 2001). In aquatic habitats in wider reaches, solar inputs are greater because the canyon rim is more open and total productive wetted area is much larger because slopes are shallower between the shoreline and channel bottom (Blinn and Yard 1999). Similarly, terrestrial habitats in wide reaches receive the same increased insolation and also have shallower slopes (Randle and Pemberton 1987) so there is a greater area of habitat available for a given rise above the river, (Figure Int-2; Carpenter et al. 1994). Narrower reaches also tend to have steep, rocky slopes and have a higher percentage of shoreline as cliff (M. Kearsley, *personal observation*). Furthermore, in narrow reaches which trend from east to west, primary productivity is limited even more because the high canyon walls block direct sunlight for much of the year (Blinn and Yard 1999, Yard 2003). The amount of sunlight also affects ectothermic animals, such as arthropods and herpetofauna, that need to bask during cooler times of the year (G. Carpenter, *personal observations*).

Hydrographs and habitats. Within this physical setting, terrestrial habitats develop via mechanisms driven by geomorphic processes. At higher elevations, fine sediments suspended in the river are trapped as the current is slowed by rocks and vegetation in channel margins or in eddies associated with debris fans and other obstructions (Figure Int-3; Schmidt and Graf 1990). Lower elevation habitats which are within active return current channels at higher flows, accumulate fine sediments and tend to support vegetation characterized by wetland species (Stevens et al. 1995). The most extensive patches of dense riparian vegetation form on large reattachment bars associated with large debris fan-eddy complexes (Schmidt and Graf 1990, Webb et al.

1999). Although these bars represent only about 1% of the total river shoreline in Grand Canyon, the proportions of different vegetation (e.g., dense tamarisk stands or Salix / *Baccharis stands)* do not differ markedly in either of these two settings (Kearsley and Ayers 2001).

Flow regulation at Glen Canyon Dam has shaped the development of riparian communities since 1963. By restricting the variation in flow to a much narrower annual range, the dam has allowed vegetation to establish at elevations between the 25,000 to 45,000 cubic feet per second (cfs) stage zones which would have been scoured in pre-dam spring floods (Turner and Karpiscak 1980, Carothers and Dolan 1982, Webb 1996). The post-dam hydrograph, driven primarily by electrical demands and water delivery requirements between 1963 and the early 1990s (Bureau of Reclamation 1996), produced a pattern of vegetation in strands (Carothers and Aitchison 1976, Johnson and Carothers 1982) in which distance above the river determines the character of plants present (Figure Int-4). The shoreline areas (from the low-water shoreline to a meter above daily high water, roughly 2.9 meters vertically between the 5000 cfs and 25000 cfs levels based on data from Randle and Pemberton (1987)) are subject to direct effects of the river such as scour and inundation. The “new high water zone” technically includes all areas between the top of the shoreline zone to the approximate 90,000 cfs shoreline, although the lower half of this area (up to 45000 cfs) represents the current zone of potential non-emergency dam operations. On average, this area represents a vertical rise of 3.3 meters. This area does not get inundated regularly, but is affected by changes in ground water levels, which in turn affect the abundance of deeply rooted perennial plant species (Carpenter et al. 1994). The “old high water zone,” begins approximately at the pre-dam annual return flood (ca. 90,000 cfs and grades into pure desert habitats above the 120,000 cfs elevation. Plants in these habitats do not seem to be responsive to current dam operations (Anderson and Ruffner 1987) or episodic flows above normal operations (Brian 1987, Waring 1996), but are likely to respond to variation in precipitation.

Previous Surveys in Grand Canyon

Plants. The earliest formal studies on plants in the river corridor were baseline surveys aimed at listing species encountered in the Park (Dodge 1936, Patraw 1936). In the last 30 years, more comprehensive species lists have been produced from ecological and taxonomic studies (Theroux 1976, Phillips et al. 1987, Ayers et al. 1995). Above the level of species lists, several investigators and groups have attempted to describe patterns in the floristics of the Colorado River corridor by creating vegetation maps. The first of these classified the vegetation in the river corridor into 12 basic types and delineated patch boundaries on 1:2400 aerial photographs (Phillips et al. 1977). A second full riparian corridor map was created by removing five non-riparian vegetation types from the original set and recalculating the areas represented by each remaining vegetation type (Ohmart 1982). Based on these data, approximately 75% of the riparian vegetation in 1972 was classified as either “dense tamarisk” or “sparse tamarisk” patches. Other mapping efforts have focused on the rims and non-river inner gorge areas (Warren et al. 1982).

Smaller sections of the river corridor have been singled out in a number of studies. Specific reaches selected for more intensive studies (“GIS reaches”) were mapped extensively in the early 1990s from orthorectified aerial photographs (Werth et al. 1993). Similar methods using many sets of orthorectified aerial photographs have been used to detect decadal and multi-decadal trends in vegetation abundance in the river corridor (Puccherelli 1986, Brian 1987, Waring 1996). In general, the conclusions have been that the new high water zone vegetation has been expanding since the imposition of flow controls from Glen Canyon Dam (Puccherelli 1986, Waring 1996); high flows in 1983 and 1984 reduced the area of new high water zone vegetation by up to 50% (Brian 1987); and the area of old high water zone vegetation may have increased slightly over a short period due to those same high flows (Puccherelli 1986, Brian 1987), but there was no significant increase in the density or areal extent of vegetation over the period 1966 to 1992 (Waring 1996).

Studies using comparisons of oblique rather than aerial photographs have documented changes over longer periods of time. By relocating photo points and duplicating photographs taken up to 110 years earlier, investigators have made a number of mostly qualitative conclusions. First, the areas below the average annual high water (86,000 cfs; Turner and Karpiscak 1980) had very little vegetation before the imposition of flow controls (Karpiscak 1976, Turner and Karpiscak 1980). Second, there is little evidence of wetland vegetation in Grand Canyon (Webb 1996), even though it may have been present in Glen Canyon in the pre-dam era (Flowers 1959, Lindsay 1959, Woodbury et al. 1959). Wetland vegetation in Grand Canyon has developed only in backwaters within the restricted range of fluctuations from Glen Canyon Dam, so that they accumulate fine sediments during periods of turbid flows and get inundated often enough for wetland species to survive (Stevens et al. 1995). Above that level, the turnover of plants is extremely slow, on the scale of one percent per century (Bowers et al. 1995). Third, repeat oblique photography has also been used over shorter periods of time to qualitatively document the negative impacts of campsite usage on vegetation, although the measures were so coarse that no quantitative conclusions could be drawn about the magnitude of the effects (Aitchison et al. 1976, Phillips et al. 1986).

Plot-based and other on-the-ground methods have been useful in documenting the impacts of specific flow events on vegetation. During the high water years of 1983 and 1984, floods scoured out individuals of *Salix*, *Baccharis* and *Typha* growing in lower-elevation habitats, and drowned much of the mesquite, acacia and cacti growing above them (Stevens and Waring 1985, 1986). In the post-flood environment, germination levels among these genera were increased (Stevens and Waring 1986), but the coarsened soil textures of the new deposits largely prevented their establishment (Waring and Stevens 1986). The experimental high flow of 1996, at roughly half the stage of the 1983 flows, had similar but more subtle effects on riparian plants (Kearsley and Ayers 1999a). In habitats closer to the river, vegetation density and cover was reduced by only about 20%, resulting from the burial of low-growing herbs and grasses by up to two meters of coarse sand (Hazel et al. 1999). The new sand contained very few seeds or other propagules (Kearsley and Ayers 1996), and was far removed from sources of water so that little recovery of herbs and grasses was seen afterwards.

Monitoring of vegetation in the river corridor, as opposed to the impact detection studies (e.g., Waring and Stevens 1986, Brian 1987, Kearsley and Ayers 1999a) described above, has taken several different forms. The repeated measure of plots in different geomorphic settings has been used to show that vegetation differs in bar-top, debris fan, channel margin and marsh habitats, and that patterns of change in these habitats are complex (Stevens and Ayers 1993, Kearsley et al. 1996). Hybrid methods, with extensive cover estimates on the ground taken in support of vegetation mapping from aerial photographs (Kearsley and Ayers 1999b, c) showed gradual increases in vegetation density between 1994 and 1998.

Although both of these monitoring methods provided useful information on the status of vegetation in a dozen kilometer-long stretches of the river, their utility as monitoring tools was limited for two reasons (Urquhart et al. 2000). First, the sample sites were not selected in a way that ensured representation of river corridor-wide conditions (e.g., Peterman et al. 1999), but were taken from a subset of relatively large eddy - debris fan complexes chosen for geomorphological studies (Beus et al. 1992). Second, the methods used did not satisfy the information needs of the funding agency. The measurement of total stem basal area by species in permanent plots did not allow for easy conclusions to be made across all species (e.g., a measure of 10 cm^2 basal area of *Equisetum* is not the same as a measure of 10 cm^2 basal area of *Acacia* in terms of biomass, productivity or cover). Also, the use of visual cover estimates in mapping studies and the subjective delineation of patch boundaries introduced biases that made the methods unsuitable for multi-year studies in which there was turnover among surveyors (Smith 1944, Hall and Okali 1978, Vales and Bunnell 1988, Helm and Mead 2004).

Arthropods. Although they are the most abundant and diverse animals in the riparian zone of Grand Canyon, arthropods are the least studied. Stevens (1976) conducted one general short-term survey of terrestrial arthropods in the Grand Canyon but did not differentiate the insects of the different river flow stage zones, lumping all into “riparian” habitats. There have been several short-term studies on specific terrestrial arthropod groups or arthropods in specific habitats (Stevens 1985, Jones 1985, Curtis and Stock 1990, Drost and Blinn 1997). Much more work has been done on aquatic insects (e.g., Polhemus and Polhemus 1976, Sublette et al. 1998) primarily because they serve as food base for game fish and native fish. Outside of Grand Canyon in the lower Colorado River corridor (downstream of Lake Mead) specific surveys have been aimed at individual taxa for ecological purposes (Andersen 1994, Neilson and Anderson 1999).

More recently, there have been two multi-trophic-level studies linking breeding insectivorous birds with arthropods in the riparian vegetation in Grand Canyon (Yard 1998, Yard et al. 2004). Results showed that terrestrial arthropods are the primary food base for common obligate riparian bird species.

Herpetofauna. Prior to the initiation of our project, there were few rigorous studies of amphibians and reptiles. As part of a larger ecological survey Tomko (1976a) made initial assessments of the densities and distributions of common lizards and toads at localities in the river corridor that had extensive patches of riparian habitat. However, small sample sizes and limited resources greatly reduced the statistical power of the density estimates. The author suggested that accurate density estimates would require a crew of 4 - 6 surveyors searching a single site for 5 - 6 days. A related study on diets of eight common lizard and amphibian species showed a great deal of overlap among several of the species in sites where they co-occurred (Tomko 1976b). The diets of *Uta stansburiana* and *Sceloporus magister* were very similar, as were the diets of the lizards

*Cnemidophorus (*now *Aspidoscelus) tigris* and *Urosaurus ornatus,* and the amphibians *Bufo woodhousei* and *Hyla arenicolor* (Tomko 1976b). Within species, however, there were also differences in diet depending on site or season. A more spatially general survey was conducted ten years later (Warren and Schwalbe 1985, 1986) that separated occurrences of different species into different river zones. Most of the observations were made in the new high water zone where lizard densities were "higher than in any other habitat in the southwestern U.S." (Warren and Schwalbe 1985).

Birds. Prior to the construction of Glen Canyon Dam, information regarding avifauna along the Colorado River in Grand Canyon was sparse and incidental (Carothers and Johnson 1975, Brown 1989). The first thorough census and inventory of birds along the Colorado River was conducted by Grand Canyon National Park (GRCA) and the Museum of Northern Arizona after the construction of Glen Canyon dam (Carothers and Sharber 1976), revealing an increase in bird density, presumably due to the increase in vegetation along the river's edge. The increase in vegetation, in turn, was directly related to lack of annual flooding that scoured the river's edge prior to dam construction (Turner and Karpiscak 1980). Studies conducted by GRCA and Glen Canyon Environmental Studies during the 1980's were among the first to document numbers of breeding bird pairs and relate these numbers to vegetation types along the river (Brown 1989), including a comparison of birds nesting in the pre-dam or old high water zone to those nesting in the post-dam or new high water zone. Bell's Vireo is an example of a species whose breeding range has expanded along with the increase in post-dam vegetation (Brown et al. 1983). Formerly the breeding range extended only to the upper reaches of Lake Mead in western Grand Canyon and possibly in the mouths of tributaries up to river mile 209, but the species is currently found nesting far upriver from Lake Mead (approximately river mile 49).

The next extensive studies on birds along the river corridor were conducted by Northern Arizona University/Colorado Plateau Research Station, 1993 – 1995 (Sogge et al.1998, Yard 1996). The objectives of Sogge et al. were to examine the direct impacts of dam-regulated flows on nesting birds along the river, patterns of habitat use with regard to patch size and vegetation composition, breeding/residence status and migratory movements, and methodologies suitable for long-term monitoring and surveying of birds. The purpose of Yard's (1996) study was to document arthropod abundance in pre-and post-dam vegetation and compare it to diet information from common insectivorous birds. The studies produced four major conclusions. First, there was virtually no direct impact of dam flows on breeding birds except possibly in a few species that may nest very close to the water's edge (e.g., Common Yellowthroat and Black Phoebe). Second, the strongest patterns between birds and habitat features showed that the number of breeding birds increased with increasing patch size and that the area and volume of woody vegetation over 2 meters (m) tall were better predictors of bird community composition than shrubs under 2 m or herbaceous ground cover. Third, breeding activity began in April, peaked in May and June, and declined rapidly in July. Interestingly, the majority of Common Yellowthroats and Yellow Warblers captured during 1993-1995 were migrant birds showing no signs of breeding. Finally, walking surveys using auditory detections rather than visual ones revealed the highest numbers of birds. Therefore walking surveys were recommended over point counts because the observer covered more area in dense riparian vegetation where visibility of birds is low.

A subsequent diet study (Yard et al. 2004) revealed that six insectivorous bird species consumed similar quantities of caterpillars and beetles, but use of other prey taxa varied among bird species. All bird species consumed the tamarisk specialist leafhopper in varying proportions. Terrestrial insects comprised 91% of all avian diets compared to 9% of prey from aquatic origin. Three of six bird species showed seasonal shifts in prey items found in diets.

The highest density of wintering waterbirds occurred within the first 15 miles downstream of Glen Canyon Dam (Stevens et al. 1997). At sites below that segment, waterbird numbers dropped exponentially and remained very low until Lake Mead, probably due to turbidity from flows from side canyons (primarily the Paria and Little Colorado Rivers) and the consequent drop in river productivity.

The Grand Canyon Monitoring and Research Center convened a protocol evaluation panel in spring 2000, to review methods and results from recent terrestrial riparian studies and to recommend protocols for future monitoring and research. John G. Blake (Urquhart et al. 2000) made recommendations for avian monitoring, including methods used by Spence (J. Spence et al. Glen Canyon N.R.A., unpublished data) as adequate for assessment of bird populations over time. However, the panel made additional recommendations to better understand the relationship between bird populations and dam flows by suggesting that avian sampling be conducted in multiple habitats including both old high water zone and new high water zone patches. The panel also recommended examination of the relationships between birds, food resources (insects), plants and other physical resources, and that site selection should be randomized and sampled during the same time of year. The avian portion of our terrestrial monitoring program was developed from the historical information presented above and the recommendations of the Protocol Evaluation Panel.

Mammals. Vernon Bailey (1935) of the U.S. Biological Survey provided the first technical review of Grand Canyon mammals to “stimulate interest and to encourage scientific research and investigation …in the Grand Canyon region.” Bailey’s list contained 85 taxa (including 5 species of bats expected to occur in Grand Canyon but not collected up to that time), which represented 66 currently recognized species (Appendix G). Although he did not list specific specimen records, his report provides important historical context for the mammal fauna of the region. During the early 1970’s two important monographs concerning the mammals of the Grand Canyon region were published. The first was Hoffmeister and Durham’s (1971) monograph on the mammals of the Arizona Strip, the area of Mohave County that is north of the Colorado River and west of Kanab Creek. Although the area is distant from the Grand Canyon, the study results provided insight into the mammal fauna of the more poorly studied western and northern portion of the Grand Canyon region. The study was based on 1,138 museum specimens collected between 1955 and 1966. Several species reported from the Arizona Strip have not yet been verified from the Grand Canyon region, but are expected, including the California leaf-nosed bat (*Macrotus californicus*), Sonoran Desert pocket mouse (*Chaetodipus penicillatus*), desert kangaroo rat (*Dipodomys deserti*), and kit fox (*Vulpes macrotis*).

The second monograph (Hoffmeister 1971) is currently the most comprehensive coverage specifically dealing with the mammals of Grand Canyon region, covering the area contained within the original boundaries of Grand Canyon National Park prior to the addition of Marble Canyon National Monument, Grand Canyon National Monument, and part of North Kaibab National Forest. Although designed primarily for the layperson, the book provided a compilation of records and reports of mammals collected during several years by mammalogists associated with the University of Illinois, as well as other available historical records and reports. A total of 73 species of mammals were listed as occurring within the park, including two non-native species, the house mouse (*Mus musculus*) and the burro (*Equus asinus)* (Appendix G). Hoffmeister also identified 6 species that might be present. Of those, 4 subsequently have been recorded from the park (i.e., spotted bat [*Euderma maculatum*], Allen's big-eared bat [*Idionycteris phyllotis*], big free-tailed bat [*Nyctinomops macrotis*]) and the elk [*Cervus canadensis]*, which was introduced. The remaining 2 species to be documented are the white-tailed jackrabbit (*Lepus townsendii*) and the non-native brown rat (*Rattus norvegicus*).

The early 1970's also marked the first comprehensive surveys of mammals along the Colorado River in the Grand Canyon region. A mammal inventory was part of a larger study to also gather information on fishes, amphibians, reptiles, and habitat features (Suttkus et al. 1978). Their study consisted of 15 trips down the Colorado River from Lees Ferry to Sand Point conducted from 1970-1976. Mammal specimens were intensively sampled at 10 sites and incidentally at an additional 31 locations. They also examined 1,053 mammal specimens. The 31 species they reported from the river corridor included one introduced species (the feral burro) and several previously unreported species such as the fringed myotis (*Myotis thysanodes*), Townsend's big-eared bat (*Corynorhinus townsendii*), black-tailed jackrabbit (*Lepus californicus*), Harris's antelope squirrel (*Ammospermophilus harrisii*), Arizona pocket mouse (*Perognathus amplus*), Merriam's kangaroo rat (*Dipodomys merriami*), and piñon mouse (*Peromyscus truei*) (Appendix G).

From 1973 to 1975 Ruffner and Tomoko (1976) conducted a capture-mark-recapture study of 9 species of rodents at 4 riparian zone sites (52.5R, 53.5R, 208.6L, 208.6R) along the Colorado River in Grand Canyon as part of a multidisciplinary ecological survey of the impacts of Glen Canyon Dam and the resultant development of a new riparian community. For small mammals they assessed demographic characteristics such as density, association with 3 habitat types (i.e., beach [= open areas of the shore and new high water zones of this study], terrace [= old high water zone], and wash [=debris fan]), annual survival, species diversity, home range, reproduction, and diet. Major findings of their study included the following. The cactus mouse (*Peromyscus eremicus*) was the most abundant species and occurred in all habitat types. Beach communities and those in the upper canyon were slightly more diverse than terrace communities, a pattern that may have been due to the presence of the deer mouse (*Peromyscus maniculatus*), a species that may no longer occur in the riparian zone. Woodrats (*Neotoma* spp.) and pocket mice (*Perognathus*, *Chaetodipus*) tended to utilize terrace habitats while the canyon mouse (*Peromyscus crinitus*) tended to use wash habitats. Home ranges tended to be linear and there was a negative correlation between range size and night temperature for *P. eremicus* and *P. maniculatus*. Survivorship was low, especially in the beach habitat, which was thought to be a thermally harsh environment. Murid rodent diets were dominated by green vegetation and arthropods. Mean litter sizes tended to be larger than those reported elsewhere and reproduction generally was limited to spring and summer.

Bats are a large group of mammals that typically are poorly sampled because special techniques are required. Drost et al. (2000) conducted the first comprehensive bat study, a 2-year survey (1996-1997) involving 24 sites sampled during 5 trips down the Colorado River from Lees Ferry to either Diamond Creek or Pierce Ferry. They used mist nets, harp traps, Anabat ultrasonic recordings, audible calls, and roost searches to determine bat occurrence, distribution, relative abundance and habitat use. Drost et al. (2000) reported 17 species, 3 of which had not been previously reported from the park (Mexican long-tongued bat [*Choeronycteris mexicana*], spotted bat [*Euderma maculatum*], western bonneted bat [*Eumops perotis*]) and 6 of which had not previously been documented from the river including the silver haired bat (*Lasionycteris noctivagans*), big brown bat (*Eptesicus fuscus*), western red bat (*Lasiurus blossevillii*), hoary bat (*Lasiurus cinereus*), Allen's big-eared bat (*Idionycteris phyllotis*), and big free-tailed bat (*Nyctinomops macrotis*).

General Surveys. There have been few surveys in the river corridor of Grand Canyon that have considered many different taxa simultaneously. Prior to the completion of Glen Canyon Dam, the University of Utah ran a series of vegetation surveys in Glen Canyon, in an effort to record and salvage information before Lake Powell filled (Woodbury et al. 1959). These were coupled with surveys of archaeological sites and other resources (Woodbury 1965). In the 1970s, the Park Service contracted with the Museum of Northern Arizona for an ecological survey of the river corridor that included distribution records for plants, insects, herpetofauna, birds and small mammals (Carothers and Aitchison 1976). Although several of the individual investigators on that project worked with multiple taxonomic groups, no effort was made to coordinate surveys to determine where linkages existed. Because the study was set up as a survey rather than a monitoring operation, there was no effort to document year-to-year variation in population sizes in a coordinated fashion or in ways that could be related to climate or the hydrograph.

Currently, the National Park Service is conducting a series of annual "bio-blitz" surveys in an effort to inventory biological resources throughout the Park (Emma Benenati, NPS Flagstaff, AZ, *personal communication*). Some of the work conducted in the river corridor involves the same groups covered by our study (e.g., vegetation, birds, herpetofauna and small mammals). However, their focus is on inventory, while our project emphasizes an integrated sampling design for quantitative estimates on population sizes, interannual variability, and relationship of riparian community status to variation in the weather and the hydrograph.

Literature Cited

Aitchison, S. W., A. M. Phillips III, and B. G. Phillips.1976. Monitoring river campsites and attraction areas. Final research report. U.S. Department of the Interior, National Park Service Contract No. CX821050007. 13 pages plus photographs.

Andersen, D. C.1994. Are cicadas (*Diceroprocta apache*) both a "keystone" and a "critical link" species in Lower Colorado River riparian communities? Southwestern Naturalist 39:26-33.

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.

Auble, G. T., J. M. Friedman and M. L. Scott.1994. Relating riparian vegetation to present and future streamflows. Ecological Applications. 4:544-554.

Austin, D. E., B. K. Fulfrost, C. Osife, T. Drye, and G. Rogers. 1996. Southern Paiute Consortium *Colorado River Corridor* monitoring and education program. Summary Report. U.S. Department of the Interior, Glen Canyon Environmental Studies contract 4-FC-40-15620.

Ayers, T. J., R. Scott, L. E. Stevens, A. M. Phillips, and K. Warren. 1995. Additions to the flora of Grand Canyon National Park. Journal of the Arizona-Nevada Academy of Science 28:70-75.

Bailey, V. 1935. Mammals of the Grand Canyon region. Grand Canyon Natural History Association, Natural History Bulletin, 1:1-42.

Beus, S. S., C. C. Avery, L. E. Stevens, M. A. Kaplinski, H. B. Mayes, and B. L. Cluer. 1992. The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam, Arizona. Final Report. U.S. Department of the Interior, National Park Service Cooperative Agreement Number 8006-8-0002.

Blinn, D. W., and M. D. Yard. 1999. Factors influencing benthic algal standing mass in the Colorado River: light, drift and velocity. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement 98-FC-40-0540. 24 pages.

Bormann, B. T. 1994. Adaptive ecosystem management in the Pacific Northwest. General Technical Report PNW GTR-341. USDA Forest Service, Portland, OR.

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.

Brown, B. T. 1989. Breeding ecology of riparian birds along the Colorado River in Grand Canyon, Arizona. Technical Report Number 25. University of Arizona Cooperative National Park Resources Studies Unit, Tucson, AZ.

Brown, B.T. 1992. Nesting chronology, density and habitat use of black-chinned hummingbirds along the Colorado River, Arizona. Journal of Field Ornithology. 63:393-400.

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

Brown, D. E., editor. 1994. Biotic communities: southwestern United States and Northwestern Mexico. University of Utah Press, Salt Lake City.

Bureau of Reclamation. 1995. Operation of Glen Canyon Dam. Final Environmental Impact Statement Summary. U.S. Department of the Interior, Bureau of Reclamation, Washington, DC. vi + 73 pages.

Carothers, S. W., and S. W. Aitchison, editors. 1976. An ecological survey of the riparian zones of the Colorado River between Lees Ferry and the Grand Cliffs: Final Report. Grand Canyon National Park Technical Report Series No. 10. U.S. Department of the Interior, National Park Service, Washington, DC. (Grand Canyon National Park. Colorado River Research Series, Contribution Number 38. xiii + 251pp. Grand Canyon, Arizona)

Carothers, S. W., and R. Dolan. 1982. Dam changes on the Colorado River. Natural History 91:74-83.

Carothers, S. W. and R. R. Johnson. 1975. Recent observations on the status and distribution of some birds of the Grand Canyon region. Plateau 47:140-153.

Carothers, S. W., and N. J. Sharber. 1976. Birds of the Colorado River. Pages 109-122 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Final Research Report. Grand Canyon National Park Technical Report No. 10. U.S. Department of the Interior, National Park Service, Washington, DC.

Carpenter, M. C., J. A. Crosswhite, and R. L. Carruth. 1994. Water-level fluctuations, water temperatures, and tilts in sand bars -6.5R, 43.1L, and 172.3L, Grand Canyon, Arizona. Prepared in cooperation with the U.S. Bureau of Reclamation, Tucson, AZ. U.S. Geological Survey, Open File Section. 32 pages + illus.

Curtis, W. M. and M. J. Stock. 1990. Invertebrate species associated with various vegetation and habitat types in the Colorado River corridor, Grand Canyon National Park. Colorado River Investigations? 9:141-149.

Dodge, N. N. 1936. Trees of Grand Canyon National Park. Natural History Bulletin No. 3. Grand Canyon Natural History Association, Grand Canyon, AZ.

Drost, C. A. and Blinn, D.W. 1997. Invertebrate community of Roaring Springs Cave, Grand Canyon National Park, Arizona. Southwestern Naturalist 42: 497-500.

Drost, C. A., J. Petterson and E. Leslie. 2000. Survey of bats along the Colorado River through Grand Canyon National Park. Final Report. Arizona Game and Fish, Heritage Grant I96031. 73 pp.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. BLM Technical Reference 1730-1. U.S. Department of the Interior, Bureau of Land Management, Denver, CO.

Ferguson, T. J. 1998. Ongtupqwa niqw pisisvayu (Salt Canyon and the Colorado River): Hopi people and the Grand Canyon. Final Report. Contract 1425-96-PD-81-20489. Bureau of Reclamation, Tucson, AZ.

Flowers, S. 1959. Vegetation of Glen Canyon. Pages 21-61 *in* A. M. Woodbury, editor. Ecological studies of flora and fauna in Glen Canyon. University of Utah Anthropological Papers No. 40 (Glen Canyon Series No. 7). June 1959. University of Utah Press, Salt Lake City, UT.

Hall, J. B., and D. U. U. Okali. 1978. Observer bias in a floristic survey of complex tropical vegetation. Journal of Ecology 66:241-249.

Hazel, J. E., M. Kaplinski, R. Parnell, M. Manone, and A. Dale. 1999. Topographic and bathymetric changes at thirty-three long-term study sites. Pages 161-183 *in* R. H. Webb, J. C. Schmidt and G. R. Marzolf, editors. The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, Washington, DC.

Helm, D. J., and B. R. Mead. 2004. Reproducibility of vegetation cover estimates in south-central Alaska forests. Journal of Vegetation Science 15:33-40.

Hoffmeister, D. F. 1971. Mammals of Grand Canyon. University of Illinois Press, Urbana, IL.

Hoffmeister, D. F., and F. E. Durham. 1971. Mammals of the Arizona Strip including Grand Canyon National Monument. Contribution from the Museum of Natural History, University of Illinois, Urbana, Illinois. Museum of Northern Arizona, Technical Series, No. 11. Northern Arizona Academy of Science and Art, Flagstaff, AZ.

Hollings, C. S., editor. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York.

Huisinga, K., and M. Yeatts. 2003. Soosoy Himu Naanamiwiwyungwa: an analysis of the Grand Canyon Monitoring and Research Center's terrestrial monitoring program and the development of a Hopi long-term plan. Final Report. Produced by the Hopi Cultural Preservation Office, Flagstaff, AZ. U.S.G.S. Grand Canyon Monitoring and Research Center Cooperative Agreement 01WRSA0358. 194 pages.

Ingles, L. G. 1965. Mammals of the Pacific States. Stanford University Press, Stanford, CA.

Johnson, R. R., and S. W. Carothers. 1982. Southwestern riparian habitats and recreation: Interrelationships and impacts in the Rocky Mountain Region. Eisenhower Consortium Bulletin # 12. Eisenhower Consortium for Western Environmental Forestry Research, Washington, DC.

Jones, S. C. 1985. New termite records for the Grand Canyon. Southwestern Entomologist 10: 137-138.

Karpiscak, M. M. 1976. Vegetational changes along the Colorado River. Pages 1-40 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Final Research Report. Grand Canyon National Park Technical Report No. 10. U.S. Department of the Interior, National Park Service, Washington, DC.

Kearsley, M. J. C., and T. J. Ayers. 1996. Effects of the 1996 Beach / Habitat Building Flows on Riparian Vegetation in Grand Canyon. Final Report. U.S. Department of Interior, Bureau of Reclamation Cooperative Agreement CA 1425-96-FC-81-05006. v + 65 pages.

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

---. 1999b. Second year transition monitoring of riparian vegetation from Glen Canyon Dam to Pearce Ferry. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement CA 1425-96-FC-81-05006 #2. 35 pages.

---. 1999c. 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.

---. 2000. Riparian vegetation monitoring in the Colorado River corridor 1998 to 1999. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement CA-1425-98-FC-40-22567. 35 pages plus appendices.

---. 2001. Review, assessment and recommendations regarding terrestrial riparian vegetation monitoring in the Colorado River corridor of Grand Canyon. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement CA 1425-00-FC-40-32887.

Kearsley, M. J. C., J. R. Spence, T. J. Ayers, K. M. Christensen, P. Rowlands, N. Brian, and A. M. Phillips. 1996. Bridging the gap: transition monitoring of riparian vegetation from Glen Canyon Dam to Pearce Ferry. Final Report. U.S. Department of Interior, Bureau of Reclamation Cooperative Agreement CA - 1425 - 96 - FC - 81 - 05006. v + 59 pages.

Korman, J. and C. Walters. 1998. Users guide to the Grand Canyon Ecosystem Model. Available from Grand Canyon Monitoring and Research Center Website at: http://www.gcmrc.gov/files/pdf/gcm_user_guide.pdf . 48 Pages.

Lindsay, D. W. 1959. Appendix A. Vascular plants collected in Glen Canyon, 1958. Pages 63-72 *in* A. M. Woodbury, editor. Ecological studies of flora and fauna in Glen Canyon. University of Utah Anthropological Papers No. 40 (Glen Canyon Series No. 7). June 1959. University of Utah Press, Salt Lake City, UT.

Neilson, S. M. and D. C. Anderson. 1999. Butterfly (Papilionoidea and Hesperoidea) assemblages associated with natural, exotic, and restored riparian habitats along the lower Colorado River, USA. Regulated Rivers and Restoration Management? 15: 485-504.

Nilsson, C., R. Jansson, and U. Zinko. (1997). Long-term responses of river-margin vegetation to water-level regulation. Science 276, 798-800.

Noon, B. R., T. A. Spies, and M. G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. Pages 21-48 *in* B. S. Mulder, B. R. Noon, T. A. Speis, M. G. Raphael, C. J. Palmer, A. R. Olsen, G. H. Reeves and H. W. Welsh, editors. The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. General Technical Report PNW-GTR-437. U.S.D.A. Forest Service Pacific Northwest Research Station, Portland, OR.

Ohmart, R. D. 1982. Past and present biotic communities of the lower Colorado River mainstem and selected tributaries. Final Report. U.S. Department of the Interior, Bureau of Reclamation Contract no. 7-07-30-V0009, modification no. 2, 1979. Volume 2, Lees Ferry to Lake Mead.

Patraw, P. M. 1936. Check-list of plants of Grand Canyon National Park. Grand Canyon Natural History Association Bulletin No. 6, Rev. Edition. Grand Canyon Natural History Association, Grand Canyon, AZ, USA.

Peterman, S. A., N. S. Urquhart, and E. B. Welch. 1999. Sample representativeness: a must for reliable regional lake condition estimates. Environmental Science and Technology 33:1559-1565.

Phillips, A. M., III. 1975. Packrats, plants, and the Pleistocene in the lower Grand Canyon. Ph.D. Dissertation. University of Arizona, Tucson, AZ.

Phillips, A. M., III, and L. Jackson. 1996. Evaluation and mitigation efforts for the March 1996 Colorado River test flow experiment. Final Report. Hualapai Tribe Cultural Resources Division, Peach Springs, AZ. 10 pages plus figures.

Phillips, B. G., A. M. Phillips III, J. Mazzoni, and M. Theroux. 1977. Riparian vegetation of Grand Canyon National Park. Map. Museum of Northern Arizona, Flagstaff, AZ. Colorado River Ecological Studies.

Phillips, B. G., R. A. Johnson, A. M. Phillips III, and N. J. Brian. 1986. Monitoring the effects of recreational use on Colorado River beaches in Grand Canyon National Park. Museum of Northern Arizona Bulletin #55. vii + 131pp. Flagstaff.

Phillips, B. G., A. M. Phillips III, and M. A. S. Bernzott. 1987. Annotated checklist of vascular plants of Grand Canyon National Park. Grand Canyon Natural History Association Monograph No. 7. Grand Canyon Natural History Association, Grand Canyon, AZ.

Polhemus, J. T. and J. S. Polhemus. 1976. Aquatic and semiaquatic Heteroptera of the Grand Canyon (Insecta: Hemiptera). Great Basin Naturalist 36: 221-226.

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.

Puckridge, J. T., F. Sheldon, D. F. Walker and A. J. Boulton. 1998. Flow variability and the ecology of large rivers. Marine and Freshwater Research. 49:55-72.

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.

Rood, S. B. and J. M. Mahoney. 1990. Collapse of riparian poplar forests downstream of dams in westers prairies: probable causes and prospects for mitigation. Environmental Management. 4:451-464.

Ruffner, G. A., and D. S. Tomko. 1976. Mammals of the Colorado River. Pages 77-94 *in* S. W. Carothers and S. W. Aitchison, editors. An Ecological Survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. Final Report. U.S. Department of the Interior, National Park Service, Grand Canyon National Park Contract No. CX 821500007. Museum of Northern Arizona, Flagstaff, AZ.

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

Shannon, J. P., D. W. Blinn, G. A. Haden, E. P. Benenati, and K. P. Wilson. 2001. Food web implications of δ13C and δ15N variability of 370km of the regulated Colorado River USA. Isotopes and Environmental Health Studies 37:179-191.

Smith, A. D. 1944. A study of the reliability of visual vegetation estimates. Ecology 25:441-448.

Smith, S. D., A. B. Wellington, J. L. Nachlinger and C. A. Fox. 1991. Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. Ecological Applications. 1:89-97.

Sogge, M. K., D. Felley, and M. Wotawa. 1998. Riparian bird community ecology in the Grand Canyon - Final Report. U.S.G.S Colorado Plateau Field Station Report. 255 pages.

Stevens, L. E. 1976. An insect inventory of Grand Canyon. In: An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs, Arizona. Colorado River Technical Report No. 10. (Eds: Carothers,S. W. and S. W. Aitchison) Museum of Northern Arizona, Flagstaff, AZ, Chapter VII.

Stevens, L. E. 1985. Invertebrate herbivore community dynamics on *Tamarix chinensis* loueiro and *Salix exigua* Nuttall in the Grand Canyon, Arizona. M.S. Thesis. Northern Arizona University, Flagstaff, AZ, USA. xi + 162 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.

---. 1995. The effects of Interim Flows from Glen Canyon Dam on riparian vegetation along the Colorado River in Grand Canyon National Park, Arizona. Final Report. U.S. Department of the Interior, National Park Service Work Order No. CA 8021-8-0002.

Stevens, L. E., and G. L. Waring. 1985. The effects of prolonged flooding on the riparian plant communities in Grand Canyon. Pages 81-86 *in* R. R. Johnson, 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; April 16-18, 1985; Tucson, Arizona. Rocky Mountain Station Forest and Range Experimental Station, Fort Collins, Colorado.

---. 1986. Effects of post-dam flooding on riparian substrates, vegetation, and invertebrate populations in the Colorado River corridor in Grand Canyon, Arizona. U.S. Department of the Interior, Bureau of Reclamation, Glen Canyon Environmental Studies Report GCES/19/87. NTIS PB88-183488. iv + 166pp.

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.

Stevens, L. E., K. A. Buck, B. T. Brown, and N. C. Kline. 1997. Dam and geomorphological influences on Colorado River waterbird distribution, Grand Canyon, Arizona. Regulated Rivers: Research and Management 13:151-169.

Stevens, R. H. 1994. Hualapai Tribe's cultural properties on and along the Colorado River through the Grand Canyon: a Hualapai Tribe research report to the United States Department of the Interior, Bureau of Reclamation, for Glen Canyon Environmental Studies. Unpublished Report. 10 pages.

Stoffle, R. W., D. E. Austin, B. K. Fulfrost, A. M. Phillips III, and T. F. Drye. 1995. Itus, Auv', Te'ek (Past, Present, Future). Managing Southern Paiute resources in the Colorado River Corridor. Final Report. U.S. Department of the Interior, Glen Canyon Environmental Studies cooperative agreement #4-FC-40-15260.

Stromberg, J.C. 1993. Fremont cottonwood-Goodding willow riparian forests: a review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science. 26:97-110.

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.

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

Sublette, J. L., L. E. Stevens and J. P. Shannon. 1998. Chironomidae (Diptera) of the Colorado River, Grand Canyon, Arizona, USA, 1: Systematics and ecology. Great Basin Naturalist 58: 97-146.

Suttkus, R. D., G. H., Clemmer and C. Jones. 1978**.** Mammals of the riparian region of the Colorado River in the Grand Canyon area of Arizona. Tulane University, Museum of Natural History Papers. No. 2. 23pp.

Theroux, M. E. 1976. Vascular flora of the Grand Canyon. Pages 41-44 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Final Research Report. Grand Canyon National Park Technical Report No. 10. U.S. Department of the Interior, National Park Service, Washington, DC.

Thoms, M. C. and K. F. Walker. 1992. Sediment transport in a regulated semi-arid river: the River Murray, Australia. pp. 239-250. *in* Robarts R.D. and M.L. Bothwell, Editors. Aquatic ecosystems in semi-arid regions. National Hydrology Research Institute Symposium number 7. Environment Canada, Saskatoon, Saskatchewan, Canada.

Tomko, D. S. 1976a. Demography of three species of Grand Canyon lizards. Pages 55-60 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. Final Report. Contract No. CX821500007. Museum of Northern Arizona, Flagstaff, AZ.

---. 1976b. Dietary characteristics of some Grand Canyon amphibians and reptiles. Pages 45-54 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. Final Report. N.P.S. Contract No. CX821500007. Museum of Northern Arizona, Flagstaff, AZ.

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. Department of the Interior, Geological Survey, Professional Paper 1132. Washington, D.C. iv + 125 pp.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

Urquhart, N. S., G. T. Auble, J. G. Blake, D. T. Bolger, T. Gerrodette, S. G. Leibowitz, D. C. Lightfoot, and A. H. Taylor. 2000. Report of a peer review panel on terrestrial aspects of the Biological Resources Program of the Grand Canyon Monitoring and Research Center. June 23, 2000. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center. Flagstaff, AZ. 49 pp.

Vales, D. J., and F. L. Bunnell. 1988. Comparison of methods for estimating forest overstory cover. I. Observer effects. Canadian Journal of Forest Research 18:606-609.

Walker, K.F. 1986. The Murray-Darling River system. pp. 631-659. *in* Walker K.F. and B.R. Davies, Editors. The ecology of river systems. Junk, Boston.

Walker, K.F., F. Sheldon and J.T. Puckridge. 1995. A Perspective on Dryland River Ecosystems. Regulated Rivers: Research and Management. 11:85-104.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, 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.

Waring, G. L., and L. E. Stevens. 1986. The effects of recent flooding on riparian plant establishment in Grand Canyon. Final Report. Cooperative Agreement IA-4-AA-40-01930. U.S. Bureau of Reclamation, Glen Canyon Environmental Studies GCES/21/87. NTIS 120.01 ENV-4.00 G751 19075. 87 pp.

Warren, P. L., and C. R. Schwalbe. 1985. Herpetofauna in riparian habitats along the Colorado River in Grand Canyon. Pages Pages347-Pages354 *in* R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Ffolliott and R. H. Hamre, editors. Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. First North America riparian conference. USDA Forest Service General Technical Report RM-120. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

---. 1986. Lizards along the Colorado River in Grand Canyon National Park: possible effects of fluctuating river flows. Final report. U.S. Department of Interior, Bureau of Reclamation Glen Canyon Environmental Studies contract 4-AG-40-01810. NTIS PB88-183538. 19 pages.

Warren, P. L., K. L. Reichhardt, D. A. Mouat, B. T. Brown, and R. R. Johnson. 1982. Vegetation of Grand Canyon National Park. Final Report. U.S. Department of the Interior, National Park Service contracts CX8210-7-0028 / CX8000-9-0033. Cooperative National Park Resources Studies Unit, University of Arizona, Tucson, AZ. iv + 140 pp.

Webb, R. H. 1996. Grand Canyon: a century of change: rephotography of the 1889-1890 Stanton expedition. University of Arizona Press, Tucson, AZ.

Webb, R. H., D. L. Wegner, E. D. Andrews, R. A. Valdez, and D. T. Patten. 1999. Downstream effects of Glen Canyon Dam on the Colorado River in Grand Canyon: a review. Pages 1-22 *in* R. H. Webb, J. C. Schmidt, G. R. Marzolf and R. A. Valdez, editors. The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, Washington, DC.

Werth, L. F., P. J. Wright, M. J. Pucherelli, D. L. Wegner, and D. N. Kimberling. 1993. Developing a geographic information system for resource monitoring on the Colorado River in the Grand Canyon. U.S. Department of the Interior, Bureau of Reclamation Report Number R-93-20. 46pp. Denver.

Wiele,SM.(1998): Modeling of flood-deposited sand distributions in a reach of the Colorado River, Grand Canyon, Arizona. U.S. Department of the Interior, U.S. Geological Survey, Water-Resources Investigations Report 97-4168. Tucson, AZ. iv + 15 pages.

Woodbury, A. M. 1965. Notes on the human history of Glen Canyon. University of Utah, Department of Anthropology, Anthropological Papers No. 74, Glen Canyon Series No. 26. University of Utah, Salt Lake City, UT.

Woodbury, A. M., S. D. Durrant, and S. Flowers. 1959. A survey of vegetation in Glen Canyon Reserve Basin. University of Utah Anthropological Papers No. 36 (Glen Canyon Series No. 5). University of Utah Press, Salt Lake City, UT.

Yard, H. K. 1996. Quantitative diet analysis of selected breeding birds along the Colorado River in Grand Canyon National Park. Final Report. U.S. Geological Survey. Colorado Plateau Research Station. Flagstaff, AZ. 41 p.

Yard, H. K. 1998. Diet analysis of selected breeding birds along the Colorado River in Grand Canyon National Park. M.Sc. Thesis, Northern Arizona University, Flagstaff, AZ. ix + 64 p.

Yard, H. K., C. Van Riper III, B. T. Brown and M. J. Kearsley. 2004. Diets of insectivorous birds along the Colorado River in Grand Canyon, Arizona. The Condor: 106:106 - 115

Yard, M. D. 2003. Light availability and aquatic primary production: Colorado River, Glen and Grand Canyons. Ph.D. Dissertation. Northern Arizona University, Flagstaff, AZ.

Table Int-1. Physical characters of geomorphic reaches of the Colorado River in Glen Canyon and Grand Canyon.

Reach #	Reach Name[1]	Reach Type[1]	Width in ft. at 25 kcfs[2]	Start Mile	End Mile	Miles
0	Glen Canyon	Wide	522.1	-15.6	0	15.7
1	Permian	Wide	307.2	0	11.3	11.3
2	Supai	Narrow	158.8	11.3	22.6	11.3
3	Redwall	Narrow	177.0	22.6	35.9	13.3
4	Lower Marble	Wide	261.5	35.9	61.5	25.6
5	Furnace Flats	Wide	272.0	61.5	77.4	15.9
6	Upper Granite	Narrow	156.8	77.4	117.8	40.4
7	Aisles	Narrow	157.9	117.8	125.5	7.7
8	Middle Granite	Narrow	151.1	125.5	139.9	14.4
9	Muav	Narrow	142.5	139.9	159.9	20
10	Lower Canyon	Wide	195.2	159.9	213.8	53.9
11	Lower Granite	Narrow	199.8	213.8	225.7	11.9

[1] Per Schmidt and Graf (1990)

[2] Generated from Randle and Pemberton (1987)

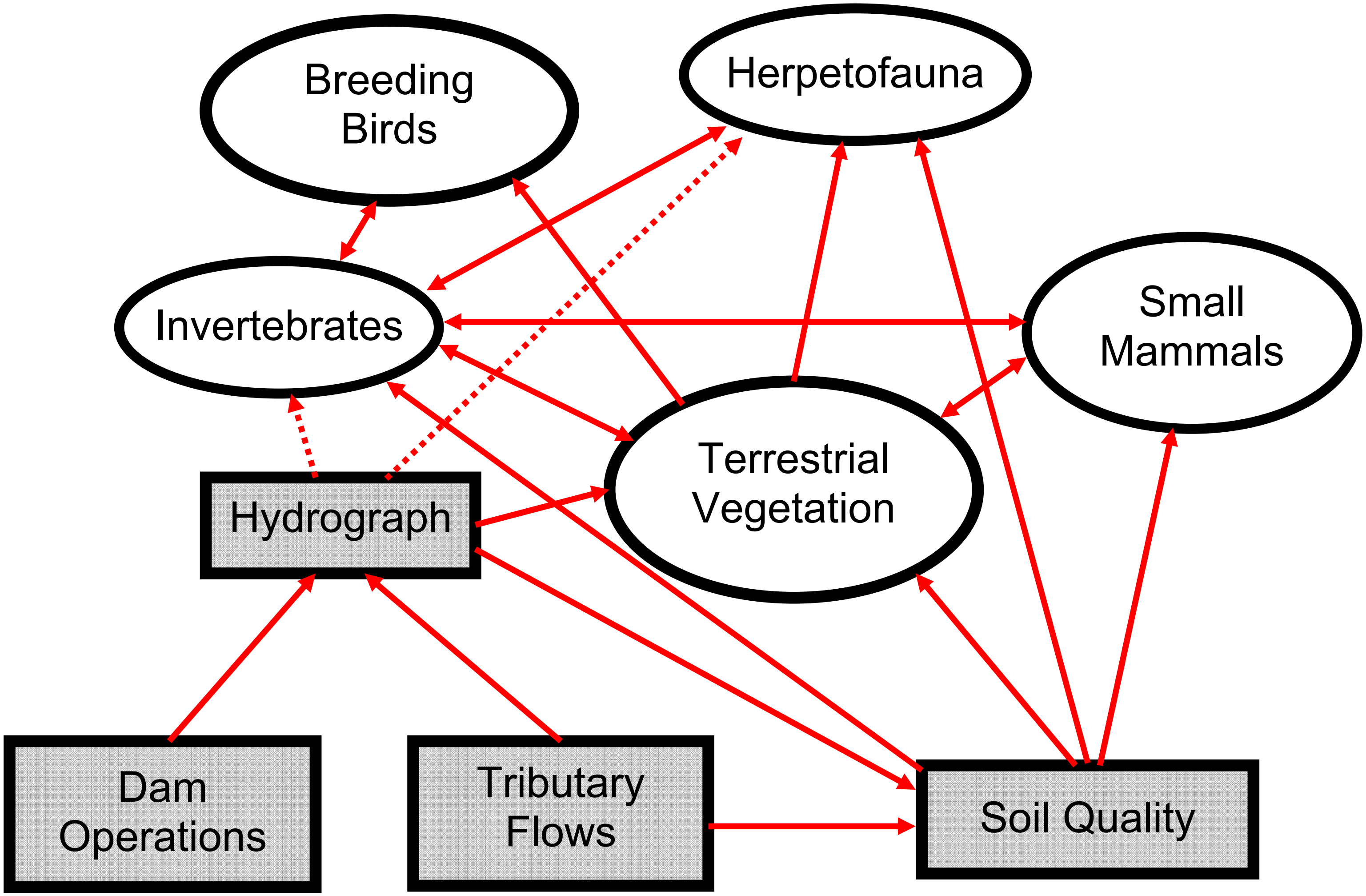


Figure Int-1. Conceptual model of relationships among elements of terrestrial riparian habitats in the Colorado River corridor of Grand Canyon . Shaded boxes show physical factors affecting biological communities, solid arrows show hypothesized direct effects, dotted line shows indirect effects.

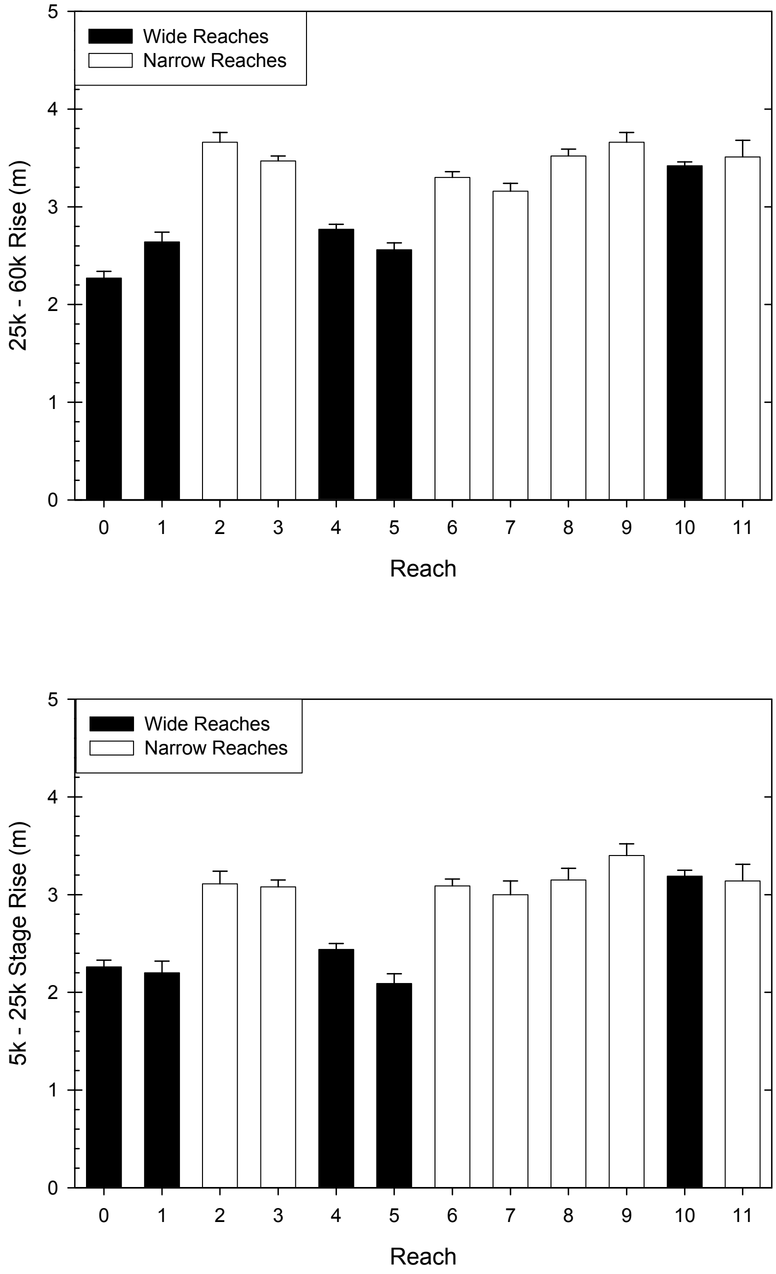


Figure Int-2. Effect of geomorphic setting on water relations in riparian habitats in Grand Canyon. The elevation difference between the water surface at 60,000 cfs (1,700 cms) and 25,000 cfs (700 cms) is much less in wider reaches (upper graph), as it is between 25,000 cfs (700 cms) and 5,000 cfs (140 cms) in the same reaches (lower graph). Thus, the soil surface at a given stage elevation in wide reaches is closer to the water table than it would be in narrow reaches. Data from Randle and Pemberton (1987).

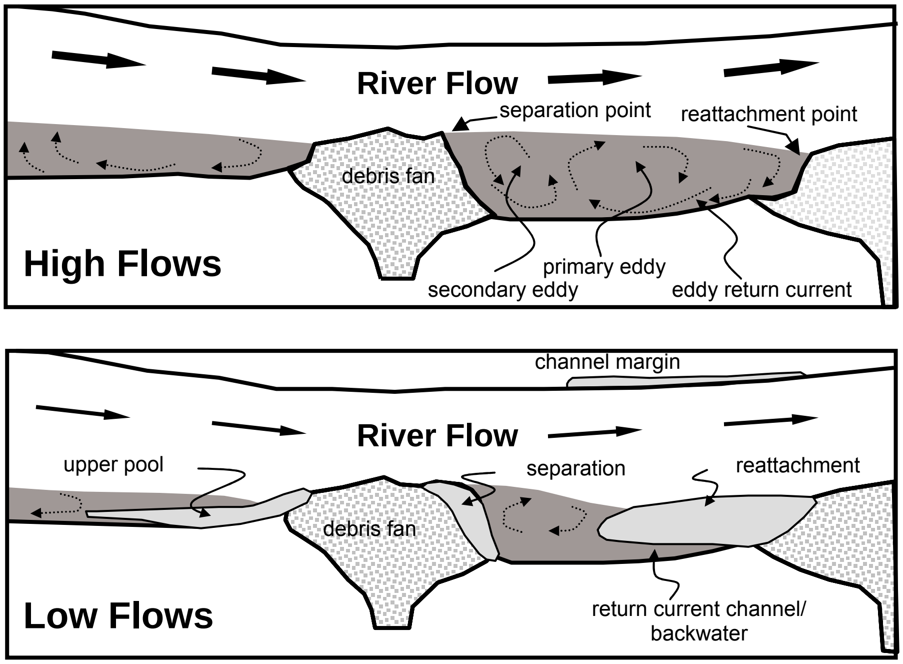


Figure Int-3. Formation of terrestrial riparian habitats is influenced by geomorphology. Upper figure: at higher flows, sediment is deposited in the slower moving water of eddies and on shorelines with obstacles such as rocks and vegetation. Lower figure: when flows recede, deposited sediments are exposed and available for colonization. After Schmidt and Graf (1990).

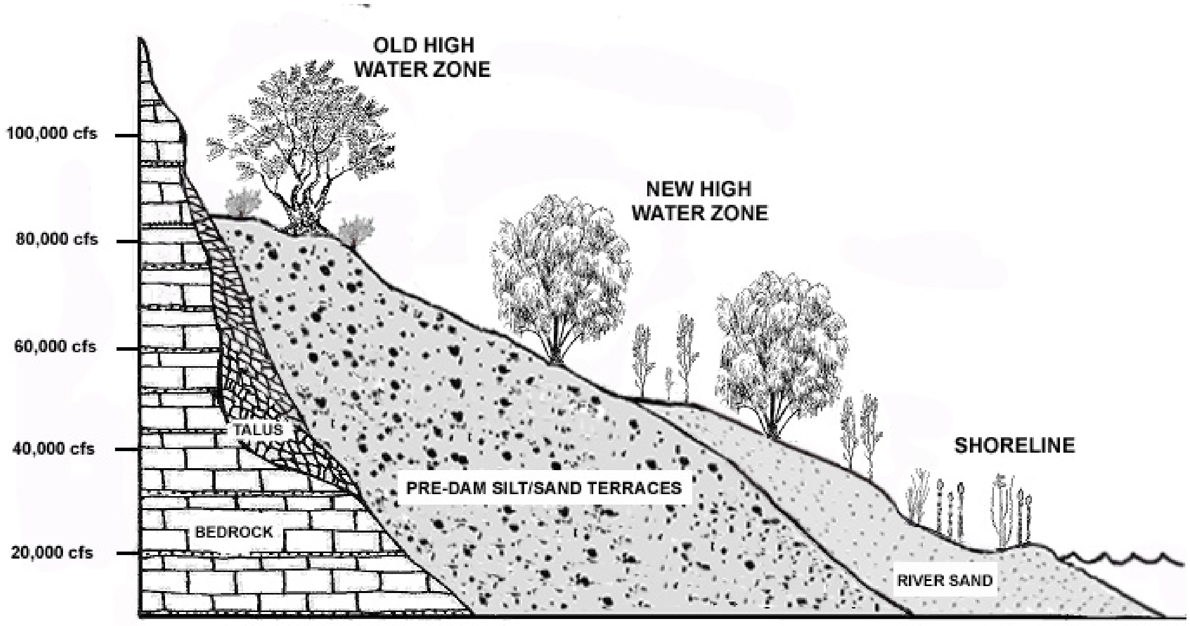


Figure Int-4. Zonation of habitats according to river stage. Reduced flood frequency and flood volume due to Glen Canyon Dam, have combined to result in the development of three well-defined vegetation zones: shoreline habitats below the 25,000 cfs (700 cms) stage, post-dam riparian habitats ("new high water zone") below the 90,000 cfs (2500 cms) stage, and pre-dam riparian habitats ("old high water zone") above that. After Carothers and Aitchison (1976).

Part II

Integrated Terrestrial Ecosystem Monitoring

Common Methods

Purpose

The integrated nature of this project meant that some elements were common to all studies. The purpose of these methods was to provide probabilistically-selected sites for all taxa to be sampled and to derive measures of precipitation and river fluctuations that could be used by all investigators on the project. Sites where habitat structure (vegetation) and faunal data were collected were selected for all groups, and data on the Colorado River hydrograph in Grand Canyon were used by all members of the study team.

Note that we attempted to provide as much consistency as possible in formatting, writing style, and common methods information used across the various chapters in this report. However, some chapter to chapter variation in writing style still exists simply because different authors wrote the different chapters. The authors listed for each chapter are ultimately responsible for the content of their chapters.

Objectives

1. Select sample sites in a way that allowed for canyon-wide conclusions to be made regarding the status of and trends in terrestrial riparian resources.
2. Delineate three hydrologic zones within each site representing shoreline, new high water and old high water zones.
3. Describe the hydrograph of the Colorado River in Grand Canyon to allow changes in resource levels to be related to the operations of Glen Canyon Dam.
4. Generate regional precipitation indices that can serve as measures of rainfall for all sites during the period of the study.

Methods

Terrestrial Ecosystem Monitoring Site selection. A long-term goal for monitoring is to develop habitat quality parameters for riparian breeding birds and other fauna important to stakeholders in the management process. This requires assessing varied habitat patches. Along the corridor, selection also requires taking into account geomorphic controls that affect vegetation density and composition (Stevens et al. 1995). A preferred approach is to develop a probabilistic randomized sampling scheme as recommended by Urquhart et al. (2000) based on a GIS vegetation base map. Unfortunately, the acquisition of imagery and development of a vegetation base map for the river corridor did not begin until May 2002, and it was not available for this pilot effort. Probabilistic sampling would be incorporated into the selection of sites after the completion of the base map.

In the absence of a GIS base map for sample site selection, criteria used to select Terrestrial Ecosystem Monitoring (TEM) sample sites were 1.) To establish integrated sites within most geomorphic reaches, as was logistically feasible. The location of the individual TEM sites had to be such that oar boats could travel downstream from one site to the next between late morning, when all the previous night's sampling gear and samples were stowed, and 5:00 p.m., when that night's sampling gear could be laid out. The outcome of this was that sites needed to be generally 30 miles apart. 2.) To establish TEM sites within geomorphic reaches having at least 100 m of shoreline for sampling in old and new high water zones and also accommodate a large field crew (24 people). 3.) To establish some of these TEM sites as "fixed sites" at bird survey sites that had been sampled consistently since the 1980's (RM 46.7R, 65.3L, 122.8L, 198.0R, Spence 1999). The idea for this criterion being that this long time series for bird data could begin to incorporate a time series for other faunal and vegetation data.

There were both benefits and drawbacks to using these as a pool of potential sites. On the positive side, if additional data from these studies were available, they could perhaps be integrated with our data to define longer-term trends. Also, because these sites were chosen as likely to support birds and other fauna, bird sites tended to be large (most > 1000 m^2) and relatively well-defined areas of at least moderately dense vegetation. On the other hand, extending conclusions about trends in these sites to the canyon as a whole is problematic at best, given that the role of "expert judgment" in selecting these sites overrode any notion of creating a random sample (Peterman et al. 1999). In addition, the sites present in this data set emphasized certain geomorphic reaches over others; wider reaches were over-represented relative to their length (Figure Com-1) and thus conclusions about change in riparian communities would be biased towards them. Sites in Narrow reaches contain less dense vegetation and cover smaller area. Populations found in these sites might be more sensitive to environmental change and could represent an early signal of more widespread changes to come. A sampling program that overemphasized wide reaches would not necessarily detect the signal until later. A case study describing a similar set of problems with regards to sampling water quality was discussed by Peterman et al. (1999).

For the TEM sample sites, four sites were retained in 2002 (locations sited above) as the "repeat" panel, and ten new were added. In 2003, five of the 2002 sites were repeated and nine new sites were added. In 2003, there were not enough new sites identified, primarily due to logistic constraints, to flesh out a complete replacement of the "rotate" panel, so some of the first year sites were repeated in the third year.

Bird Survey Site selection. Spence et al. (2006, in prep during this pilot) determined that the minimum sample number for bird surveys needed to be at least 64 sites visited three times during the breeding season (April-June). Additionally, Spence (1999) identified a pool of 110 bird sites that had been sampled over the years, either every year a bird survey was conducted since the 1980's, or surveyed periodically in the 1990's depending on the contractor. The long time-series of data associated with some sites (Brown 1989, SWCA 1995, Sogge et al. 1998, Spence et al. 1999) provided a compelling reason to include these sites in the sampling regiment. Yet, there was a need to expand the sampling arena beyond those areas that focused on wider, more heavily vegetated sections of the river corridor, the bulk of the 110 sites. Additionally, at a given site, bird surveyors had to complete their work before 10:00 a.m. in the early summer months, after which detection of many bird species declines (Sogge et al.

1998, Spence et al. 1998). Logistic constraints limited the number of sample sites that could be completed in a day to five to six sites, and still make it to the integrated camps for that day. Further randomization of bird sites faced the same dilemma that was present for selection of sampling for integrated sites (i.e., the lack of a vegetation base map).

With this information in hand, bird survey sites were selected each year after the Integrated Sample Sites were selected. Survey sites from the pool of 110 were selected such that all sites were sampled at least once during the pilot study. New sites were added, based on visual examination of the digital aerial orthophotos of the river corridor taken in 2000 and 2002. Emphasis was placed on sites that appeared to have patches of at least 100 m (along river) of moderately dense vegetation in the new high water zone and on sites in narrow reaches that had been under-sampled in previous studies. In each subsequent year (2002, 2003), approximately one third of the sites from the 2001 surveys were retained in a “repeat” panel, and two thirds of the previous year’s sites were replaced by another “rotate” panel. A minimum of 64 sites were sampled each year. Terrestrial Ecosystem Monitoring sample sites were included in the bird survey sites. This sampling approach retained previous survey sites, expanded area covered by the surveys, and reduced investigator impacts at all sites. The sampling design is a modified augmented rotating panel design (Table Com-2; see Urquhart et al. 1998). Probabilistic sampling would be incorporated into the selection of sites after the completion of the base map.

Sample Schedule Although the general outline of sampling was constant for the three years, there was some variation due to logistical and administrative constraints (Table Com-1). For example, in 2001 funding was not made available until April, so there could be no winter bird / waterbird / raptor survey trip in that year. Instead, the funding cycle was shifted forward four months, so that it ran from April 1 to March 30. For the same reason, the spring all-faunal plus vegetation structure sampling trip was not split into upper and lower halves in 2001 as recommended by the review panel in 2000 (Urquhart et al. 2000). This changed in 2002 and 2003 after the project was underway. Similarly, rather than laying out vegetation dynamics transects during the winter of 2001 when vegetation was largely dormant, that activity was performed in July of 2001. In addition, we took advantage of the fact that data on riparian invertebrates was collected in 2000 and 2001 during the summer as part of an unrelated project (Yard and Cobb, unpublished data), and added summer sampling for invertebrates, herpetofauna and mammals in 2002 and 2003.

Site subdivision, patch delineation and area calculations. In order to connect patterns among vegetation types and between vegetation and the hydrograph, each site was subdivided into two or three hydrologic zones. The integrated sampling sites were subdivided into three zones: old high water zone, new high water zone and shoreline. The old high water zone encompassed the high elevation (xeroriparian) habitats that represented the pre-dam riparian community. The lower boundary of this zone, at approximately the 90,000 cfs stage elevation (Carothers et al. 1979, Schmidt and Graf 1990), was determined by the lower end of the distribution of species typical of the pre-dam riparian community, including such species as *Acacia greggii*, *Prosopis glandulosa*, *Fallugia paradoxa*, *Celtis reticulata*, *Ephedra* spp., and *Atriplex canescens* (Clover and Jotter 1944, Webb 1996, Webb et al. 1999). The upper boundary of the zone was defined as the point where these species were replaced by more desert vegetation. The lowest zone, the shoreline zone, was defined as the area between the bottom of daily fluctuations and one meter above the top of daily fluctuations during the river trip when surveys were conducted. The new high water zone was defined as the area between the shoreline zone and the old high water zone, usually representing the stage elevations between approximately 25,000 and 90,000 cfs.

In those patches where only birds and vegetation were surveyed, the patch was split into only two sections: new high water zone and old high water zone. Although initially it was thought that tracking breeding birds using the shoreline for foraging would provide interesting information on the direct effects of the hydrograph on songbirds, their extreme mobility and quick response to the movement of surveyors made it difficult to assign them to the shoreline or new high water zone with any degree of certainty. Therefore, the new high water zone in bird patches was defined as the areas between the old high water zone and the river's edge and so includes both the new high water zone and shoreline areas.

In order to determine the areas of the patches in which the surveys were done, polygons were created in a GIS. First, the boundaries between zones at the sites surveyed in 2001 were drawn on true color aerial images (scales varying from 1:600 – 1:2400) from an overflight in March 2000. Initially this took place in the GCMRC offices and was based on the memory of surveyors and clues from vegetation characters on the images. These boundaries were transferred to a GIS using Arc Map software by project personnel, and patch areas were calculated from these data. Better imagery became available from a May 2002 overflight and those images were used for all 2002 and 2003 patch boundary delineations, based on similar methods. Boundaries at all sites were field checked and revised ensure the accuracy of boundaries. The revised boundaries were incorporated into the GCMRC GIS database.

When integrated monitoring sites were placed in bird sites, the upstream and/or downstream boundaries sometimes had to be shifted to accommodate the 100m transects being sampled by the pitfall and small mammal traps (see ARTHROPODS section for description of the transects). Transect ends were approximated on the aerial images, and boundaries of a given site were defined as beginning approximately upstream and downstream of these points. Figure Com-2 shows the differences between integrated site and bird patch polygons at the same site.

During the period of this study (2001 – 2003), 112 sites were selected for breeding bird surveys and vegetation structure measurements. From these, 34 were designated as integrated monitoring sites, in which arthropod, herpetofaunal and small mammal surveys were conducted as well. Within all sites, shoreline, new high water and old high water zones were delineated on aerial photographs and this information was entered and made available in the GCMRC GIS.

Hydrograph and precipitation data. In order to determine the contribution of dam discharges to differences between years in vegetation structure, we examined daily minimum, maximum and mean stream flow gage data from the U.S. Geological Survey's gage at Glen Canyon Dam (USGS 2004). For each spring trip, we determined the maximum and minimum flows, as well as the mean flow for the 30 days prior to the launch of the trip. Because single days with unusual flows could throw off the analysis, a "top of fluctuations" level was defined as the average plus one standard deviation of all daily flow maxima from that period.

To account for the effects of precipitation on vegetation growth, we gathered monthly data from rain gages in northern Arizona and southern Utah from the Western Regional Climate Center's website (WRCC 2004). Although there were three weather stations within Grand Canyon National Park (Bright Angel R.S., Phantom Ranch, and Grand Canyon N.P. 2), they measured only the area in and immediately around the inner gorge and we felt that our selection of data from 12 regional gages better represented the Canyon as a whole (Table Com-3). . Because each gage measured 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. This converted monthly totals into monthly deviations from average scaled to the natural variability in that station. We then calculated regional normalized rainfall for each month by taking the mean of the normalized monthly data from all 12 gages.

To report information on seasonal precipitation, we divided the year into three seasons relevant to the southwestern U.S. region where monsoonal patterns dominate: 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 similar to the monthly standardized precipitation measures above.

Figure Com-3 shows the hydrograph at the Grand Canyon Gage, just above Bright Angel Creek, for the period 2001 – 2003. In order to make the information useful to the adaptive management process, it is presented in this report by "water years" (October 1 through September 30), which is the current time increment used by water managers for planning releases. By convention, the units of flow are presented as thousands of cubic feet per second (kcfs) rather than in cubic meters per second (cms) for the same reason.

Two significant patterns are evident in the hydrograph. First, winter flows were high (14 to 15 kcfs) during 2000 / 2001. In 2001 / 2002, flows were high only in December, and lower by 2 kcfs to 3 kcfs the rest of the winter. Winter flows were much higher in the winter of 2002 / 2003. The second pattern concerns late summer flows. These were highest in 2003, averaging roughly 15 kcfs from June through September, with fluctuations topping out at approximately 19 kcfs during that period. Although average flows reached 15 kcfs in 2001 and 2002, they did not do so until sometime in July, and even then the top end of fluctuations remained 2 to 3 kcfs lower than in 2003.

Table Com-4 shows the standardized monthly precipitation index from the 12 weather stations in the Grand Canyon region between 2000 and 2003. The first half of 2001 was relatively wet, with most of the first eight months ending up with higher than average precipitation. After that, however, precipitation in 11 of the next 12 months was solidly below average. The winter of 2002 to 2003 was close to normal, overall, but beginning in early 2003, five of the next six months had below normal precipitation.

Literature Cited

Brown, B. T. 1989. Breeding ecology of riparian birds along the Colorado River in Grand Canyon, Arizona. Technical Report Number 25. University of Arizona Cooperative National Park Resources Studies Unit, Tucson, AZ.

Carothers, S. W., S. W. Aitchison, and R. R. Johnson. 1979. Natural resources, white water recreation, and river management alternatives on the Colorado River, Grand Canyon National Park, Arizona. Pages 253-259 *in* R. M. Linn, editor. First conference on scientific research in the national parks. National Park Service Transactions and Proceedings Series Number 5. U.S. Department of Interior, National Park Service, Washington, DC.

Clover, E. U., and L. Jotter. 1944. Floristic studies on the canyon of the Colorado and tributaries. American Midland Naturalist 32:591-642.

Peterman, S. A., N. S. Urquhart, and E. B. Welch. 1999. Sample representativeness: a must for reliable regional lake condition estimates. Environmental Science and Technology 33:1559-1565.

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

Sogge, M. K., D. Felley, and M. Wotawa. 1998. Riparian bird community ecology in the Grand Canyon - Final Report. U.S.G.S Colorado Plateau Field Station Report. 255 pages.

Spence, J. 2006. The riparian and aquatic bird communities along the Colorado River from Glen Canyon Dam to Lake Mead, 1996-2000. Final report to U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona. Interagency Agreement No. 1425-98-AA-40-22680. 284p.

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

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

Spence, J., C. T. LaRue, N. L. Brown, and J. Muller. 1999. Winter and breeding avifauna monitoring along the Colorado River in Glen and Grand Canyons. Draft Final Report submitted to Grand Canyon Monitoring and Research Center. Glen Canyon National Recreation Area, National Park Service.

SWCA Environmental Consultants. 1995. Breeding bird status along the Colorado River in lower Grand Canyon. Final Report. Submitted to Hualapai Department of Natural Resources and U.S. Bureau of Reclamation, Glen Canyon Environmental Studies.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

Urquhart, N. S., G. T. Auble, J. G. Blake, D. T. Bolger, T. Gerrodette, S. G. Leibowitz, D. C. Lightfoot, and A. H. Taylor. 2000. Report of a peer review panel on terrestrial aspects of the Biological Resources Program of the Grand Canyon Monitoring and Research Center. June 23, 2000. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center. Flagstaff, AZ. 49 pp.

USGS. United States Geological Survey. 2000. Integrated monitoring with respect to riparian vegetation, avifauna (including Southwest Willow Flycatcher), and terrestrial fauna along the Colorado River ecosystem. Fiscal Year 2001 Solicitation for Cooperative Agreement Proposals. Grand Canyon Monitoring and Research Center, Flagstaff, AZ. Oct. 26, 2000. Terrestrial Ecosystem Activities, Project 1.

USGS. United States Geological Survey. 2004. USGS Real Time Surface Water Data. Data for all USGS gaging stations available from http://waterdata.usgs.gov/nwis/.

Webb, R. H. 1996. Grand Canyon: a century of change: rephotography of the 1889-1890 Stanton expedition. University of Arizona Press, Tucson, AZ.

Webb, R. H., D. L. Wegner, E. D. Andrews, R. A. Valdez, and D. T. Patten. 1999. Downstream effects of Glen Canyon Dam on the Colorado River in Grand Canyon: a review. Pages 1-22 *in* R. H. Webb, J. C. Schmidt, G. R. Marzolf and R. A. Valdez, editors. The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, Washington, DC.

WRCC. Western Regional Climate Center. 2004. Western U.S. Climate Historical Summaries. Climatological Data Summaries (Temperature and Precipitation). http://www.wrcc.dri.edu/climsum.html.

Table Com-1. Terrestrial Ecosystem Monitoring Project 2001 - 2003 Field Activities

Year	Dates	Breeding Birds	SWWFL Surveys	Overwintering Birds	Water birds	Vegetation Structure	Vegetation Dynamics	Veg. Transect Layout	Invertebrates	Mammals	Herpetofauna
FY 2001	Apr 30 - May 17	X				X			X	X	X
	May 15 - May 30	X	X								
	May 31 - Jun 17		X								
	Jun 18 - Jul 2							X			
	Jun 22 - Jul 10		X								
	Aug 27 - Sep 13						X		X	X	X
	Jan 26 - Feb 4 ‘02			X	X			X			
FY 2002	Mar 30 - Apr 14	X				X^1			X^1	X^1	X^1
	Apr 26 - May 11	X				X^2			X^2	X^2	X^2
	May 15 - May 31		X^3								
	May 30 - Jun 15	X	X						X		X
	Jun 22 - Jul 10		X^4								
	Aug 29 - Sep 13						X		X	X	X
	Jan 19 - Jan 30 ‘03			X	X			X			
FY 2003	Apr 3 - Apr 18	X				X^1			X^1	X^1	X^1
	May 1 - May 16	X				X^2			X^2	X^2	X^2
	May 15 - May 31		X								
	Jun 26 - Jul 11	X	X						X	X	X
	Aug 21 - Sep 5						X		X	X	X
	Jan 16 - Jan 28 ‘04			X	X						

[1] Non-Avifauna sampling from Phantom Ranch to Diamond Creek only
[2] Non-Avifauna sampling from Lees Ferry to Phantom Ranch only
[3] Willow flycatcher survey performed by Frank Brandt on an NPS trip
[4] Willow flycatcher survey performed by Arizona Game and Fish personnel

Table Com-2. Design of the temporal sampling pattern for breeding bird survey patches. Logistical and other constraints have modified this planned pattern and actual numbers of sites visited varied by year.

	2001	2002	2003
Repeat Panel	27	27	27
Rotate Panel 1	48		
Rotate Panel 2		48	
Rotate Panel 3			48
Total planned:	75	75	75

Table Com-3. Weather stations used in calculating regional precipitation patterns relevant to changes in riparian habitats.

Station Name	Station[1]	Location	Elev.[2]
Colorado City	021920	Colorado City, AZ	1530
Pipe Springs Nat'l Mon.	026616	Pipe Springs, AZ	1500
Wahweap	029114	Wahweap, AZ	1130
Page	026180	Page, AZ	1300
Lees Ferry	024849	Lees Ferry, AZ	960
Bright Angel Ranger Station	021001	Grand Canyon, AZ	2560
Phantom Ranch	026471	Grand Canyon, AZ	780
Grand Canyon N.P. 2	023596	Grand Canyon, AZ	2070
Temple Bar	028516	Temple Bar, AZ	470
Kanab	424508	Kanab, UT	1530
Mexican Hat	425582	Mexican Hat, UT	1300
St. George	427516	St. George, UT	840

[1] National Climatic Data Center number assigned to weather station.
[2] Elevation in meters.

Table Com-4. Standardized monthly precipitation index for 2000 – 2003. Standardized precipitation is calculated as the difference of a month's total from the station's 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	-0.308
October	2.631	-0.729	0.075	-0.190
November	-0.481	-0.345	0.079	0.410
December	-0.638	0.393	-0.221	-.234

[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).

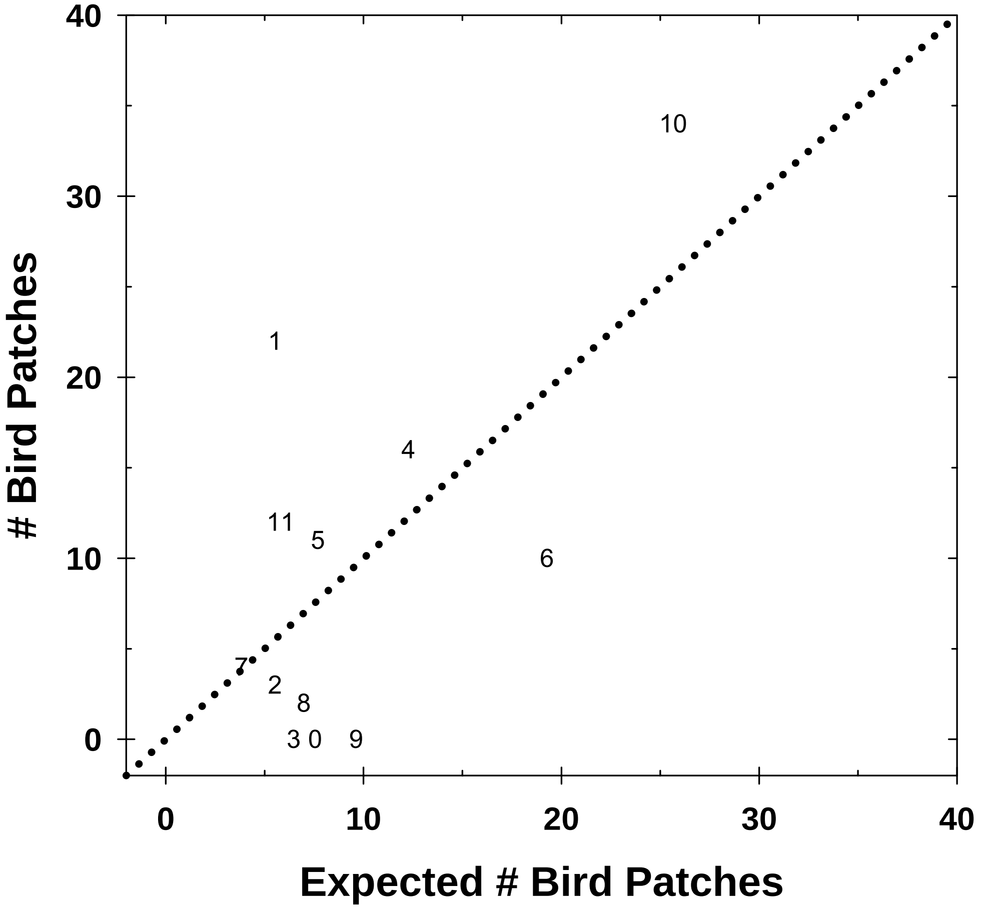


Figure Com-1. Non-representativeness of bird patches surveyed during previous projects by geomorphic reach. Numbers on the graph represent geomorphic reach numbers (in Table Int-1). Placement of the reach numbers indicates the actual number of patches surveyed in that reach verses the expected number. Expected number of bird patches was generated by multiplying the total number of patches surveyed by the proportion of the total Canyon length represented by that reach. The dashed line represents the predicted relationship.

Figure Com-2. Aerial imagery of the survey area at “Pre-Parashant” site (RM 198 R) showing a) area surveyed for birds and b) integrated sampling area where pitfall and small mammal trap transects were laid out. In the former case, the area of the new high water zone would include both the “NHWZ” and “SHORE” areas.

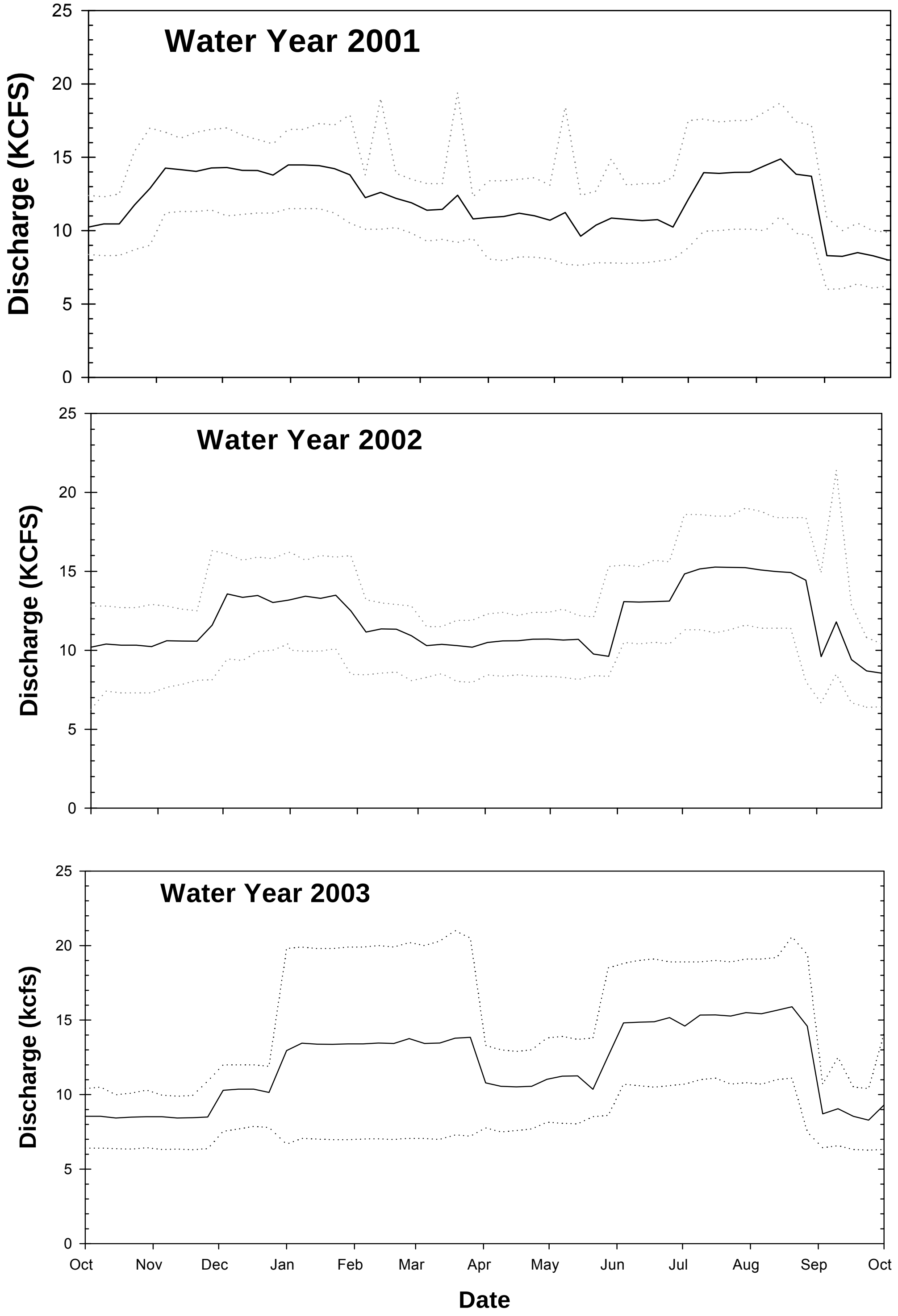


Figure Com-3. Hydrograph of the Colorado River at the Grand Canyon Gage during Water Years 2001 – 2003. Water Years are the planning unit for water managers on the Colorado River. Solid line indicates mean daily flow, dotted line above and below it show maximum and minimum daily flow, respectively.

Vegetation Structure and Habitat Measures

Michael J. C. Kearsley
Northern Arizona University

Purpose of Vegetation Structure Studies

The purpose of collecting vegetation structure data is to document levels of and detect trends in the abundance, 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 can then be used to derive measures related to primary productivity and biomass of vegetation that can be related statistically to the habitat quality for animal taxa of interest in these sites.

Objectives

1) To measure total vegetation volume (TVV) of woody species in new high water zone and old high water zone patches where bird surveys are 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 that had been sampled each year to those that had been surveyed only once.

5) To collect information on plant total vegetative cover on the integrated faunal survey transects.

6) To test for vegetation compositional changes along the survey transects between 2002 and 2003.

Methods

Over the three-year span of this project, we used two measurements of vegetation abundance in the bird patches and faunal transects. First, for both bird patches and integrated sampling transects, we measured vegetation density and productivity as total vegetation volume (TVV; Mills et al. 1991). This measures the number of 10 cm radius cylinders above a given point that have woody vegetation in them and has been shown to be a useful measure of habitat quality for breeding birds (Mills et al. 1991). Second, because not all animals were expected to respond to the abundance of woody vegetation, we also measured the plant species composition around the integrated sampling transects (see ARTHROPODS section for details on transects). Species present in 3 m radius circles around each pitfall trap were placed into one of six broad cover classes of a modified Daubenmire scale (Table Str-1). For the purposes of analyses in this report, plant species composition was defined as mean abundance across 10 sampling points by species.

Bird patch vegetation structure. Each bird survey site was divided into new- and old high water zones patches (see COMMON METHODS section above). In patches where little or no old high water zone vegetation was present, due to cliffs, steep talus or because that area was just too small, no vegetation survey was conducted. In each vegetated patch, we used tables of six-digit random numbers to determine the locations of 20 random points. The first digit was used as the number of paces forward, the second was used to determine whether to turn left (odd) or right (even), the third was the number of paces from that point, the fourth was the direction of the second turn, the fifth was the number of paces from that point and the last determined whether to hold the rod at arm's length to the left (odd) or right (even). 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 that had live vegetation within 10 cm of the rod was recorded, 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. The recording of "vacant" decimeters allowed us to calculate the original formulation of TVV according to Mills et al. (1991), so that our measures could be related to data collected earlier (e.g., Sogge et al. 1995, Spence 2000).

Because previous 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 our data to the original format by making two changes. 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. Although doing so stripped off the identity of the species responsible for the vegetation density, Mills et al. (1991) demonstrated that it was the density of vegetation and the total number of occupied decimeters, not the identity nor the diversity of the species present that best predicted the density of breeding birds. Second, the original TVV measures recorded "hits" from woody species only (Mills et al. 1991). 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 TVV value for each patch based on woody species only. The final data were expressed as the number of "hits" per 20 sampling points per patch.

<u>Transect vegetation structure</u>. Each integrated monitoring site was divided into three hydrologic zones: shoreline (water's edge to the 25,000 cfs stage elevation), new high water zone (upper shoreline boundary to 90,000 cfs stage elevation) and old high water (upper boundary of new high water zone to ca. 150,000 cfs stage elevation where vegetation grades into desert scrub; see "Common Methods" section above). In each of these zones, an arthropod pitfall transect consisting of 10 pitfall traps at 10 meter intervals was established (see ARTHROPODS 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 up slope 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.

<u>Transect plant species composition.</u> We recorded vegetative 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 Str-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.

Data error checking. Data were extensively checked for errors in several ways before analysis. At the end of each day in the field, data sheets were examined to ensure that all header information (date, site, collectors, etc.) were complete, and that species codes used matched those used for this study. After entering data from each patch into a spreadsheet file, the site name, species codes, and TVV or cover scale data were all checked against the original data sheet to catch entry errors. After data were entered, site names were compared with those in the GCMRC GIS site information database and in the faunal data files to ensure consistency.

Statistical Analyses:

Bird patch 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 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 significantly, we substituted the normalized winter precipitation and one top of fluctuations to determine whether these explained inter-annual differences. Details regarding the calculation of these measures are given in the Common Methods section above.

To determine if there were changes in TVV values from the integrated faunal sampling transects, we performed a similar set of ANOVAs on TVV collected there. First, we performed an unbalanced, mixed effects ANOVA with year, zone and width as fixed effects, and a random site effect nested within width, plus interaction effects between year and zone and width and zone. 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), we re-ran separate ANOVAs for each zone. 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 the top of fluctuations from the pre-trip hydrograph.

Faunal transect cover and composition analysis. To summarize and analyze changes in plant species composition data from the faunal sampling transects we calculated cover estimates and compared composition among zones and across years (data were collected only 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 they designated (Table Str-1), then arcsine-square root transforming that data (Zar 1999). For each transect, each species' cover was calculated as the mean of the 10 observations per transect, and transect total cover 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 the observed pattern arising from chance alone. Values for statistically significant ANOSIM R typically vary between 0.01 and 0.10, with values above that range being very rare.

In cases where the ANOSIM analysis indicated a significant difference between years, we used an Indicator Species Analysis (Dufrêne and Legendre 1997) to determine which species' abundances differed significantly between 2002 and 2003 within each zone. 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 (Dufrêne and Legendre 1997).

Investigator impacts. In order to determine whether investigators were having an effect on the vegetation in these sites during TVV surveys, we took advantage of the fact that some sites were visited two or three times during the three-year period (repeat panels) and others were visited only once (rotate panels). For this analysis, TEM and bird patches which had been visited twice in the three years were grouped with sites which had been visited three times. For both TEM sites and bird patches, the analytic methods were the same. A mixed-effects ANOVA, equivalent to a repeated measures analysis (SAS Institute 2001, p. 260), was performed with TVV as the response variable and reach width (narrow / wide, per Schmidt and Graf 1990), year and panel type as fixed effects, and site as a random effect, nested within panel type. Interaction effects between year and width and panel type were also included, as were interactions between width and panel type. Because we had detected strong interactions between zone and year in other analyses described above, we analyzed changes in each zone separately (shoreline, new high water and old high water for TEM patches, new high water and old high water only for bird patches). We did not expect to find a difference between panel types, because plots were assigned randomly and sparse and dense plots would have been assigned to panels in equal proportions. We predicted that investigator impacts would show up as a significant interaction between year and panel type, because the effects of surveyors trampling vegetation, distributing seeds through the site and compacting the soil would show up only after the first year or two. We predicted that this effect would be even more pronounced in TEM sites than in bird patches because half the TVV points in TEM patches were taken along the transects where arthropod, mammal and herpetofaunal survey crews had to work as well as vegetation crews.

In addition, because sites in “repeat” panels were all part of a list of sites selected by avifauna investigators in previous studies, and the “rotate” panels contained plots selected in later years to fill out the overall site list, we needed to determine whether plots in the two panel types differed physically. We compared the areas of new high water zone bird patches in the two types of panels (36 “repeat”, 76 “rotate”) using an independent samples t-test. The TEM patches were a subset of the bird patches, so we only tested the larger group for differences.

Results

Bird patch vegetation structure. New high water zone patches had significantly higher vegetation density, as measured by TVV, than old high water zone patches (Figure Str-1; $F_{(1,201)} = 78.03$, $p < 0.05$). However, the analysis revealed a significant statistical interaction between the effects of year and zone (i.e., the two zones behaved differently in the two years; $F_{(2,201)} = 3.43$, $p < 0.05$) so that each zone had to be analyzed for year to year 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 Str-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; $F_{(2,59)} = 2.59$; ns). In the old high water zone, TVV increased by roughly 20% in 2002 over 2001, and by another 5% in 2003 (Year effect; $F_{(2,45)} = 2.42$, ns). Because neither of these changes was statistically significant, 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 (Figure Str-2). 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, so that each zone had to be analyzed separately for year effects. In the shoreline transects, TVV increased in each of the three years, but the pattern was 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 these 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 top of fluctuations ($F_{(1,8)} = 3.20$, $p < 0.01$) contributed to the “year” effect. The effects of these two factors are presented graphically in Figure Str-3.

Faunal transect composition change. The two-way crossed analysis of similarity (ANOSIM) performed on the cover data collected in 2002 and 2003 showed both zone and year effects. As would be expected, the three zones differed significantly in species composition, measured as abundance by species ($R = 0.538$, $p = 0.001$). In addition, 2002 and 2003 differed significantly in overall species composition, even when the effects of zone were accounted for ($R = 0.05$, $p = 0.034$). When we split out data from 2002 and 2003 by 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 ($R = 0.115$, $p = 0.015$).

Based on the indicator species analysis, the change in the composition of the new high water zone transects resulted from changes in the abundances of both woody and herbaceous species, nearly all showing increases in 2003. Tamarisk, arrowweed and mesquite all had higher abundances in 2003 than 2002, as did herbaceous species such as annual bromes, six-weeks fescue, Bermuda grass and spiny aster. Only one species, scratchgrass (*Muhlenbergia asperifolia*) had higher abundances in 2002 than in 2003.

Investigator impacts. We detected some differences between sites visited repeatedly and those visited only once during the period 2001 to 2003, but not in a manner predicted. In new high water zone bird patches, repeat panels had significantly more dense vegetation than those in rotate panels (panel type effect: $F_{(1,46)} = 5.91$, $p < 0.05$; Figure Str-4), and there was a trend for repeat panels to have smaller year-to-year changes than those surveyed only one time (panel type * year interaction: $F_{(2,46)} = 3.08$, $p = 0.056$). In old high water zone patches, there was no difference between the TVV in rotate and repeat panels ($F_{(1,34)} = 0.414$, n.s.; Figure Str-4) or between the behavior of the two panel types across years (panel type * year interaction; $F_{(2,46)} = 2.76$, n.s.)

There were similar patterns in the TEM patches. In shoreline patches, there was a non-significant trend towards higher TVV values of sites in repeat versus rotate panels (panel type effect; $F_{(1,27)} = 1.82$, $0.05 < p < 0.10$; Figure Str-5), but no difference between the behavior of sites in the two panel types (panel type * year interaction; $F_{(2,4)} = 1.09$, n.s.). In new high water zone patches, there was a trend towards greater TVV in sites in repeat panels (panel type effect: $F_{(1,27)} = 3.05$, $0.05 < p < 0.10$) and a tendency for sites in repeat panels to behave differently than those in rotate panels (panel type * year interaction: $F_{(2,4)} = 4.22$, $p = 0.10$). In old high water zone patches, there was no difference between the panel types ($F_{(1,27)} = 0.321$, n.s.) nor in the behavior of patches in the two types over time ($F_{(2,4)} = 0.514$, n.s.).

There were no differences in the areas of patches in the repeat and rotate panels (Figure Str-6; $t_{(110)} = 1.348$, n.s.). Repeat panel plots were slightly larger (1.06 vs. 0.81 ha), but these differences were not significant. The largest site surveyed (-8.0 R) was a “rotate” site, as were four of the eight largest sites.

Discussion

The data collected on vegetation density and composition demonstrated significant year-to-year variability in the new high water zone and non-statistically significant 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 1990a, b, Stromberg 1993). Riparian vegetation also responds to degrees of change from previous years (Szaro and DeBano 1985, Stromberg and Patten 1990a, b, Stromberg 1993, Shafroth et al. 2000).

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. Rather it highlights two problems with the data: one statistical, the other methodological. First, many of the shoreline transects had no vegetation at all, having been scoured by flows which fluctuated daily between 5,000 and 20,000 cfs during the spring. The presence of many "zero density" sites creates more than the normal amount of within-year variability, which decreases the power of a test to detect differences (Zar, 1999). 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. They are located at a point 0.5 to 1 meter above the top of recent fluctuations, rather than at some fixed point. Thus in April 2003, the previous month's high flows were above 19,000 cfs and in 2002 the level was 12,000 cfs. Based on the 150 transects measured as part of the VEGETATION DYNAMICS section (below) the elevation of a shoreline transect would have risen more than 90 cm, on average, between 2002 and 2003 (see data in Randle and Pemberton 1987 for stage to discharge relationships). Therefore, even if one assumes that beaches are fairly steeply sloped near the water (15 degrees, = 27% slope), a drop of 90 cm in the top of fluctuations would have caused us to shift the location of a shoreline transect, on average, approximately 3.5 meters further down slope. Although this distance could be covered easily by animals, it would result in us sampling vegetation in completely different spots in those two years. The statistical power of using "matched" locations in each year would then be lost. Even if there were an overall change in the larger shoreline zone, it might not be detected in the narrow swath (2 m) covered by our structure measurements.

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 did not affect the density of vegetation along the shoreline according to our data, but more time may tell a different story.

Slight increases in the TVV measured 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.

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 1996) have been connected to river flows only anecdotally, except in the case of unusual events (Brian 1987, Kearsley and Ayers

1999). In this report, however, we have made a direct link between vegetation and specific flow levels within the range of normal power plant operations. This is important because by refining this connection, we provide a way to predict the response of terrestrial riparian habitat quality to decisions made about the hydrograph for the upcoming year. This is a useful tool for three reasons. First, the design for selecting sample sites has removed much of the investigator bias from vegetation monitoring, and that allows statistically valid generalizations to be extended to the entire river corridor in Grand Canyon. Second, each of the three years has had different combinations of high or low flow and above or below average precipitation. Third, enough time had elapsed using a consistent sampling program to detect these patterns. More years of data under different flow and precipitation regimes will further refine this useful tool. Furthermore, because greater sample size (here: numbers of sampling years) usually increases the power to detect significant trends (Zar 1999) we expect that further sampling will allow us to extend our ability to predict changes in vegetation abundance into the old high water zone and, perhaps, to the shoreline zone as well.

Differences between faunal sampling transect and bird patch responses of vegetation density likely are caused by the higher variability of bird patches. The transects span consistent elevations within sites, corresponding to approximately 30,000-35,000 cfs in the new high water zone and 85,000-100,000 cfs 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; old high water: 90,000-150,000 cfs). In addition, the requirements for TEM sites, including 100^+ m of habitat across 3 zones plus camping areas plus the presence of old high water zone vegetation, further restrict 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.

Finally, we succeeded in minimizing the impacts of repeated surveys on the vegetation in our sites. The statistical power to detect trends gained by including a set of sites in a repeat panel did not come at the expense of the integrity of the vegetation in those sites. The trends towards differences seen in behavior of sites in the two new high water zone panel types in both bird patches and TEM sites were opposite to those predicted by a hypothesis of investigator impacts. The fact that we detected a significantly greater TVV level in the bird patch repeat panels may have more to do with the manner in which sites have been selected than anything else. Sites chosen in 2001 were from a list of sites selected by investigators previously because they contained relatively dense vegetation that would supports birds and therefore be worthwhile for the purpose of breeding bird surveys (e.g., Sogge et al. 1995, Spence et al. 1999). In 2002 and 2003, however, sites were added which expanded the original list by including smaller and less dense sites. Because the rotate panel would necessarily include more marginal sites than sites in the repeat panel, which were all taken from the original set of birder sites, we should have expected higher TVV in the “repeat” panel.

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. 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.

Kearsley, M. J. C., and T. J. Ayers. 1996. The effects of Interim Flows from Glen Canyon Dam on riparian vegetation in the Colorado River Corridor, Grand Canyon National Park, Arizona. Final Report. U.S. Department of the Interior, National Park Service Cooperative Agreement CA-8041-8-0002. v + 39 pages.

---. 1999. Riparian vegetation responses: snatching defeat from the jaws of victory and *vice versa*. Pages 309-327 *in* R. H. Webb, J. C. Schmidt, G. R. Marzolf and R. A. Valdez, editors. The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, Washington, DC.

Larsen, D. P., T. M. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. BioScience 51:1069-1078.

Mills, G. S., J. B. Dunning, and J. M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103(3):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.

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.

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

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

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.

Sogge, M. K., D. Felley, H. Yard, and P. Hodgetts. 1995. Avian community monitoring in the Grand Canyon: 1995 Progress report. National Biological Service Colorado Plateau Research Station / Northern Arizona University Report. 29 pages.

Spence, J. R. 2000. Summary of the 1996-1999 avian monitoring program along the Colorado River from Glen Canyon Dam to Upper Lake Mead. Unpublished report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center, Flagstaff, AZ. 20 pages.

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

Spence, J., C. T. LaRue, N. L. Brown, and J. Muller. 1999. Winter and breeding avifauna monitoring along the Colorado River in Glen and Grand Canyons. Draft Final Report submitted to Grand Canyon Monitoring and Research Center. Glen Canyon National Recreation Area, National Park Service.

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

---. 1990b. Seed production and seedling establishment of a southwest riparian tree, Arizona walnut (*Juglans major*). Great Basin Naturalist 50:47-56.

Szaro, R. C., and L. F. DeBano. 1985. The effects of streamflow modification on the development of a riparian ecosystem. Pages 211-215 *in* R. R. Johnson, 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.

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. Pages 71-85 *in* V. Barnett and K. F. Turkman, editors. Statistics for the environment. John Wiley and Sons, New York.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

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.

Zar, J.H. 1999. Biostatistical analysis. 4th Edition. Prentice-Hall, Inc. Englewood Cliffs, NJ, USA. 663 pages.

Table Str-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%

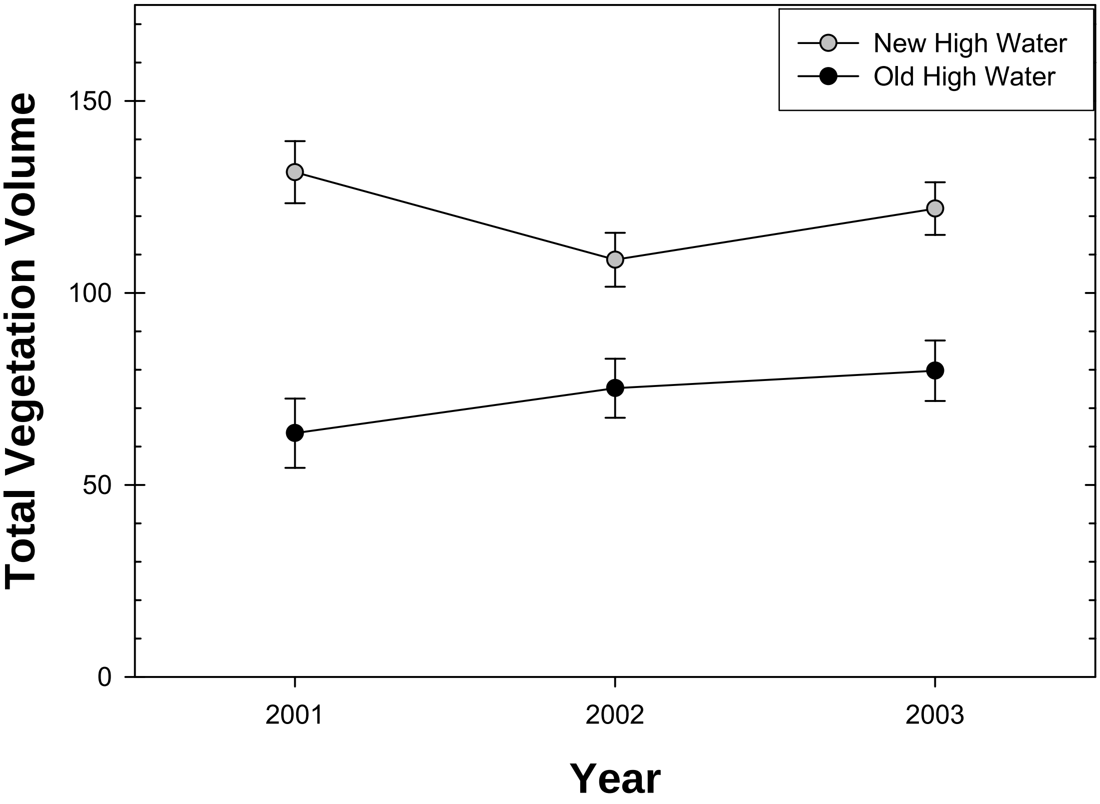


Figure Str-1. Total vegetation volume measures in new high water and old high water bird patches in from 2001 to 2003. Data are presented as number of vegetation “hits” per 20 sampling points per patch. Vertical bars represent +/- 1 standard error.

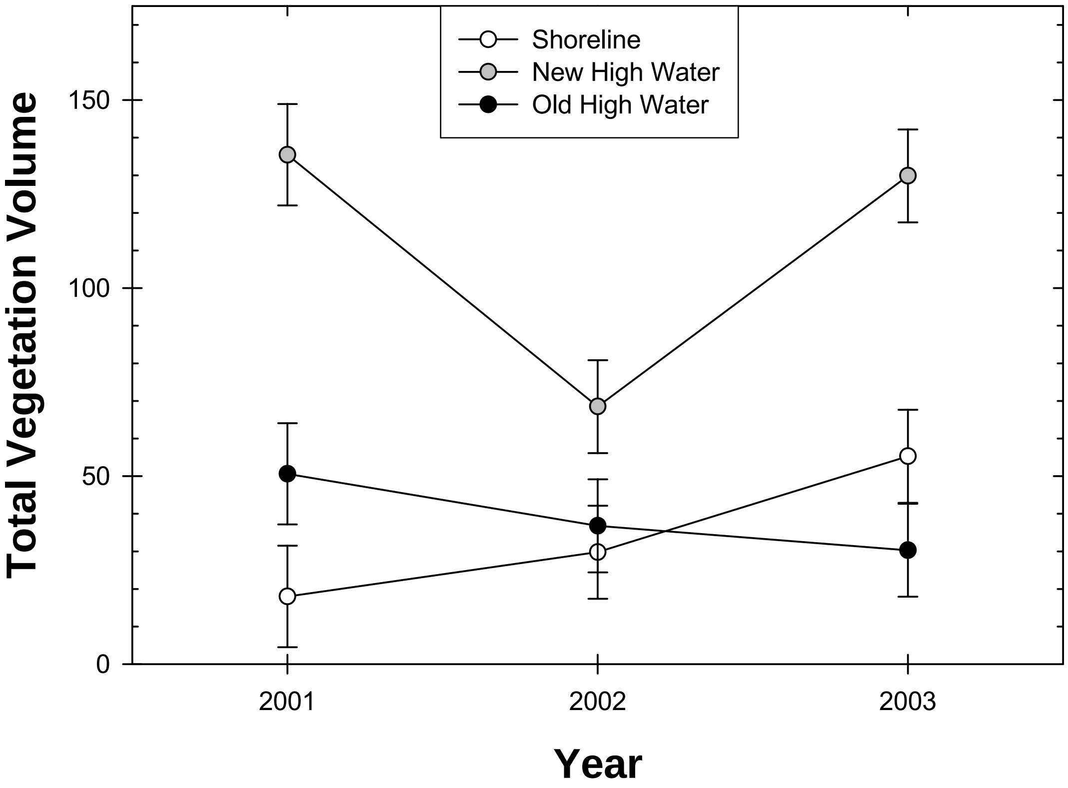
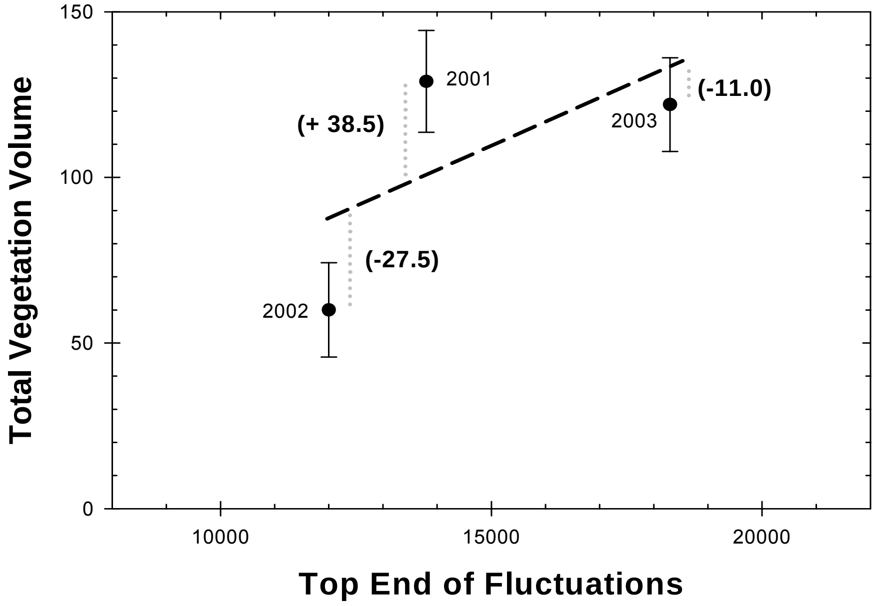


Figure Str-2. Total vegetation volume measures from faunal transects in the integrated monitoring sites. Data are presented as average number of vegetation “hits” per 20 sampling points per patch. Vertical bars represent +/- 1 standard error**.**



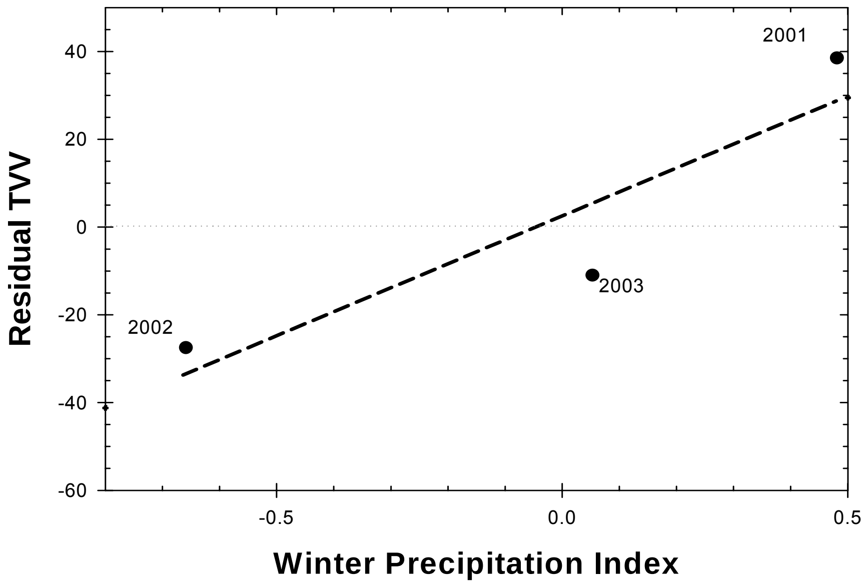


Figure Str-3. New high water zone total vegetation volume vs. river flow and precipitation. Above: Most between-year variation in vegetation density is explained by the upper end of daily flow fluctuations. Points show the average number of "hits" per 20 sampling points per patch. Vertical bars = +/- 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: Residual variation from the fit of TVV to flows is explained by deviation of precipitation from normal values. Dashed line represents the least squares regression fit.

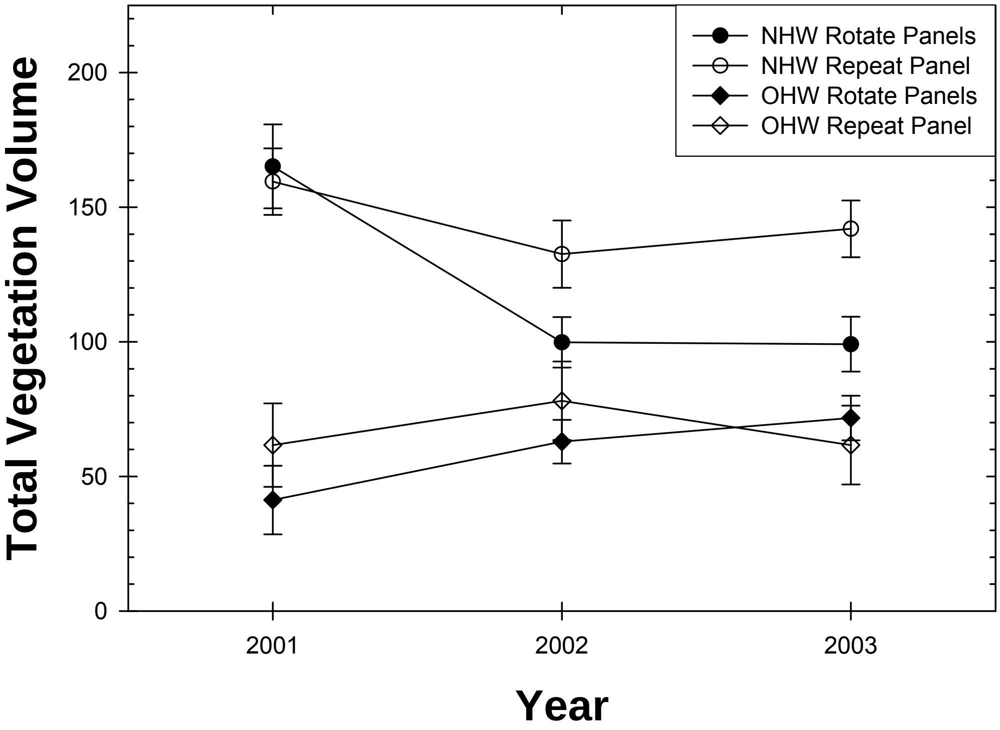


Figure Str-4. TVV measured in bird patches in rotate (closed) and repeat (open) panels of new high water (diamonds) and old high water (circle) zones. Vegetation in repeat panels was more dense in the new high water zone but not in the old high water zone. No interaction between panel and year was detected. Data are presented as number of vegetation "hits" per 20 sampling points per patch. Vertical bars represent ± one standard error.

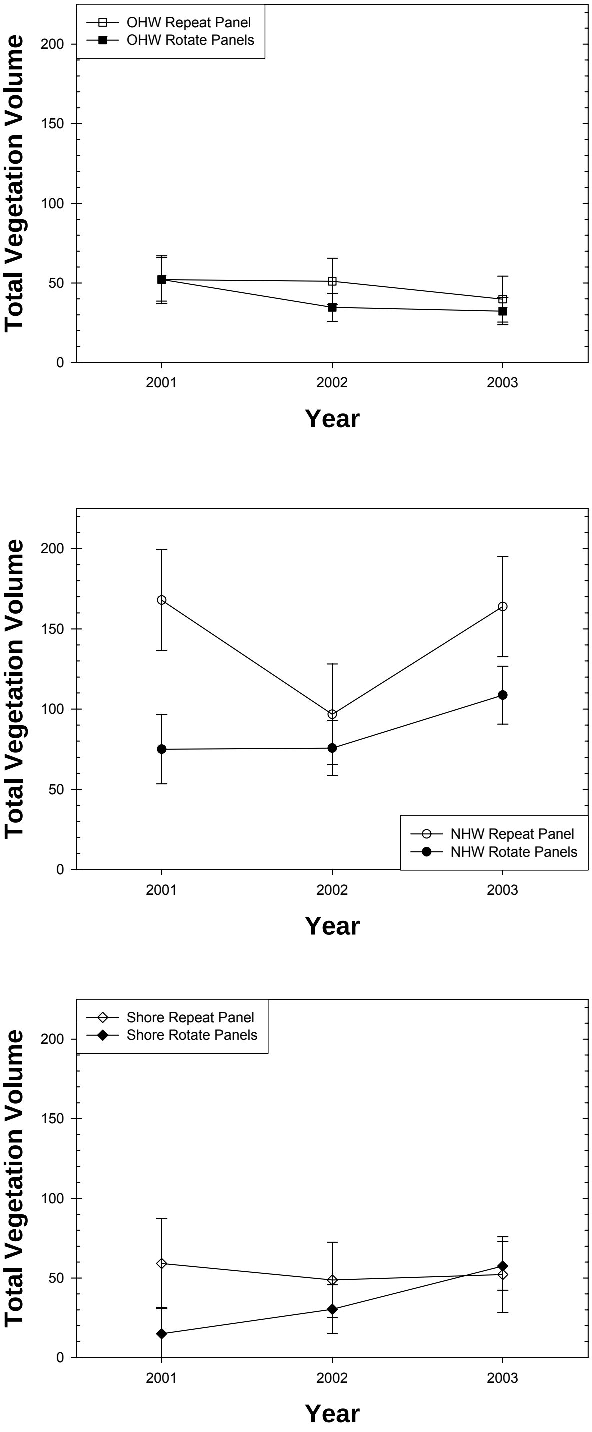


Figure Str-5. Total vegetation volume in the old high water zone (upper), new high water zone (middle) and shoreline (lower) patches of TEM sites. Open symbols represent repeat panels, closed symbols are rotate panels. Data are presented as number of vegetation “hits” per 20 sampling points per patch. Vertical bars represent ± one standard error.

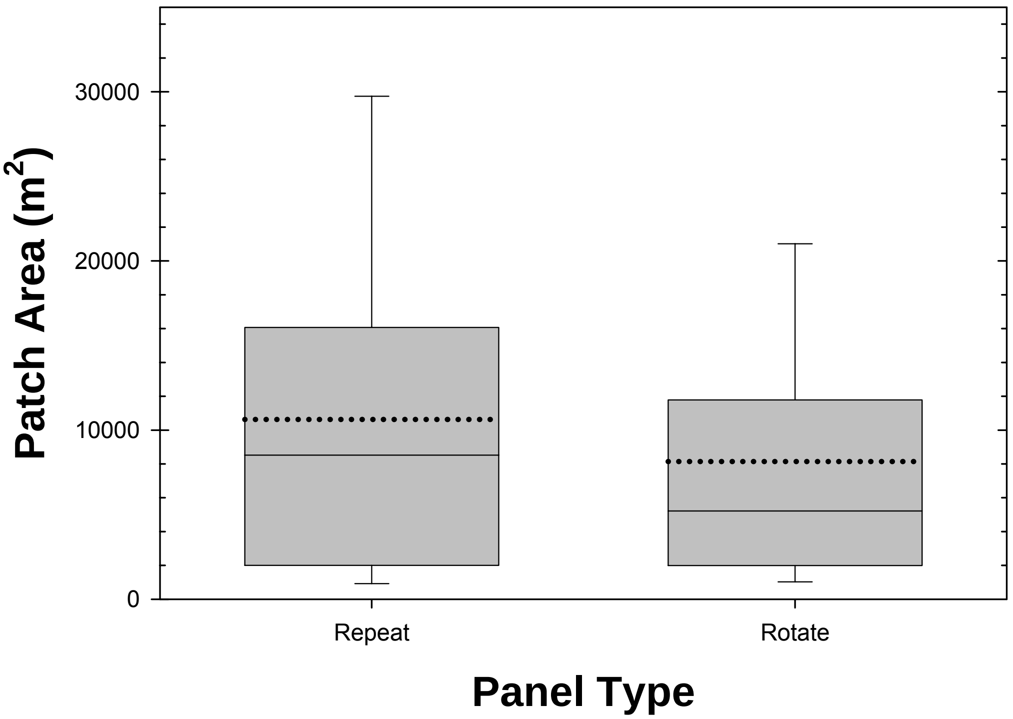


Figure Str-6. Distribution of patch areas of repeat and rotate panels of new high water zone patches. Solid horizontal lines represent 25th, 50th, and 75th quantiles, dashed line shows the mean, and bar ends represent the 5th and 95th quantiles of the distribution.

Arthropods

David C. Lightfoot[1], Sandra L. Brantley[1], Neil S. Cobb[2], and Robert J. Delph[2]
[1] The University of New Mexico
[2] Northern Arizona University

Purpose

The purposes of the arthropod studies were to first 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 were several general questions that we attempted 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 on 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 were to:

1. Determine the species composition and relative abundances of arthropods associated with the SHOR, NHWZ and the OHWZ 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;
5. Develop a voucher and reference collection for Grand Canyon riparian arthropod specimens representing those taxa found during this project;
6. Provide basic ecological information on Grand Canyon riparian arthropods to integrate with vegetation and vertebrate animal information produced from this and other research projects;
7. Provide arthropod data for other biological, cultural, and physical resource information needs.

Methods

Study sites and sampling points. For a discussion of the site selection methods, see the COMMON METHODS section above. A total of 34 sites were selected for focused sampling of all terrestrial arthropods. Four of the sites were repeatedly sampled in 2001, 2002, and 2003 (46.7R, 65.3L, 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 was 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 and reduce investigator impacts on the environment.

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 50–100 m upstream or downstream from the camp, depending on constraints imposed by the local topography. The transect representing the SHOR was situated one meter up-slope from the existing daily highest river level line which was visible as a damp high water line on the shore. Thus the location of the transect itself varied up- and down-slope between surveys, depending on the recent hydrograph. The transects representing the OHWZ and the NHWZ were situated in the middle of each of those zones' range of elevation above shoreline. In general, the NHWZ transect was placed between the 35,000 and 45,000 cubic foot per second (cfs) stage elevations and the OHWZ transect was placed between the 100,000 and 120,000 cfs stage elevations (refer to COMMON METHODS section above for details on transect placement). The NHWZ vegetation was usually dominated by tamarisk. The OHWZ vegetation was usually less dense and was characterized by mesquite (*Prosopis glandulosa*), desert shrubs (*Atriplex canescens, Ephedra* spp., *Encelia farinosa*) and cat-claw acacia (*Acacia greggii*). 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 study site area (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 resulting from elevation differences. We attempted to avoid elevation-based sampling bias resulting in earlier seasonal development and activity of the same taxa in the lower reaches of the canyon. For 2003 we reverted back to the 2001 schedule and did not divide the spring trip into two separate trips. For a table of survey activities, see the COMMON METHODS section above. 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.

Ground-dwelling arthropods. Ground-dwelling arthropods are associated with soil characteristics and are therefore useful indicators of changes in soil texture, nutrient content and moisture as may be expected from dam-altered river flows. Pitfall or pit traps are a widely used technique used to sample ground-dwelling arthropods, and have 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.

Plant-dwelling arthropods. Arthropods that live on vegetation are taxonomically and ecologically different from those that occur on the ground. Plant-dwelling arthropods are usually associated with particular plant taxa and/or plant architecture. We sampled plant-dwelling arthropods to relate arthropod consumers to vegetation, and to use plant arthropods as indicators of vegetation structure. Plant arthropods must be sampled using different methods than ground arthropods. We 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 with a 2 meter radius from each pitfall trap was swept with the insect sweep nets to dislodge and collect all arthropods resting on the foliage. Twenty sweeps were consistently taken from each sampling volume, regardless of the density or presence of vegetation foliage. 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 quickly transferred into a one-gallon plastic zip-lock bag by inverting the net bag, and the bag was kept closed between sampling points to prevent arthropods from escaping. 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. Some taxa are best preserved dry; they were placed in tissue paper, and sealed in small plastic containers with naphthalene as a preservative.

In addition, qualitative sweep samples were taken from the dominant plant taxa (see VEGETATION STRUCTURE section above) 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.

<u>Flying insects</u>. 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 and which preservative is appropriate. 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. For the purposes of this study we chose to focus on moths because they are often closely associated with particular plants, which are food for the caterpillars.

<u>General collecting</u>. To enhance our ability to inventory many arthropods, we also conducted general collecting at each site as time permitted. General collecting involved searching as many environments and habitats in the riparian corridor as time permitted 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. Most specimens obtained during general collecting were placed in vials with 70% ethanol or naphthalene, while others were pinned or pointed immediately depending on the size and fragility of the specimen. All specimens were labeled as to habitat and water level zone, river mile and date.

<u>Night surveys for scorpions and other nocturnal arthropods</u>. Scorpions are among the most conspicuous of ground dwelling arachnids along the Colorado River of the Grand Canyon. Scorpions are nocturnal arthropods, which feed primarily on other

smaller arthropods such as insects, spiders and sometimes even smaller scorpions (Polis 1993). Studies have shown that because scorpions feed infrequently across multi-year life spans the adults will often feed on the juveniles of other scorpions including juveniles of their own species when food availability is scarce (Lighton 2001 and Warburg 1998).

As do most other ground dwelling arthropods, scorpions often fall in pitfall traps as well. However, our one-night duration pitfall traps can only be partially useful in determining the relative abundance and species richness of the scorpions in the canyon. Since scorpion cuticles have the ability to fluoresce under ultraviolet light, they are quite easily seen at night using a hand held portable UV-black light, which is a common field technique used by scorpion researchers to detect scorpions (Fasel et al. 1997, Lawrence 1954, Stahnke 1972 and Stachel et al. 1999). Therefore, quantitative counts of specific species of scorpions can be conducted easily without having to actually collect the scorpions. In addition, scorpions usually do not congregate in large numbers, making it easier to keep track of individuals.

In order to document the abundance and species richness of scorpions at the sites, an inventory of scorpions was conducted each night at every site, with the use of a portable UV-light. At least 2 people walked through and spent time/effort in each of the water zones, (SHOR, NHWZ and OHWZ) counting scorpions and recording the numbers of each species seen in each zone. In addition a few specimens from each site were collected and used as reference specimens. Nocturnal scorpion surveys were conducted approximately one to three hours after sunset, the time of evening when scorpion and other nocturnal arthropod activity appeared to be greatest based on our preliminary observations.

Specimen preparation, identification, and voucher collections. 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 were sorted, and counts of numbers of individuals by taxa were 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 taxonomic classification for this project followed Arnett (2000) for insects to the family level, and Poole and Gentili (2003) for the genus and species ranks, Coddington and Levi (1991) for spiders, Fet (2002) for scorpions, and Dindal (1990) for centipedes (Chilopoda), millipedes (Diplopoda), harvestmen (Opiliones), pseudoscorpions (Pseudoscorpiones), mites (Acari), and isopods (Isopoda).

Arthropod data analyses. We have produced three principal arthropod data sets representing the three principal quantitative sampling methods; 1) ground-dwelling arthropod data collected from pitfall traps, 2) plant-dwelling arthropod data collected from vegetation sweep net samples, and 3) flying insect data collected from UV light traps and Malaise traps. These data sets were analyzed separately because they represent different taxonomic groups, were collected in different ways, and have potentially different inherent sampling biases. 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 of the above three data sets separately. SAS (SAS 2003), and SPSS (SPSS 2003) were used for parametric ANOVA statistical analyses.

Non-parametric Multi-Response Permutation Procedures (MRPP) analyses utilizing PC-ORD software (MjM Software Design 1999) also were performed for the ground-dwelling and plant-dwelling arthropod data to test for differences in arthropod species composition between water zones. MRPP provides a statistical test of differences in species composition between sampling groups (water zone) based on species occurrence and numbers of individuals per species. MRPP was performed on matrices represented by taxa that 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). Thus we limited these analyses to the 38 species of ground arthropods and 45 species of plant arthropods, which satisfied this condition.

We pooled data for individual species into taxonomic groups, or operational taxonomic units (OTU's) that are relevant to the goals of this study. Arthropod species within family, or even order level taxonomic groupings often share similar ecological characteristics (e.g., all Homoptera are plant sap-feeding insects). However, species in some groups do not share similar ecological characteristics at the same taxonomic rank (e.g., Coleoptera include herbivores (weevils), predators (ground beetles), and detritivores (darkling beetles). We therefore defined OTU's based on taxonomic and ecological trophic similarities, so that the taxonomic ranks of OTU's varied across arthropod groups. Techniques such as designation of OTU's for rapid post field sample processing are known to be useful and effective (Wilkie et al. 2003). The Results section below shows analyses for all arthropods combined (for each sampling method separately) and for the arthropod functional/taxonomic groups (see the Results for listings of those functional/taxonomic groups).

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). Arthropods may therefore respond quickly to environmental change, so we used Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) to determine if any arthropod species sampled from this study are appropriate water zone indictor species. ISA analysis was performed using PC-ORD software (MjM Software Design 1999) 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.

We used correlation analysis to examine relationships among arthropod functional/ taxonomic groups. Non-parametric Spearman-rank correlation analysis was used since much of the data was based on counts and not normally distributed. Individual arthropod species were pooled into functional/taxonomic groups to increase counts and provide more robust correlation analyses. These correlation analyses were meant to address individual pair-wise comparisons of particular arthropod OTU's and other variables for descriptive purposes, so we were not concerned with overall or family wide error rates. SAS (2003) and SPSS software were used for correlation analyses.

Results

We have recognized 1,122 arthropod taxa from the three-year (2001-2003) inventory sampling (Appendix B). Many of those taxa are identified to the species level, but we were not able to identify many others below the genus, family, or order rank. Appendix B also provides information on which water zones each taxon was found in. Voucher specimens for all taxa are housed at the Insect Collection at NAU, and the Division of Arthropods, Museum of Southwestern Biology, UNM.

Ground-dwelling arthropods. From 2001-2003 we sampled and identified 180 species (OTU's) of ground-dwelling arthropods from our pitfall trap samples (Appendix B). Arthropod species richness (counts of species) did not significantly differ across water zones over the three-year period, but species richness was significantly ($F_{2,243}$ =12.3, p<0.0001) greater in 2001 than 2002 or 2003 (Figure Art-1). Total counts of all individual ground arthropods were significantly different ($F_{2,243}$=9.9, p<0.0001) across the water zones over the three-year period, with the greatest abundance in the OHWZ, while the SHOR and NHWZ did not differ from each other (Figure Art-2). Ground arthropod abundance was significantly ($F_{2,243}$ =3.7, p=0.03) different over the three-year period: 2001 had significantly more individuals than 2003, but 2002 and 2001 were not different from each other, and 2002 and 2003 were not different from each other. The majority of individuals were ants, which were highly variable among sites and zones. Species richness dropped somewhat since 2001. Abundance 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.

MRPP analysis of ground arthropod taxa revealed that the species composition of ground arthropods were significantly different (A=0.03, p<0.0001) between the three water zones. The species composition of ground arthropod assemblages also differed significantly (A=0.01, p=0.003) within each water zone, among the three years.

Two species (both introduced) of isopods (sow-bugs) were significantly ($F_{2,243}$=5.3, p=0.005) more abundant in the SHOR than the OHWZ over the three-year period, but the SHOR and NHWZ were not different from each other, and the NHWZ and OHWZ did not differ. There was no significant difference in isopod abundance among the three years, nor was there a significant zone/year interaction. Both species of isopods require moist conditions, and were associated with damp shoreline environments

Forty-six species of ground-dwelling spiders were significantly ($F_{2,243}$=7.7, p=0.0006) more abundant in the SHOR zone than either the NHWZ or OHWZ over the three-year period. There was no significant difference in ground spider abundance from 2001-2003. (Figure Art-3). Most of those spiders were 2 species of wolf spiders, one restricted to shoreline (*Arctosa littoralis*) and one (*Camptocosa parallela*) 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 B). Over the three years of this study spider numbers remained relatively stable.

Seven species of crickets were significantly ($F_{2,243}$=3.1, p=0.01) more abundant in the SHOR than either the NHWZ or the OHWZ over the three-year period (Figure Art-4). Crickets were also significantly ($F_{2,243}$=5.6, p=0.04) more abundant in 2001 than 2002 or 2003. 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 was 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 comphrehendens*) found in the OHWZ were desert rock-slope specialists and typically not found near the river.

The abundance of seven species of ground and plant dwelling lygaeid seed bugs was significantly ($F_{2,243}$=6.5, p=0.002) greater in the OHWZ than the other two zones. Seed bugs were significantly ($F_{2,242}$=6.1) more abundant in 2001 than 2002 or 2003, and there was a significant ($F_{2,242}$=6.5, p<0.0001) zone/year interaction effect. A single species of *Nysius* was very abundant during the spring of 2001 only, and was associated with particularly dense stands of the spring annual tansy-mustard (*Descurainia*) in the OHWZ during the El Nino spring of 2001.

Twenty-seven species of carabid ground beetles were significantly ($F_{2,243}$=27.2, p<0.0001) more abundant in the SHOR zone over the three-year period (Figure Art-5). Carabid beetles were also significantly ($F_{2,243}$=7.0, p=0.001) more abundant in 2001 than either 2002 or 2003, and there was a significant ($F_{2,243}$=3.0, p=0.02) zone/year interaction effect. 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 be represented by many species, but with few individuals from each taxon. Their numbers also tended to be relatively stable (except for the high numbers in spring 2001).

Fifteen species of darkling beetles were not significantly different across the three water zones. 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.

The twenty-one species of ants formed the most abundant group of ground arthropods over the three years of the study. Ants were significantly ($F_{2,243}$=5.6, p=0.004) more abundant in the OHWZ (Figure Art-6). There was no significant difference in ground ant abundance over the three years, but there was a significant ($F_{2,243}$=2.6, p=0.04) zone/year interaction effect. The most widely distributed ant species was *Pogonomyrmex maricopa*, a seed harvester. Other common species included *Dorymyrmex insana*, a predator/scavenger of other insects; *Forelius pruinosus*, a predator/scavenger of other insects and nectar feeders; *Pheidole ceres*, another seed collector, and *Solenopsis xyloni*, an omnivorous native fire ant.

ISA resulted in 17 species of ground arthropods with high probablility levels (p<0.05) as indicator taxa for the three water zones; 5 species were indicators of the

SHOR, 4 species were indicators of the NHWZ, and 8 species were indicators of the OHWZ (Table Art-1). Indicator values of 25 and greater, with probabilities <0.05 or less are considered to be robust and significant.

At least 3 families of scorpions were commonly observed in Grand Canyon: the Vaejovidae, which contained at least 4 species, (Beck's Scorpion, *Paruroctonus becki*, Yellow Ground Scorpion, *Vaejovis confusus*, Sawfinger Scorpions, *Serradigitus harbisoni* and *Serradigitus subtilimanus*), the Iuridae, which had one species, Giant Desert Hairy Scorpion, *Hadrurus spadix*, and one species of Buthidae, the Bark Scorpion, *Centruroides exilicauda* which is the most common species and is the most venomous.

Of all scorpion species measured at the canyon, *C. exilicauda* was the most abundant species, comprising of an average of ~9/site. The NHWZ had the greatest abundance of *C. exilicauda*, while the OHWZ had the lowest abundance of *C. exilicauda*. The Vaejovidae were counted together as one group of scorpions the vaejovids, since they were difficult to distinguish visually. They were also commonly observed averaging numbers of ~2/site and tended to be found in the NHWZ and OHWZ. Vaejovids were not as common as *C. exilicauda*, however this group is similar in relative size and appearance and is common throughout the western United States in the Great Basin in Arizona, Utah, Southern Nevada, Idaho and New Mexico (Williams 1987). *H. spadix* was the largest species in comparison to all other species found in the canyon and was also the least common. This species was recorded at all three water zones through out the three-year study and was usually found at one or two sites per trip.

The numbers recorded are based solely on counts conducted at night when scorpions are most active. During the day most scorpions hide under rocks, wood and fallen debris. It is possible that many of the scorpions usually travel from the OHWZ to the NHWZ at night for feeding purposes and then return to the OHWZ. Furthermore, scorpion numbers can be affected by weather, temperature and even moonlight. Studies have shown that scorpions are less active during moonlit nights than at dark nights (Skutelsky 1996). In addition, some morphological differences can be seen between *C. exilicauda* of the Grand Canyon compared to *C. exilicauda* found in other parts of Arizona. It is possible that because of geographic isolation many scorpion species in the canyon can show some genetic differences as well as morphological differences between similar species not found in the canyon. For example a study done in Colombia showed biogeographical evidence that some similar species will not recognize each other for mating demonstrating genetic isolation due to geographical differences (Lourenco 1991). Therefore, it is imperative to conduct more quantitative counts of scorpions along the Colorado River to compare numbers in various climatic conditions and also to assess biogeographical characteristics among similar taxa.

<u>Plant-dwelling arthropods</u>. From 2001-2003 we sampled and identified 396 species of plant-dwelling arthropods from our vegetation sweep net samples (Appendix B). 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 (Figure Art-7). Total counts of all individual plant arthropods were significantly ($F_{2,243,}$=3.9, p=0.02) greater from the SHOR, and the NHWZ and OHWZ did not differ significantly form each other (Figure Art-8). There was no significant year to year difference in plant arthropods

over the three-year period, but there was a significant ($F_{2,243,}$=2.9, p=0.02) zone/year interaction.

MRPP analysis of plant arthropod taxa revealed that the species composition of plant arthropods was significantly different (A=0.01, p=0.0002) between the three water zones. The species composition of plant arthropod species assemblages also differed significantly (A=0.01, p<0.0001) within each water zone, among the three years.

Forty-five species of 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. Over all three years, the abundance of plant-dwelling spiders did not differ significantly across the three water zones, but spider abundance was significantly ($F_{2,243}$=6.6, p=0.002) greater in 2002 than 2001 and 2003, which did not differ from each other, and there was no year/zone interaction.

Abundance of forty-one species of plant bugs (Hemiptera; Miridae) and other less frequent true bugs (Hemiptera) were not significantly different across the three water zones during 2001-2003. Several species of mirid plant bugs were especially common on herbaceous plants near the shoreline. Plant bug abundance did not significantly differ across the three years either.

Sixty-five species of plant hoppers (Homoptera; Cicadellidae, Psyllidae, Cixiidae) and aphids (Homoptera; Aphidae) occurred across the three water zones. Overall, many species of native leafhoppers out-numbered the introduced tamarisk leafhopper (*Opsius stactogalus*), which is host specific to tamarisk or salt-cedar (*Tamarisk ramosissima*). Over the three years, plant hopper and aphid abundance was significantly ($F_{2,243}$=3.7, p=0.03) greater in the SHOR than the other water zones. Plant hoppers and aphids reached peak abundances in spring of 2003, but counts did not differ significantly over the three years, nor was there a significant zone/year interaction.

Fifty-nine species of plant-dwelling beetles were found across the three water zones. Plant dwelling beetles (specifically two species of weevils) were significantly ($F_{2,243,}$=4.1, p=0.02) more abundant in the OHWZ than the other zones over the three years. The weevils associated with acacia and mesquite accounted for those differences. There was no annual difference in plant beetles over the three years, nor was there a zone/year interaction.

Twelve species of caterpillars were found on plants, the most common of which were inchworms of geometrid moths (Geometridae; *Semiothisa* spp.) 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 ($F_{2,243,}$=7.9, p=0.0005) more abundant in the OHWZ than the other water zones (Figure Art9). There was no significant difference in caterpillar numbers between years, nor was there a significant zone/year interaction.

Ninety-four species of plant-dwelling flies (Diptera), represented largely by 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 ($F_{2,243,=}$13.5, p=0.0001) more abundant in the SHOR than the other water zones (Figure Art10). Overall, fly abundance on plants was significantly ($F_{2,243,}$=4.1, p=0.001) greater in 2003, and there was a significant ($F_{2,243,=}$4.1, p=0.003) zone/year interaction effect.

Seventeen species of plant-dwelling ants were not significantly different in abundance across the three water zones from 2001-2003. 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, nor was there a significant zone/year interaction.

ISA resulted in 11 species of plant arthropods and one group (various caterpillar taxa) with significant probabilities (p<0.05) as indicator taxa for the three water zones; 6 species were indicators of the SHOR, 1 species was an indicator of the NHWZ, and 5 species were indicators of the OHWZ (Table Art-1).

Moths. We have collected 347 taxa of moths between 2002-2003 from our black-light and Malaise samples (Appendix B). Of these 347 taxa of moths, 154 taxa were 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 which may be an endemic species to Grand Canyon (Pogue 2004). 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 Art-11) and abundance of moths (Figure Art-12) and the abundance of major moth taxa (Figures Art-13-15) showed the same pattern, where highest diversity and abundance occurred in non-drought years (2001) and in the OHWZ. The Tiger Moths, which were primarily represented by *Cisthene angelus*, were especially abundant in 2001 and uncommon to rare in the other years. The two most common moths, the Owlet and Looper moths, both showed similar patterns of highest abundance in the OHWZ, especially in 2001 (Figures Art-13-14)

Unlike other arthropod taxa, we found little abundance differences for moths between the SHOR and the NHWZ. The Microlepidoptera (Figure Art-15) and to a lesser degree the owlet moths did show a 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 from plant foliage sampling (Figure Art-9).

ISA resulted in 25 species of moths and one group (various micro-lepidoptera taxa) that were significant (p<0.05) as indicator taxa, all for the OHWZ only (Table Art-1).

River Stage and Rainfall. Two spikes in arthropod abundance have occurred during this study: spring of 2001 and 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 and perhaps algal components 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 (*Descurainia* 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.

<u>Exotic arthropods</u>. We have identified six non-native species of arthropods from our surveys that were introduced into Grand Canyon by human activity. The tamarisk leafhopper (*Opsius stactogalus*) was accidentally introduced into the Southwest United States with tamarisk. We found *O. stactogalus* on tamarisk throughout Grand Canyon, often very abundant, but we did not observe any negative impacts on tamarisk. *Opsius stactogalus* was found only in association with tamarisk 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 Turkestan Cockroach (*Blatta lateralis*), which is native to southwest Asia, was found in the SHOR at only one location, also associated with exotic Bermudagrass. The European honeybee (*Apis mellifera*) was observed commonly throughout Grand Canyon. Foraging workers were especially common on tamarisk flowers throughout the spring and early summer months. At this time, we are not aware of any other exotic arthropods in Grand Canyon.

All six of the exotic species listed above were associated with exotic plants (tamarisk 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 colonize human-altered river environments in the Southwest (Ellis et al. 2000). Since exotic species probably compete with native species for food and habitat resources (e.g., European honey bees use the same nectar resources as native bees and wasps), the impacts of exotic arthropod species on the ecology of the Grand Canyon riparian ecosystem(s) should be given consideration in future research efforts.

Arthropod assemblages across study sites. Cluster analysis was performed on ground and plant arthropod quantitative data using PC-ORD software (MjM Software Design 1999) to examine patterns species compositional changes throughout Grand Canyon. The Sorensen (Bray and Curtis) distance measure, and Ward's hierarchical grouping algorithm were used. Upper reach and lower reach sites were intermixed, and no groupings of arthropod species assemblages were found relative to distance along the river. These results indicate that the arthropod species composition is relatively consistent throughout Grand Canyon from Lee's Ferry to Diamond Creek.

Arthropod relationships with habitat patch size. Zone type was more important to ground arthropod abundance than site size within zones except for ants in the OHWZ (r=0.38, p=0.05), and spiders (r=0.41, p=0.03) and isopods (r=0.44, p=0.03) in NHWZ. Absolute site area may be less important to these groups than the overall amounts of cover or bare ground within zones.

No plant-dwelling arthropods were significantly correlated with vegetation patch size. Based on our data, numbers of arthropods from plant foliage sweep samples are independent of habitat patch size.

Within group ground arthropod relationships. A community of ground-dwelling arthropods appeared through correlations among carabid beetles and spiders (r=0.37, p=0.04), carabids and crickets (r=0.41, p=0.02), spiders and tenebrionid beetles (r=0.44, p=0.01), spiders and isopods (r=0.39, p=0.04), and crickets and carabids (r=0.41, p=0.02) in the SHOR zone. In the NHWZ spiders and crickets (r=0.36, p=0.05), isopods and carabids (r=0.50, p=0.004) were correlated. In the OHWZ crickets and isopods (r=0.45, p=0.01) were correlated, as were tenebrionids and ants (r=0.56, p=0.001). In all three zones the taxa group together because of their preferences for similar substrate or vegetation cover. Ants were widely distributed across sites and zones and were correlated only with tenebrionids in the OHWZ.

Within group plant arthropod relationships. Plant bugs were positively correlated with plant spiders in the SHOR (r=0.49, p=0.007), and OHWZ (r=0.54, r=0.002), with plant ants in the NHWZ (r=0.45, p=0.01) and OHWZ (r=0.46, p=0.01), and with plant beetles in the NHWZ (r=0.49, p=0.007). Plant hoppers were positively correlated with plant beetles in the NHWZ (r=0.44, p=0.02) and with plant flies (r=0.57, p=0.001) and with plant spiders (r=0.41, p=0.03) in the OHWZ. Plant beetles were additionally positively correlated with plant ants in the NHWZ (r=0.65, p=0.0002) and in the OHWZ (r=0.53, p=0.003), and with caterpillars (r=0.45, p=0.01) and spiders (r=0.71, $p<0.0001$) in the OHWZ. Plant ants and plant spiders were positively correlated in the OHWZ (r=0.47, p=0.01). These significant positive correlations indicated that plant beetles, bugs, hoppers, caterpillars, spiders and ants may be tracking the same variable environmental resources across the study sites. Only one positive cross-group correlation was found in the SHOR, four in the NHWZ, and seven in the OHWZ.

Ground arthropod and plant arthropod relationships. Carabid ground beetles were positively correlated with plant hoppers (r=0.50, p=0.03), plant flies (r=0.44, p=0.05), plant ants (r=0.50, p=0.03) and plant spiders (r=0.47, p=0.04) in the OHWZ. Carabid beetles are indicators of moist and potentially productive environments, indicating that sites with relatively moist productive OHWZ environments also support large numbers of those plant arthropods. Carabid ground beetles also were positively correlated with plant flies in the NHWZ (r=0.49, p=0.03), probably for the same reasons, although carabid beetles and their larvae may also feed on the larvae of flies at the soil surface and subsurface.

Ground ants were positively correlated with plant bugs in both the NHWZ (r=0.55, p=0.01) and OHWZ (r=0.52, p=0.02). The majority of plant bugs were lygaeid seed bugs (*Nysius*), and the majority of ground ants were seed harvester ants (*Pogonomyrmex*), indicating that ground ants and plant bugs were most abundant at sites where plant seed production was high. Ground ants also were highly positively correlated with plant hoppers in the NHWZ (r=0.80, p<0.0001). That relationship likely resulted from other species of ants that nest in the ground but forage on plants, tending the plant hoppers and aphids for honeydew extracts. Ground ants and plant spiders also were positively correlated (r=0.45, p=0.05) in the OHWZ, perhaps both indicators of higher insect food availability at some sites in the OHWZ. Ground spiders and plant spiders were negatively correlated (r= -0.46, p=0.05) in the NHWZ, indicating possible competitive interactions for food resources in that zone, or indirectly indicating contrasting environmental needs in that zone.

Ground crickets and plant caterpillars were positively correlated (r=0.65, p=0.002) in the OHWZ, indicating that sites with high plant productivity for caterpillars also had higher soil moisture or habitat structure, and perhaps food for crickets. Isopods and plant flies were also positively correlated (r=0.47, p=0.04) in the NHWZ, perhaps indicating that both are most abundant at sites with higher soil moisture in that zone.

Darkling beetles and plant hoppers were positively correlated (r=0.48, p=0.03) in the NHWZ, yet we do not know what environmental factors may cause this relationship.

New arthropod species discovered during this study. During the course of this study, we collected several species of arthropods that are new to science, and are currently only known from the terrestrial riparian zone of Grand Canyon: a new species of noctuid moth in the genus *Schinia* has recently been described by Pogue (2004); another species of noctuid moth in the genus *Acontia* (Pogue personal communication); a carabid beetle in the genus *Nebria* (D. Kavanaugh, California Academy of Sciences, personal communication); two new predatory mites in the genera *Erythraeus* and *Lasioerythraeus* (Cal Welbourn, Florida State Collection of Arthropods, personal communication). In addition, we collected specimens of 5 new species of mutillid wasps (velvet ants) also known from the western U.S. but not yet described (J. Pitts, Utah State University, personal communication). Specimens of the wolf spider *Camptocosa parallela*, are currently being used in a phylogenetic analysis of the genus (G. Stratton, University of Mississippi, personal communication). As we continue to obtain information on some of the more taxonomically difficult groups (e.g., leafhoppers, flies), we may reveal more undescribed arthropod species from this research.

Discussion

To date we have recognized a total of 923 arthropod taxa from our quantitative samples, and a total of 1,122 arthropod taxa from all sampling methods combined including general collecting. Comparative community composition analyses demonstrated that the taxonomic composition of ground-dwelling, plant-dwelling, and night-flying arthropods were distinctly different between each of the three water zones. We also found a number of specific species of ground-dwelling, plant-dwelling, and night-flying arthropods that were significant indicator species for each of the three water zones, based on abundance, consistency across samples, and specificity of occurrence within a particular water zone.

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 distributions of the large numbers of arthropod taxa showed no pattern with regard to site location along the river, but did show strong associations with water zone, seasons, and years (seasonal patterns were presented in previous annual reports). The large number of arthropod taxa along with their variety of habitat and seasonal specializations, 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 strongly influenced by soil texture and moisture conditions, which in shoreline and new high water zones, are directly affected by discharges from Glen Canyon Dam. They are also related to overall habitat structure resulting from variation in topography and vegetation structure and cover (Antvogel and Bonn 2004) which, themselves, are indirectly linked to dam operations. We have identified large series of ground-dwelling arthropod species that were associated with each of the three water zones, including 17 species that were 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 (Lightfoot and Whitford 1989). We have identified all of these insect groups from our samples, and demonstrated water zone and annual patterns, including 12 species that were indicator taxa for the water zones.

The light trap 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. Additionally, all indicator species of moths were from the OHWZ only. 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 precipitation.

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-feeding 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 may be occurring, and are reflected in our data. We will need additional years of arthropod, rainfall, and river stage data before we can begin testing for relationships between those.

As links between the processes of primary productivity and decomposition and 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. We agree with the findings of Yard et al. (2004) that most species of breeding passerine bird species were utilizing plant-dwelling arthropods such as caterpillars as prey in the OHWZ, and less so in the NHWZ. Our results also confirm a greater number of pair-wise positive arthropod/bird species relationships in the OHWZ compared to the NHWZ. In contrast, our results demonstrate positive relationships between more species of birds and ground-dwelling arthropods in the NHWZ than in the OHWZ (see INTEGRATION section below). These findings further demonstrate a complex riparian ecosystem with linkages between plants, arthropods and vertebrate predators, and different relationships between these organisms in the different water zones. We did not survey bats in this study, but other 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, Yard et al. 2004). 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.

A number of ground and plant arthropods appear to be indicators of soil moisture, vegetation canopy cover, and vegetation productivity. Ground-dwelling isopods and ground beetles are known to be associated with moist soil conditions (Ellis et al. 2001, Antvogel & Bonn 2004, Cartron et al. 2003), and their presence in NHWZ and OHWZ sites indicates a range of soil moisture conditions in those zones across study sites. Plant bugs, hoppers and flies were correlated with isopods and ground beetles (which require high soil moisture), especially in the OHWZ, indicating that all of those arthropods were associated with moist, productive environments. Plant bugs and plant hoppers are known to be correlated with increased plant productivity, plant taxonomic diversity, and plant architecture (Strong et al. 1984). Plant flies include species whose larvae live as parasites or parasitoids in animal and plant host tissue, as well as many species whose larvae live in organic soil detritus. A number of lizard, bird, and rodent species also were associated with those arthropods that require high soil moisture, indicating overall higher moisture and productivity of certain sites. In contrast, ground-dwelling ants and darkling beetles tend to occur in drier habitats, and in this study appear to be indicators of drier, open sites. The correlations of granivorous seed bugs (*Nysius*) on both vegetation and the ground surface, ground-dwelling granivorous ants (*Pogonomyermex*) and granivorous pocket mice (*Chaetodipus*), indicates a community of granivores that occur in open sites with herbaceous plants that produce preferred seeds.

Correlation analysis only allows us to examine relationships in variation of counts or densities of select organisms across a series of sites. We can only speculate on why those relationships occurred based on our knowledge of the biology and ecology of those organisms. These analyses are based only on three years of data. Longer-term data should support or refute these initial findings, and provide more insight into relationships between arthropods, the physical environments, and other animals and plants across the three water zones in Grand Canyon.

Of the six exotic arthropod species that we found in Grand Canyon, two were associated with tamarisk, and two with bermudagrass, both of which also are non-native species. All were found in the SHOR and NHWZ, yet the OHWZ remains dominated by native arthropods. 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. Furthermore, the OHWZ will probably decline over time since large floods no longer provide water and soil scouring and nutrient deposition necessary for the re-establishment of vegetation such as mesquite and acacia. As such, we predict an eventual decline and loss of the biologically rich OHWZ, which is dominated by native species, and a perpetuation of the human-created NHWZ supporting exotic species. Those exotic species also compete with native species for food and habitat resources, and should be considered ecologically important taxa for future monitoring efforts. For example, European honey bees use the same nectar resources from flowers as native bees and wasps, and native detritivores use the same leaf litter resources as isopods. Studies along the Rio Grande in New Mexico have revealed similar relationships between a human altered post-dam riparian ecosystem environments and increases in exotic tamarisk and exotic isopods (Ellis et al. 2001, Cartron et al. 2003).

This inventory and monitoring project was primarily designed to address the ecological effects of Gen Canyon Dam on terrestrial riparian arthropods of Grand Canyon. Yet, there are interests in arthropods beyond the ecological roles of arthropods presented in this report. Some arthropod taxa are of special interest to both Native American tribes, and to recreational visitors in Grand Canyon. The Hopi are particularly interested in spiders, dragonflies, and butterflies (Huisinga & Yeatts 2003). Spiders comprise a significant part of the arthropods sampled in this research, but dragonflies and butterflies do not. Dragonflies and related damselflies (Order Odonata) do live and breed in the smaller side-canyon streams of Grand Canyon, but not in the Colorado River. We have sampled adult dragonflies and damselflies as part of our general inventory, but they are not part of our quantitative sampling regime because they do not typically occur along the riparian corridor other than occasional adult insects flying by. Butterflies are not particularly common in Grand Canyon, especially along the riparian corridor. We sampled butterflies as part of a general inventory, but they are a small component of the monitoring effort. Spiders are common riparian arthropods in Grand Canyon, and in that respect, they are an important group of arthropods of Hopi concern for future monitoring studies. Recreation visitors in Grand Canyon are particularly concerned about arthropods that pose health concerns, especially scorpions, spiders, ants, and biting flies. Our sampling methods are well suited to provide useful information on those arthropods relative to habitat affiliations, and relative abundance throughout Grand Canyon.

We continue to develop the reference/voucher specimen collections of arthropods from this project. We are working with more than 1,000 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 serve best as bioindicators of environmental change appropriate for the purpose of this project.

Results to date demonstrate that arthropods are the most diverse and abundant group of organisms occurring along the terrestrial riparian corridor of Grand Canyon. Terrestrial arthropods are known to have great potential for resource and conservation management of terrestrial ecosystems in general (Kremen et al. 1993), and specifically for Southwest riparian ecosystems (Williams 1993, Cartron et al. 2003). The findings presented here demonstrate cross-taxa interactions between plant and animal species, both within water zones, and between water zones. These findings indicate that each of the three water zones support unique biotic communities, with unique species compositions and interactions among those species. These findings further demonstrate that select indicator taxa of arthropods can be identified from this study that are appropriate for future long-term monitoring of terrestrial biotic communities in relation to river water fluctuation in Grand Canyon.

Evaluation of arthropod inventory and monitoring methods.

General collecting, night collecting scorpions with portable UV lights, vegetation sweep-net sampling, pitfall traps, light traps, Malaise traps all proved useful in collecting a wide variety of diurnal, nocturnal, ground-dwelling, plant-dwelling, and flying arthropods along the terrestrial riparian zone of the Colorado River in Grand Canyon. No single method would have would have adequately sampled the wide taxonomic and ecologically specific range of arthropods that we found.

Pitfall traps were the most efficient and robust method for sampling ground arthropods across the different riparian water zones. The traps were inexpensive, easy to install and remove, and adequately sampled a relatively consistent set of taxa across all three water zones, and providing us with 17 indicator species (Table Art-1). Vegetation sweep sample were useful, but we feel that the method is not ideal primarily because we were not able to sample the upper tree canopies (i.e., above 2 m). This problem meant that in wooded areas, especially in the NHWZ, our foliage samples were in shaded areas below the tree canopies, and under-represented the arthropods on the tree foliage. Additionally, the plant arthropod taxa were very diverse and dynamic over time, adding much time and effort to analyses. Vegetation sweep sampling could be modified to reach the foliage canopy with use of ladders and/or extension nets, but such modifications would add cost in terms of sampling time and difficulty. Light and Malaise traps were effective at sampling flying insects, but we do not know the extent of the light trap sampling areas, and whether or not light traps in one zone may have attracted insects from another zone. Light traps and Malaise traps were also time consuming to install and uninstall at study sites, and expensive to maintain and operate. Although light and Malaise trap samples resulted in a large number of water zone indicator species, all were moths, and all were limited to the OHWZ only.

We recommend the use of pitfall traps targeting ground-dwelling arthropods as the simplest, most effective way to sample arthropods for future monitoring studies of dam effects on the hydrologic zonation of terrestrial riparian biota. However, if future monitoring goals include the need to integrate trophic interactions including plants, insects, and birds, then we recommend including plant-dwelling insects, but with improved sampling, and reduced taxonomic precision to simple ecological functional groups such as caterpillars, flies, beetles, etc. Also, if future monitoring goals are to include interactions between the aquatic river system and the terrestrial riparian system, then Malaise trap sampling of chironomid midge adults should be used. Refer to the RECOMMENDATIONS section of this report for more detailed recommendations relative to arthropods and future monitoring efforts.

Literature Cited

Antvogel, H. and A. Bonn. 2004. Environmental parameters and microspatial distribution of insects: a case study of carabids in an alluvial forest. Ecography 24:470-482.

Arnett, R. H., Jr. 2000. American Insects. CRC Press, Boca Raton, FL.

Beck, J., C. H. Schulze, K. E. Linsenmair and K. Fiedler. 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. and K. Fiedler. 2003. Faunal composition of geometrid moths changes with altitude in an Andean montane rain forest. Journal of Biogeography 30:431-440.

Coddington, J. A. and H. W. Levi. 1991. Systematics and evolution of spiders (Araneae). Annual Review of Systematics and Evolution 22: 565-592. Platnick, N. I. 2002. World Spider Catalog V. 3.0. (web site).

Cartron, J. E., M. C. Molles, Jr., J. F. Schuetz, C. S. Crawford, and C. N. Daham. 2003. Ground arthropods as potential indicators of flooding regime in the riparian forest of the middle Rio Grande, New Mexico. Environmental Entomology 32:1075-1084.

Dindal, D. L., editor. 1990. Soil Biology Guide. John Wiley and Sons, New York, NY.

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. Henry Holt and Co., New York. 92pp.

Fasel, A., P.-A. Muller and E. Vauthey. 1997. Photoluminescence of the African scorpion "Pandinus imperator". Journal of photochemistry and photobiology B 39 (1):96.

Fet, V. 2002. Catalog of the Scorpions of the World (1758-1998). New York Entomological Society, New York.

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

Holmes R. T. and 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 and 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.

Huisinga, K. and M. Yeatts. 2003. An analysis of the Grand Canyon Monitoring and Research Center's terrestrial monitoring program and the development of a Hopi long-term plan. Technical Report to the Grand Canyon Monitoring and Research Center, Cooperative Agreement No. 01WRSA0358.

Kremen, C., R. K. Colwell, T. L. Erwin, D. D. Murphy, R. F. Noss, and M. A. Sanjayan. 1993. Terrestrial arthropod assemblages: their use in conservation planning. Conservation Biology 7:796-808.

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

Lawrence, R. F. 1954. Fluorescence in Arthropoda. Journal of the Entomological Society (South Africa) 17:167-170.

Leon-Cortes, J. L., J. J. Lennon, and C. D. Thomas. 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.

Lighton, J. R. B., P. H. Brownell, B. Joos and R, J. Turner. 2001. Low metabolic rate in scorpions: implications for population biomass and cannibalism. Journal of Experimental Biology 204:607-613.

Lourenco, W. R. 1991. The scorpions of Colombia, II. The fauna of the Santa Marta and eastern Cordilleran Regions. Biogeographic approach (Arachnida: Scorpiones). Senckenbergiana biologica 71:275-288.

MjM Software Design. 1999. PC-ORD: multivariate analysis of ecological data. Version 4. Gleneden Beach, OR.

Pogue, M. G. 2004. A new species of *Schinia* Hubner from riparian habitats in the Grand Canyon (Lepidoptera: Noctuidae: Heliothinae). Zootaxa 788:1-4.

Polis, G. A. 1993. Scorpions as model vehicles to advance theories of population and community ecology: The role of scorpions in desert communities. Memoirs of the Queensland Museum 33:401-410.

Poole, R. W. and P. Gentili, editors. 2003. Nomina Insecta Nearctica. Entomological Information Services, P.O.Box 4350 Rockville, MD.

SAS. 2003. Statistical Analysis Systems, Version 8.23 for PC’s, Cary, NC.

SPSS for windows. Rel. 12.0.1.2003. Chicago, IL. SPSS Incorporated.

Skutelsky, O. 1996. Predation risk and state-dependent foraging in scorpions: Effects of moonlight on foraging in the scorpion *Buthus occitanus*. Animal Behaviour 51:49-57.

Stachel S. J., S. A. Stockwell and D. L. Van Vranken. 1999. The fluorescence of scorpions and cataractogenesis. Chemistry & Biology 6(8):531-539.

Stahnke, H. L. 1972. UV light, a useful field tool. Bioscience 22:604-607.

Strong, D. R., Jr., J. H. Lawton, and T. R. E. Southwood. 1984. Insects on plants: community patterns and mechanisms. Havard University Press, Cambridge, MA.

Thomas, D and E. Sleeper. 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.

Warburg, M. R. 1998. Qualitative and quantitative analysis of intra-and interspecific behavioural patterns among scorpions. Journal of Ethology 16:115-121.

Wilkie, L., C. Gerasimose, and M. Gray. 2003. A quality control protocol for terrestrial invertebrate biodiversity assessment. Biodiversity and Conservation 12:121-146.

Williams, K. S. 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. Restoration Ecology 1:107-116.

Williams, S. C. 1987. Lectotype designation and redescription of *Serradigitus wupatkiensis* Stahnke (Scorpiones: Vaejovidae). Pan-Pacific Entomology 63(4):363-67.

Yard, H. K., C. Van Riper III, B. T. Brown and M. J. Kearsley. 2004. Diets of insectivorous birds along the Colorado River in Grand Canyon, Arizona. The Condor 106:106-115.

Young, S. 1994. Insects that carry a global warning. New Scientist 14:32.

Table Art-1. Ground and plant associated arthropod species that were significant 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 probability level. IS values of 25 and greater with probabilities of <0.05 are considered to be robust, significant indicator taxa.

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	*Schizocosa*	*celerior*	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	*Bradycellus*	*nitidus*	SHOR	13.1	0.001
Coleoptera	Carabidae	*Tetragonoderus*	*fasciatus*	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	*Pogonomyrmex*	*maricopa*	OHWZ	33.8	0.006
Hymenoptera	Mutillidae	*Sphaeropthalma*	sp.	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	*Apion*	sp.	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

Moths

Order	**Family**	**Genus**	**Species**	**Water Zone**	**Value**	***p***
Lepidoptera	Noctuidae	*Acontia*	*arida*	OHWZ	32.4	0.001
Lepidoptera	Noctuidae	*Acontia*	*bella*	OHWZ	11.1	0.003
Lepidoptera	Noctuidae	*Aleptina*	*semiatra*	OHWZ	39.5	0.002
Lepidoptera	Noctuidae	*Allerasteria*	*albiciliatus*	OHWZ	36.7	0.001
Lepidoptera	Noctuidae	*Conochares*	*arizonae*	OHWZ	38.5	0.003
Lepidoptera	Noctuidae	*Micrathetis*	*costiplaga*	OHWZ	6.8	0.04
Lepidoptera	Noctuidae	*Pseudohadena*	*vulnerea*	OHWZ	10.8	0.02
Lepidoptera	Noctuidae	*Heteranassa*	*mima*	OHWZ	31.5	0.002
Lepidoptera	Noctuidae	*Bulia*	*deducta*	OHWZ	8.3	0.03
Lepidoptera	Noctuidae	*Bulia*	*californica*	OHWZ	13.3	0.05
Lepidoptera	Noctuidae	*Drasteria*	*pallescens*	OHWZ	19.1	0.03
Lepidoptera	Noctuidae	*Toxonprucha*	*volucris*	OHWZ	38.3	0.001
Lepidoptera	Noctuidae	*Polia*	sp.	OHWZ	18.9	0.03
Lepidoptera	Noctuidae	*Trichoclea*	*decepta*	OHWZ	11.6	0.02
Lepidoptera	Geometridae	*Euacidalia*	sp.	OHWZ	30.4	0.001
Lepidoptera	Geometridae	*Glaucina*	sp.	OHWZ	8.4	0.008
Lepidoptera	Geometridae	*Semiothisa*	*s-signata*	OHWZ	25.2	0.003
Lepidoptera	Geometridae	*Semiothisa*	*pallidata*	OHWZ	22.3	0.008
Lepidoptera	Geometridae	*Semiothisa*	sp. 2	OHWZ	27.1	0.002
Lepidoptera	Geometridae	*Eupethecia*	sp.	OHWZ	8.6	0.02
Lepidoptera	Arctiidae	*Cisthene*	*angelus*	OHWZ	28.7	0.01
Lepidoptera	Arctiidae	*Euchetes*	*zella*	OHWZ	23.9	0.001
Lepidoptera	Pyralidae	*Helvibotys*	*helvialis*	OHWZ	16.0	0.04
Lepidoptera	Saturniidae	*Sphingicampa*	*hubbardi*	OHWZ	11.3	0.02
Lepidoptera	Notodontidae	unknown genus	sp.	OHWZ	11.5	0.02
Lepidoptera	microleps	various taxa		OHWZ	42.5	0.009

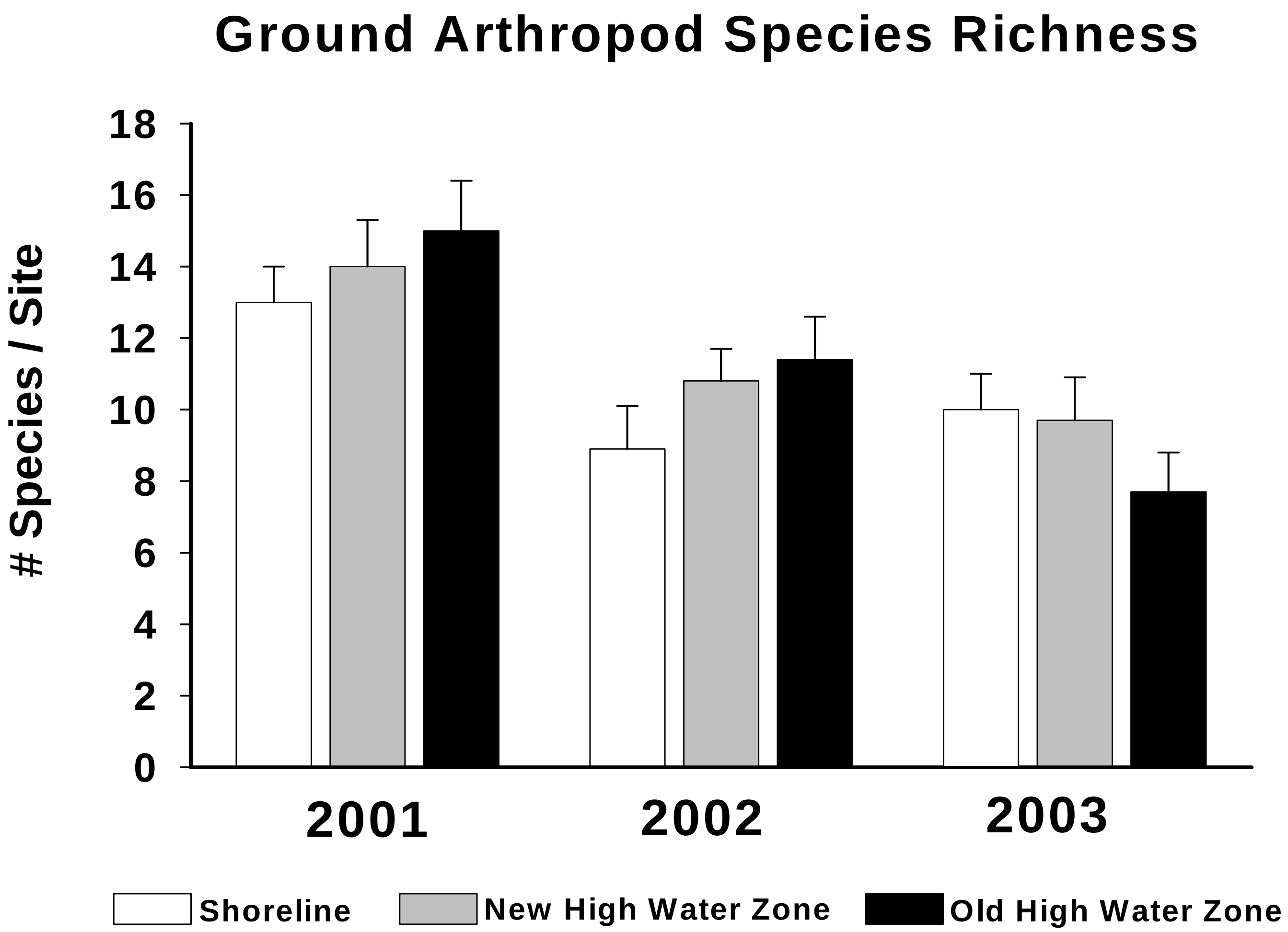


Figure Art-1. Counts of all species of all ground-dwelling arthropods by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

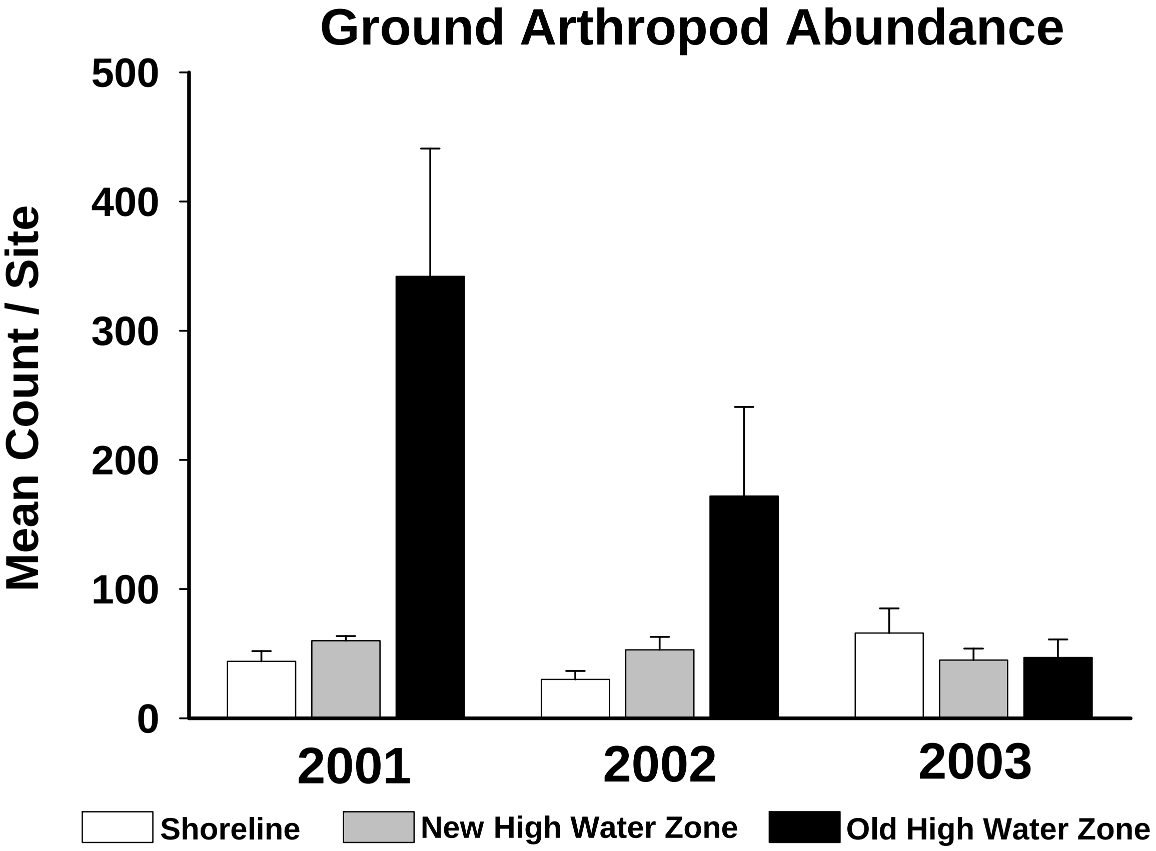


Figure Art-2**.** Counts of all individuals of all ground-dwelling arthropods by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

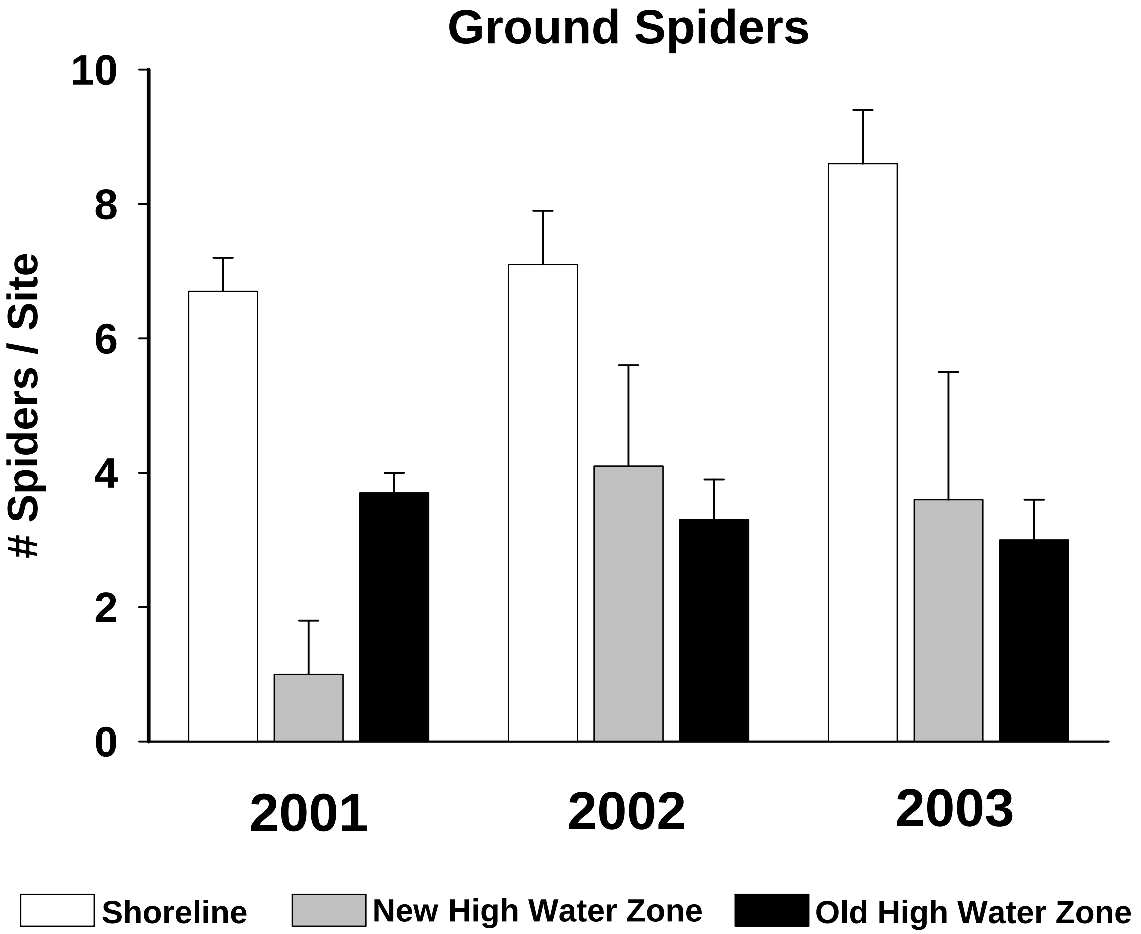


Figure Art-3. Counts of all individuals of all ground-dwelling spiders by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

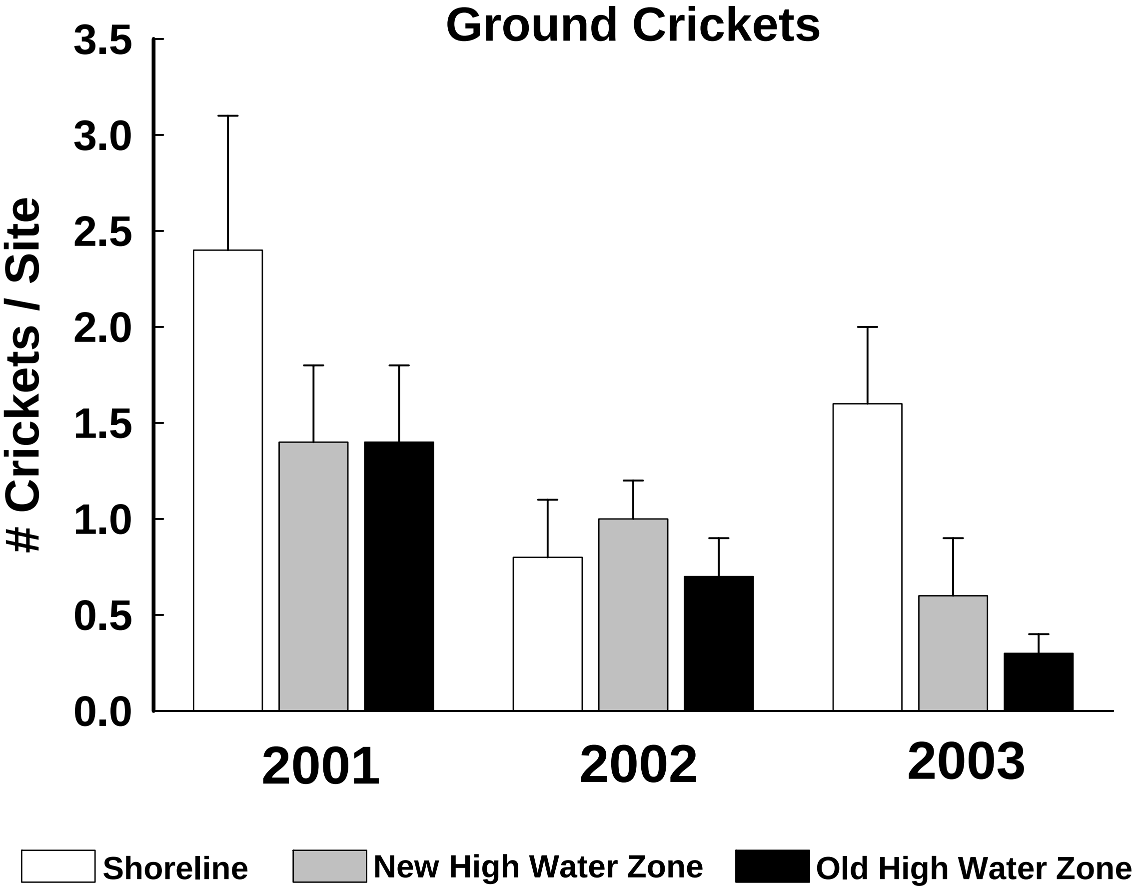


Figure Art-4. Counts of all individuals of all ground-dwelling crickets by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

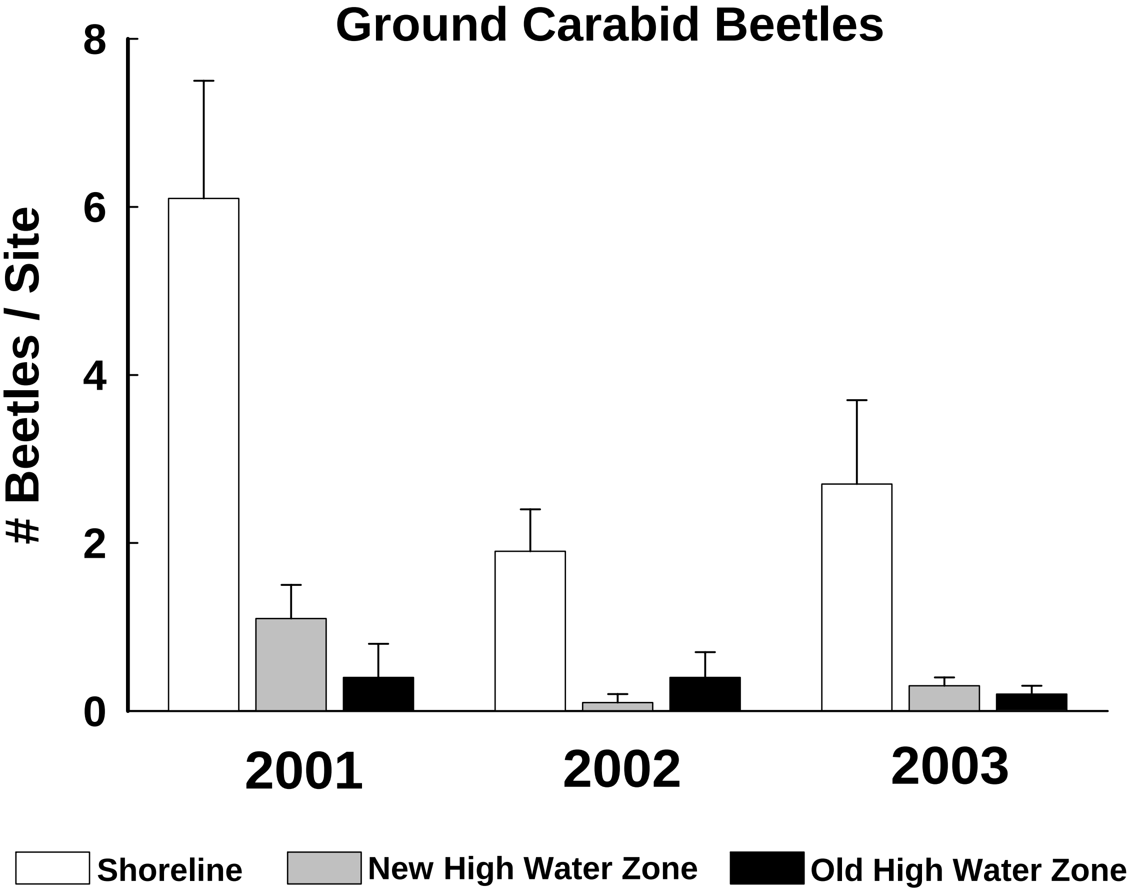


Figure Art-5. Counts of all individuals of all ground-dwelling carabid beetles by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

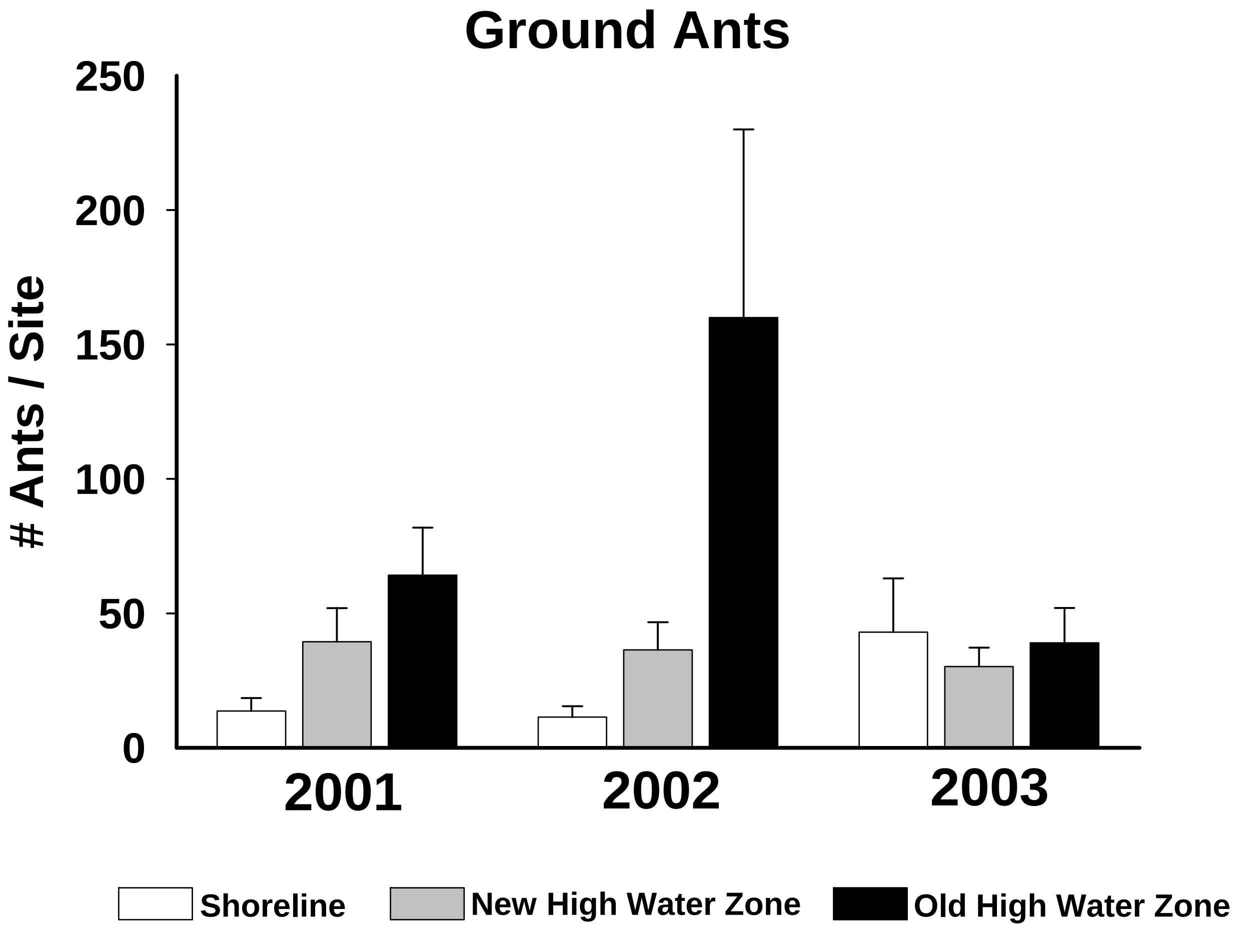


Figure Art-6. Counts of all individuals of all ground-dwelling ants by year across all water zones. Values are means from ten pooled pitfall traps per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

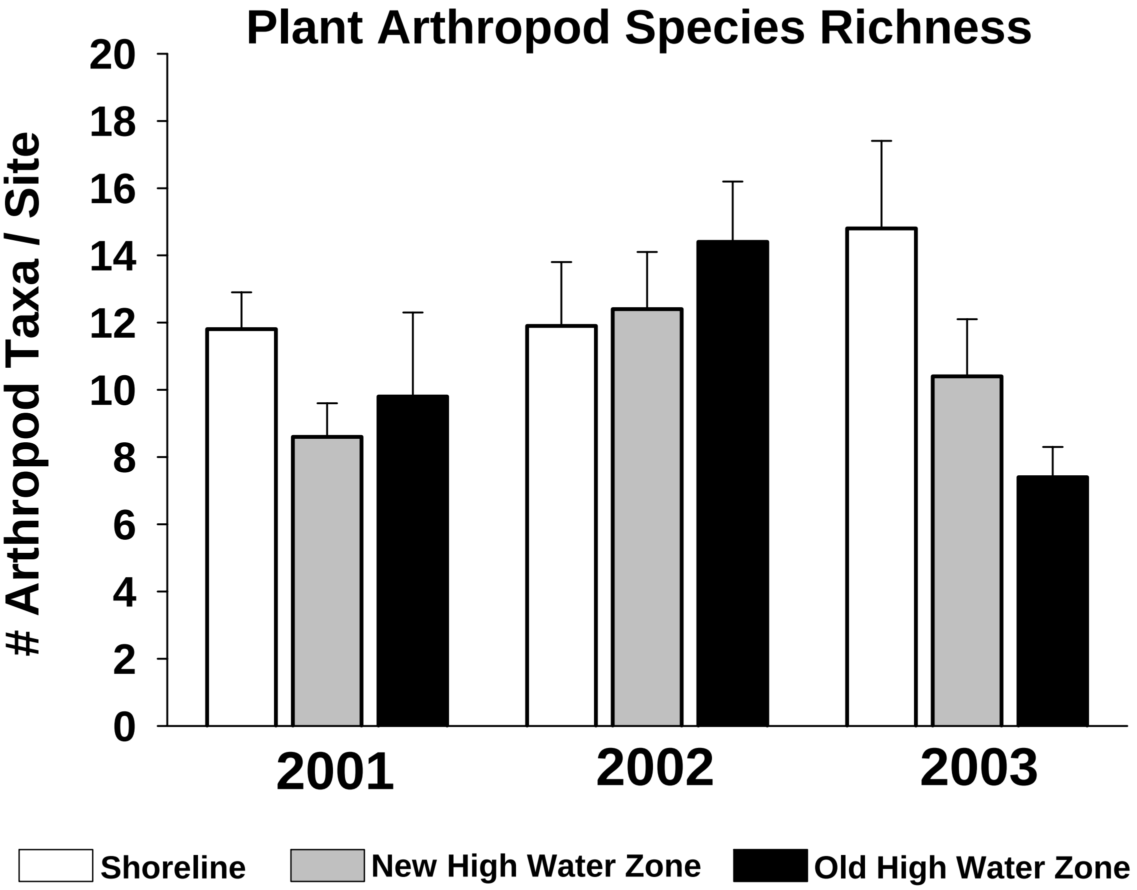


Figure Art-7. Counts of all species of all plant-dwelling arthropods by year across all water zones. Values are means from ten pooled sweep-net samples per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

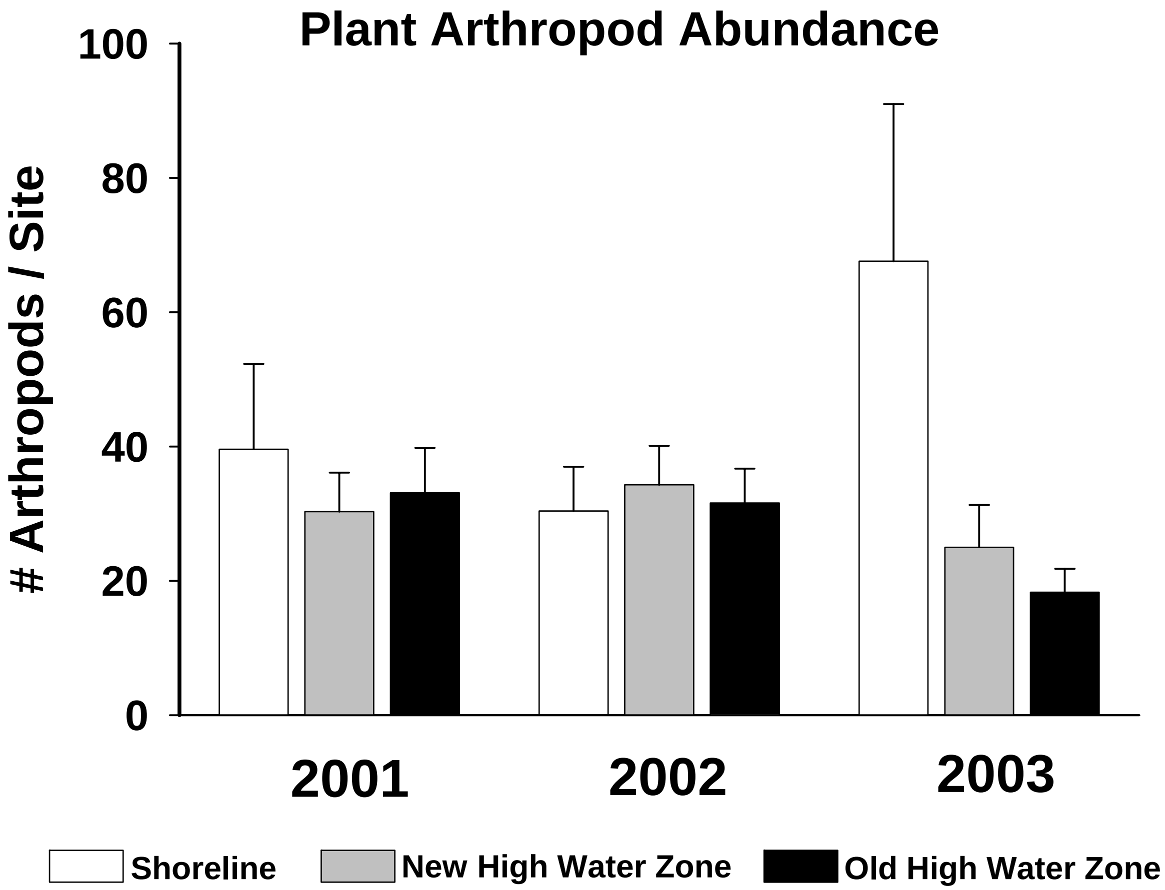


Figure Art-8. Counts of all plant-dwelling arthropod individuals by year across all water zones. Values are means from ten pooled sweep-net samples per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

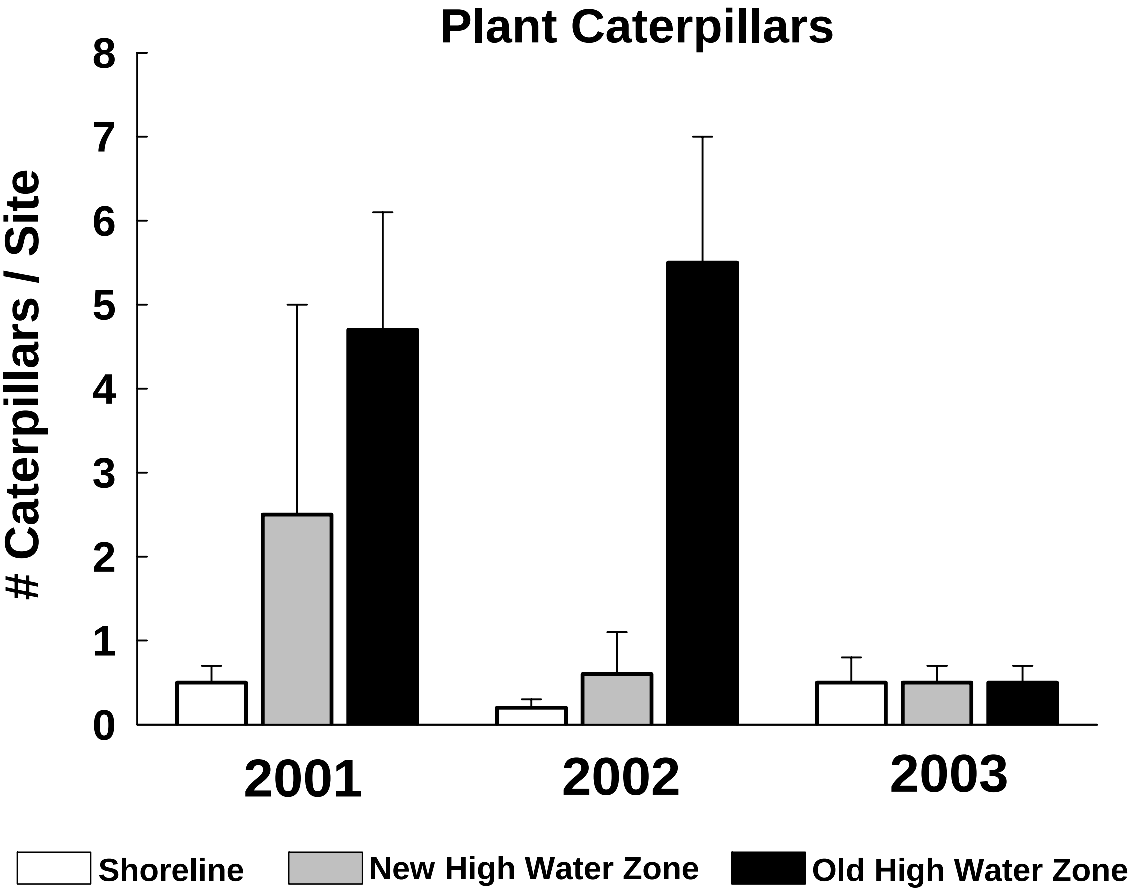


Figure Art-9. Counts of all individuals of all plant-dwelling caterpillars by year across all water zones. Values are means from ten pooled sweep-net samples per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

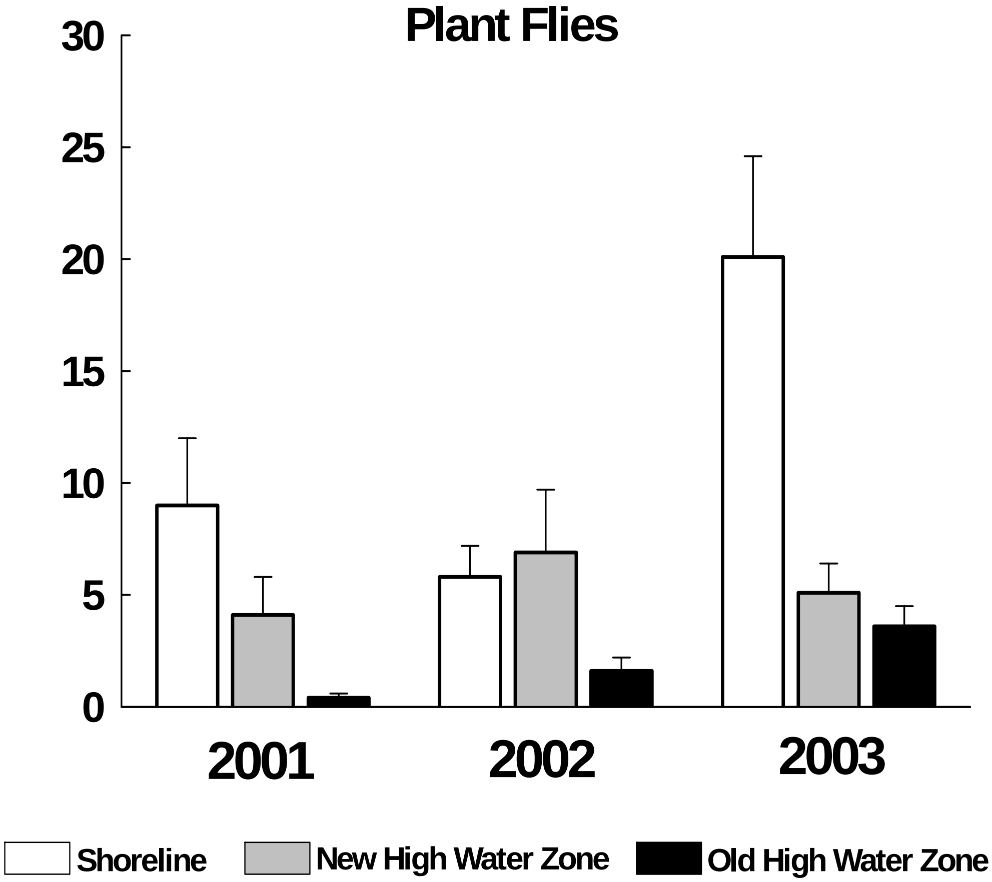
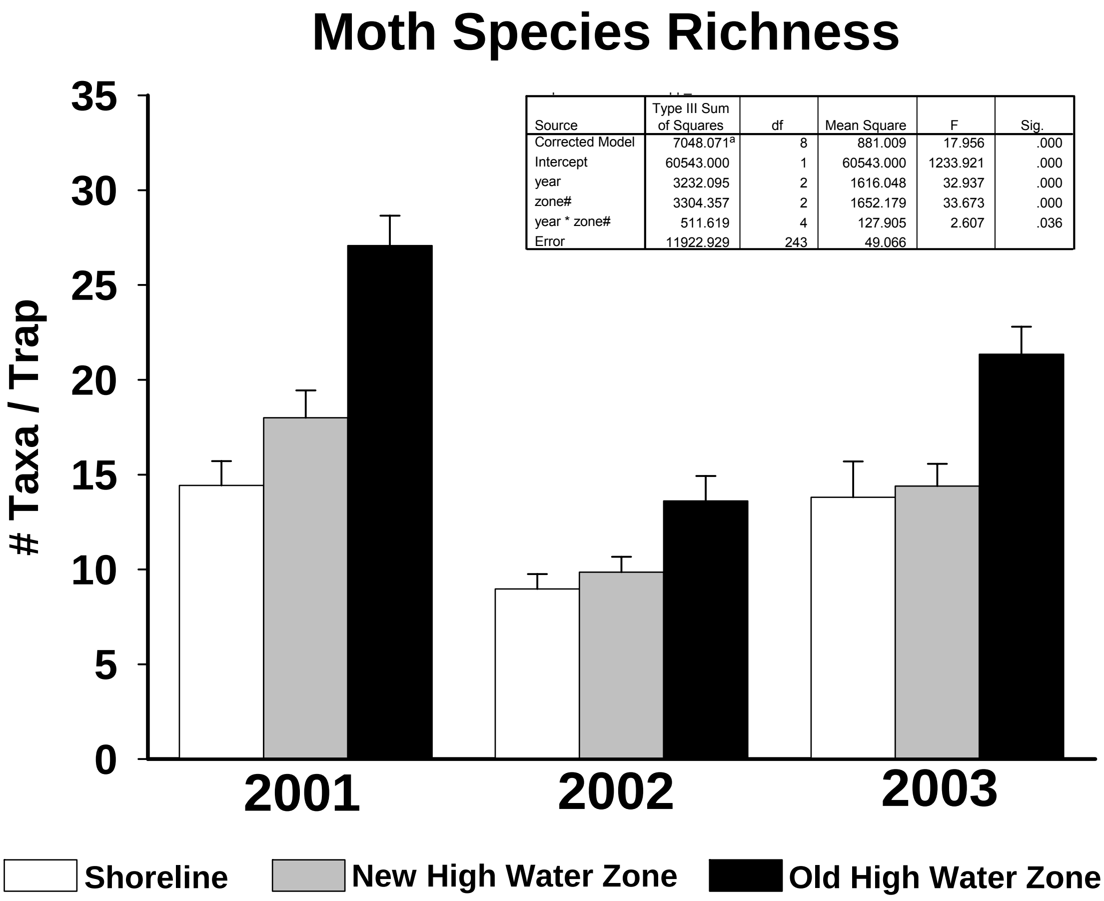
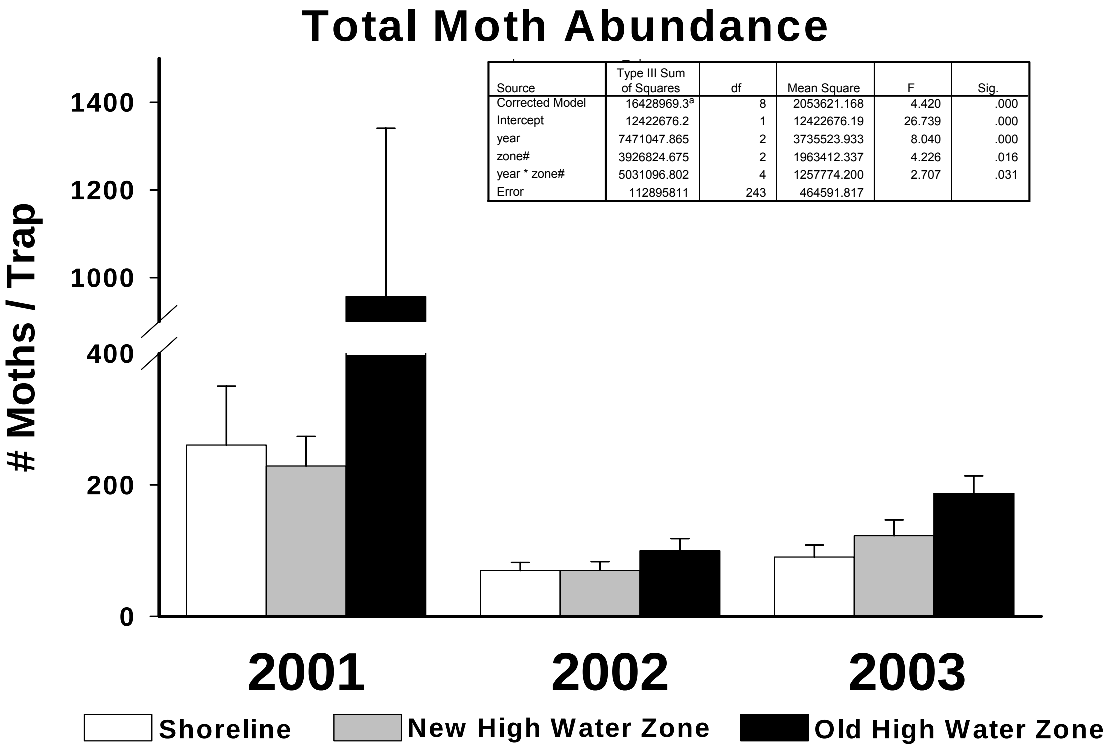


Figure Art-10. Counts of all individuals of all plant-dwelling flies by year across all water zones. Values are means from ten pooled sweep-net samples per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.



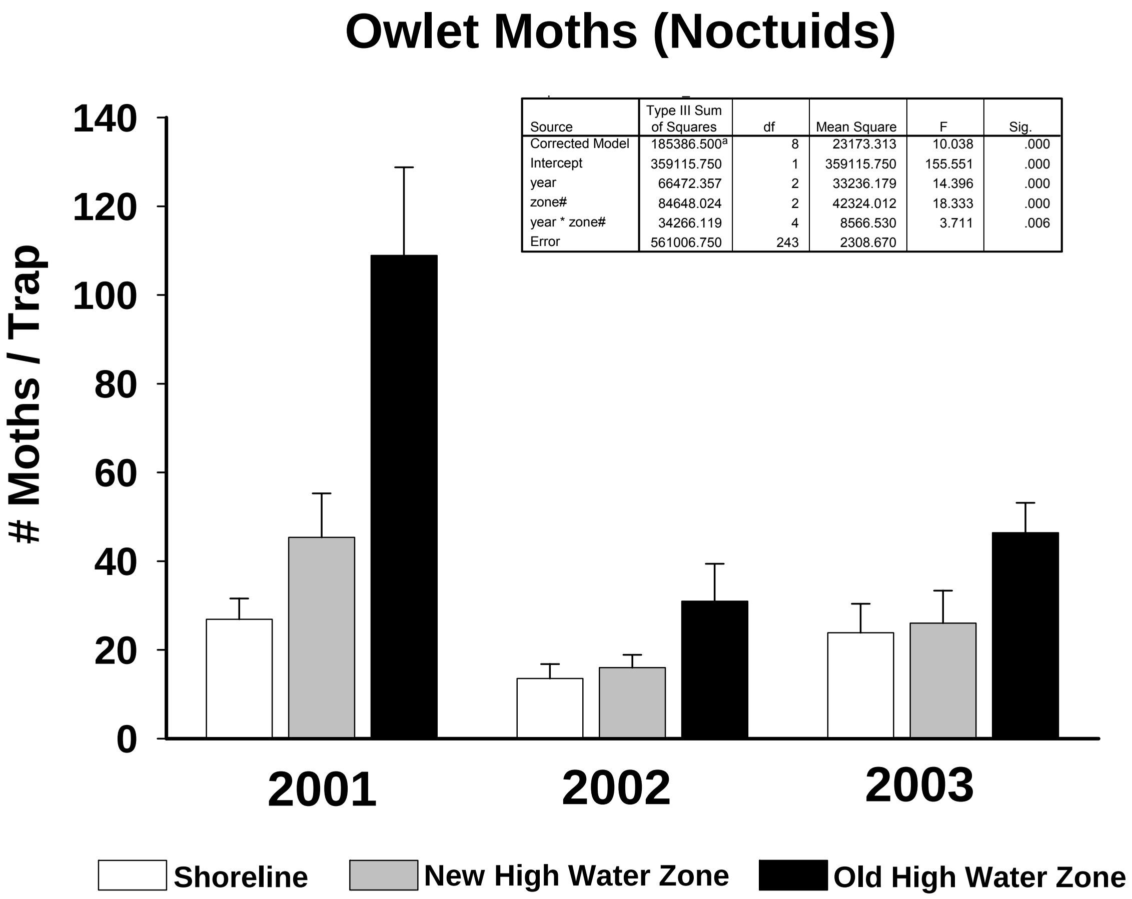
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7048.071[a]	8	881.009	17.956	.000
Intercept	60543.000	1	60543.000	1233.921	.000
year	3232.095	2	1616.048	32.937	.000
zone#	3304.357	2	1652.179	33.673	.000
year * zone#	511.619	4	127.905	2.607	.036
Error	11922.929	243	49.066		

Figure Art-11. Counts of all individuals of all Lepidoptera species collected by Malaise and light traps in the three hydrologic zone. Values are from pooled abundance between the two trap types per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.



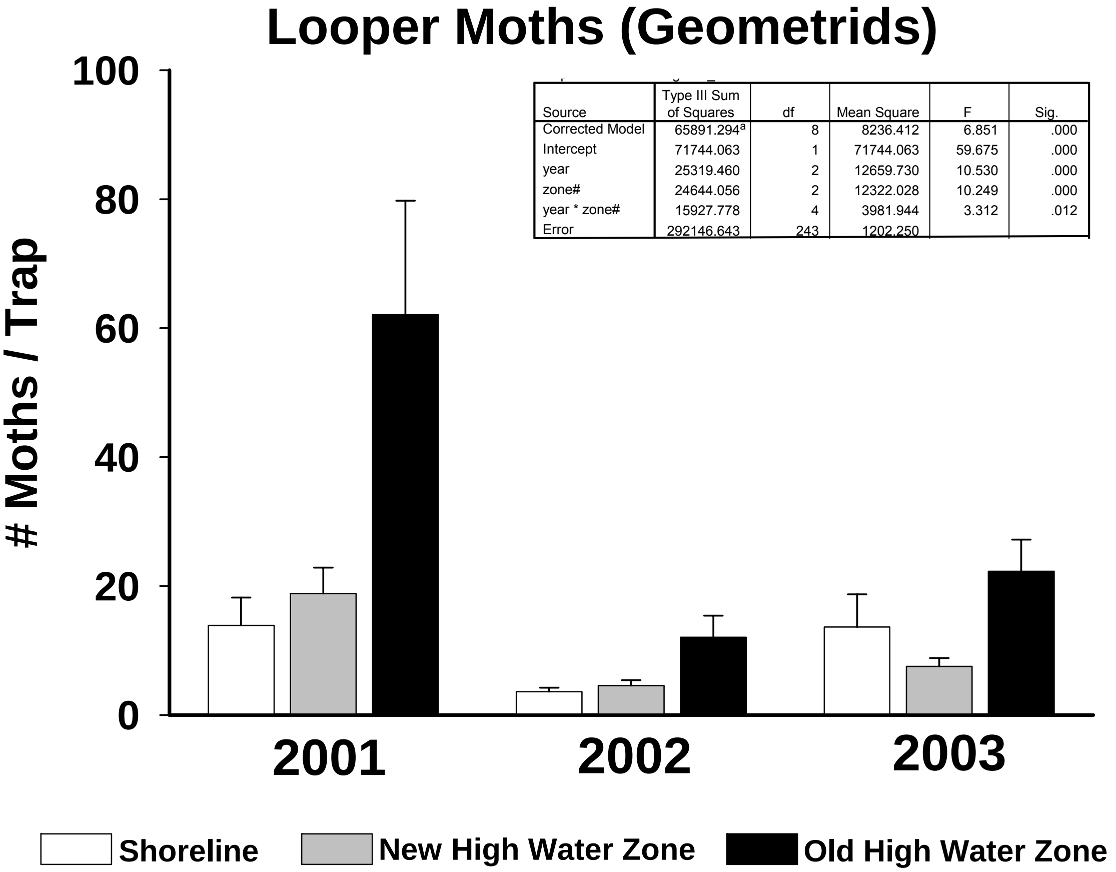
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16428969.3[a]	8	2053621.168	4.420	.000
Intercept	12422676.2	1	12422676.19	26.739	.000
year	7471047.865	2	3735523.933	8.040	.000
zone#	3926824.675	2	1963412.337	4.226	.016
year * zone#	5031096.802	4	1257774.200	2.707	.031
Error	112895811	243	464591.817		

Figure Art-12. Counts of all individuals of all Lepidoptera collected by Malaise and light traps in the three hydrologic zone. Values are from pooled abundance between the two trap types per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.



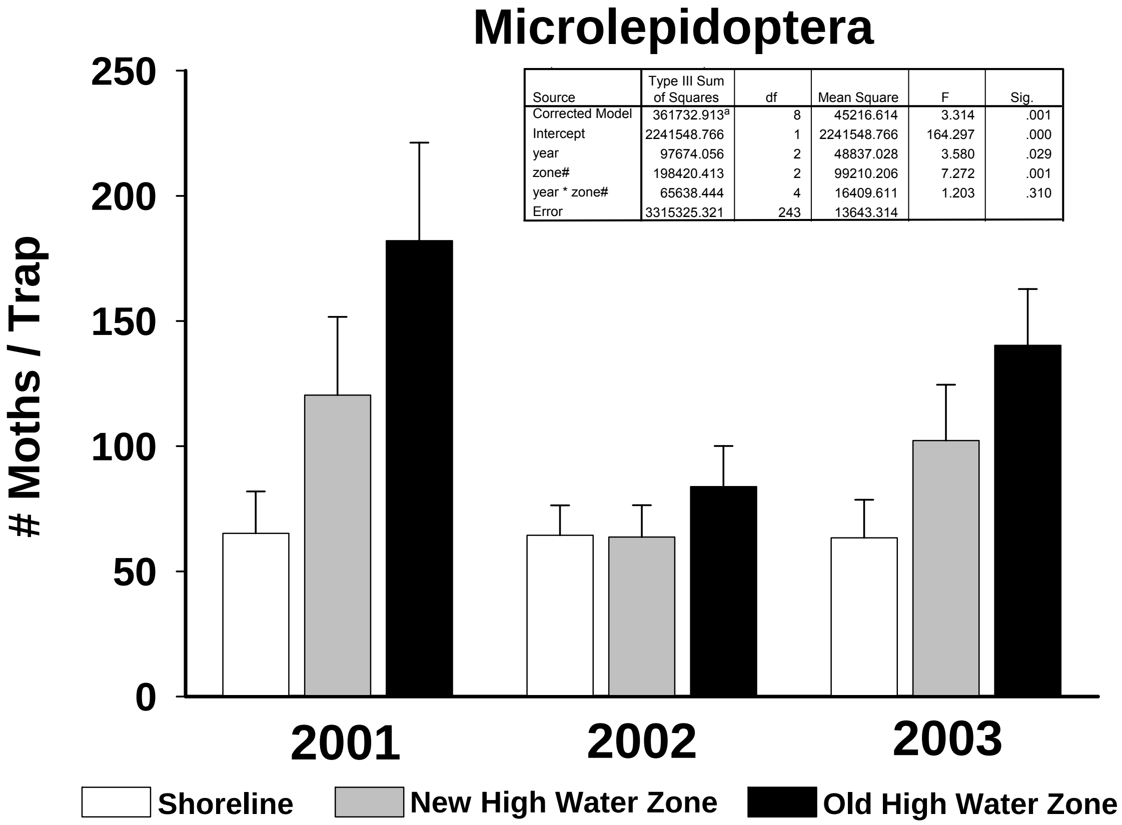
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	185386.500[a]	8	23173.313	10.038	.000
Intercept	359115.750	1	359115.750	155.551	.000
year	66472.357	2	33236.179	14.396	.000
zone#	84648.024	2	42324.012	18.333	.000
year * zone#	34266.119	4	8566.530	3.711	.006
Error	561006.750	243	2308.670		

Figure Art-13. Counts of all individuals of Owlet Moths collected by Malaise and light traps in the three hydrologic zone. Values are from pooled abundance between the two trap types per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.



Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	65891.294[a]	8	8236.412	6.851	.000
Intercept	71744.063	1	71744.063	59.675	.000
year	25319.460	2	12659.730	10.530	.000
zone#	24644.056	2	12322.028	10.249	.000
year * zone#	15927.778	4	3981.944	3.312	.012
Error	292146.643	243	1202.250		

Figure Art-14. Counts of all individuals of Geometrid (looper) moths collected by Malaise and light traps in the three hydrologic zone. Values are from pooled abundance between the two trap types per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.



Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	361732.913[a]	8	45216.614	3.314	.001
Intercept	2241548.766	1	2241548.766	164.297	.000
year	97674.056	2	48837.028	3.580	.029
zone#	198420.413	2	99210.206	7.272	.001
year * zone#	65638.444	4	16409.611	1.203	.310
Error	3315325.321	243	13643.314		

Figure Art-15. Counts of all individuals of Microlepidoptera collected by Malaise and light traps in the three hydrologic zones. Values are from pooled abundance between the two trap types per water zone over all sites, and over spring and fall seasons, +/- one standard error of the mean.

Herpetofauna

Geoffrey C. Carpenter
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.

The term "*herpetofauna*" is used here to represent both amphibians and reptiles.

Objectives

1. To accumulate inventory/distribution records of herpetofauna along the river corridor, to include photographic vouchers when possible.

2. To determine the linear (upstream/downstream) distribution of herpetofauna in the river corridor.

3. To assess 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.

4. To 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.

5. To investigate herpetofaunal species composition in relation to vegetation, other vertebrate animals, and, to arthropod community structure, across the three hydrologic riparian zones.

6. To assess effectiveness of survey/monitoring techniques for characterizing herpetofaunal communities across the three riparian hydrologic zones over time (season, year).

7. Relate herpetofauna abundance and distribution to patterns of precipitation and dam operations.

Methods:

During 2001, a total of 14 sites were selected for focused sampling of terrestrial reptiles and amphibians within the three hydrologic riparian zones. These sites were used also for arthropod transect sampling, and for small mammal trapping. Study transects and sampling schedules are described in detail in the COMMON METHODS section of this report.

Early and late summer seasons support different species and age class compositions within the three hydrologic zones, and activity patterns of reptiles and amphibians 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, i.e., often the site remained shaded all morning and direct sunlight was never available for basking lizards). The best possible conditions were those times during a site visit when temperatures and incident sunlight were most favorable for herpetofaunal activity during a 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 movement and profiles/silhouettes of reptiles and amphibians. 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, and scats and tracks were recorded as evidence of a particular species presence. Notes and ancillary data concerning substrate, temperature, other microhabitat measures, and behaviors were also recorded (Figure Hrp-1). Transects and the habitat patches that contained them were thoroughly surveyed during peak daytime activity periods for diurnally active reptiles and amphibians (these are times during the mornings and evenings when temperature and light conditions are most suitable for herpetofaunal activity). Weather and terrain permitting, night operations to search for nocturnally active reptiles and amphibians were undertaken (usually in concert with nighttime scorpion searches by members of the arthropod sampling crew), but very few reptiles and amphibians 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 one site, it is difficult to use raw capture data to make comparisons among different sites. Data from both spring and fall trips each year were pooled for analysis by year.

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 reptiles and amphibians at these sites to acquire additional herpetological records along the corridor. Sampling at these sites consisted of a pedestrian survey for reptiles and amphibians and herpetofauna sign in each zone. Collecting standardized data at these sites was difficult at best due to several constraints such as (1) time the site was visited was often too early or too late in the morning to coincide with peak activity times for herpetofauna (2) time spent at site was limited by the time required for the vegetation crew to complete their sampling (3) sites were often shaded for the entire duration of the site visit, hence no sunlight was available for lizard basking, and few lizards were censuses.

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 reptiles and amphibians were also recorded.

Data Analysis

To determine if the species composition of herpetofauna 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

Seventeen species of herpetofauna were observed in 2001. These included toads (2), frogs (1), lizards (6), and snakes (8). In 2002, 18 species of reptiles and amphibians were observed; 18 species of reptiles and amphibians were observed during 2003 at TEM (18) and VEG-BIRD (11) sites; two toads (Woodhouse's toad, red-spotted toad), one frog (canyon treefrog), six lizards (side-blotched lizard, western whiptail lizard, desert spiny lizard, tree lizard, chuckwalla and desert horned lizard), and five snakes (Grand Canyon rattlesnake, speckled rattlesnake, blacktail rattlesnake, coachwhip and striped whipsnake).

During all three years of the study the most commonly encountered reptiles and amphibians were four lizard species (Western whiptail, *Aspidoscelis (Cnemidophorus) tigris*); desert spiny, *Sceloporus magister*; side-blotched, *Uta stansburiana*, and tree lizard, *Urosaurus ornatus*) and two toads (Woodhouse's toad, *Bufo woodhousei*; and the red-spotted toad, *B. punctatus*,). Not all species were observed at all sites. However, further results, analyses and discussion of trends in the hydrological zones across years and seasons presented below are based on three years' (2001, 2002 and 2003) data, during which more than one season was sampled.

A graph of species richness (Figure Hrp-2) 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.

Figure Hrp-3 shows that the most commonly encountered reptiles and amphibians 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. The same pattern existed in 2001 and 2002. For descriptive purposes, data that are not being specifically related to TEM sites were pooled to enhance sample sizes in analyses below.

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 Hrp-4). The two toads and the tree lizard exhibited the greatest use of the fluctuation/shore zone (Figure Hrp-5).

In terms of overall observations in each zone, we see that all seven common species are using all three of the zones (Figure Hrp-5). 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 (also reported by Tomko, 1976 and 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 Hrp-6 presents numbers of the common species observed during 2003's spring, summer and fall trips. A few seasonal patterns are evident. First, spring was the most active time for most species. In fact, counts for five of the seven most common species (Woodhouse's toad, side-blotched lizard, Western whiptail, spiny lizard and tree lizard) were highest during the spring sampling. Second, side-blotched lizard activity was highest during the spring, dropped off during the heat of the summer, then spiked again during fall (late-summer) sampling. Third, numbers of active whiptails decreased overall from spring to summer to fall. This is not unexpected as whiptails (especially adults) are known to become inactive by late summer (Etheridge and Wit, 1993; Pianka, 1970). Additionally, adult sightings for most lizard species were generally lower during the fall trip, when the proportions of sub-adults, juveniles, and hatchlings are higher (Figure Hrp-7).

A MRPP analysis (PC-ORD, Version 4.10) revealed significant differences in the species composition of the three hydrologic zones ($A = 0.05667923$, $p < 0.001$) indicating that the herpetofaunal composition of the three zones differ from one another. 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. The MRPP analysis also reveals significant differences between seasons ($A = 0.00947285$ $p = 0.00012582$), indicating that the herpetofaunal communities vary by season. No such trends were evident by year. 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.

The results from an Indicator Species Analysis (ISA: PC-ORD, Version 4.10) are presented in Table Hrp-2. The ISA uncovered three species whose presence was significantly connected with a given zone. The Western whiptail (*A. tigris*) were significantly associated with the new high water zone and the side-blotched lizard (*U. stansburiana*), and spiny lizard (*S. magister)* were 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.

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 (e.g., river mile 92.3 L). 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 herpetofauna activity on a site at a particular time, and to collect reliable information for monitoring, inventory, and other purposes.

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.

Use of a zone also may be attributed to foraging strategy and/or substrate affinities. Active foragers, such as whiptails (Vitt and Ohmart 1974), 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 arrowweed rooting out arthropod prey. In fact, similar survey studies have reported that whiptails are the only reptile or amphibian 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 herpetofaunal 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 side-blotched lizard, are indicators of the 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 reptiles and amphibians 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.

While this is somewhat redundant with material in the Integration section of this report, it merits mention here that statistical diagnostics to uncover relationships among reptiles, amphibians and arthropods indicate that there is an association between the common reptiles and amphibians 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 reptiles and amphibians 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 Hrp-7 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 and also with the hydrograph and the precipitation data. For example, it will be necessary to sample herpetofauna communities in the corridor at least three times a year for several years in order to reveal demographic trends and subsequently tie them 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 have been run with existing 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.

While preliminary results from this study reveal that abundant lizard species may serve as indicators of new high water and old high water vegetation zones, and the toads as indicators of fluctuations zones, we cannot expect to acquire an thorough 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, which include sampling efforts among different seasons within the same and subsequent years to capture the complexity of these dynamic systems. Moreover, these studies should include sampling at repeat sites for two or three days at a time, using mark-recapture techniques to estimate population size and assess demographic parameters among the abundant diurnal lizard species.

In sum, data from three years of this study allow for only 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 herpetofauna 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. Refer to the RECOMMENDATIONS section of this report for discussions of reptile sampling problems and recommendations for the inclusion of herpetofauna in future montioring studies.

Literature Cited

Dufrêne,M; Legendre,P (1997): Species assemblages and indicator species: the need for a flexible asymmetric approach. Ecol. Monogr. 67, 345-366.

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.

Tomko, D. S. 1976. Demography of three species of Grand Canyon lizards. Pp. 5-60. IN. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona : Technical Report No. 10 / S.W. Carothers, S.W. Aitchison, M.M. Karpiscak, G.A. Ruffner, N.J. Sharber, P.L. Shoemaker, L.E. Stevens, M.E. Therous, D.S. Tomko.

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 Hrp-1. Herpetofaunal species oberserved during the 2001-2003 Terrestrial Ecosystem Monitoring sampling trips.

LIZARDS

COVA, *Coleonyx variegatus* (banded gecko)
ASTI, *Aspidoscelis 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

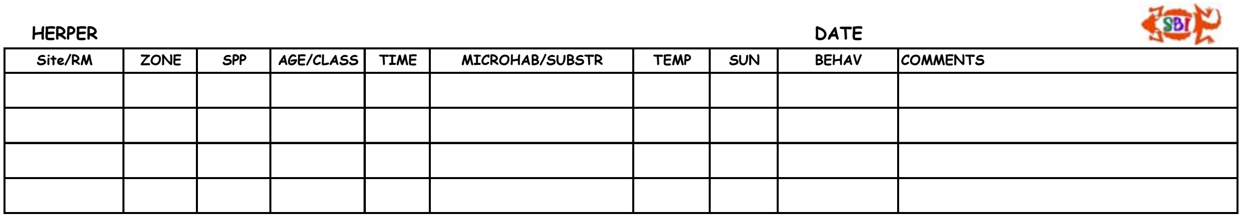
CRMI, *Crotalus mitchelli* (speckled rattlesnake)
CRMO, *Crotalus molossus* (black-tailed rattlesnake)
CRVI, *Crotalus viridis abyssus* (Grand Canyon pink rattlesnake)
HYTO, *Hypselglene torquata* (night snake)
LAGE, *Lampropeltus getulus* (king snake)
MAFL, *Masticophis flagellum* (red racer)
MASP, *Masticophis spp?* (whipsnake, spp.)
MATA, *Masticophis taeniatus* (striped whipsnake)
PIME, *Pituophis melanoleucus* (gopher snake)
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)

Table Hrp-2. Observed random indicator groups from Indicator Species Analysis for Grand Canyon river corridor reptiles and amphibians, 2001-2003.

Species	Hydrologic Zone	Indicator Value	p
Western Whiptail	NHWZ	21.5	0.0010
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 Hrp-1. Sample data sheet for TEM herpetofauna surveys**.**

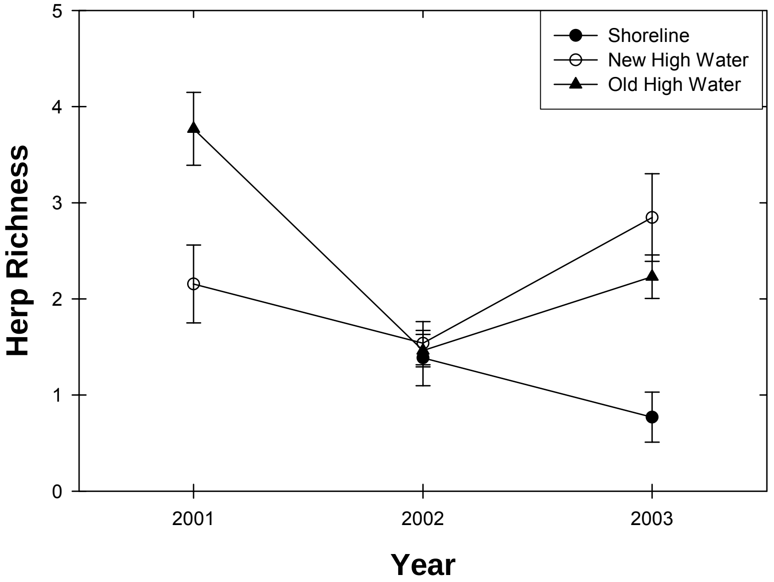


Figure Hrp-2. Species richness (number of species) of reptiles and amphibians in the three hydrologic zones during 2001-2003.

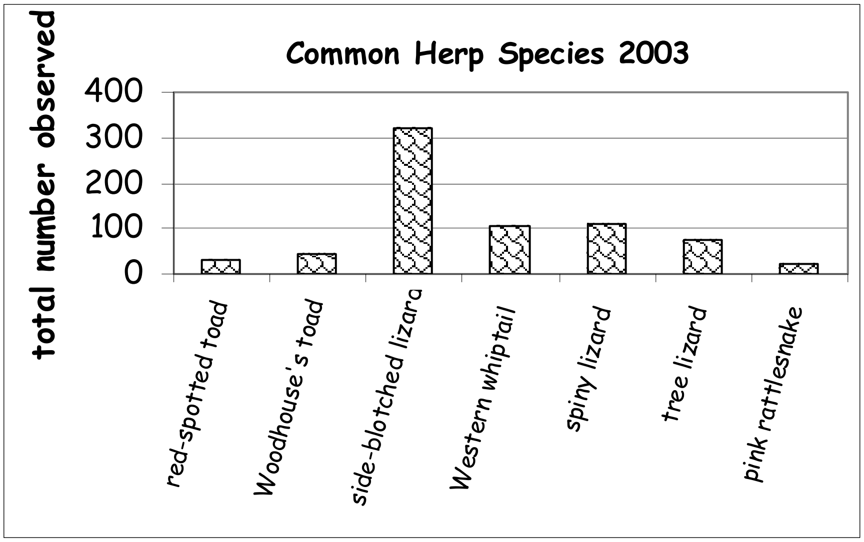
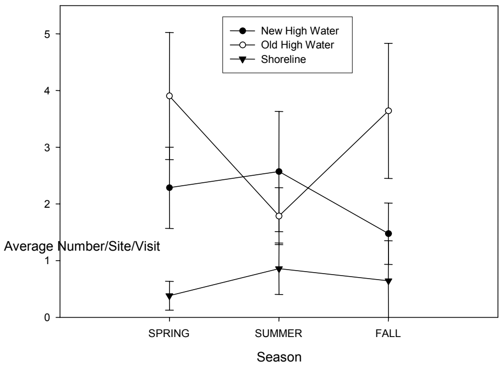
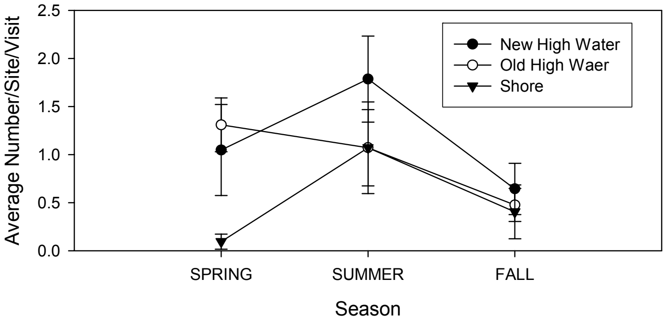


Figure Hrp-3. The seven most commonly encountered reptiles and amphibians during TEM trips 2003.

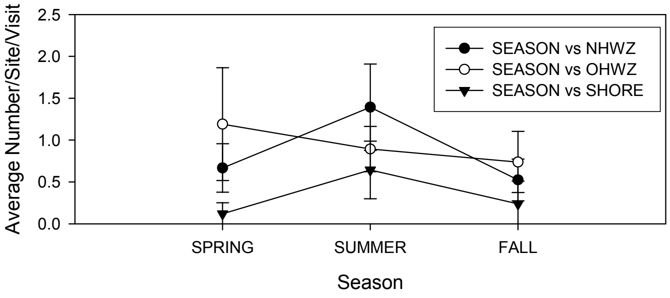
Side-blotched Lizard



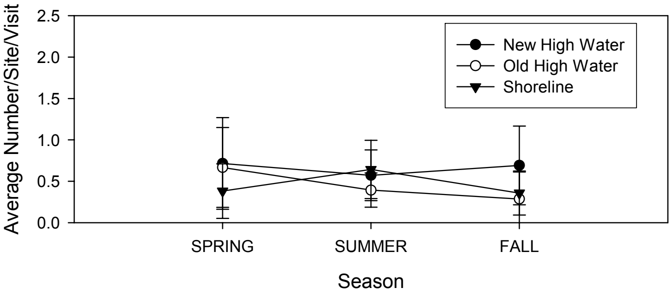
Western Whiptail Lizard

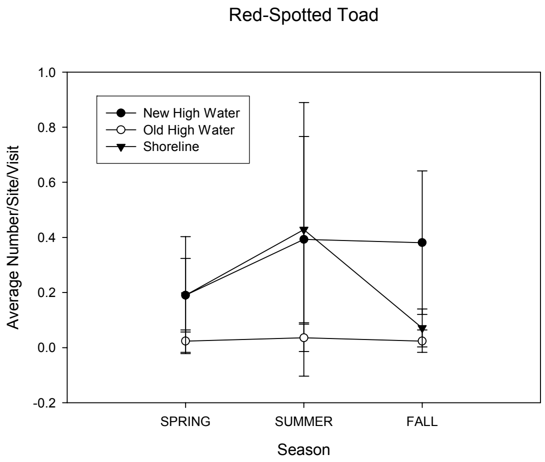


Spiny Lizard

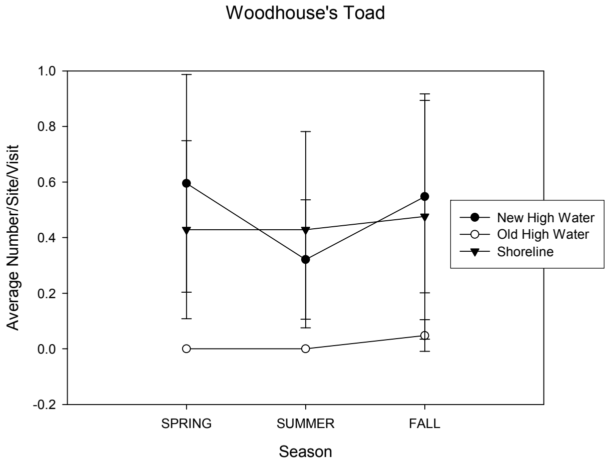


Tree Lizard

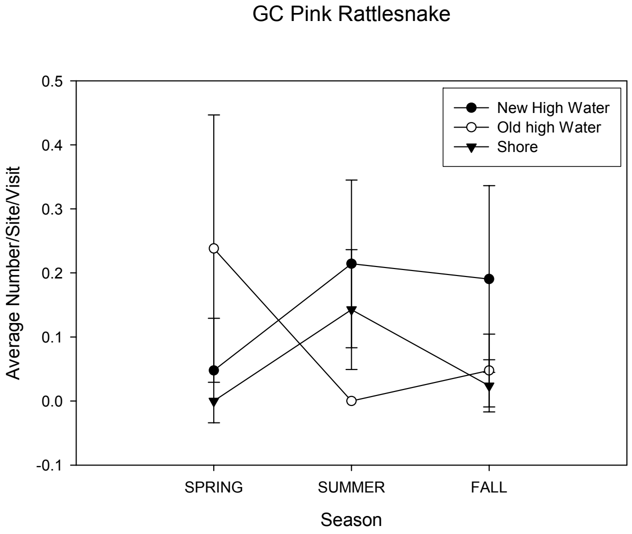




Red-Spotted Toad



Woodhouse's Toad



GC Pink Rattlesnake

Figure Hrp-4. The seven most commonly encountered reptiles and amphibians in each of the three hydrologic zones, pooled data for 2001-2003

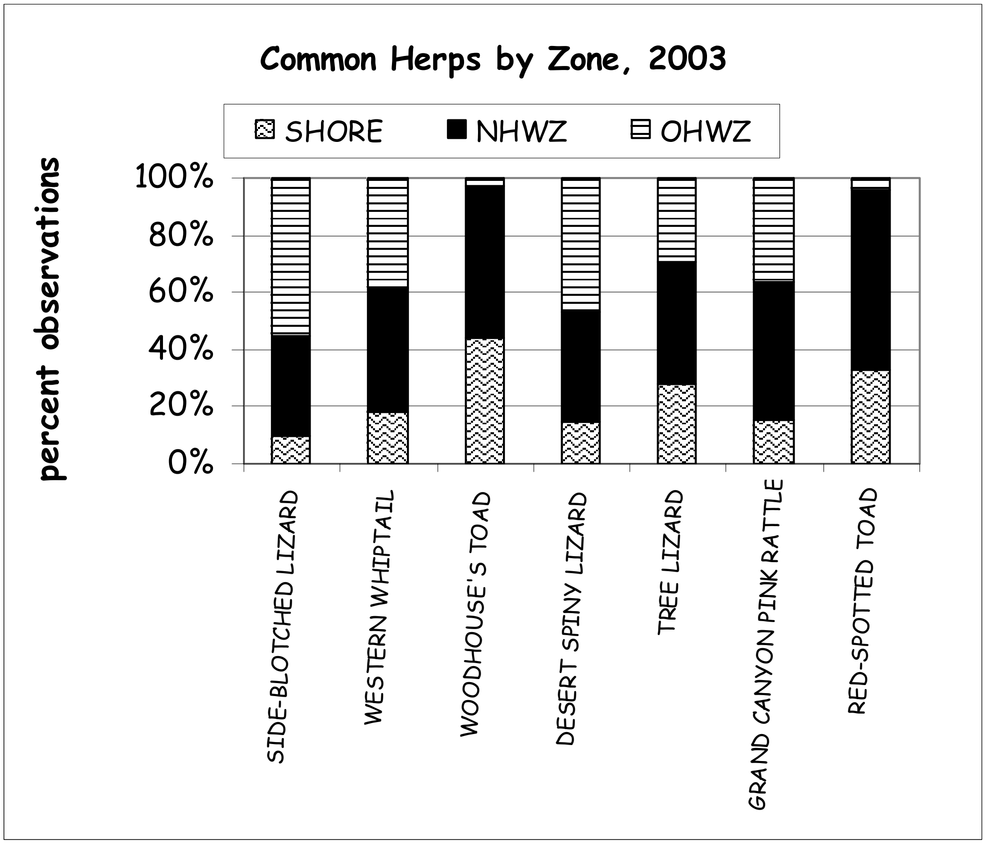


Figure Hrp-5. Percentage of observations of the seven most commonly encountered reptiles and amphibians in each of the three hydrologic zones, 2003**.**

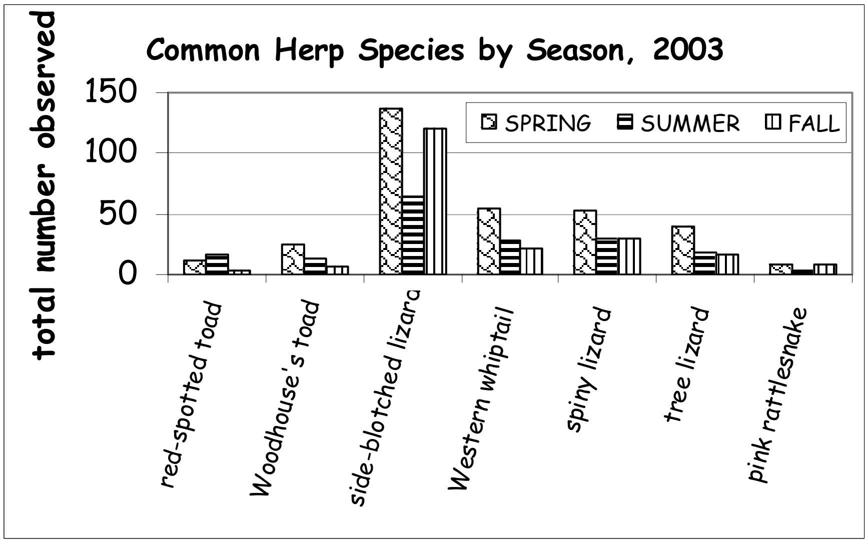


Figure Hrp- 6. The seven most common reptiles and amphibians observed, by season, on Grand Canyon TEM trips during 2003.

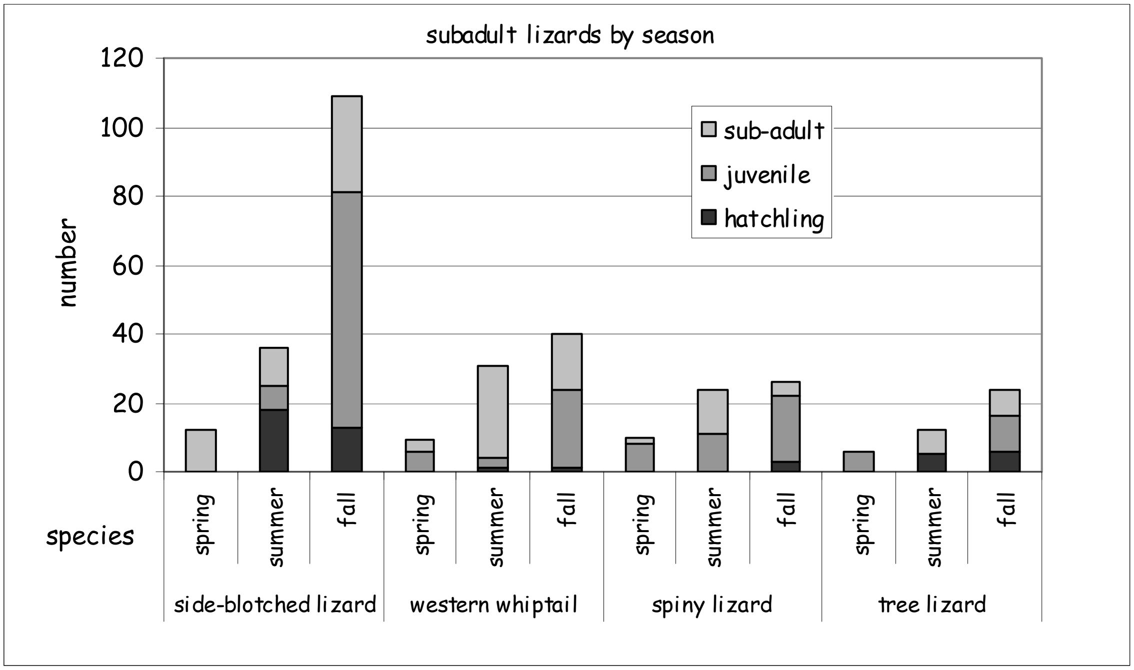


Figure Hrp-7. Sub-adult, juvenile, and hatchling lizards, by season, on Grand Canyon TEM trips during 2003.

Mammals

Jennifer K. Frey
New Mexico State University

Purpose

The purpose of the mammal study was to inventory and monitor mammal communities in three different hydrologic riparian zone habitats along the Colorado River in the Grand Canyon. The mammal studies focused on small terrestrial mammals. Potential small terrestrial mammals in the Colorado River corridor include most species of rodents (i.e., except beaver, muskrat, and porcupine) and shrews from the southwestern United States. These species can be systematically and consistently sampled using the same methodological techniques. Given that nearly half (48%) of all mammal species known from the Grand Canyon region are rodents (Appendix G), a focus on small mammals represents the majority of mammal diversity and density in the region. Second, small terrestrial mammals provide important ecosystem functions, such as prey for other vertebrates, nutrient cycling, and plant seed dispersal and germination. Further, individual species often are specialists that can be used as sensitive indicators of specific habitat features. Thus, small mammals are an ideal focal group for monitoring studies of ecosystem health and functioning.

Objectives

1) Inventory mammal resources in the riparian zone of the Colorado River in the Grand Canyon.

2) Develop, initiate, and assess the efficacy of a standardized monitoring methodology for small mammals in three different hydrologic riparian zones.

3) Monitor and assess spatial trends in small mammal communities, especially in relation to the different hydrologic riparian zones.

4) Monitor and assess temporal trends in small mammal communities, especially in relation to river flow dynamics.

Methods

Sample periods and study sites. Small mammals were sampled at 14 locations once during spring and once during fall each year. With the exception of spring 2002 and 2003, each sampling period consisted of a single trip down the river starting at Lees Ferry and ending at Diamond Creek (Table Mam-1). During spring 2002 and 2003, sampling was separated into two periods. The lower canyon (i.e., below Phantom Ranch) was sampled first while the upper canyon (above Phantom Ranch) was sampled about 2 weeks later. This provided a control for differential vegetation green-up associated with elevation changes along the river corridor. A supplemental sampling period occurred during summer 2003 in order to increase opportunity for documenting rare species.

A total of 31 sites in 10 geological reaches were sampled during the 3-year study (Table Mam-2; see General Project Methods section for details on site selection). Of these sites, 16 were on the left shore and 15 were on the right shore. Five were sampled each year to serve as a temporal control. These sites were Above Saddle (46.7 R [i.e., mile 46.7 right shore]), Across Lava Chuar (65.3 L), 92.3 L, Forster (122.8

L), and above Parashant (198.0 R). In addition, a site just below National Canyon (166.5 L) was sampled in both 2001 and 2003.

Small terrestrial mammal field sampling. Small mammals were sampled with standard (3 x 3.5 x 9 inch) aluminum folding Sherman® live-traps. Although some other traps can more efficiently capture certain species (e.g., Slade et al. 1993, O'Farrell et al. 1994, Woodman et al. 1996), standard folding aluminum Sherman traps were selected for this study because they allow for animals to be released unharmed and they are relatively lightweight, portable, and inexpensive. Traps were baited with an oatmeal and peanut butter mixture. Precautions were taken to avoid spilling bait on the ground and all spilled bait was removed. Traps were placed in 3 parallel 100 m transects of 50 traps set at 2 m increments. One transect was located within each of the three hydrologic riparian zone (i.e., shoreline zone, new high water, old high water) and was situated 4 m upslope from the corresponding arthropod transect. Traps were set in the evening and removed the following morning. Captured animals were identified based on external characteristics, measured (i.e., tail length, hind-foot length, ear length), and sex and reproductive status were determined. After data collection animals were released at the capture site.

Trapping effort at each site during a trip was 150 trap-nights (trap-nights = number of traps x number of nights), which totaled 750 trap-nights per hydrologic riparian zone per trip and 2,100 trap-nights per season. There were a total of 14,700 trap-nights during the study (Table Mam-1). To put this level of effort into perspective, Jones et al. (1996) recommend 500 trap-nights for preliminary inventory of a habitat type. Thus, the sampling effort in this study was high. Although such standardized transects are not optimal for inventory purposes, standardized arrays are desired for monitoring purposes because they provide for consistency and replication and they allow for estimates of relative abundance (Conroy 1996, Jones et al. 1996).

Voucher specimens. Representatives of each species captured in Sherman traps were prepared as museum voucher specimens. Voucher specimens physically and permanently document data by providing confirmation of species identification and assuring that the study can be accurately repeated, reviewed, and reassessed (Yates 1985). They are considered the only reliable means of corroborating the provenance of data accumulated during a study and documented in reports of a study (Reynolds et al. 1996:63). Per park requirements, the number of mammals that could be collected for voucher specimens was severely restricted. Specimens were either trap mortalities or euthanized with chloroform. Specimens were preserved either as an intact body preserved in alcohol or the skull was removed and dried and the remainder of the body was preserved in alcohol (see method in Yates et al. 1996). Tissue samples from each voucher specimen and embryos from each pregnant female voucher specimen were preserved in alcohol.

Medium and large mammal field sampling. Medium and large mammals were sampled through observation of individuals or their sign. Observations were recorded while traveling down the river as well as at sample sites. For each observation, the species, number of individuals, date, location, and other notes were recorded. Special attention was directed at monitoring beaver activity because little is known regarding their distribution and function in the Colorado River (Ruffner 1983).

Literature review. A review of literature was conducted in order to compile records of mammals from the Grand Canyon region. This included species limited to the Colorado River corridor, as well as species that occur primarily on the north and south rims. Records were compiled by source, river side, ecosystem, basis for inclusion, and status. This summary compilation provides a comprehensive review of the mammals of the Grand Canyon region.

Statistical Analyses

Refer to the COMMON METHODS section of this report for a description of methods for determining patch area, river flow, and precipitation variables. Variable 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 most statistical analysis due to nature of the sampling methodology and for most species small sample sizes. T-tests were used to test for differences in numbers of observations of some ungulates on either side of the river. Statistical analyses and comparisons excluded the summer 2003 sample periods.

Results

Small terrestrial mammals captured. A total of 29 species of mammals were documented during the study (see Appendix G). This included 9 small mammal species that were captured on monitoring transects (Figure Mam-1). There was a total of 1,412 captures of small mammals on the monitoring transects for an overall trap success of 11.2 %.

The cactus mouse (*Peromyscus eremicus*) was the most common small mammal. It was more common than all other small mammal species combined, making up 53.5 % of captures (Figure Mam-1). Not only was it the most abundant small mammal (6.0/100 trap-nights), it also was the most widely distributed (Figure Mam-2). It was captured on both sides of the river including 29 of the 31 locations. The next most common and widely distributed small mammals were the desert woodrat (*Neotoma lepida*; 1.4/100 trap-nights), canyon mouse (*Peromyscus crinitus*; 1.3/100 trap -nights), and brush mouse (*Peromyscus boylii*; 1.3/100 trap-nights; Figure Mam-1). While each of these species accounted for approximately 12 % of the captures, they varied in distribution ranging from 74.1 to 41.9 % of the sites, respectively (Figure Mam-2).

The remaining 5 species were captured on only one side of the river. The rock pocket mouse (*Chaetodipus intermedius*) and white-throated woodrat (*Neotoma albigula*) occurred on the left (south) side of the river. When this restricted distribution is considered, the relative abundance of rock pocket mice (1.2/100 trap-nights on left shore) was nearly equivalent to that of the desert woodrat, canyon mouse, and brush mouse. Further, the rock pocket mouse was captured at 81.2% of the sites on the left shore. In contrast, the white-throated woodrat was considerably less common (0.4/100 trap-nights on left shore) and had a more restricted distribution (30.8 % of the sites on left shore). The long-tailed pocket mouse (*Perognathus formosus*) was restricted to the right (right) side of the river. However, relative to the rock pocket mouse on the left side, it was considerably less abundant (0.6/100 trap-nights on right shore) and was only captured at 26.7 % of the sites on right shore.

The harvest mouse (*Reithrodontomys megalotis*) has a potential distribution that encompasses the entire riparian zone on either side of the Colorado River in Grand Canyon. However, this species was extremely rare (0.02/100 trap-nights) and was only captured at two sites (Above Saddle 46.7 R, Spring Canyon 204.5 R). This species' occurrence is tightly linked to the availability of tall, dense herbaceous vegetation. In the Grand Canyon, this habitat only occurs in highly fragmented patches within the shoreline zone and, to a lesser extent, the new high water riparian zones. Thus, the distribution and abundance of the western harvest mouse is probably highly influenced by dam operations.

The Ord's kangaroo rat (*Dipodomys ordii*) was the least common species encountered during this study. A single individual was captured at Lees Ferry (-0.4 R). This species is known from non-forested habitats on the rim of the Grand Canyon, exclusive of the region west of Prospect Valley (Hoffmeister 1986). As of yet, Lees Ferry is the only known location where this species is known to occur within the Grand Canyon

Influence of hydrologic zone on small mammal richness and abundance. Small mammal richness and abundance were highest in the old (highest) water zone and lowest in the water (i.e., shoreline zone) zone (Figure Mam-3). The old high water zone often was associated with the steeper sides of the canyons that afford more structure for small mammals. In addition, two uncommon species (*Perognathus formosus*, *Dipodomys ordii*) were only captured in this zone. With the exception of *Reithrodontomys megalotis*, which was not caught in the old high water zone, each of the other small mammal species was captured in all three zones.

Temporal, spatial, and environmental variation in small mammal abundance. Abundance of small mammals differed significantly by year (ANOVA: $F_{(2, 410)} = 3.792$; $p = 0.023$; Figure Mam-3). 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 small mammal abundances were relatively constant (Figure Mam-3 and were not significantly different across years (ANOVA: $F_{(2, 157)} = 1.714$, $p = 0.184$). In contrast, fall relative abundances across the three years were significantly different (ANOVA: $F_{(2, 250)} = 4.565$; $p = 0.011$) and all were higher than the preceding spring (Figure Mam-3).

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 ($F_{(2, 60)} = 19.398$, $p = 0.000$), season ($F_{(1, 30)} = 58.240$, $p = 0.000$), and site ($F_{(30,24)} = 2.5465$, $p = 0.011$). Further, although year was not a significant influence on abundance ($F_{(2, 9)} = 0.244$, $p = 0.788$), there was a significant interaction between year and season ($F_{(2, 8)} = 9.016$, $p = 0.009$) as well as between zone and season ($F_{(2, 61)} = 9.933$, $p = 0.000$). Consequently, an ANOVA was calculated for each season separately. During spring, only water zone exhibited a significant influence on small mammal abundance ($F_{(2, 61)}$ = 6.234, p = 0.003). However, during fall zone ($F_{(2, 61)}$ = 23.183, p = 0.000), year ($F_{(2, 9)}$ = 5.943, p = 0.023), and site ($F_{(20, 10)}$ = 8.405, p = 0.001) were significant influences on small mammal abundance.

Based on simple Spearman correlations, small mammal abundance exhibited a significant positive correlation with patch area (r_s = 0.209, p = 0.001), minimum river flow ($r_{s\,=}$ 0.261, p = 0.000), mean river flow ($r_{s\,=}$ 0.207, p = 0.001) and a significant negative correlation with percent cliff at shoreline ($r_{s\,=}$ -0.174, p = 0.006) and precipitation deviation ($r_{s\,=}$ -0.223, p = 0.000). However, due to the nature of the data (e.g., multiple y for any given x) 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). Finally, small mammal abundance was significantly greater in wide versus narrow reaches (one-way ANOVA: $F_{(1, 247)}$ = 9.010, p = 0.003).

Stepwise multiple regressions were used to determine 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 ($F_{(1, 39)}$ = 6.047, p = 0.018; Figure Mam-4) and patch area in the new high water zone ($F_{(1, 39)}$ = 8.621, p = 0.006; Figure Mam-5). 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 (shore zone: $F_{(1, 40)}$ = 5.955, p = 0.019; new high water: $F_{(1, 40)}$ = 7.219, p = 0.010; old high water: $F_{(1, 40)}$ = 7.693, p = 0.008; Figure Mam-6).

Temporal, spatial, and environmental variation in small mammal richness. Overall richness of small mammals was low and relatively constant. Overall richness was 7 in 2001, 8 in 2002, and 8 in 2003. All species were captured each season with the following exceptions. The white-throated woodrat was not captured during spring or fall 2002. This species was captured at two sites in 2003 (65.3L and 71.3L). Neither of these sites was 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 accounted for the absence of white-throated woodrat during 2002. The western harvest mouse was captured during spring and fall 2002 and fall 2003. Ord's kangaroo rat was only captured in spring 2002 at Lees Ferry (-0.4 R); this site was not sampled during 2001 or 2003.

Small mammal abundance and richness were highly correlated (Spearman correlation: r_s = 0.824, p = 0.000). Thus, it is not surprising that significant factors related to species richness were similar to those related to abundance (Figure Mam-3). 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 ($F_{(2, 60)}$ = 16.849, p = 0.000), season ($F_{(1, 30)}$ = 60.766, p = 0.000), and site ($F_{(30, 24)}$ = 2.308, p = 0.015). Further, although year was not a significant influence on richness ($F_{(2, 9)}$ = 1.721, p = 0.233) there was a significant interaction between year and season ($F_{(2, 8)}$ = 6.730, p = 0.019). Consequently, ANOVA was run for each season separately. During spring, water zone ($F_{(2, 60)}$ = 8.361, p = 0.001), as well as site ($F_{(30, 15)}$ = 2.600, p = 0.025), exhibited a significant influence on small mammal richness. However, during fall, water zone ($F_{(2, 62)}$ = 15.641, p = 0.000) and year ($F_{(2, 9)}$ = 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. These included a significant positive relationship with patch area (r_s = 0.251, p = 0.000), minimum river flow ($r_{s\,=}$ 0.192, p = 0.002), and mean river flow ($r_{s\,=}$ 0.142, p = 0.025), and a significant negative relationship with percent cliff at shoreline ($r_{s\,=}$ -0.203, p = 0.001) 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: $F_{(1, 247)}$ = 4.989, p = 0.026).

Stepwise multiple regressions were used to determine 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 ($F_{(1, 39)}$ = 6.389, p = 0.016; Figure Mam-7) and patch area in the new high water zone ($F_{(1, 39)}$ = 14.205, p = 0.001; Figure Mam-8). 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 ($F_{(1, 40)}$ = 7.450, p = 0.009; Figure Mam-9), patch area in the new high water zone ($F_{(1, 40)}$ = 7.031, p = 0.011; Figure Mam-10), and total catchment area in the old high water zone (Figure Mam-11). The relationship between total catchment area and species richness in the old high water zone was largely driven by site 198.0R. This site was unusual in that it had an extremely large total catchment area but a small local catchment area (Figure Mam-12).

Mammals observed. Of the 29 species of mammals documented during this study 20 were identified through observation (Appendix G). The most frequently observed species was the American beaver (*Castor canadensis*; 333 observations). Most observations of beaver were of the distinctive sign it makes (e.g., burrows, slides, cut limbs), which were readily observable from boats. The species was distributed throughout the canyon (Figure Mam-13). However, frequencies of observation varied widely by river reach. Evidence of beaver was most common in wide reaches such as Lower Marble and Lower Canyon, while evidence of beaver was uncommon to absent in narrow reaches such as Supai, Redwall, Upper Granite, and Muav. Wide river reaches provide earth banks needed for burrowing and woody riparian vegetation, which is used for food. Many narrow reaches provide neither burrow sites nor food resources.

With 314 observations, bighorn sheep (*Ovis canadensis*) were the second most commonly observed mammal. Evidence of this species was observed throughout the canyon. Observation instances were approximately equivalent on either the right (77 instances) or left (74 instances) side of the river (Figures Mam-14 and Mam-15). However, a t-test indicated that the number of individuals or types of sign observed was significantly higher on the right side of the river (x = 2.36, SD = 1.93) as compared to the left side of the river (x = 1.76, SD = 1.45; $t_{(141)} = -2.188$, p = 0.030). Groups often consisted of several females and lambs. The largest group observed consisted of 8 mature females, 2 young females, and 2 lambs. Spatial variation in the frequency of observations of bighorn sheep was evident (Figures Mam-14, Mam-15). Frequency of observation did not appear to be related to reach type. However, the distribution of observations did suggest that bighorn sheep abundance might be lower in areas with higher human disturbance. For example, bighorn sheep observations were rare or absent in the vicinities of Lees Ferry, Navajo Bridge, Little Colorado River, Phantom Ranch, Toroweap Road, and Diamond Creek.

The third most commonly observed mammal was the mule deer (*Odocoileus hemionus*; 60 observations). Mule deer were observed throughout the river corridor, although the frequency of observations varied dramatically by reach (Figure Mam-16). Observations of mule deer were more common in wide reaches such as Lower Canyon and were particularly abundant in the upper portion of the river in the Lower Marble and Furnace Flats reaches. An exception was that no mule deer were observed in the Permian Reach near Lees Ferry and Navajo Bridge. The paucity of mule deer observation in these areas may be due to greater human disturbance. Mule deer observations were rare to absent in narrow reaches such as Supai, Redwall, and Upper Granite. Mule deer were more often observed on the right side of the river (26 observations) as compared to the left (18 observations). However, the number of individuals or types of sign observed was not significantly different on either side ($t_{(42)} = -0.086$, $p > 0.05$; left: x = 1.33, SD = 0.49; right: x = 1.35, SD = 0.49). Mule deer were usually seen as single animals or pairs of animals. Unlike bighorn sheep, they were never observed in herds.

Coyotes (*Canis latrans*) were the most frequently observed carnivore (Figure Mam-17). Other carnivores observed (from most to least frequently observed) included ringtail (*Bassariscus astutus*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), mountain lion (*Felis concolor*), raccoon (*Procyon lotor*), and spotted skunk (*Spilogale gracilis*). In addition, tracks and other signs of a small fox were observed at several locations; these were tentatively identified as kit fox (*Vulpes macrotis*). However, Hoffmeister (1986) did not include the Grand Canyon as within the range of this species in Arizona. The occurrence of kit fox in the canyon should be verified with physical evidence.

Two species of rodents were observed, but not captured. The rock squirrel (*Spermophilus variegatus*) was commonly observed on both sides of the river throughout the canyon (Figure Mam-17). The white-tailed antelope squirrel (*Ammospermophilus leucurus*) was only observed at 5 locations including –0.4 R, 36.0 L, 174.3 R, 174.5 R, and 202.0 R. Hoffmeister (1986) depicted a broader distribution on both sides of the river.

Two leporids, the black-tailed jackrabbit (*Lepus californicus*) and a cottontail (*Sylvilagus* sp.) were observed at Lees Ferry. The cottontail was probably a desert cottontail (*S. audubonii*). However, it possibly was a mountain cottontail (*S. nuttallii*), which has been reported from near Page (Hoffmeister 1986). Specimens are needed to confirm the identity of these rabbits.

A single white goat was observed at 9.2 L in the new high water zone feeding on salt cedar. This location is just below 8.0 L Creek on the Navajo Reservation and the goat was likely a stray from a domesticated herd.

Several species of bats were documented during this study. These included 2 western pipistrelle (*Pipistrellus hesperus*) that were found floating in the river at 93.2 and 122.8. A dead pallid bat (*Antrozous pallidus*) was observed at 46.5 R. Bats identified as California myotis (*Myotis californicus*) were observed at 46.7 R and 190 L. Finally, distinctive calls of 2 species were heard. The most commonly heard call was that of the big free-tailed bat (*Nytinomops macrotis*), which were heard throughout the canyon. Calls of the spotted bat (*Euderma maculatum*) were heard at 4 locations between river miles 22 and 65.3.

Voucher specimens. A total of 28 individuals representing 10 species were preserved as museum voucher specimens (Appendix F). These included animals euthanized specifically for voucher material as well as salvaged dead animals. For example, the two western pipistrelles (*Pipistrellus hesperus*) that were found floating in the river were salvaged and prepared as specimens. A total of 29 embryos were preserved that were taken from pregnant female specimens.

Mammals of the Grand Canyon region. A compilation of records of mammal from the Grand Canyon region that were obtained from the literature review and field study is presented in Appendix G. A total of 93 species have been documented from the Grand Canyon region. This level of mammal diversity vastly exceeds that for many other regions, including entire states (Frey and Yates 1996). The mammals of the Grand Canyon region includes 5 non-native species, at least 3 that have been extirpated from the region, and 1 that is accidental. Of the 93 documented species, at least 47 (50.5%) have been reported from the Colorado River corridor. During this study, a total of 29 species were documented. This represents approximately 62% of the mammals that have been recorded from the river corridor. Most of the species known from the corridor that were not encountered during this study were either bats or species with restricted distributions near Lake Mead, which was not sampled.

Discussion

The small mammal monitoring protocol proved to be efficient, consistent, and provided adequate sample sizes for statistical analyses. Small mammal abundance and richness were strongly influenced by a number of river flow, habitat, and environmental factors. Small mammals can serve as sensitive and appropriate indicators for monitoring the influence of dam operations on the riparian ecosystem. Further, observational methods were able to provide information on distribution and abundance of some species such as beaver, bighorn sheep and mule deer. No new species of mammal were documented in the Grand Canyon riparian zone. However, at least one species, the deer mouse (*Peromyscus maniculatus*), which was previously regularly documented from the riparian zone (e.g., Ruffner and Tomoko 1976), was not encountered during this study.

Small mammal abundance was strongly influenced by season, water zone, and specific site characteristics. Spring small mammal abundance was low and consistent, while fall small mammal abundance was high and variable. Further, abundance was virtually always highest in the old high water zone and lowest in the water zone. During spring, water zone was the most important influence on abundance while during fall, year, site and zone were 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 influencing small mammal abundance included precipitation and river flow. Minimum river flow was a particularly important influence on small mammal abundance.

Like abundance, small mammal richness was strongly influenced by season, water zone, and specific site characteristics. Small mammal richness was higher when abundance was higher. This was probably due to the greater likelihood of sampling rare species such as the western harvest mouse during peaks in population. Water zone may be the most important factor determining species richness of small mammals. During spring, water zone and site were the most important influence on richness, while during fall water zone and year were important. Important site-specific characteristics that were important in determining spring richness were 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 also was a significant determinant of species richness, which probably relates to availability of different habitat types. Similar to patterns of small mammal abundance, both precipitation and river flow were important in determining species richness patterns. River flow level was most important in determining richness in the water zone.

As predicted, small mammal abundance and richness were most significantly influenced by river flow (especially minimum river flow and flow fluctuation), and hence dam operations, in the shore zone. The influence of river flow on small mammal abundance and richness differed by season. During this study, river flow variables (i.e., minimum flow, maximum flow, mean flow) averaged lower in spring and higher in fall. However, river flow fluctuation was much more variable in spring. This was especially evident during spring 2003 when there were extremes for both minimum and maximum river flow. During spring in the shore zone, small mammal abundance was higher during higher minimum river flows while small mammal richness declined with higher river fluctuation. This suggests that minimum river flows might be responsible for controlling spring carrying capacities in the shore zone, but that dramatic spring river fluctuations may eliminate species from the shore zone (at least at certain sites). In contrast, during fall small mammal abundance and richness declined with higher minimum river flow. This effect of minimum flow on small mammal abundance in fall also extended into the new high water and old high water zones. This indicates that the influence of river flow on small mammal abundance extends beyond the zone where plants are immediately affected. However, the mechanism for this influence is not understood. Continued studies are warranted to more fully understand the mechanisms controlling mammal diversity in the riparian zone of the Grand Canyon. Refer to the RECOMMENDATIONS section of this report for more detailed discussions about problems with mammal sampling and recommendations for future monitoring studies.

Acknowledgements

I am especially thankful for the efforts of Andrew Hope who was a key member of the mammal crew on each of the trips. He not only provided excellent leadership, but he also insured consistency of methods and data collection from trip to trip. I would also like to thank other people who were members of the mammal crew including, Geoff Banzhof, Kelly Brosnan, Lisa Gelczis, Mitchel Hannon, John Kendall, Jason Malaney, and Heather Ristow.

Literature Cited

Baker, R. J., L. C. Bradley, R. D. Bradley, J. W. Dragoo, M. D. Engstrom, R. S. Hoffmann, C. A. Jones, F. Reid, D. W. Rice, and C. Jones. 2003. Revised checklist of North American mammals north of Mexico, 2003. Occasional Papers, Museum of Texas Tech University, 229:1-24.

Bailey, V. 1935. Mammals of the Grand Canyon region. Grand Canyon Natural History Association, Natural History Bulletin, 1:1-42.

Berger, J. 1977. Organizational systems and dominance in feral horses in the Grand Canyon. Behavioral Ecology and Sociobiology, 2:131-146.

Cockrum, E. L. 1960. The Recent mammals of Arizona: their taxonomy and distribution. University Arizona Press, Tucson, 276 pp.

Conroy, M. J. 1996. Techniques for estimating abundance and species richness: abundance indices. Pp. 179-193 in (Wilson, D. E., F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster, eds.). Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, 409 pp.

Drost, C. A., J. Petterson, and E. Leslie. 2000. Survey of bats along the Colorado River through Grand Canyon National Park. Unpublished report to Arizona Game and Fish Department, Phoenix.

Frey, J. K. and T. L. Yates. 1996. Mammalian diversity in New Mexico. New Mexico Journal of Science 36: 4-37.

Halloran, A. F. 1964. The mammals of Navajoland. Series 4. Navajoland Publications, Navaho Tribal Museum, Window Rock, Arizona, 23 pp.

Hoffmeister, D. F. 1971. Mammals of Grand Canyon. University of Illinois Press, Urbana, 183 pp.

Hoffmeister, D. F. 1986. Mammals of Arizona. University of Arizona Press and Arizona Game and Fish Department, Tucson, 602 pp.

Hoffmeister, D. F., and F. E. Durham. 1971. Mammals of the Arizona Strip including Grand Canyon National Monument. Museum of Northern Arizona, Technical Series, 11:1-44.

Jones, C. W. J. McShea, M. J. Conroy, and T. H. Kunz. 1996. Capturing mammals. Pp. 115-155 in (Wilson, D.E., F.R. Cole, J.D. Nichols, R. Rudran, and M.S. Foster, eds.). Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, 409 pp.

Kelson, K. R. 1951. Speciation in rodents of the Colorado River drainage. University of Utah Biological Series, 9:1-125.

O'Farrell, M. J., W. A. Clark, F. . Emmerson, S. M. Juarez. 1994. Use of mesh live trap for small mammals: are results from Sherman live traps deceptive? Journal of Mammalogy, 75:692-699.

Reynolds, R. P., R. I. Crombie, R. W. McDiarmid, and T. L. Yates. 1996. Keys to a successful project: voucher specimens. Pp 63-68 in (Wilson, D. E., F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster, eds.). Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, 409 pp.

Ruffner, G. A. 1983. Abundance and distribution of beaver and coyote willow in Grand Canyon, Arizona. Final Report. National Park Service, Resource Management Division, Grand Canyon National Park, Grand Canyon, AZ. 23 pp.

Ruffner, G. A., and D. S. Tomko. 1976. Mammals of the Colorado River. Pp. 61-107 *in* An ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona (submitted by S. W. Carothers, ed.). Colorado River Research Program, Grand Canyon National Park, Technical Report 10.

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

Slade, N. A., M. A. Eifler, N. M. Gruenhagen, Davelos. 1993. Differential effectiveness of standard and long Sherman live traps in capturing small mammals. Journal of Mammalogy, 74:156-161.

Stevens, L. 1983. The Colorado River in Grand Canyon: a comprehensive guide to its natural and human history. Red Lakes Books, Flagstaff, Arizona, 115 pp.

Suttkus, R. D., G. H. Clemmer, and C. Jones. 1978. Mammals of the riparian region of the Colorado River in the Grand Canyon area of Arizona. Tulane University Museum of Natural History, Occasional Papers, 2:1-23.

Wilson, D. E., F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster. 1996. Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, 409 pp.

Woodman, N., R. M. Timm, N. A. Slade, and J. Doonan. 1996. Comparison of traps and baits for censusing small mammals in neotropical lowlands. Journal of Mammalogy, 77:274-281.

Yates, T. L. 1985. The role of voucher specimens in mammal collections: characterization and funding responsibilities. Acta Zoologica Fennica 170:81-82

Yates, T. L., C. Jones, and J. A. Cook. 1996. Preservation of voucher specimens. Pp 265-273. in (Wilson, D.E., F.R. Cole, J.D. Nichols, R. Rudran, and M.S. Foster, eds.). Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, 409 pp.

Table Mam-1. Schedule of mammal sampling and effort as part of the integrated terrestrial ecosystem monitoring of the riparian zone along the Colorado River in Grand Canyon.

Year	Season	Dates	River Traveled	Sites	Trap-Nights
2001	Spring	30 Apr - 17 May	Lees Ferry to Diamond Creek	14	2,100
	Fall	27 Aug - 12 Sep	Lees Ferry to Diamond Creek	14	2,100
2002	Spring	5 Apr - 13 Apr	Phantom Ranch to Diamond Creek	8	1,200
	Spring	25 Apr - 1 May	Lees Ferry to Phantom Ranch	6	900
	Fall	28 Aug - 13 Sep	Lees Ferry to Diamond Creek	14	2,100
2003	Spring	9 Apr - 17 Apr	Phantom Ranch to Diamond Creek	8	1,200
	Spring	1 May - 7 May	Lees Ferry to Phantom Ranch	6	900
	Summer	26 Jun - 10 Jul	Lees Ferry to Diamond Creek	14	2,100
	Fall	21 Aug - 4 Sep	Lees Ferry to Diamond Creek	14	2,100
Total				31	14,700

Table Mam-2. Site descriptions and year surveyed for mammals as part of the integrated terrestrial ecosystem monitoring of the riparian zone along the Colorado River in Grand Canyon. Sites are indicated by river mile and right (R) or left (L) shore as heading downstream.

Site	Name	Reach Name[1]	Reach Type[1]	Year
-0.4 R	Lee's Ferry	Permian	wide	2002
8.0 L	Jackass	Permian	wide	2002
22.0 R	Wedding Cake	Supai	narrow	2002
23.0 L	23.0 L	Redwall	narrow	2003
37.3 L	Tatahatso	Lower Marble	wide	2002
40.8 R	Buck Farm	Lower Marble	wide	2003
43.1 L	Anasazi Bridge	Lower Marble	wide	2001
46.7 R	Above Saddle	Lower Marble	wide	2001, 2002, 2003
50.4 L	WWFL	Lower Marble	wide	2001
51.5 L	Not Nam	Lower Marble	wide	2003
65.3 L	Across Lava Chuar	Furnace Flats	wide	2001, 2002, 2003
71.3 L	Cardenas	Furnace Flats	wide	2003
74.4 R	Shinumo	Furnace Flats	wide	2001
92.3 L	Schist Fist	Upper Granite	narrow	2001, 2002, 2003
103.3 R	Not 104	Upper Granite	narrow	2003
122.8 L	Forster	Aisles	narrow	2001, 2002, 2003
133.0 L	Talking Heads	Middle Granite	narrow	2002
140.0 L	Below Fishtail	Muav	narrow	2003
164.5 R	Tuckup	Lower Canyon	wide	2002
166.5 L	Below National	Lower Canyon	wide	2001, 2003
171.1 R	Stairway	Lower Canyon	wide	2001
174.7 R	Cove	Lower Canyon	wide	2001
180.8 R	Cinderhotfa	Lower Canyon	wide	2003
186.5 L	Club 186	Lower Canyon	wide	2002
194.0 L	Walapai Acres	Lower Canyon	wide	2001
198.0 R	Preparashant	Lower Canyon	wide	2001, 2002, 2003
202.0 R	202 Canyon	Lower Canyon	wide	2001
202.5 R	Below 202	Lower Canyon	wide	2003
204.5 R	Spring Canyon	Lower Canyon	wide	2002
209.0 L	Granite Park	Lower Canyon	wide	2001
211.5 R	Fall Canyon	Lower Canyon	wide	2002

[1] Per Schmidt and Graf (1990).

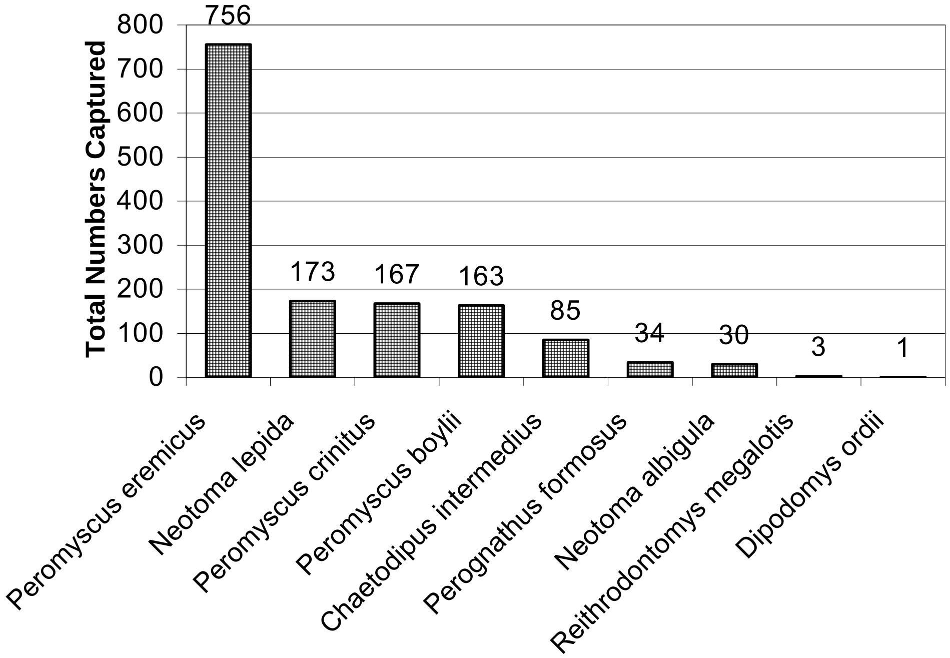


Figure Mam-1. Total number of small mammals captured from 2001 through 2003.

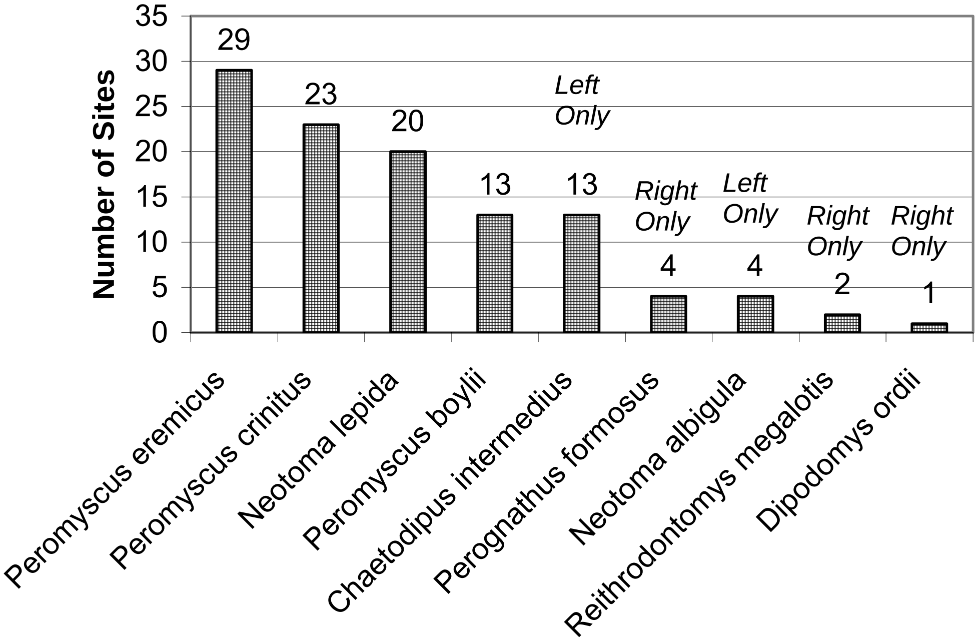
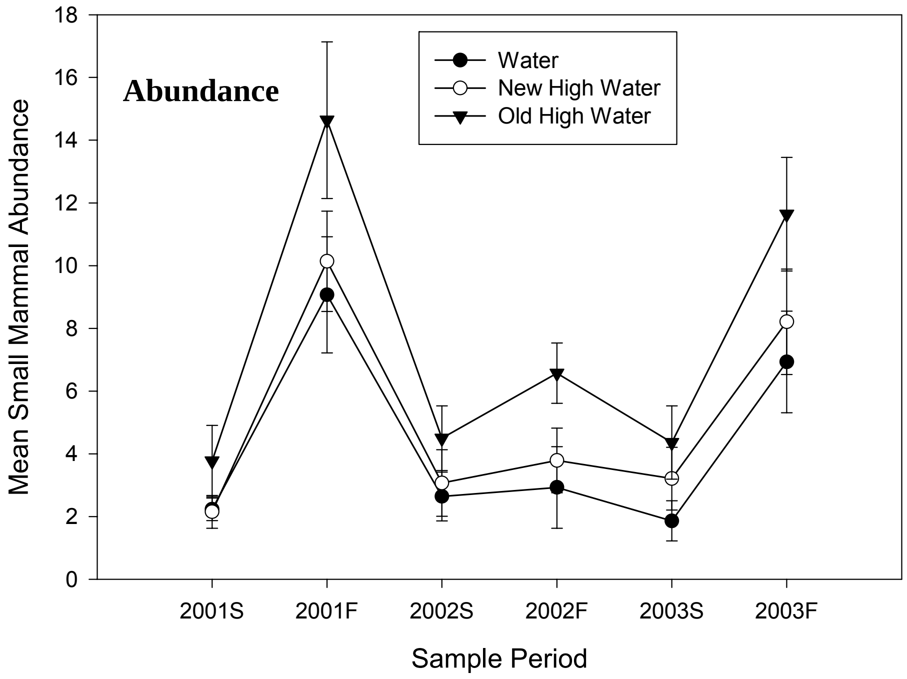


Figure Mam-2. Total number of sites (of 31 total) where each species of small mammal was captured from 2001 through 2003.



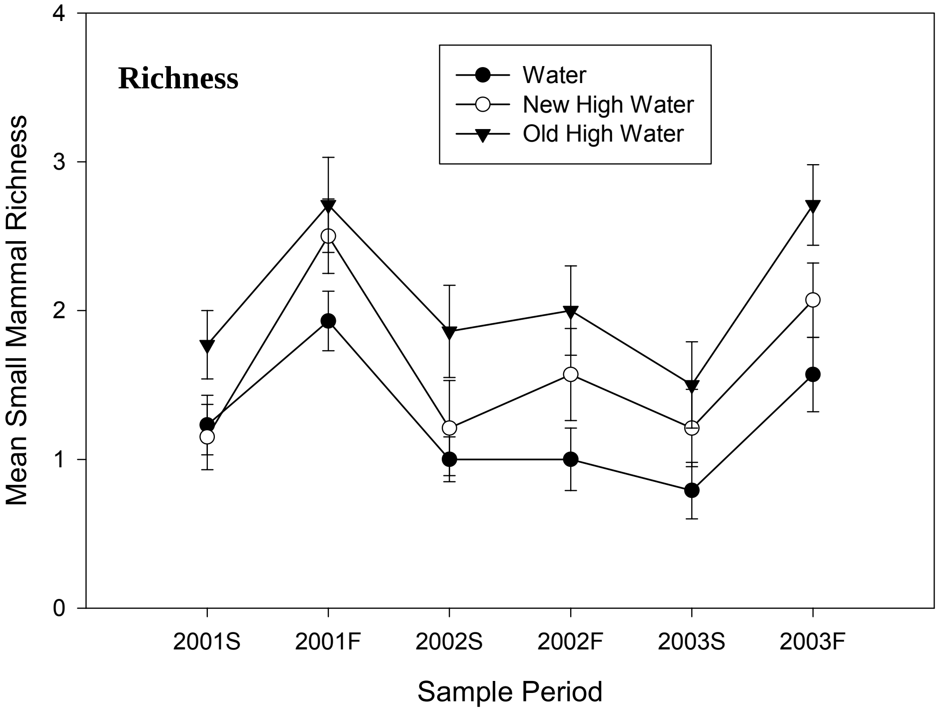


Figure Mam-3. Small mammal abundance (top) and richness (bottom) by water zone during each sampling period from 2001 through 2003**.**

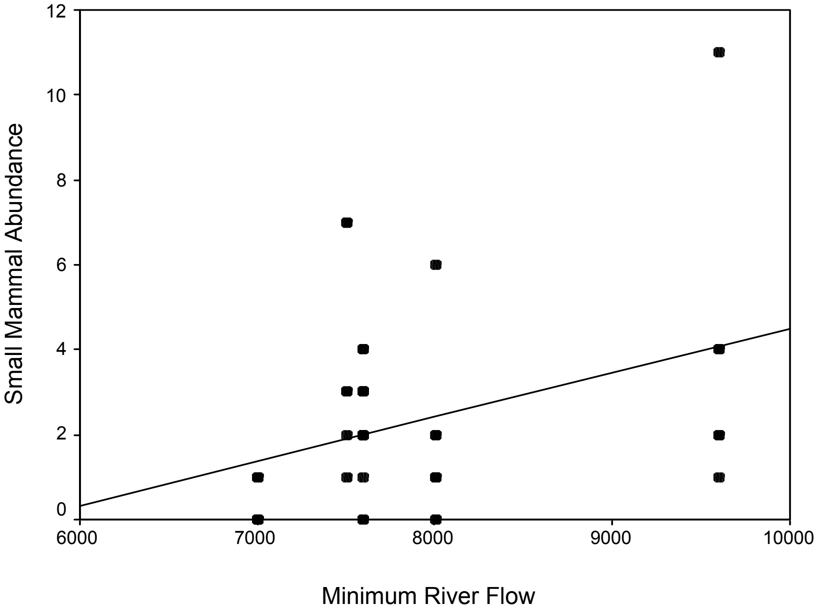


Figure Mam-4. Relationship between minimum river flow and small mammal abundance during spring in the shore zone.

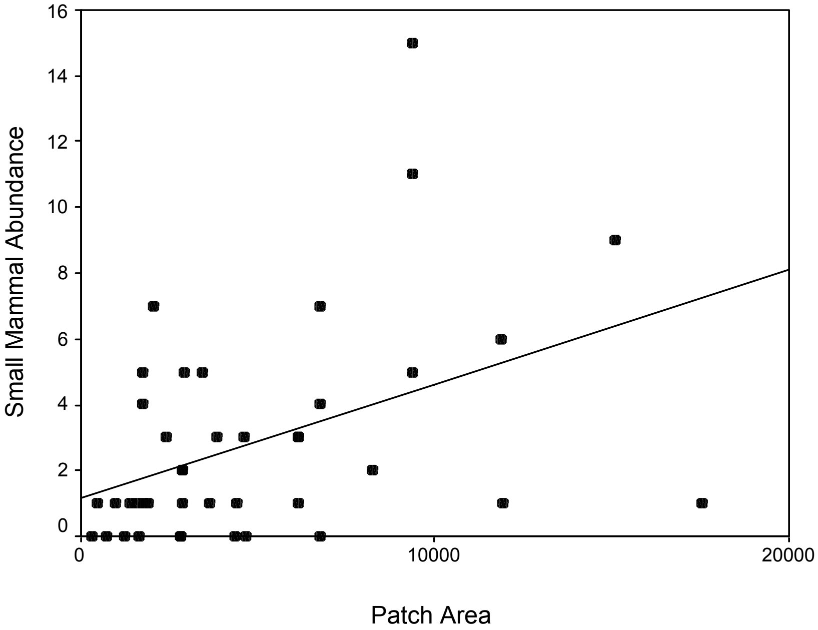


Figure Mam-5. Relationship between patch area, in square meters and small mammal abundance during spring in the new high water zone.

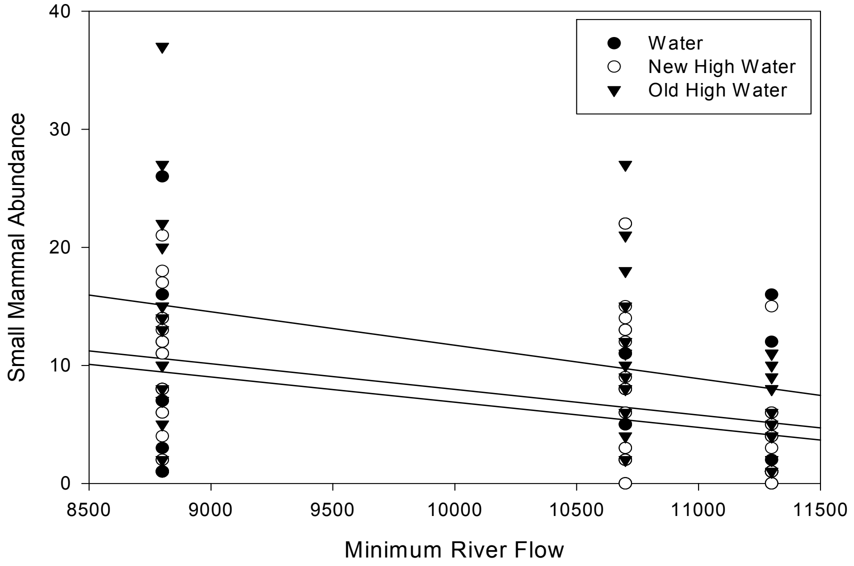


Figure Mam-6. Relationship between minimum river flow and small mammal abundance during fall in each water zone.

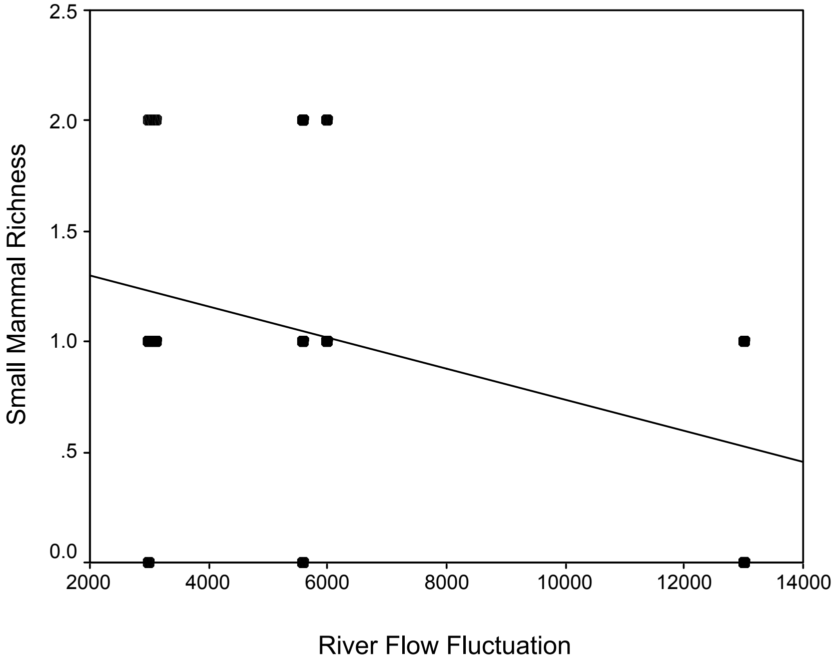


Figure Mam-7. Relationship between river flow fluctuation and small mammal richness during spring in the shore zone.

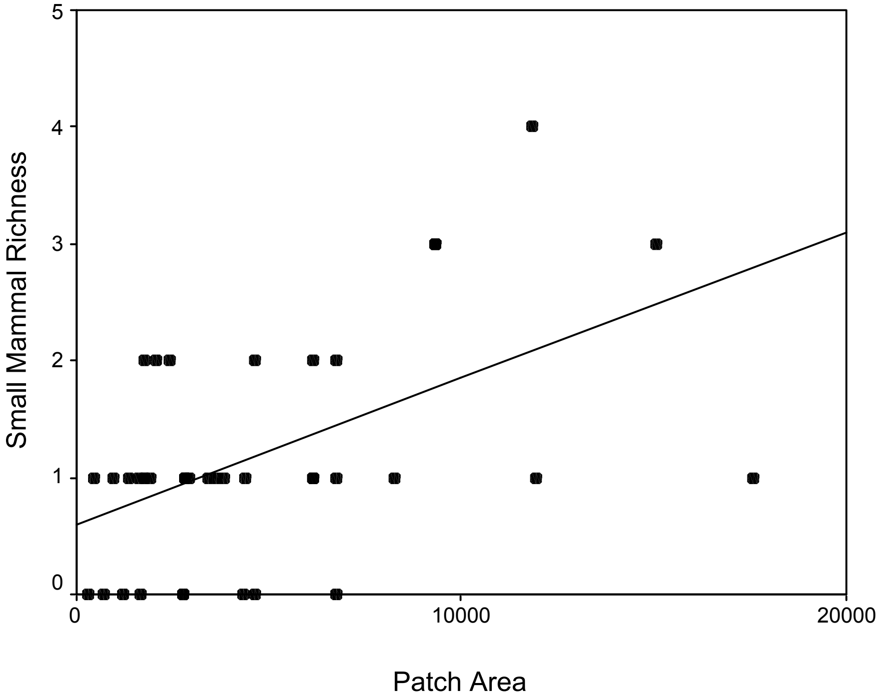


Figure Mam-8. Relationship between patch area and small mammal richness during spring in the new high water zone.

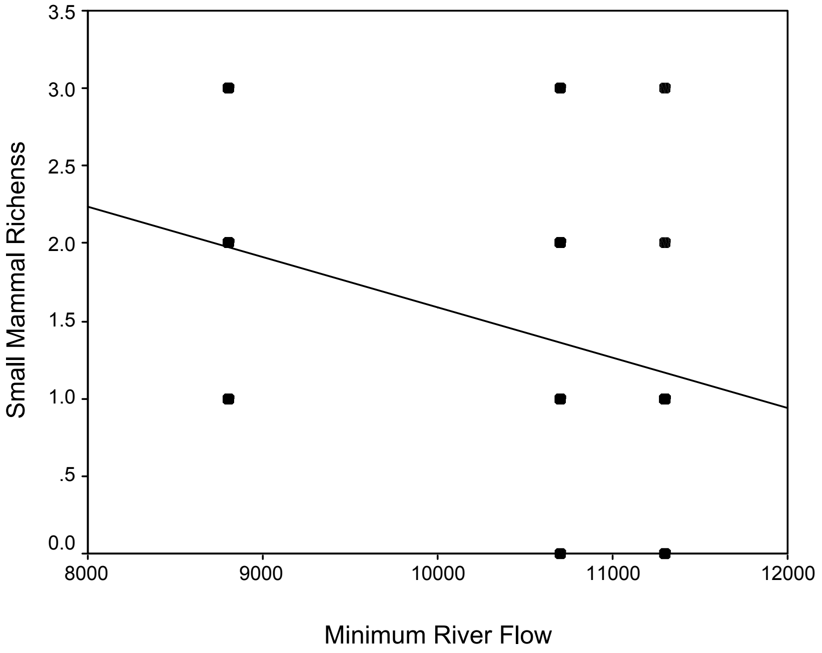


Figure Mam-9. Relationship between minimum river flow and small mammal richness during fall in the shore zone.

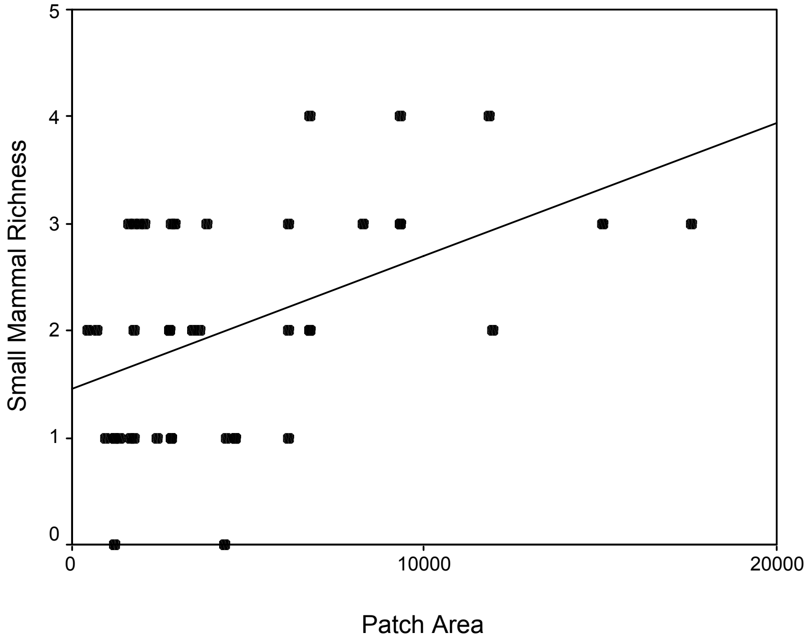


Figure Mam-10. Relationship between patch area and small mammal richness during fall in the new high water zone.

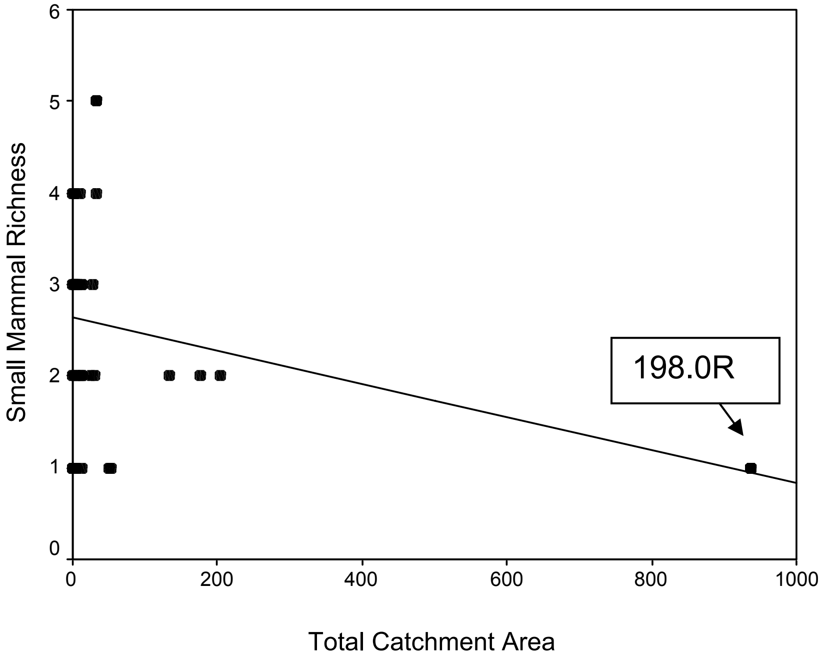


Figure Mam-11. Relationship between total catchment area and small mammal richness during fall in the old high water zone.

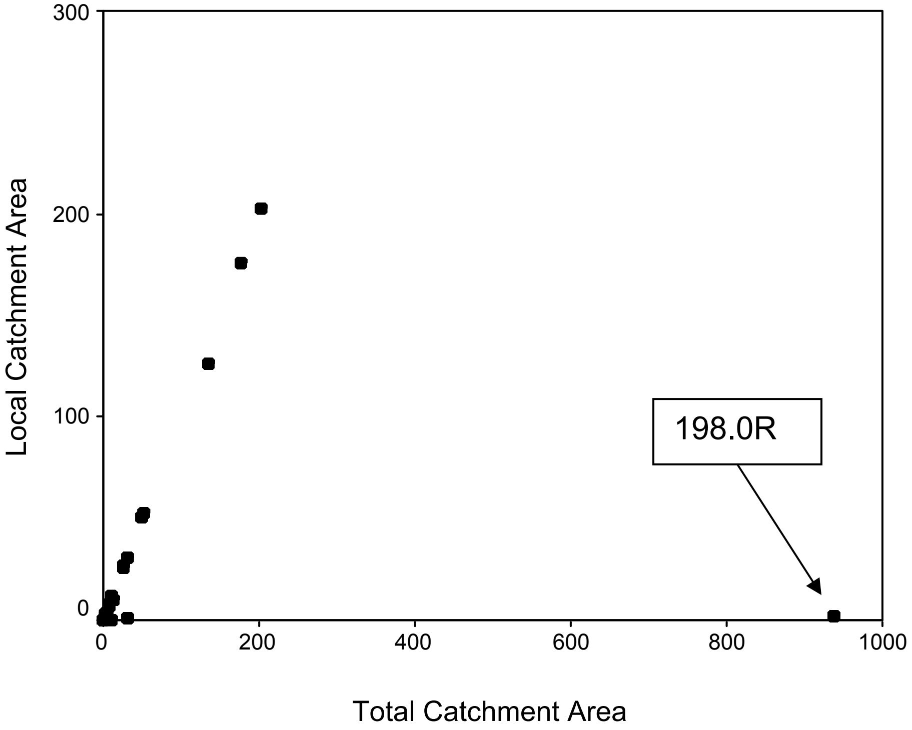


Figure Mam-12. Relationship between total catchment area and local catchment area (both in square km) illustrating the unusual catchment area of site 198.0 R.

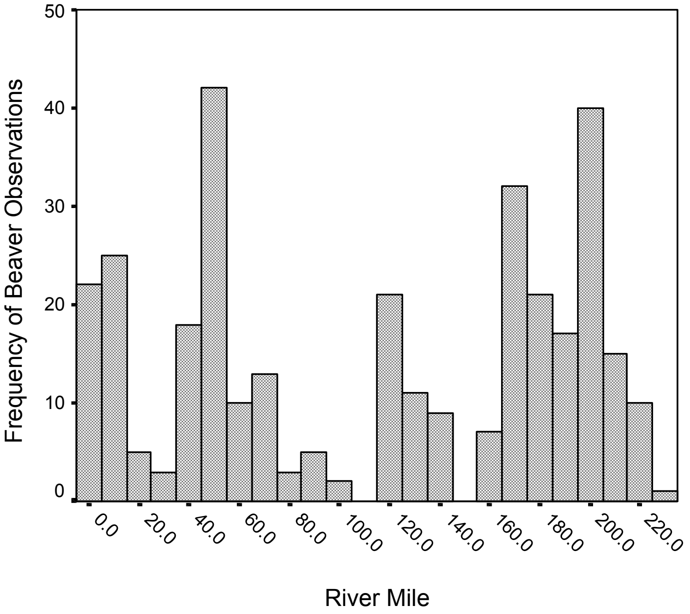


Figure Mam-13. Frequency of observation of American beaver (*Castor canadensis*) from 2001 through 2003 by river mile.

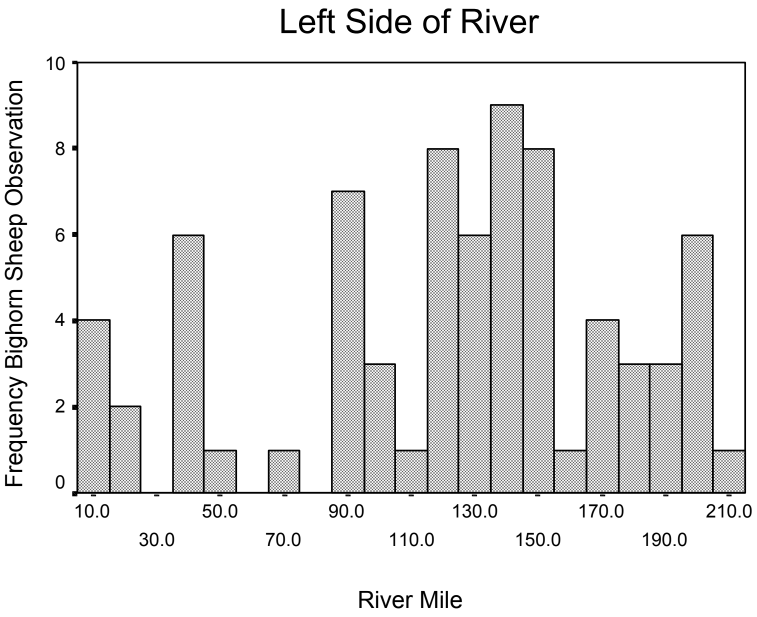


Figure Mam-14. Frequency of observation of bighorn sheep (*Ovis canadensis*) on left (south) side of the river from 2001 through 2003.

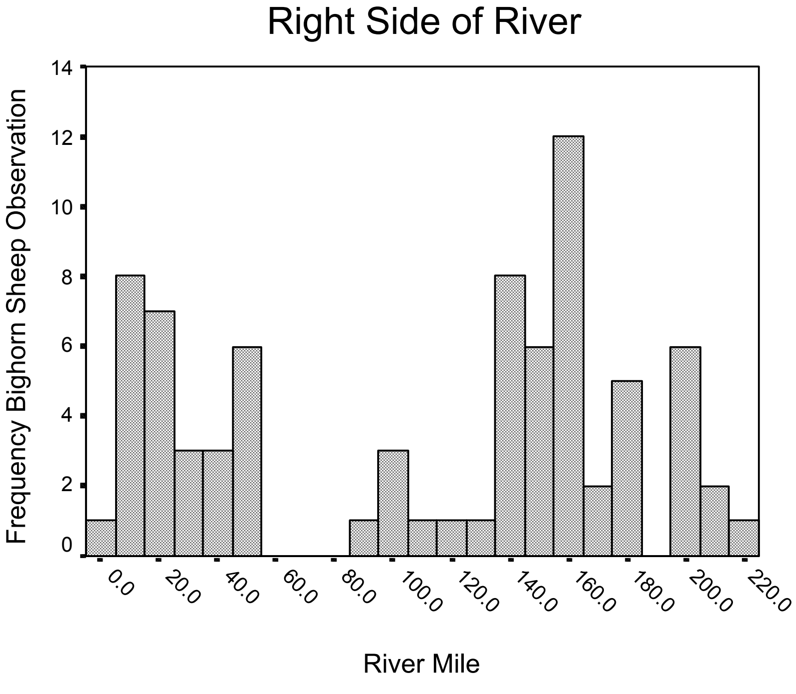


Figure Mam-15. Frequency of observation of bighorn sheep (*Ovis canadensis*) on right (north) side of the river from 2001 through 2003.

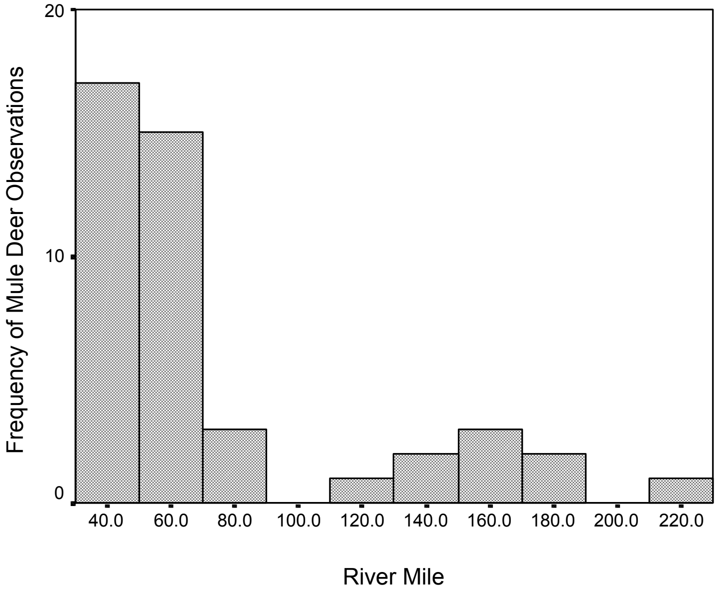


Figure Mam-16. Frequency of observation of mule deer (*Odocoileus hemionus*) by river mile from 2001 through 2003.

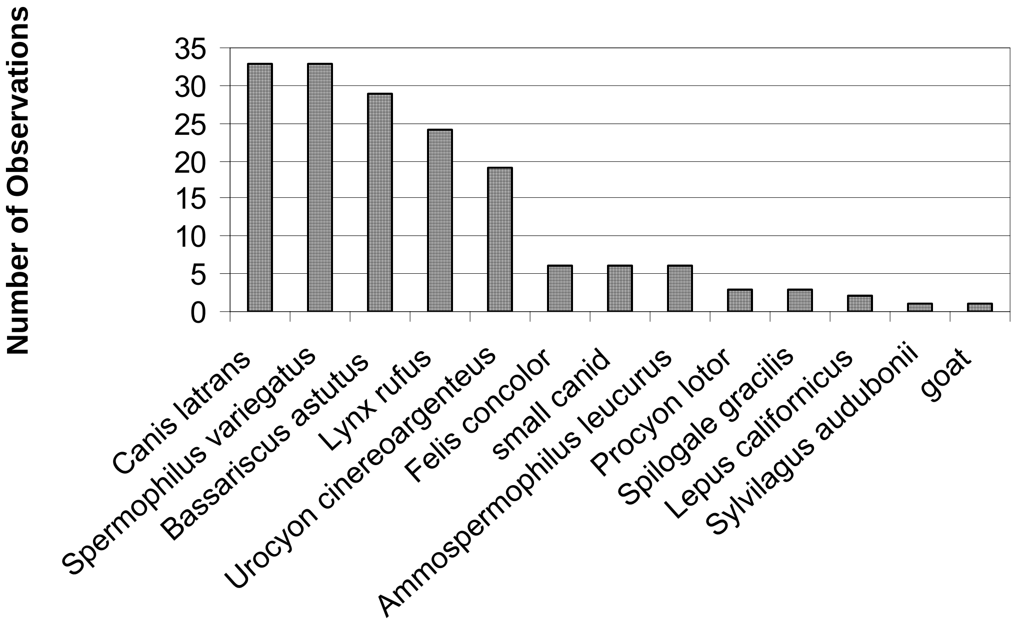


Figure Mam-17. Total number of observations of carnivores, ground squirrels, leporids, and goats from 2001 through 2003.

Integration and Interpretation of Vegetation and Faunal Abundance Patterns

Michael J.C. Kearsley[1] and
David C. Lightfoot[2]
[1]Northern Arizona University,
[2]University of New Mexico

Purpose

The work described in this section integrates information about vegetation, arthropods, herpetofauna, birds, and small mammals across the three hydrologic riparian zones of the integrated survey sites. This integration will allow us to better understand the interrelationships among species and habitats along the river corridor.

Objectives

1. To relate breeding bird abundance in old- and new high water zones to vegetation density and composition data.
2. To relate the abundance and taxonomic composition of arthropods to vegetation density in three hydrologic zones of the integrated survey sites.
3. To relate the abundance and species composition of breeding birds to the abundance of arthropods in vegetation patches of the new- and old high water zones of the integrated survey sites.
4. To relate the abundance of herpetofauna to vegetation density in three hydrologic zones of the integrated survey sites.
5. To relate the herpetofauna to the abundance of arthropods in three hydrologic zones in the integrated survey sites.
6. To relate small mammals to vegetation density in the three hydrologic zones of the integrated survey sites.
7. To relate small mammals, to the abundance of arthropods in the three hydrologic zones of the integrated survey sites.

Methods

The data for this section were collected for inventory and monitoring purposes as described in the previous sections. Site selection criteria have already been outlined in the Common Methods section. Here we are concerned with the relationships among plant and animal species represented in those data sets, so the methods described below relate only to how data were prepared and analyzed during the numerical examination of those relationships. The examination of the relationships between pairs of taxa is presented in the following sections.

Bird / vegetation relationships.

<u>Methods.</u> In order to better understand the ways in which breeding birds in terrestrial habitats are related to vegetation, we performed two sets of analyses. First, we ran correlations between total breeding bird densities and total vegetation density to

confirm patterns seen in other Arizona and New Mexico riparian habitats (Mills et al. 1991). Second, we correlated the abundance of individual bird species with potentially relevant subsets of the plant community to determine if we could detect finer scale connections.

There are many ways to measure the vegetation component of bird habitat quality (e.g. MacArthur and MacArthur 1961, MacArthur and Horn 1969, Brown 1989). However, other researchers in this system (Brown 1989, Spence et al. 1999) have found it useful to measure vegetation density as total vegetation volume (TVV; Mills et al. 1991) which has also been shown to be a good predictor of breeding bird density in other riparian areas in Arizona where vegetation height is generally below 8m.

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 data were collected simultaneously are included here. The vegetation structure data were 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 there was an overall relationship between the riparian breeding bird community and vegetation, we compared overall densities of birds to total vegetation abundance, measured as TVV. Mills et al. (1991) calculated breeding bird density (BBD) as:

$$BBD = 2*DTBBP + DNTBB$$

where DTBBP is the density of territorial breeding bird pairs and DNTBB is the density of non-territorial breeding birds. In the original formulation, the density of birds derived from the use of variable width transects (per Emlen 1971). Because our data came from bird counts collected during walking surveys that covered each patch entirely, the bird data had to be processed in several steps. First, breeding bird density, measured as per Mills et al. (1991), concerns only those species that 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, based on the assumption that one individual of a territorial species represented a pair in the patch. 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).

The graph of breeding bird density versus patch area (Figure Ing-1) revealed two important relationships. First, there was a strong negative and non-linear dependence of density on area. This may have resulted from less efficient searching in larger patches by surveyors, or a disproportionately high use of patch edges by birds so that interior portions of the larger patches were not occupied, or perhaps 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 bird 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 covariates, and 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.

In order to determine if bird-plant relationships at a finer scale could be detected using our data, we performed another set of correlations on individual bird species and major subsets of data collected on vegetation cover along the transects in the TEM sites in 2003. For these analyses, we wanted to work with only those bird species that were sufficiently abundant so that we could document relationships where they existed. Therefore, we included only those bird species which were located in at least 4 of the TEM patches and which had a count of at least four individuals in one patch. For vegetation characters, we used plant cover data collected along transects at the integrated monitoring sites, since cover seemed to be a better indication of plant abundance and included many more species than the total vegetation volume data (see Kearsley et al. 2001 for a comparison). Using this data set, we combined cover estimates for groups of woody species or grass species which were present in at least 3 new- or old high water patches and which accounted for at least one percent of cover in those patches. Only one individual plant species, tamarisk, was singled out, owing to its prevalence in our plots and continuing management interest. Otherwise plant species were combined into categories listed in Figure Ing-2. The “total new high water woody” category included both common trees and shrubs such as tamarisk, willows, species of *Baccharis*, and common shrubs, and the “total native new high water woody” included all those but excluded tamarisk. The “total old high water trees” category included only mesquite and acacia, and the “old high water shrubs” included all other old high water zone woody species. Because both vegetation and bird communities differ between hydrologic zones, we ran separate analyses for new- and old high water zone patches.

We analyzed relationships between these groups in two ways. First, we ran simple correlations between all pairs of bird and vegetation variables. Because the data were not normally distributed and had non-constant variance across the data set, we used the non-parametric Spearman's rho (r) correlation for the analysis. Because we had a maximum of 14 observations for any one correlation, we increased the significance level for these tests, and considered any of them with associated probabilities of less than 0.15 to be of interest. And second, after visually examining scatterplots of these data pairs, we used quantile regression (Cade and Richards 2001, Cade and Noon 2003) where there seemed to be a relationship but for which there were other, unmeasured factors which limited bird abundances below some upper limit.

Results. There was a strong, positive relationship between our breeding bird density estimates and vegetation density as measured by TVV (Figure Ing-3). 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 Ing-4; $F_{(1,81)} = 6.201$, $p < 0.001$).

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 Ing-3; $Q_{99} = 23.276 + 0.2285*TVV$; $p = 0.0078$). In old high water zone patches, patches with more dense vegetation also had higher breeding bird densities (Figure Ing-4; $Q_{99} = 27.602 + 0.1561*TVV$; $p = 0.0428$).

Interestingly, the overall 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 Ing-5; $F_{(2,96)} = 2.053$, $p = 0.134$). 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 Ing-5; $F_{(2,81)} = 2.501$, $p = 0.088$). This may, in part, be due to our sampling a set of patches of slightly increased mean area over the course of the study (Figure Ing-6). However, the change in area in new- and old high water zone patches would account for less than one third of the observed decrease. Mean patch areas increased from 0.92 to 1.21 ha in new high water zone patches and from 0.83 to 1.00 ha in old high water zone patches. Applying the regression line developed from patches greater than 0.25 ha in Figure Ing-1, this corresponds to predicted decreases of 1.8 birds / ha in new high water zone patches and 1.0 birds / ha in old high water zone patches. The actual decreases were 5.8 and 6.3 birds / ha, respectively between 2001 and 2003.

The further examination of the data showed that there were more details to the relationship between birds and vegetation, and that this was more apparent in the old high water zone (Figure Ing-2). In the new high water zone patches, it appears that House Finch density was related to woody species productivity. Correlations with both total cover (Figure Ing-2; $r = 0.431$, $p = 0.123$) and tamarisk cover ($r= 0.437$, $p = 0.117$) were positive. Yellow Warbler densities were positively correlated with total (i.e., including Bermudagrass) grass cover ($r = 0.517$, $p = 0.058$), but negatively correlated with native grass (excluding Bermudagrass) cover ($r = -0.441$, $p = 0.115$). Most other significant correlations were negative relationships with grass abundance. Black-chinned Hummingbirds and Bewick's Wren were negatively correlated with both exotic grass cover and native grass cover ($r = -.437$, $p = 0.117$, and $r = -0.465$, $p = 0.094$, respectively).

In the old high water zone patches, patterns were stronger and more consistent (Figure Ing-2). Tree cover in these patches, the sum of mesquite and acacia cover, was positively correlated with the densities of Bewick's Wren ($r = 547$, $p = 0.043$), Black-chinned Hummingbirds (r = 0.566, p = 0.035), Ash-throated Flycatcher (r = 0.638, p = 0.016), House Finches (r = 0.777, p = 0.001), Blue-gray Gnatcatchers (r = 0.665, p = 0.009), and Lucy's Warblers (r = 0.872, p = 0.001). The cover of old high water zone shrubs was negatively correlated with Bewick's Wrens (r = -0.584, p = 0.028), House Finches (r = -0.599, p = 0.024), and Lucy's Warblers (r = -0.563, p = 0.036). Native grass cover was negatively correlated with Black-chinned Hummingbirds (r = -0.610, p = 0.020), and House Finches (r = -0.473, p = 0.087). Total vegetative cover was positively correlated with Ash-throated Flycatchers (r = 0.518, p = 0.058) and Blue-gray Gnatcatchers (r = 0.660, p = 0.01). Total bird densities were correlated with total vegetative cover (r = 0.438, p = 0.117) and old high water tree cover (r = 0.882, p = 0.001), and negatively correlated with old high water shrub cover (r = - 0.499, p = 0.069) and native grass cover (r = -0.461, p = 0.097).

We had mixed results applying quantile regression to these relationships in searching for the "limiting resource" patterns discussed by Cade and Noon (2003). None of the relationships found with non-parametric correlations in the new high water zone were improved, or even found to be statistically significant, when vegetation cover was related to the 90th and 99th percentile of bird densities. In the old high water zone, however, correlations with the upper quantiles of Ash-throated Flycatcher densities with tree cover (p = 0.0004) and total cover (p = 0.026) were improved over those using non-parametric correlations. Likewise, correlations with the upper quantiles of Lucy's Warbler densities with tree cover (p = 0.0016) and total cover (0.053) were better than those with Spearman's rho (r). Finally, Blue-gray Gnatcatcher correlations using quantile regression were statistically better than those with non-parametric correlations with tree cover (p = 0.0006) and total cover (p = 0.009).

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 were found most often where the vegetation was 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 that serve as "breeding currency". It may also be that the density of woody vegetation in these patches provides a cooler, shadier nesting site that 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). Our data show a relationship that is decidedly "wedge" shaped (see Figures ING-3 & 4), 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 unconstrained alluvial river in the Tucson Valley which were, perhaps, more continuous and homogeneous than the isolated patches in the deeply incised Grand Canyon. The patches surveyed by Mills and his colleagues ranged in size from 12 to 90 hectares whereas delineated "patches" in the Canyon ranged from less than 0.05 to 3.5 hectares. The sampling intensity in our patches (at least 5.5 points per hectare) is at the upper end of intensities recorded by Mills (2.5 to 6.5 points per hectare), so that it is unlikely that we somehow missed the true value of TVV in our patches because our sampling was low. 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 (see reviews in Rappole and McDonald 1994, Sherry and Holmes 1996, Rappole et al. 2003). Rappole et al. (2003) found that in general, bird idensities in breeding grounds are variable, but all are lower than their carrying capacity. Third, food resources not measured by woody production may be limiting the numbers of birds in some Grand Canyon patches. For example, the density of bird species that feed on arthropods with aquatic juvenile stages or seeds and flowers of herbaceous plants would not be directly related to woody plant density. Fourth, high densities of exotic species, specifically tamarisk, in our study sites may not support the same density of birds supported by native species.

The correlations between individual bird species and vegetation characters are an interesting contrast between the two hydrologic zones. There are few significant relationships in the new high water zone, perhaps because of the importance of non-native species there, and the recent post-dam formation of these habitats and their colonization (e.g., Brown et al. 1983, Brown and Johnson 1985). Some of the negative correlations between bird densities and grass cover may be due to marginally negative correlations between woody species and grasses, even though only house finches were related to woody cover. However, areas with dense grass cover likely do not have the nectar resources for hummingbirds, which are negatively correlated with grass abundance. In the old high water zone, the patterns were much clearer. The densities of most of the bird species included in the analysis were positively correlated with the abundance of mesquite and acacia. It is not clear to us whether this is an indication that patches with more tree cover have higher productivity and levels of flowering and therefore higher abundances of arthropod herbivores and pollinators, or if it simply means that trees in the old high water zone patches provided nest sites that shrubs and grasses did not. In either case, higher cover of trees in the old high water zone is an indication of better habitat for breeding bird communities. The many negative correlations with bird densities and shrub cover are likely spurious and a consequence of the negative correlation between shrub cover and tree cover ($r = -0.543$, $p = 0.045$) in these patches.

Arthropod / Vegetation Relationships

Methods. Because each of the quantitative sampling methods resulted in a different arthropod fauna (see ARTHROPOD SURVEYS section above), we analyzed the relationships between arthropods and vegetation separately for each arthropod sampling method. Ground arthropods were collected in pitfall traps with methods described in the Arthropod Surveys section, as were plant (“sweep” sampled) arthropods. Rather than analyze each of the 928 arthropod taxa separately, we pooled abundance data within groups. In some cases these were orders (e.g., “isopods”, “spiders”), families (e.g., “tenebrionids”) or even higher taxa to create a more general picture of these relationships. Data on total vegetation volume (TVV) were collected as described in the Vegetation Structure section. Patch vegetation height was defined using the top of the meter increment containing the top-most vegetation contact at each of the 20 sampling points. The “top” of the patch was defined as one standard deviation above the average highest meter with vegetation contacts at each of these 20 points.

In order to determine which arthropods were related to different elements of the vegetation, we correlated abundances of arthropod taxa with the total vegetation volume and with the abundance of major species (e.g., willow, tamarisk, mesquite) as measured by TVV, in addition to the height of each patch. Because neither arthropod abundances nor TVV, especially by species, satisfy the assumptions of parametric correlation analyses (bivariate normality, equal variance; Sokal and Rohlf 1995), we used the non-parametric Spearman’s rank correlation for the analyses. In performing all these tests with the same data, we understand that we have an overall error rate above the traditional five percent, and we did not use a Bonferroni adjustment. However, this analysis is primarily exploratory in nature, so we are willing to accept the increased error rate.

Results. Several ground-dwelling arthropods showed significant correlations with overall vegetation structure (Figure Ing-7). Carabids were positively correlated with total vegetation volume in the new high water zone (r=0.38, p=0.01) but negatively correlated in the old high water zone (r=-0.32, p=0.05). Isopods were found primarily along the shore as well, yet they were positively correlated with vegetation volume in the old high water zone (r=0.35, p=0.03). In the new high water zone spiders (r=0.35, p=0.03), crickets (r=0.43, p=0.006) and isopods (r=0.32, p=0.04) were positively correlated with total vegetation volume, as were the shoreline zone crickets (r=0.31, p=0.05). Several arthropod groups in new high water zone were correlated with total vegetation height: carabid beetles (r=0.37, p=0.02), spiders (r=0.46, p=0.003), crickets (r=0.50, p=0.0009) and isopods (r=0.31, p=0.05). Isopods in the old high water zone were also significantly correlated (r=0.31, p=0.05) with total vegetation height, a similar result to the correlation with total vegetation volume above.

Ground arthropod relationships with individual plant species were more complex. Although tenebrionid beetles are scavengers/decomposers they were correlated significantly with some plant species: mesquite which was rare in the shoreline zone (Figure Ing-8; r=0.50, p=0.006), acacia in the old high water zone (r=-0.44, p=0.02), tamarisk which was rare in the old high water zone (r=0.46, p=0.01) and arrowweed which was rare in the shoreline zone (r=0.38, p=0.04). For spiders there was a significant correlation with mesquite in the new high water zone (r=0.41, p=0.03). Crickets were positively correlated with tamarisk in new high water zone (r=0.43, p=0.002). Isopods rarely occurred in old high water zone but were correlated with mesquite there (r=0.54, p=0.003). In the shoreline zone they were correlated with mesquite (r=0.36, p=0.05) and arrowweed (r=0.38, p=0.04).

Since ground arthropods were primarily detritivores, not herbivores, we believe that the positive and negative relationships between ground arthropods and vegetation were largely indirect, were directly due to abiotic environmental features that were reflected by vegetation structure. For example, tall, dense, woody vegetation, and species of plants that represented such vegetation structure, probably created darker, cooler, moister, and leaf litter rich microenvironments that were favorable to many ground-dwelling, nocturnal, detritus consuming arthropods. In contrast, locations with sparse vegetation and associated plant species, represented open, sunny, dry soil surface environments, that favored other diurnal ground arthropods such as seed harvester ants, mutillid wasps, and wolf spiders.

Arthropods collected from sweep samples showed a different set of relationships with vegetation structure (Figure Ing-7). Plant ants in the shoreline were the only arthropods that were positively correlated (r=0.46, p=0.009) with total vegetation volume measured along our transects. Plant hoppers (leafhoppers and other Homoptera; r= -0.51, p=0.004), plant flies (r= -0.47, p=0.007), and plant spiders (r= -0.52, p=0.003) were all negatively correlated with total vegetation volume in the old high water zone. Plant hoppers were positively correlated with plant height in the new high water zone (r=0.35, p=0.05), but negatively correlated with plant height in the old high water zone (r= -0.39, p=0.03). Plant ants were positively correlated with plant height in the shoreline zone (r=0.36, p=0.05). Plant spiders (r= -0.51, p=0.006) and plant flies (r= -0.41, p=0.02) were negatively correlated with plant height in the old high water zone.

Plant arthropods' relationships with individual plant species were centered primarily on two native plants. Mesquite had the most positive correlations with plant arthropods of all plant species analyzed. Mesquite canopy cover was positively correlated with ants (r=0.38, p=0.04) in the shoreline zone, with plant bugs (r=0.40, p=0.03), caterpillars(r=0.47, p=0.01), and flies (r=0.39, p=0.04) in the new high water zone, but no arthropods were correlated with variation in mesquite canopy cover in the old high water zone where mesquite was dominant. Tamarisk had the greatest canopy cover of most plants across sites, yet no plant arthropods were positively correlated with variation in tamarisk canopy cover. Plant spiders were negatively correlated (r= -0.56, p=0.002) with tamarisk canopy cover in the new high water zone. Plant hoppers (r=0.37, p=0.05) and plant flies (r=0.37, p=0.05) were positively correlated with coyote willow canopy cover in the shoreline zone. Arrowweed canopy cover was positively correlated with flies (r=0.37, p=0.05) in the new high water zone.

Many of the relationships between plant-dwelling arthropods and vegetation also may have been due to the physical structure of the vegetation, and to some extent sampling problems. Negative relationships between vegetation volume and height may have resulted from sampling below the foliage canopy of tall woody vegetation. Plant arthropods were sampled to a maximum height of 3 m, and dense woody vegetation patches were much taller than that. In such locations, our samples included the woody, branched understory, not the foliage crown of the vegetation. Ants nested in the ground, and traveled to and from the vegetation crown, thus crossing our sampling areas. Most foliage-feeding insects would have been in the crown foliage, not the woody subcanopy branches. Our data resulted in more positive correlations between arthropods and low vegetation such as herbs and low shrubs found along the shore.

Summary. Ground arthropods exhibited stronger relationships to overall vegetation abundance than the plant-dwelling taxa (Figure Ing-7). For ground dwelling herbivores and detritivores, such as crickets and isopods, this is likely due to greater abundance of foliage and leaf litter in more productive habitats. Predatory species, such as spiders and carabid beetles are probably more successful with a larger prey base supported in patches with more vegetation. Tall, dense, woody vegetation, and species of plants that represented such vegetation structure, probably created microenvironments that were favorable to many ground-dwelling, nocturnal, detritus-consuming arthropods. In contrast, locations with sparse vegetation and associated plant species, represented open, sunny, dry soil surface environments, that favored other diurnal ground arthropods such as seed harvester ants, mutillid wasps, and wolf spiders.

The lack of a connection between TVV and plant arthropods is puzzling. The negative correlations may be due to position effects in the canopy. These results indicate that within patches of old high water zone vegetation that we sampled, greater vegetation volume did not provide better habitat for those plant arthropods. To the contrary, greater vegetation volume appears to have limited plant arthropod numbers within our sampling locations. This may result from foliage shading effects. Plant arthropods were sampled to a maximum height of 3 m, and dense woody vegetation patches were much taller than that. In such locations, our samples included the woody, branched understory, not the productive foliage crown of the vegetation. Similar logic applies to the relationships between arthropods and individual plant species, illustrated in Figure Ing-8, although the patterns there are more consistent. All correlations between ground arthropods and plant species were positive, indicating that herbivores and detritivores were most abundant in more productive patches and predatory species such as spiders and carabid beetles were probably tracking a greater abundance of prey. Plant dwelling arthropods had primarily positive relationships with individual plant species, probably for the same reasons. Plant-dwelling spiders were negatively correlated with tamarisk in the new high water zone, probably due to sample positioning effects mentioned earlier.

Mesquite and arrowweed are important species in our patches; however there was a lack of measurable variation in insect abundance associated with mesquite in old high water zone patches. We interpret these findings to indicate that mesquite is important to those arthropods when it occurs in the new high water zone and shoreline patches. Mesquite also is important to arthropods in the old high water zone, but site to site variation was probably not sufficient given our study site sample size to provide strong correlations across sites within the those patches.

Herpetofauna / Vegetation Relationships

Methods. Data on herpetofaunal abundance were collected as part of the site surveys described in the Herpetofauna Surveys section earlier. Because they were collected in a series of walking surveys throughout the entire site, and because larger sites would naturally have more animals, we needed to convert abundances to densities. We divided the total number of herpetofauna and of individual species, by site area from the GIS, as was done in the breeding bird section. Data on total vegetation volume (TVV) were collected as described in the Vegetation Structure section above. To explore the relationship further, we included TVV from all species, only woody species, and only herbaceous species in our analyses.

We analyzed the relationships between herpetofaunal density and vegetation density in two ways. First, we performed a correlation analysis for relationships between the total density of herpetofauna and TVV. Because neither measure met the assumptions of linear correlation (bivariate normality, constant variance), we used non-parametric Spearman’s rho (r) correlation. Second, for several reasons, the number of herpetofauna that can be supported in a site is likely to be more than that seen there on any particular day. For example, herpetofauna are sensitive to temperature, and herpetofauna activity drops off above and below an acceptable range. Because we were unable to work at a site for several days during which we could wait for optimal conditions to develop, the surveys took place on days and during parts of days when the temperature was below or above that ideal. Therefore, we also used quantile regression to determine if vegetation density set some kind of upper limit on herpetofauna abundance (Cade and Noon 2003). We regressed the 90th percentile of herpetofauna abundance against TVV.

Results. The density of herpetofauna was not associated with vegetation density in any form. Overall results, pooling all zones, showed no correlation between herpetofaunal density and TVV (r = 0.0269, n = 42, n.s.). Nor was there a relationship with TVV in the zones separately (shoreline: r = 0.174, n = 14, ns; new high water: r = -0.1657, n = 14, ns; old high water: r = 0.324, n = 14, ns). Similar patterns were observed in the relationships between total herpetofaunal density and herbaceous TVV and non-herb TVV with data pooled across all three zones. When densities in each of the zones were considered separately, no patterns were apparent with non-parametric correlations. The herbaceous portion of the TVV had a slightly negative correlation with herpetofauna density in the new high water zone (r = -0.435, n = 14, p = 0.119), and a slightly positive correlation in the shoreline (r = 0.498, n = 14, p = 0.069).

The quantile regression of 90th percentile of the herpetofaunal densities with TVV showed a marginally significant negative relationship (Figure Ing-11; Density = 78.62 - 0.217*TVV, p = 0.147). Within the new high water zone, the relationship was negative as well (Density = 232.37 - 0.946*TVV, p = 0.084). In the old high water zone, the results were similar to the straight nonparametric analysis, with no significant relationship between the two (Density = 80.45 - 0.27*TVV; p = 0.54). In the shoreline, there was no relationship between them (Density = 109 - 0.30*TVV, p = 0.91).

Summary. Given that the diet of only one species of Grand Canyon herpetofauna, the Chuckwalla, includes plants, it is not surprising that there were few significant relationships between herpetofauna and vegetation. The relationship between vegetation cover and the herpetofauna is likely negative in that vegetation probably interfers with the foraging of lizards and snakes, providing cover for prey items, and reducing the effectiveness of basking sites for warming. It is also far more likely that herpetofaunal densities are related to other habitat variables, such as the presence and abundance of structure in the form of coarse woody debris and boulders.

Herpetofauna / Arthropod Relationships

Methods. For reasons explained under the vegetation / arthropod section above, arthropod data from pitfall samples were separated from sweep samples. As with the earlier section, the 180 arthropod taxa collected in pitfall traps were pooled into higher taxonomic groups to allow easier interpretation of patterns that emerged. The herpetofaunal abundance data from the walking surveys were converted to densities by dividing by the area of the patch surveyed. Data were analyzed in the three hydrologic zones separately.

The analysis consisted entirely of correlation analysis. The data did not satisfy the assumptions of parametric correlation analysis, so the non-parametric Spearman’s rho (r) was employed here. Although the use of many separate correlations increases the overall experiment-wide error rate, these analyses are strictly exploratory, and designed only to highlight potentially interesting patterns.

Results. There were a number of interesting correlations between ground-dwelling arthropods and herpetofauna in our study sites (Figure Ing-12). Carabids were associated with the Side-blotched Lizard (r=0.42, p=0.03) in the new high water zone. Tenebrionids were significantly correlated with two lizard species in the old high water zone: Side-blotched Lizard (r=0.55, p=0.002) and the Western Whiptail Lizard (r=0.42, p=0.03). Ant correlations with the same two lizard species were significant: Side-blotched Lizard (r=0.50, p=0.008) and the Western Whiptail Lizard (r=0.44, p=0.02). Spiders were correlated positively with the Western Whiptail Lizard (r=0.42, p=0.03) and Desert Spiny Lizard (r=0.38, p=0.05) in the new high water zone, and negatively with the Tree Lizard in new high water zone (r= -0.42, p=0.03). For crickets the only significant correlation with lizard density was for the Desert Spiny Lizard in old high water zone (r=0.43, p=0.03). Isopods were correlated only with the Western Whiptail Lizard in new high water zone (r=0.45, p=0.02).

Although diurnal lizard species are largely ground- or boulder dwellers and not likely predators of plant-dwelling arthropods, several interesting correlations emerged from the data. Western Whiptail Lizard densities were positively correlated with plant hoppers (r=0.45, p=0.02), plant beetles (r=0.49, p=0.01), and caterpillars (r=0.52, p=0.007) in the new high water zone, and with plant beetles in the old high water zone (r=0.42, p=0.03). The Desert Spiny Lizard was positively correlated with caterpillars (r=0.51, p=0.04) and plant flies (r=0.54, p=0.03) in the shoreline zone. Densities of the Side-blotched Lizard were positively correlated with plant beetles (r=0.48, p=0.01) in the old high water zone, and Side-blotched Lizards were negatively correlated with ants (r= -0.42, p=0.03) in the new high water zone.

Summary. It is not clear whether the correlations seen in the ground arthropod - herpetofauna correlations represent functional, trophic relationships or if they represent joint distributions with an unmeasured factor. Because many tenebrionids are chemically defended, the association between them and the lizards probably has more to do with similar substrate preferences than to predator/prey relationships. Similarly, ants are not normally associated as prey items for whiptail lizards, so their correlation was probably for the same reasons as the tenebrionids. Spiders, crickets and isopods probably make up part of the prey base for lizards in the Canyon. Overall, a careful diet analysis, as suggested by Tomko (1976) would lead to a clearer understanding of the correlations we have shown here.

Bird / Arthropod Relationships

Methods. Only spring (bird breeding season) survey data were used for this analysis, and plant- and ground dwelling arthropods were considered separately, and these were pooled into higher taxonomic groups. As with the TVV / bird analysis, bird abundance data from walking surveys were divided by patch areas to yield density estimates. The arthropod sampling came from equal effort surveys in each site, so that no conversion was necessary. Because no bird data was collected specifically in the shoreline zone habitats, only new- and old high water patches are considered in this analysis.

Results. Ground dwelling arthropods had a number of interesting correlations with bird densities (Figure Ing-9). Carabids were significantly correlated with three bird species in the new high water zone: Lucy's Warbler r=0.42, p=0.009), Ash-throated Flycatcher (r = 0.39 p=0.02) and Yellow Warbler (r=0.36, p=0.03). The number of ants in pitfall traps was not correlated with bird densities in the new high water zone or the old high water zone. Tenebrionid beetles were correlated with Bell's Vireo (r=-0.34, p=0.04) and Common yellowthroat (r=-0.33, p=0.04) in the new high water zone. Spiders were significantly correlated only with Lucy's Warbler in the new high water zone (r=0.38, p=0.02). Crickets were correlated with more bird species' densities than any other ground arthropod group: in the new high water zone with Lucy's warbler (r=0.41, p=0.01), Blue-gray Gnatcatcher (r=0.56, p=0.0003), Yellow warbler (r=0.45, p=0.004), Bewick's Wren (r=0.49, p=0.002) and Common Yellowthroat (r= 0.37, p=0.02). In the old high water zone crickets were again correlated with Bewick's Wren (r=0.89, p<0.0001). Isopods were correlated with 4 bird species in the new high water zone: Lucy's Warbler (r=0.33, p=0.04), Yellow Warbler (r=0.53, p=0.0007), Bewick's Wren (r=0.45, p=0.005), and Yellow-breasted Chat (r=0.40, p=0.01). In the old high water zone they were correlated with estimates of Lucy's Warbler (r=0.37, p=0.03) and Bewick's Wren (r=0.70, p<0.001) abundances.

Plant arthropods also had a number of significant relationships with breeding bird densities (Figure Ing-10). Lucy's Warblers were positively correlated with flies in both the new high water zone (r=0.41, p=0.01) and old high water zone (r=0.41, p=0.02), and with plant beetles (r=0.44, p=0.008) in the new high water zone, and with plant bugs (r=0.51, p=0.003) in the old high water zone. Lucy's Warblers were negatively correlated with plant spiders (r= -0.40, p=0.02) in the old high water zone. Blue-gray Gnatcatchers were positively correlated only with plant bugs (r=0.52, p=0.002) in the old high water zone. Ash-throated Flycatchers were positively correlated with plant flies (r=0.56, p=0.0009) and plant bugs (r=0.37, p=0.03) and only in the old high water zone. Ash-throated Flycatchers were negatively correlated with plant spiders (r= -0.54, p=0.0008) and plant ants (r= -0.35, p=0.04) in the new high water zone. Bell's Vireos were positively correlated with plant bugs in both the new high water zone (r=0.37, p=0.03) and the old high water zone (r=0.39, p=0.03). Yellow Warblers were negatively correlated with ants (r= -0.47. p=0.004) in the new high water zone, and negatively with plant hoppers (r= -0.53, p=0.001), plant flies (r= -0.36, p=0.04) and ants (r = -0.38, p < 0.05) in the old high water zone. Bewick's Wrens were correlated with caterpillars (r=0.40, p=0.02) in the old high water zone. Densities of Common Yellowthroats, Canyon Wrens, Say's Phoebes, and Yellow-breasted Chats were not positively correlated with any of the selected plant arthropod groups.

Summary. There were a number of consistent patterns that emerged from this analysis. Lucy's Warblers were positively associated with many species of both ground- and plant dwelling arthropod groups. This is especially true in the new high water zone. Yellow Warblers are positively associated with several ground-dwelling species, but negatively with plant arthropods. This may be due to similar habitat requirements as ground arthropods, which are negatively associated with plant-dwelling species, or it may be due to competitive interactions or predation on the plant-dwelling insects and no interaction at all with ground dwellers. The negative correlations with tenebrionids may come from a beetle preference for open ground and a bird preference for cover.

Plant spiders and plant ants were consistently negatively correlated with a number of bird species including Lucy's Warblers, Ash-throated Flycatchers, Bell's Vireos, and Yellow Warblers. This may be due to predation by the bird species, or competition with predatory ants and spiders that are utilizing the same prey base. The high correlations between Lucy's Warblers and plant dwelling beetles, bugs and flies may indicate that these are important food resources for the birds. The high number of negative correlations between plant dwelling bugs and bird species, relative to those in ground-dwelling arthropods may indicate that predation on plant-dwelling insects by birds is higher than it is on the ground. As mentioned above, plant arthropod sampling missed the productive vegetation crown foliage in stands of tall, woody vegetation, and our sampling and analyses probably obscured some relationships between birds and plant-dwelling arthropods. These questions should be directly addressed with behavioral studies and simultaneous gut sampling of birds.

Small Mammal / Vegetation Relationships

Methods. Small mammal abundance data were collected from the trapping done in the integrated monitoring sites. Unlike bird and herpetofaunal data, they were collected with an equivalent sampling intensity in each of the hydrologic zones, with 50 trap-nights per zone per site. Therefore, no site area corrections were necessary before the analysis. The vegetation volume data (TVV) was collected along the traplines in these zones and, as in the other analyses, is expressed as a per 20 point quantity.

Because neither of the data sets satisfied the assumptions of parametric correlation analysis (constant variance and bivariate normality), we used the non-parametric Spearman's rho (r) to test for a relationship between the two. Because species of *Peromyscus* are known to depend on seeds for at least some of the year, we also correlated the abundance of the total of all *Peromyscus* in a site with the cover of grasses and annuals in the sites. In addition, we used quantile regression (Cade and Richards 2001, Cade and Noon 2003) to test for the existence of an asymptotic relationship between mammal abundance and TVV and *Peromyscus* abundance and the cover of seed-producing species. Again, we raised the acceptable probability to 0.15, owing to small sample sizes.

Results. The correlation analysis showed no detectable relationship between TVV and the abundance of all small mammals when data from all zones were pooled ($r = -0.131$, $n = 42$, $p = 0.409$). Separating out each of the zones did not improve the relationship (shoreline: $r = -0.130$, $n = 14$, ns; new high water: $r = -0.333$, $n = 14$, $p = 0.245$; old high water: $r = -0.057$, $n = 14$, $p = 0.844$). The overall relationship, across all zones, was not improved by using quantile regression (Mammals = 9.287 - 0.01*TVV, $p > 0.40$), nor was it improved for shoreline mammals (Mammals = 1.92 + 2.98*TVV, $p > 0.20$) or old high water (Mammals = 16.9 - 0.031*TVV, $p = 0.98$). However, the number of mammals was negatively related to the abundance of vegetation in the new high water zone (Figure Ing-13; Mammals = 12.3 - 0.041*TVV, $p = 0.062$). When data on *Peromyscus* were compared to the cover of grasses and annuals with all zones considered simultaneously, the relationship was positive, but non-significant (*Peromyscus* = 7.98 + 0.121*cover, $p = 0.202$).

Summary. We did not find any general relationships between the density of small mammals and the abundance of vegetation. Only in the new high water zone was there a relationship, and that indicated that the densest stands of vegetation (primarily dense tamarisk stands) supported the lowest numbers of mammals. It is more likely that the small mammals were associated with the presence of physical habitat features like coarse woody debris, substrate texture, and the presence of boulders.

Small Mammal / Arthropod Relationships

Methods. Data on small mammal abundance were taken from the trapping described in the Small Mammal Survey section above. Because the data came from equal sampling in each of the sites, no correction was necessary for size or sampling extent and straight abundance numbers could be used. Arthropod data were from plant sweeps and pitfall traps only. As with other synthesis sections, taxa within each of these groups were pooled into higher taxonomic groups to make interpretation easier.

Results. Ground-dwelling arthropods had a number of positive correlations with three species of small mammals (Figure Ing-14). Significant carabid correlations with small mammals occurred only in the new high water zone and only for the species that are known to at least occasionally include insects in their diet: woodrats (r=0.40, p=0.03) and deer mice (r=0.46, p=0.01). There was no association between tenebrionid beetles and rodents. The only significant correlation between ants and mammals was with pocket mice in the new high water zone (r=0.57, p=0.001). There was a significant correlation between spiders and woodrats in the shoreline zone (r=0.41, 0.03) and in new high water zone (r=0.38, p=0.04), and with deer mice in new high water zone (r=0.43, p=0.02). In the shoreline zone, the only significant correlation between crickets and rodents was for deer mice (r=0.47, p=0.009). Isopod correlations with rodents were significant only for two species: woodrats in shoreline zone (r=0.41, p=0.02) and new high water zone (r=0.51, p=0.005), and deer mice in new high water zone (r=0.36, p=0.05) and old high water zone (r=0.39, p=0.03).

Even though there are not likely to be any direct interactions between rodents and plant dwelling arthropods, there were several significant correlations in our study sites (Figure Ing-15). Pocket mice were the group of rodents that exhibited the most positive correlations with plant insects. Pocket mice numbers were positively correlated with numbers of caterpillars (r=0.42, p=0.02) and plant flies (r=0.47, p=0.01) in the new high water zone, and with plant hoppers (r=0.39, p=0.04), plant beetles (r=0.49, p=0.006), and plant flies (r=0.63, p=0.0003) in the old high water zone. Murid mice were positively correlated with plant bugs (r=0.40, p=0.03) in the old high water zone, and with caterpillars (r=0.39, p=0.04) in the shoreline zone. Murid mice were negatively correlated (r= –0.39, p=0.04) with plant spiders in the new high water zone. Woodrats were not correlated with any plant-dwelling arthropods.

Summary. The correlations detected here are likely related to both trophic interactions and competitive interactions. The positive correlation between ground-dwelling ants and pocket mice is probably due to use of similar seed resources. It is possible that there is competition between pocket mice and ants in years when seeds are scarce. With the plant-dwelling arthropods, the situation is probably similar. Since pocket mice are largely granivores, these relationships probably result from pocket mice and those insect groups sharing preferences for similar environmental factors, although some of those insects may serve as food resources for pocket mice. Murid mice do feed on insects, so relationships between murids and plant bugs and plant caterpillars may be due to mice using them as a food resource, and those with plant spiders may reflect their both keying in on areas with high prey abundances.

Overall Summary of Biotic Interactions along the Riparian Corridor

We found positive relationships between increased vegetation cover and foliage density and some arthropod groups and birds. Many ground-dwelling and plant-dwelling arthropods were probably associated with dense vegetation because the vegetation provided more food and habitat resources for plant-dwelling herbivores and predators, and cooler microenvironments with more food resources at the soil surface underneath the canopy for ground-dwelling detritivores and predators. Breeding birds were apparently associated with dense vegetation patches in response to better foraging due to increased plant insect densities, especially caterpillars and flies, and optimal nesting sites. Positive relationships between birds and some ground arthropods such as nocturnal crickets are likely spurious, and more likely resulting from both groups of animals utilizing the same general habitat patches. We did not find relationships between vegetation and the herpetofauna nor the small mammal fauna. Other than chuckwalla lizards, amphibians and reptiles encountered in this survey do not directly utilize plant resources, other than vegetation as habitat structure. Most are associated with soil or rock substrates, and were probably more closely associated with those features of the environment than with vegetation. The majority of the herpetofauna found during this survey were small, predaceous lizards, which prefer open, rocky environments where insolation is high. Diurnal flies, ants, spiders and other arthropods of those open rocky areas were probably key food resources for lizards, but not adequately sampled by pit traps or vegetation sweep nets. Small mammals do utilize plant resources as food and habitat, but the species found in our surveys are more likely associated with soil and rock substrates habitats than vegetation. Positive relationships between heteromyid rodents and seed harvesting ants likely resulted from both groups of animals occurring in greater abundances where soil surface seed resources were high. Positive relationships between murid rodents and plant-dwelling arthropods, such as caterpillars, were likely due to the rodents utilizing those insects as food resources.

Overall, our integrative findings demonstrate that Grand Canyon riparian environments that support dense stands of vegetation also support larger numbers of animals. This relationship is particularly important in the old high water zone where greater numbers of plant-feeding insects such as caterpillars, provided food for higher-level consumers such as birds and murid rodents. Sites with high levels of vegetation and thus net primary productivity did support greater numbers of animals. We were also able to determine some specific relationships between animals and vegetation, and among the various animal groups themselves.

The overall integrative findings reported here are simply descriptive relationships that we found among the plants and animals that we studied. The intent was to provide an overall biotic community assessment of how plants and animals may be linked to each other and the physical environment in Grand Canyon. Correlation analysis only tests for statistically significant relationships between variables and their interpretation is open to speculation and inductive reasoning. Only experimental manipulations or other controlled experiments will test for processes causing such relationships. The simple correlation approach was meant to provide the basic information about how different organisms were related to each other to demonstrate patterns of biotic interactions. We hope that this information will be useful to other researchers investigating the ecological processes that may explain those patterns. This report represents the first attempt for a comprehensive integrative inventory and monitoring effort for the terrestrial riparian plants and animals of the riparian corridor in Grand Canyon.

Literature Cited

Brown, B. T. 1989. Breeding ecology of riparian birds along the Colorado River in Grand Canyon, Arizona. Technical Report Number 25. University of Arizona Cooperative National Park Resources Studies Unit, Tucson, AZ.

Brown, B. T., and R. R. Johnson. 1985. Glen Canyon Dam, fluctuating water levels, and riparian breeding birds: the need for management compromise in the Colorado River in Grand Canyon. Pages 76-80 *in* R. R. Johnson, 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.

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

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

Cade, B. S., and J. D. Richards. 2001. User manual for Blossom Statistical Software. U.S. Geological Survey, Midcontinent Ecological Science Center, Fort Collins, CO.

Emlen, J. T. 1971. Population densities of birds derived from transect counts. The Auk 88:323-342.

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

Kearsley, M. J. C., N. Cobb, H. Yard, D. Lightfoot, G. Carpenter, S. Brantley, and J. Frey. 2001. Inventory and monitoring of terrestrial riparian resources in the Colorado River corridor of Grand Canyon: an integrative approach. Annual report. U.S. Geological Survey Cooperative Agreement / Assistance Award 01 WRAG 004. Grand Canyon Monitoring and Research Center. 77 pages. 18 December 2001.

MacArthur, R. H., and H. S. Horn. 1969. Foliage profile by vertical measurements. Ecology 50:802-804.

MacArthur, R. H., and J. W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

Mills, G. S., J. B. Dunning, and J. M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103(3):468-479.

Rappole, J. H., and M. V. McDonald. 1994. Cause and effect in population declines of migratory birds. The Auk 111:652-660.

Rappole, J. H., D. I. King, and J. Diez. 2003. Winter- vs. breeding-habitat limitation for an endangered avian migrant. Ecological Applications 13:735-742.

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

Sherry, T. W., and R. T. Holmes. 1996. Winter habitat quality, population limitation, and conservation of Neotropical-Nearctic migrant birds. Ecology 77:36-48.

Sokal, R. B., and F. J. Rohlf. 1995. Biometry, 3rd Edition. W.H. Freeman and Company, San Francisco.

Spence, J., C. T. LaRue, N. L. Brown, and J. Muller. 1999. Winter and breeding avifauna monitoring along the Colorado River in Glen and Grand Canyons. Draft Final Report submitted to Grand Canyon Monitoring and Research Center. Glen Canyon National Recreation Area, National Park Service.

Tomko, D. S. 1976. Dietary characteristics of some Grand Canyon amphibians and reptiles. Pages 45-54 *in* S. W. Carothers and S. W. Aitchison, editors. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and Grand Wash Cliffs. Final Report. N.P.S. Contract No. CX821500007. Museum of Northern Arizona, Flagstaff, AZ.

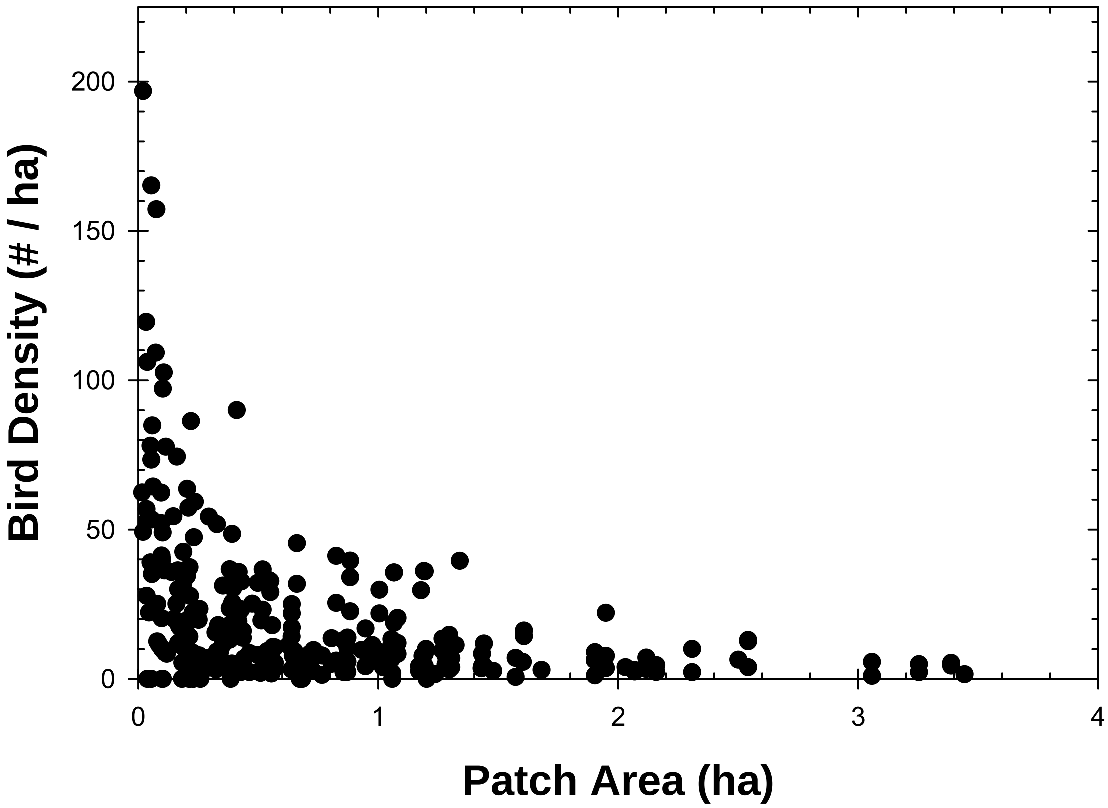


Figure Ing-1. Estimates of breeding bird density decrease with increasing patch area, as does variance in breeding bird density estimates in both new high water zone and old high water zone plots. Data are from three years of surveying.

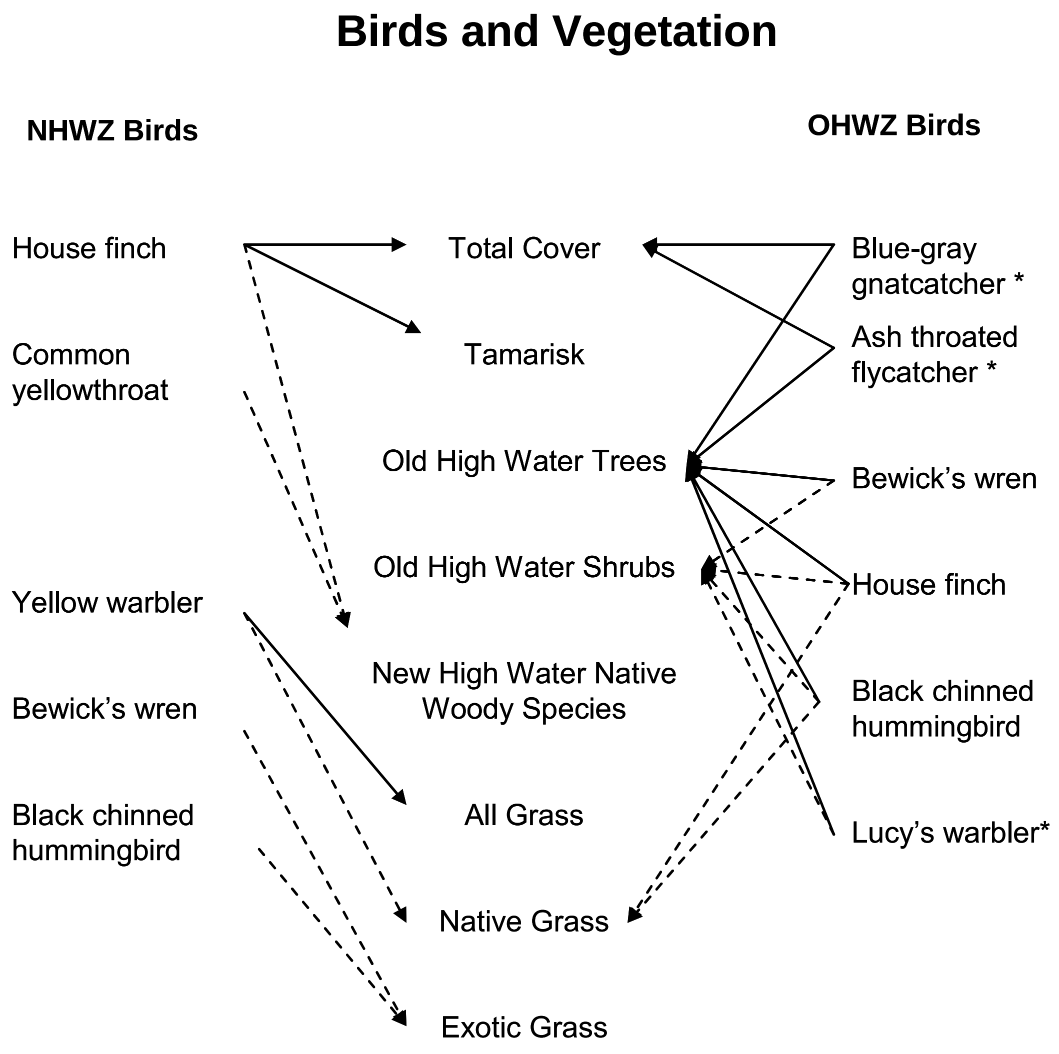


Figure Ing-2. Relationships between estimated densities of individual bird species and aspects of vegetation in the integrated monitoring sites. Solid lines indicate positive correlations, dashed lines are negative relationships. Asterisks indicate cases in which quantile regressions were stronger than the non-parametric correlations/

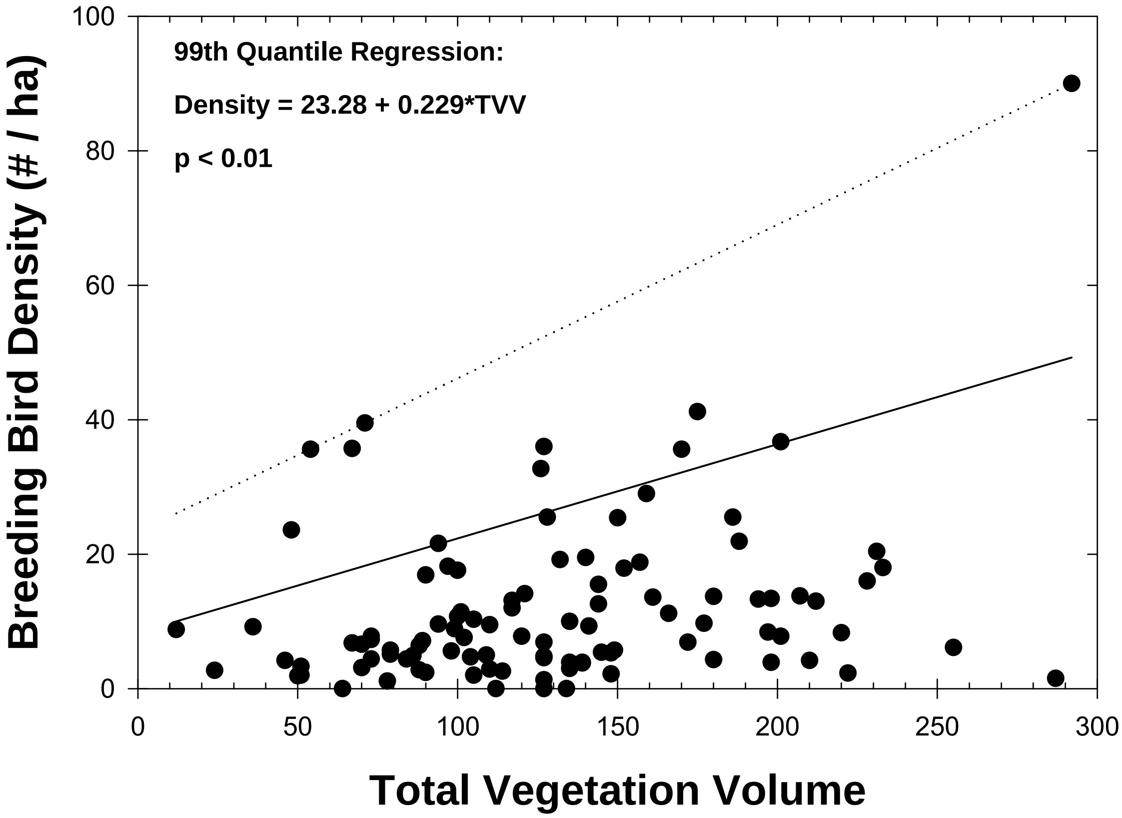


Figure Ing-3. Breeding bird density and total vegetation volume in new high water zone bird patches larger than 0.25 ha. Solid line is least squares regression line. Dotted line shows the 99^{th} quantile regression line.

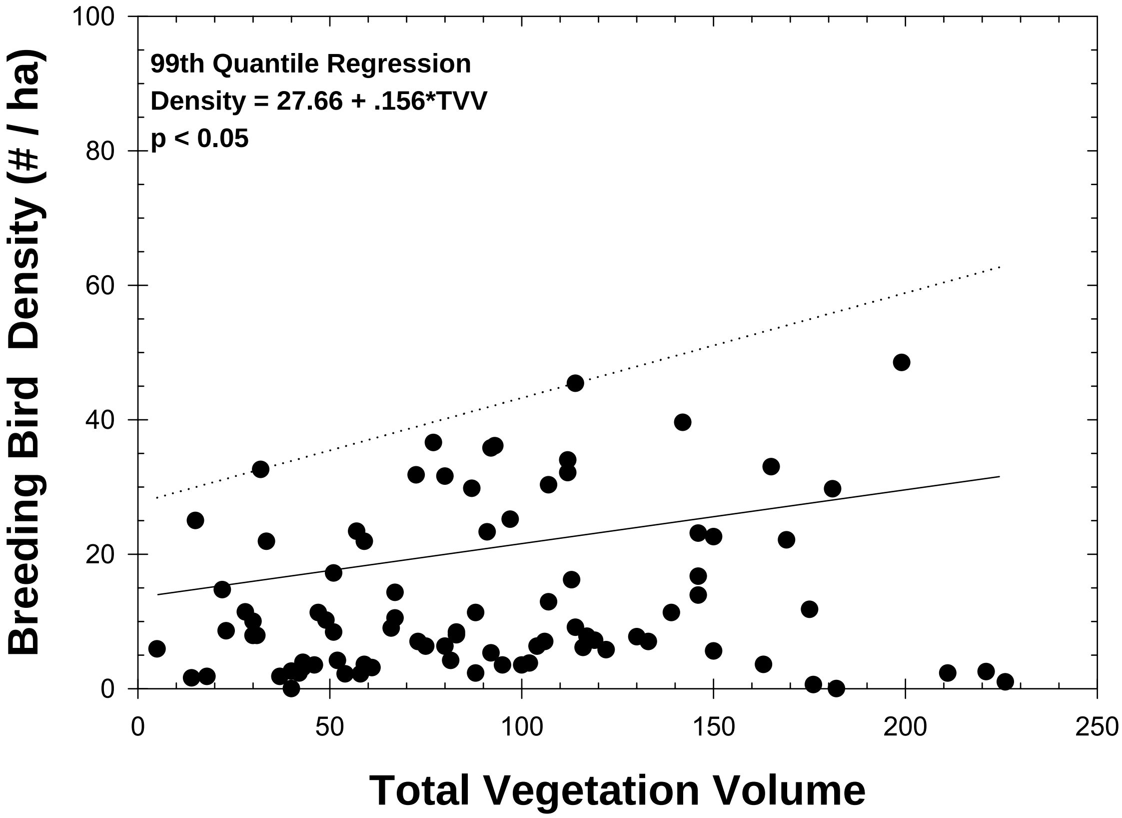


Figure Ing-4. Breeding bird density and total vegetation volume in old high water zone bird patches larger than 0.25 ha. Solid line is least squares regression line. Dotted line shows the 99th quantile regression line.

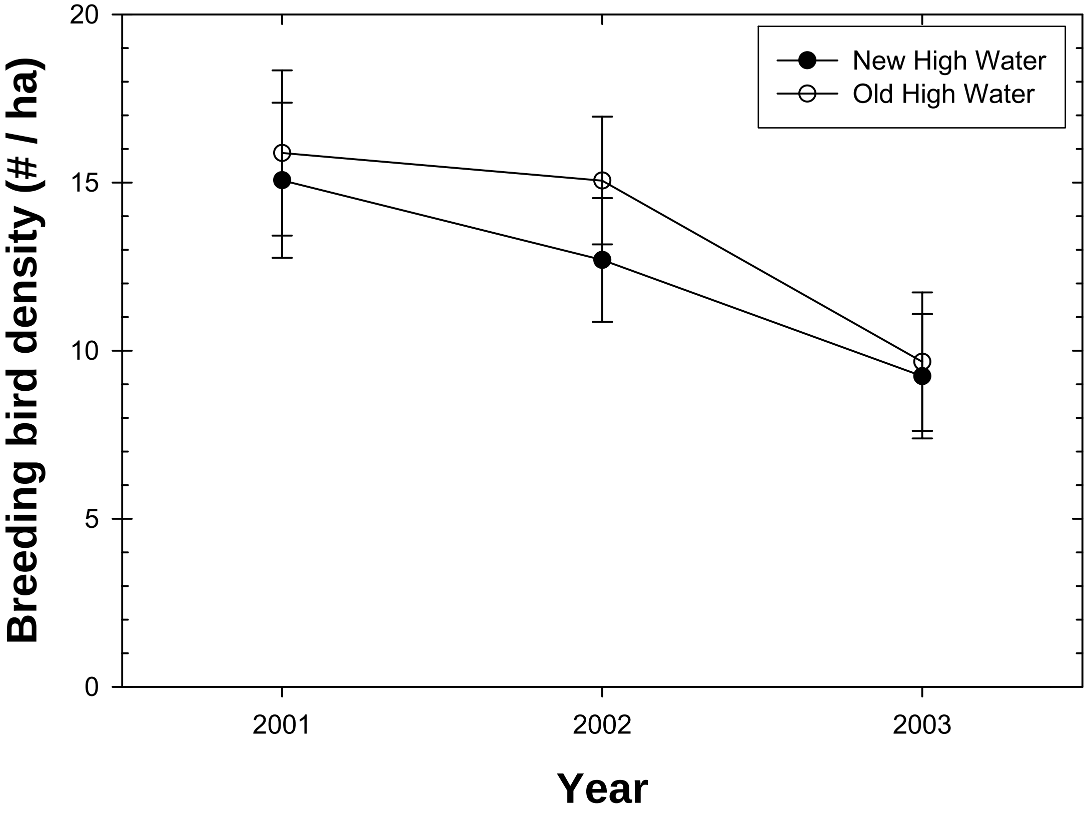


Figure Ing-5. Mean breeding bird densities decreased in both new high water zone and old high water zone patches greater than 0.25 ha between 2001 and 2003. Vertical bars represent +/- 1 standard error.

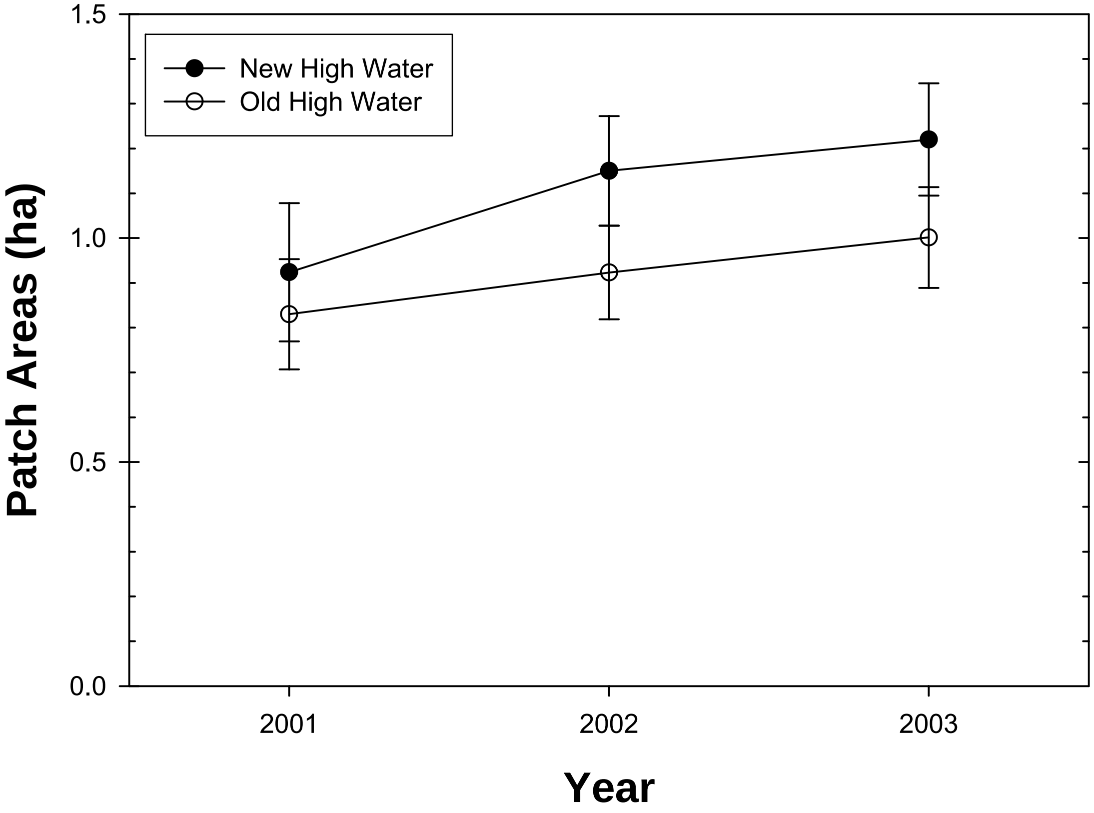


Figure Ing-6. Mean areas of larger bird patches surveyed increased between 2001 and 2003, potentially leading to decreases seen in breeding bird densities in the patches. Vertical bars represent +/- 1 standard error.

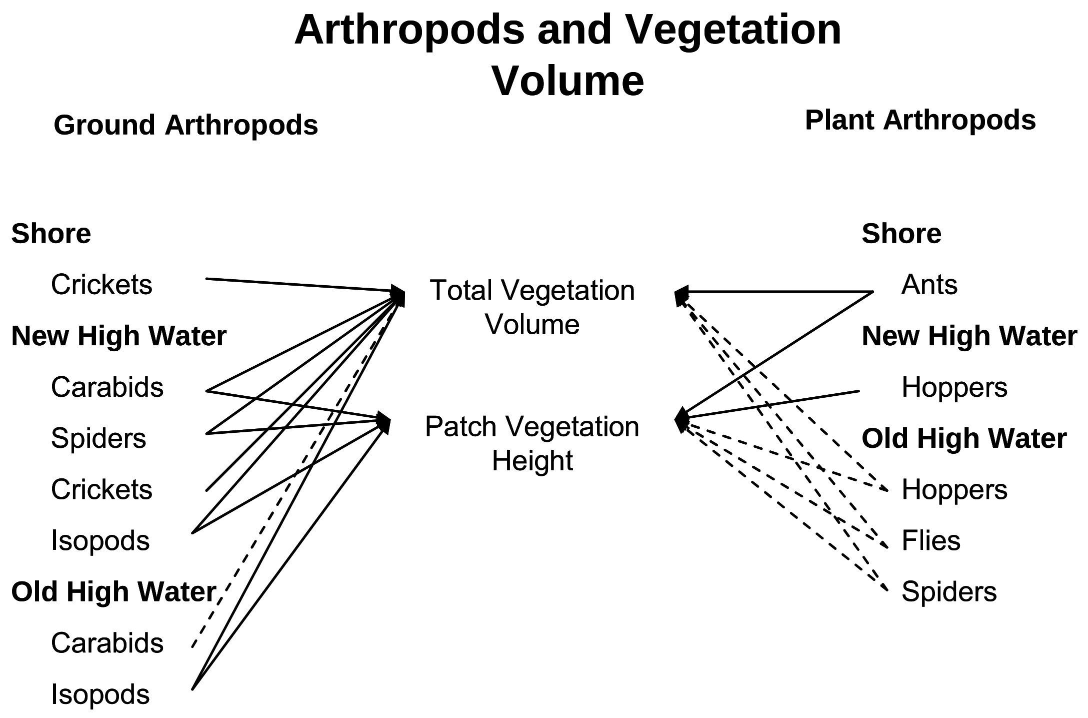


Figure Ing-7. Relationship between arthropod taxa and total vegetation volume and patch plant height. Solid lines indicate positive correlations, dashed lines show negative relationships.

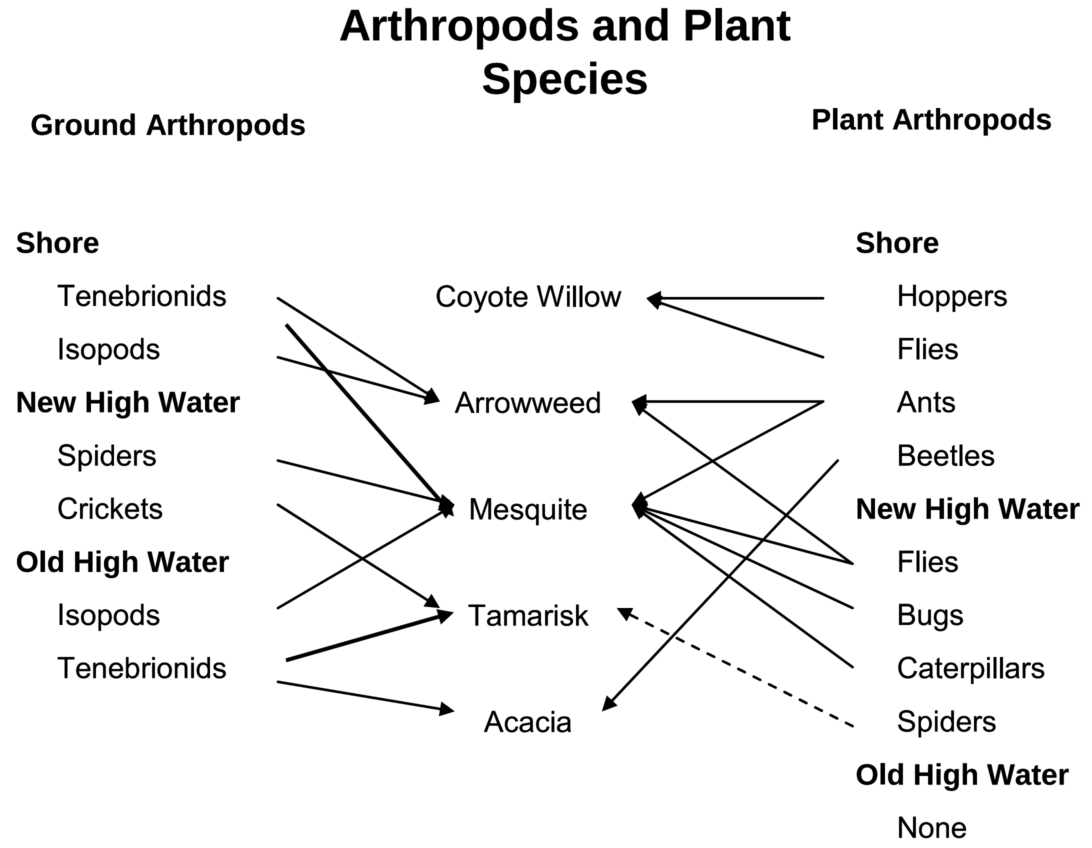
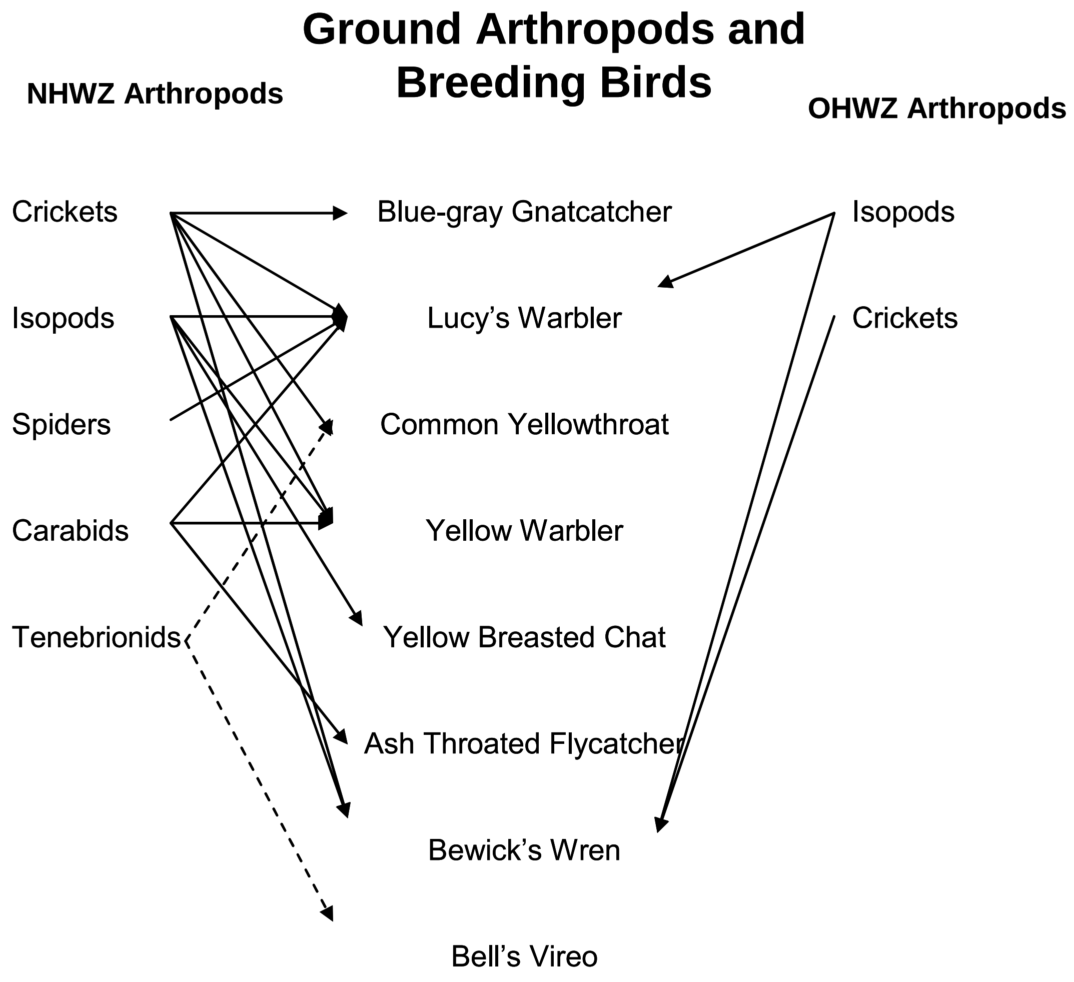


Figure Ing-8. Relationships between plant and ground dwelling arthropods and individual species of plants. Solid lines indicate positive correlations, dashed lines show negative relationships.



Ground Arthropods and Breeding Birds

Figure Ing-9. Significant non-parametric correlations between ground-dwelling arthropods and species of breeding birds. Solid lines indicate positive correlations, dashed lines show negative relationships.

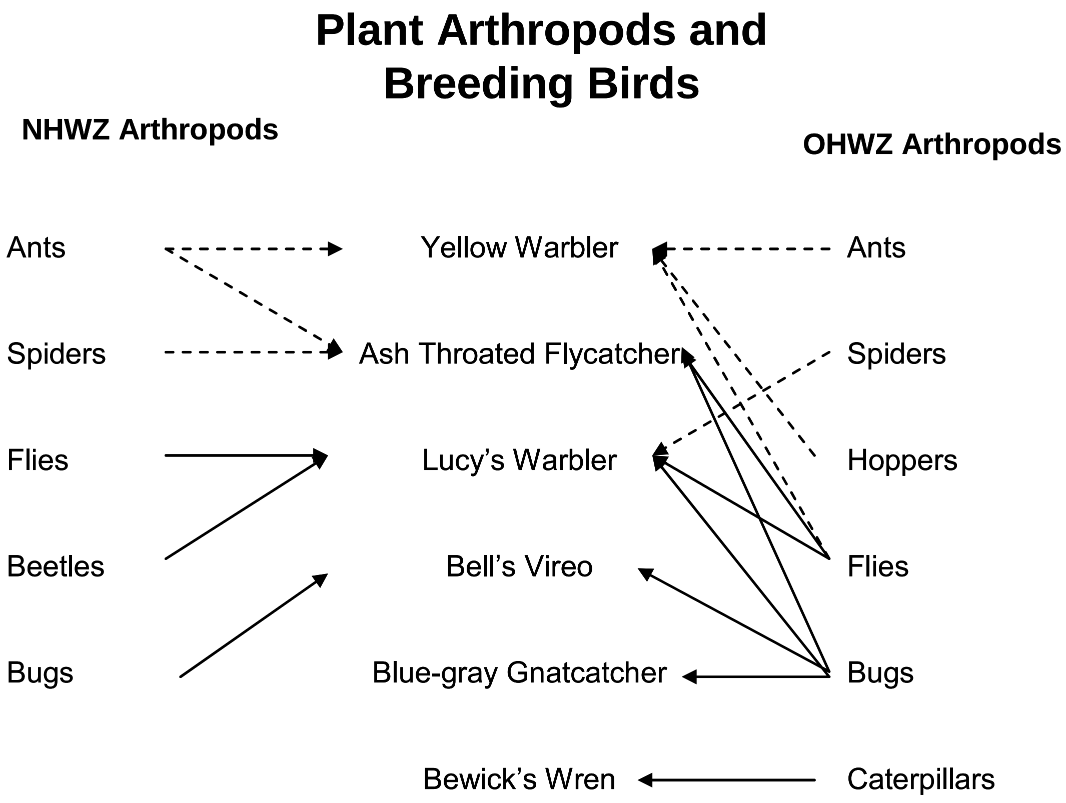


Figure Ing-10. Significant non-parametric correlations between plant-dwelling arthropods and individual bird species. Solid lines indicate positive correlations, dashed lines show negative relationships

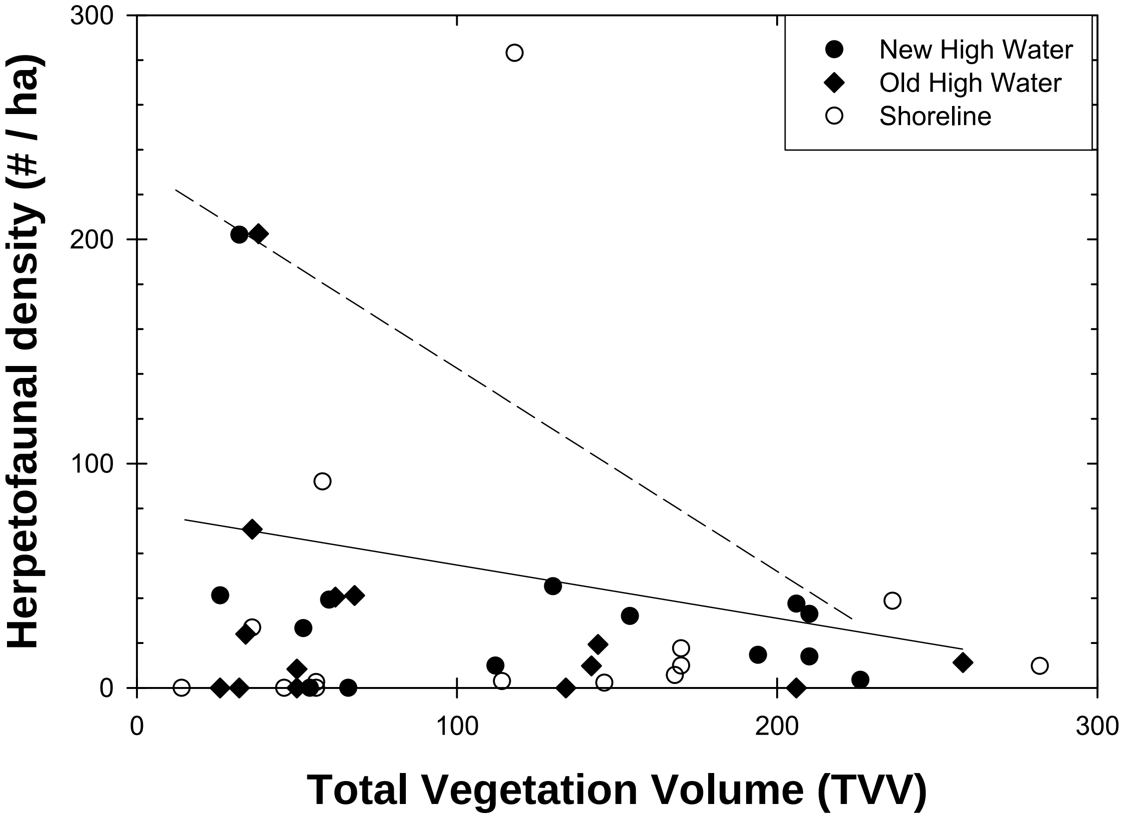


Figure Ing-11. Relationship between herpetofaunal densities and vegetation structure in the monitoring sites. Solid line represents the least squares regression line, the dashed line shows the regression of the 90th quantile of herp density with TVV.

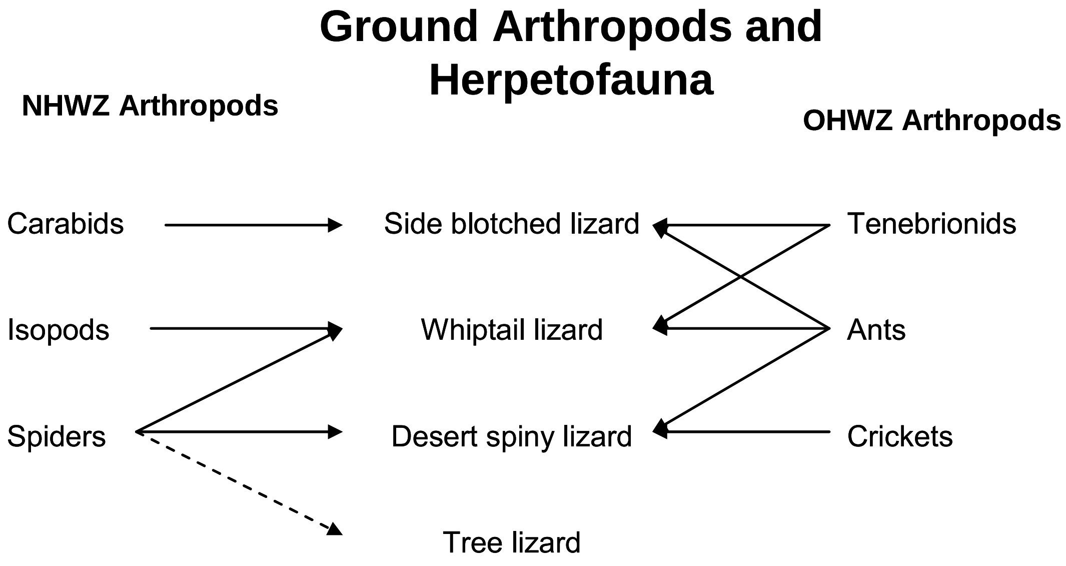


Figure Ing-12. Relationships between ground dwelling arthropods and herpetofauna. Solid lines indicate positive correlations, dashed lines show negative relationships.

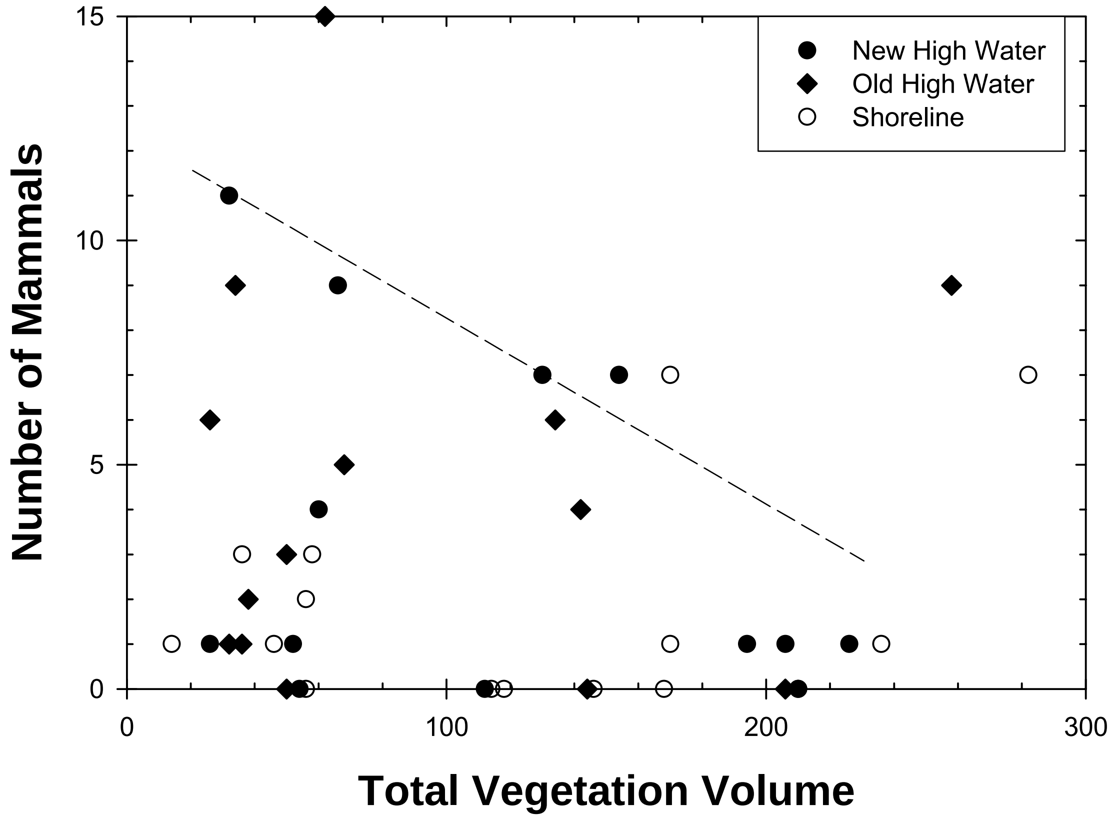


Figure Ing-13. Relationship between small mammal abundance and total vegetation volume in the integrated sampling sites. Dashed line shows the regression of the 90th quantile of small mammal densities in the new high water zone with total vegetation volume.

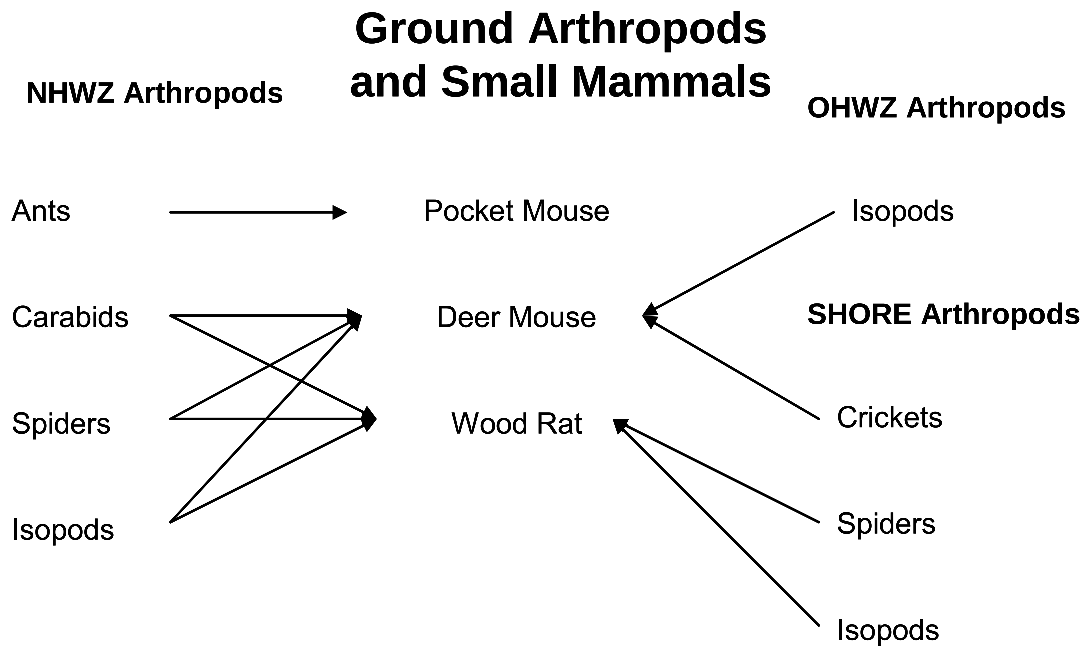


Figure Ing-14. Significant correlations between ground dwelling arthropods and small mammals. Solid lines show positive correlations, dashed lines show negative relationships.

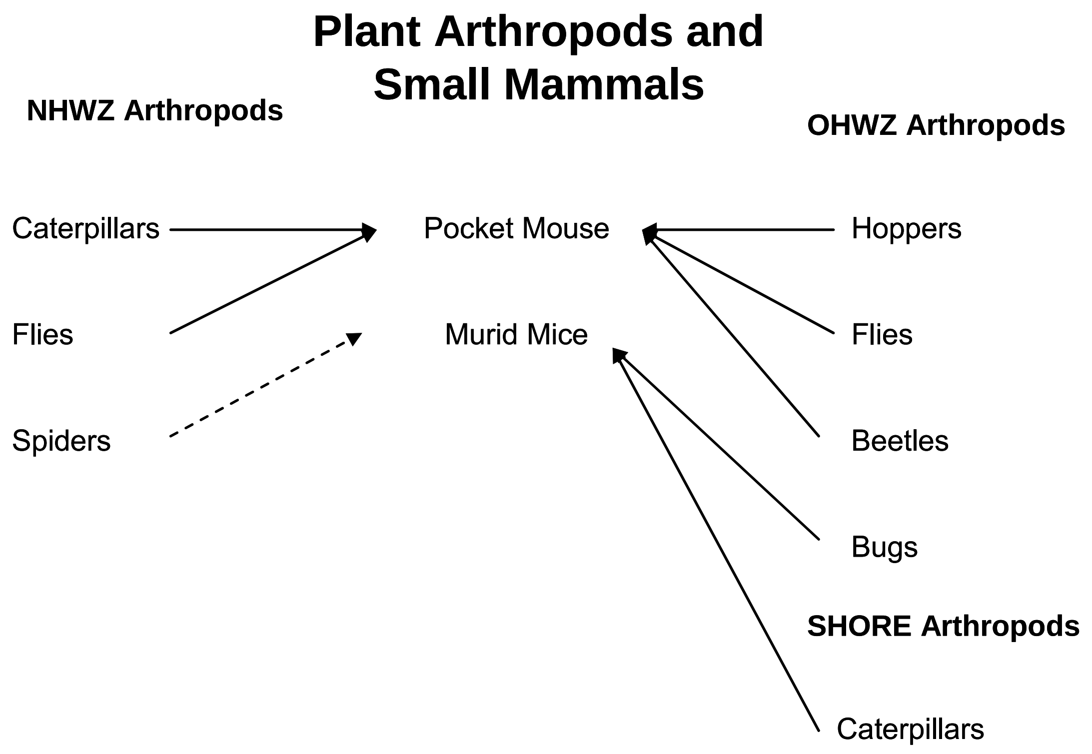


Figure Ing-15. Significant correlations between plant dwelling arthropods and small mammals. Solid lines show positive correlations, dashed lines show negative relationships

Part III
Related Surveys of Vegetation and Avifauna

Vegetation Dynamics

Michael J. C. 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

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 data from 2001 and 2002 to test for flow-related changes.

6) To determine if investigators were having a measurable impact on vegetation at sites which were visited each year during surveys.

Methods

Vegetation Dynamics Transects. Sample site selection for the vegetation dynamics data had to satisfy three major concerns. First, it had to be probability based, due to recommendations of the 2000 protocol review panel (Urquhart et al. 2000). Even the best minds in a field can introduce systematic biases when sample locations are chosen based on personal judgment and "representativeness" of sites (Peterman et al. 1999). Second, the sampling had to take into account geomorphic influences on vegetation. Reach characteristics, such as reach width and direction of canyon trending have strong effects on productivity and diversity in both aquatic and near-shore habitats (Stevens et al. 1997a, b, Kearsley and Ayers 1999b). Third, it had to allow the linking of vegetation change to river flow independent of precipitation because the hydrograph is the single most important stressor in terrestrial riparian systems (Malanson 1993, Shafroth et al. 1998, 2000), and monitoring activities must be linked to important stressors if they are to be useful (Noon et al. 1999). Previous vegetation monitoring projects in the river corridor (e.g., Stevens and Ayers 1993, Kearsley and Ayers 1996, 1999a) could connect vegetation change and dam operations only anecdotally, and were not designed to separate the effects of precipitation from those of dam operations.

To document vegetation dynamics, sampling was based on the STARS model of Randle and Pemberton (1987) which predicts elevation rise based on river stage. The model uses 704 cross-sections between Lees Ferry and Diamond Creek which were located at flow controlling points, such as debris fans, cobble bars and other constrictions. In the model, the river is considered to be a series of drop-and-pool segments in which the elevation of the water surface at a given point is controlled by the next cross section downstream (Randle and Pemberton 1987). The cross-sections therefore define 703 segments which formed the pool of potential samples.

In cooperation with Dr. Scott Urquhart, then of Oregon State University, we designed a probability based sample site selection. Each of the 703 river segments was assigned to its geomorphic reach (per Schmidt and Graf 1990), and then assigned a random selection order number, from 1 to 703, in a reach stratified, spatially randomized pattern based on the EPA's EMAP sampling program (Urquhart et al. 1998, Herlihy et al. 2000). The first 100 would be visited in 2001. Within each of those 100 segments, a point on one side of the river was selected at a random distance upstream from the lower cross section, as the point where the transect would begin. That point was located on the October 1984 black and white aerial photos used during the creation of the STARS model. Mileages, to the nearest 0.01 mi. for the vegetation transects were interpolated between the tenth mile marks on the photos, and lines were drawn through them perpendicular to the river channel at that point. In order to have a more recent version of these localities for field work, these lines were then drawn on similarly scaled images from the March 2000 digital black and white aerial photographs made available from the GCMRC GIS department.

In June 2001, each of the 100 segments was visited on a river trip whose purpose was to establish and document the transects prior to sampling in September. Using cues from shoreline morphology, locations of large rocks, channel features, etc., the starting points of the transects at the river's edge direction of the transect were identified. At this point, the transect was labeled either "usable' or "unusable" based on several criteria. Sites could be unusable for physical reasons (e.g., cliffs), safety reasons (in the middle of a rapid with no other access possible), or administrative reasons (e.g., traditional cultural property sites, Kanab Ambersnail sites). In these cases, photographs were taken of the site from the boat and the segment was excluded. At usable sites, a 50 m tape was run upslope from the starting point at the water's edge, perpendicular to the river’s flow, to a point above the 60 kcfs line using the cross-river point for lining up. The stage was approximated using cues from the location of old high water zone vegetation and debris from the 1996 45 kcfs flows. The top point of the transect and one or more points along the transect were marked with dots of blue, white, or pink nail polish then covered with a cairn of one or more small stones. If the entire transect was not visible from the top point, another point above the 60 kcfs elevation from which the entire transect was visible was also marked to serve as a local elevation control point. The elevation difference between the elevation control point and the previous day's high water line was measured to the nearest 5cm using an Abney level and a survey rod marked in meters and centimeters. All points and the tape lying along the transect were documented photographically and in written descriptions to make it easier to reestablish the transect and reoccupy the elevation control point during censuses in the fall.

Finally, the stage elevation of the elevation control points was determined using the height measurement and a numerical model of stage / discharge relations in Grand Canyon. After returning to Flagstaff, the hydrograph for the entire trip in 15 minute increments was acquired (USGS 2004; stations at Lees Ferry 09380000 and Phantom Ranch 09402500). These data were used as input to the Colorado River Flow and Sediment Storage / Graphic User Interface (CRFSSGUI) model (Korman and Walters 1998) which uses STARS model data and information on channel gradient, width and roughness to predict the timing and height of the hydrograph at any point along the river. Part of the output from the model run was an estimate of the high stage, which decreases with distance downstream due to flow attenuation. Given the field height measurement from elevation control point to the previous day's high water mark, the stage of that mark from the CRFSSGUI model, and the stage-to-discharge relationship available from the STARS model, the heights from the elevation control point to the 15, 25, 35, 45, and 60 kcfs stage elevation points were calculated.

To reduce investigator impacts and expand the area surveyed over the three years while still retaining statistical power in the first several years of sampling, an augmented serially rotating panel design was chosen for site selection (Urquhart et al. 1998). From the 100 sites visited in 2001, 60 of the 63 usable sites located in June 2001 were surveyed in September 2001. In the winter of 2002 we visited sites which had been given random selection order numbers 101 to 160 to locate transects for the second rotate panel. In 2003, we visited sites 161 to 240 to generate enough sites for the third rotate panel. Originally the plan was to have 20 sites in the repeat panel and 40 in each of three rotate panels. However, because a higher than expected proportion of the sites examined in 2002 were unusable (32 new "usable" sites), a slight deviation was necessary. In 2002, 25 of the 2001 sites were revisited and 35 new sites, including the three unused from 2001, were surveyed. In 2003, the original plan was reinstated and 20 of the 2001 sites were visited and 40 new sites were visited. After 2003, there are enough sites so that plans can include a regular cycle of 20 repeat sites and 40 new sites each year (Table Dyn-1). Similar methods have been employed to find sites in the Glen Canyon reach above Lees Ferry in which 6 usable sites have been located. These sites have been randomly allocated to three pairs which are assigned to years one, two or three.

Vegetation Sampling. Vegetation sampling was conducted in the fall each year as part of the integrated monitoring sampling trips (see COMMON METHODS section above). Transects between Lees Ferry and Diamond Creek were sampled during downriver trips. Upriver sites were sampled on day trips from Lees Ferry. Due to logistical constraints involving very long mileage days on the water, one or two sites were missed each year from the pool of 60 downstream and 2 upstream sites. However, a minimum of 60 sites were surveyed each year.

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 (Figure Dyn-1). 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 at 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 Dyn-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. We did not weight by abundance of each species because we were more interested in the small changes that result from recruitment into the frames than by the slow changes of common and abundant species.

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. Preliminary analyses of 2001 and 2002 data had shown that zones behave differently across years, producing a significant statistical interaction between year and zone terms. 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 COMMON METHODS section above for a complete description of how these measures were derived).

<u>Compositional analysis</u>. 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 and 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. The test statistic, R, varies between -1 and +1. Results of analyses of data from differing plots usually produce an R value of between 0.01 and 0.1, with values over 0.20 being rare. 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 (Sokal and Rohlf 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 COMMON METHODS 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.

Investigator impacts. To determine whether sites which were surveyed every year were being negatively affected by trampling and other forms of disturbance, we took advantage of the fact that some sites were visited two or three times during the three-year period (repeat panels) and others were visited only once (rotate panels). For this analysis, plots in the two transects which had been visited twice in three years were grouped with those which had been visited all three years. We performed mixed-effects split-plot ANOVAs, equivalent to a repeated measures analysis (SAS Institute Inc. 2001, p. 260), for vegetative cover and species richness in the plots. Predictor variables included reach width (narrow / wide, per Schmidt and Graf 1990), year and panel type as fixed effects, and site as a random effect, nested within panel type. Interaction effects between year and width and panel type were also included, as were interactions between width and panel type. Because we had detected strong interactions between stage level (15, 25, 35, 45, and 60 kcfs) and year in the other analyses described above, we analyzed changes at each stage level separately. We did not expect to find a difference between panel types, because plots were assigned in a strictly random manner. We predicted that investigator impacts would show up as a significant interaction between year and panel type, because surveyors tromping through the site would break branches, crush herbaceous plants and compact the soil.

Results

Univariate vegetation measures. At all stage levels, the analysis showed a loss of total vegetative cover in 2002 and 2003 (Figure Dyn-2, Table Dyn-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 Dyn-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 Dyn-3, Table Dyn-4). 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 Dyn-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 Dyn-4). There were no statistically detectable changes in richness at the 25 and 35 kcfs elevations between 2001 and 2003. However, 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 than either of them in our plots (Figure Dyn-4, Table Dyn-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 Dyn-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. An examination of differences among years showed that the species which showed up in wetter years were bromes and other opportunistic upland annuals which did not germinate in drier years.

Compositional analysis. The ANOSIM 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.

Substrate texture. The surface texture of soils in the plots changed only in the lowest plots (Figure Dyn-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 ($F_{(1, 31)} = 3.27$, $0.05 < p < 0.10$).

Investigator impacts. We did not find any investigator impacts in the transects which were visited repeatedly. In plots at none of the five stage elevations was vegetation in one type of panel consistently denser than in the other (Figure Dyn-7). Nor was the behavior of cover in the plot in the panel visited repeatedly different from the plots which were visited only once in the three years of surveys. The same was true for species richness in the transects (Figure Dyn-8). Neither type of plot contained more species consistently, nor were there any detectable differences in the changes of richness from one year to the next between the two plot types.

Discussion

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 might 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 result was in line with our expectations for two reasons. First, we predicted a major change in substrate texture and there was 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 associated with 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 effects of precipitation on wetland scores of the plots results from non-wetland species which germinate and grow during wetter years. Those species tend to be annual bromes and mustards, which are categorized as either upland or facultative upland species. When moisture conditions allow those upland species to establish in the lower elevation plots, they shift the wetland score to a lower value, or drier environment vegetation classification. 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 (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.

We had expected that there would be some loss of cover or loss of species in sites visited annually based on experiences of previous monitoring studies. Although their design did not allow for the analysis of these patterns, aerial photographs of intensely surveyed marshes showed obvious trailing along transects where surveyors would traverse between plots, even several years after the surveys were discontinued (personal observation). Here, we expected there to be a progressive loss of cover and species richness after three years of trampling and soil disturbance. Alternatively, disturbance may have created openings in which new species could establish. We find the lack of detectable investigator impacts in the case of these surveys to be reassuring. In an analysis of panel data on water quality in a similar design, the statistical power gained through the use of repeat panels declines after the first cycle is finished (Urquhart et al. 1993), so that annual visits to any site is unnecessary for statistical purposes, and all plots can be placed into rotate panels. Doing so, however, would require us to increase the number of available transects to more than 180 (3 panels of 60 plots vs. 1 panel of 20 plus three panels of 40). For this, we would have to run another transect set-up trip because we have fewer than 150 transects to draw from at the present time.

Most of the conclusions drawn in this section will remain tenuous 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.

Floyd,DA; Anderson,JL (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.

Herlihy, A. T., D. P. Larsen, S. G. Paulsen, N. S. Urquhart, and B. J. Rosenbaum. 2000. Designing a spatially balanced, randomized site selection process for regional stream surveys: the EMAP Mid-Atlantic pilot study. Environmental Monitoring and Assessment 63:95-113.

Kearsley, M. J. C., and T. J. Ayers. 1996. The effects of Interim Flows from Glen Canyon Dam on riparian vegetation in the Colorado River Corridor, Grand Canyon National Park, Arizona. Final Report. U.S. Department of the Interior, National Park Service Cooperative Agreement CA-8041-8-0002. v + 39 pages.

---. 1999a. Second year transition monitoring of riparian vegetation from Glen Canyon Dam to Pearce Ferry. Final Report. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center Cooperative Agreement CA 1425-96-FC-81-05006 #2. 35 pages.

---. 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.

Korman, J., and C. Walters. 1998. Users guide to the Grand Canyon Ecosystem Model. Available from Grand Canyon Monitoring and Research Center Website at: http://www.gcmrc.gov/whatwedo/products/simmodels/simmodels.htm . 48 Pages.

Malanson, G. P. 1993. Riparian landscapes. Cambridge University Press, New York.

Noon, B. R., T. A. Spies, and M. G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. Pages 21-48 *in* B. S. Mulder, B. R. Noon, T. A. Speis, M. G. Raphael, C. J. Palmer, A. R. Olsen, G. H. Reeves and H. W. Welsh, editors. The strategy and design of the effectiveness monitoring program for the

Northwest Forest Plan. General Technical Report PNW-GTR-437. U.S.D.A. Forest Service Pacific Northwest Research Station, Portland, OR.

Peterman, S. A., N. S. Urquhart, and E. B. Welch. 1999. Sample representativeness: a must for reliable regional lake condition estimates. Environmental Science and Technology 33:1559-1565.

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.

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

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

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.

Sokal, R. B., and F. J. Rohlf. 1995. Biometry, 3rd Edition. W.H. Freeman and Company, San Francisco.

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., K. A. Buck, B. T. Brown, and N. C. Kline. 1997a. Dam and geomorphological influences on Colorado River waterbird distribution, Grand Canyon, Arizona. Regulated Rivers: Research and Management 13:151-169.

Stevens, L. E., J. P. Shannon, and D. W. Blinn. 1997b. Colorado River benthic ecology in Grand Canyon, Arizona, USA: dam, tributary and geomorphological influences. Regulated Rivers: Research and Management 13:129-149.

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

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

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

Urquhart, N. S., G. T. Auble, J. G. Blake, D. T. Bolger, T. Gerrodette, S. G. Leibowitz, D. C. Lightfoot, and A. H. Taylor. 2000. Report of a peer review panel on terrestrial aspects of the Biological Resources Program of the Grand Canyon Monitoring and Research Center. June 23, 2000. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center. Flagstaff, AZ. 49 pp.

USGS. 2004. USGS Real Time Surface Water Data. Data for all USGS gaging stations available from http://waterdata.usgs.gov/nwis/.

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 Dyn-1. Temporal sampling pattern design for vegetation transects surveyed downstream of Lees Ferry. Note that the design was modified slightly in 2002 due to a high proportion of potential sites that were found to be unusable.

	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:	60	60	60	60	60

Table Dyn-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 Dyn-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 Dyn-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 Dyn-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	Top of Fluctuations	Flow Coeff.	Precip
15 kcfs	n.s.	n.s.	n.s.	n.s.
25 kcfs	$F_{(2,46)} = 27.86$ $P < 0.001$	$F_{(1,46)} = 52.54$ $P < 0.001$	0.0000304	$F_{(1,46)} = 32.67$ $P < 0.001$
35 kcfs	$F_{(2,46)} = 32.91$ $P < 0.001$	$F_{(1,46)} = 63.26$ $P < 0.05$	0.0000390	$F_{(1,46)} = 35.10$ $P < 0.001$
45 kcfs	$F_{(2,46)} = 13.29$ $P < 0.001$	$F_{(1,46)} = 14.34$ $P < 0.001$	0.0000380	$F_{(1,46)} = 25.40$ $P < 0.0001$
60 kcfs	$F_{(2,40)} = 9.450$ $p < 0.05$	$F_{(1,46)} = 6.61$ $P < 0.05$	0.000044	$F_{(1,46)} = 21.21$ $P < 0.0001$

Flow Coeff. = Coefficient of “top of fluctuations” in full model.

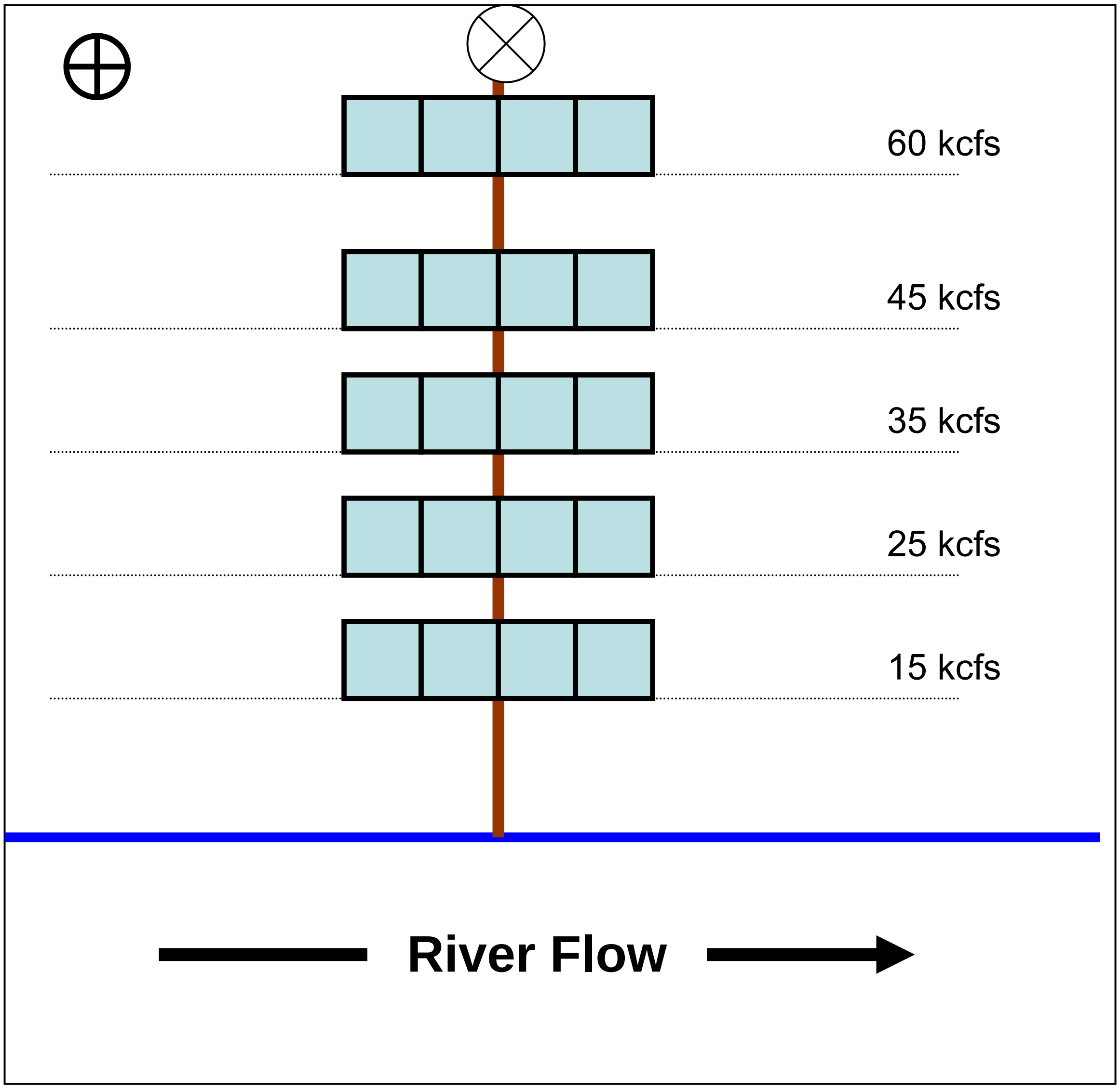


Figure Dyn-1. Diagram of sample transect in plan view. Transect (thick vertical line) is perpendicular to river flow, running from documented top point (Circle X) to the water's edge. Meter-squared survey plots (shaded boxes) are placed up- and downstream of the transect at estimated stage elevation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

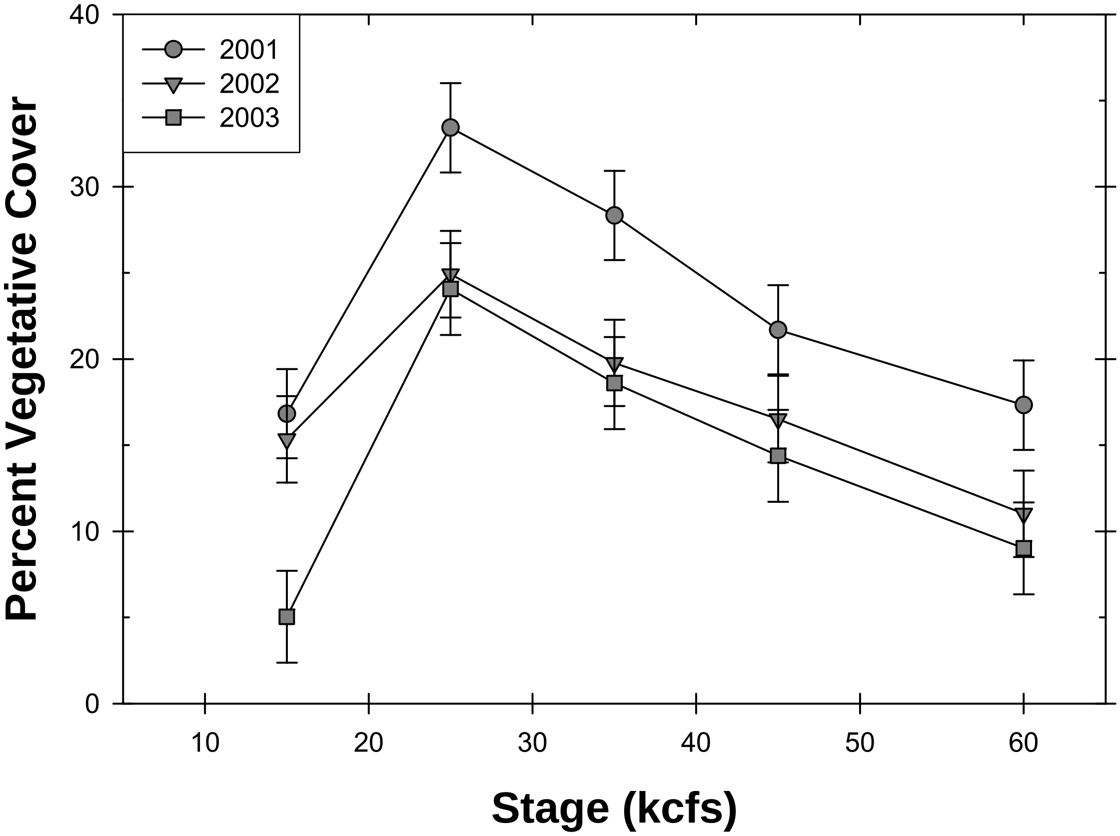


Figure Dyn-2. Percent vegetative cover at five stage elevation zones between 2001 and 2003. Vertical bars represent +/- 1 standard error.

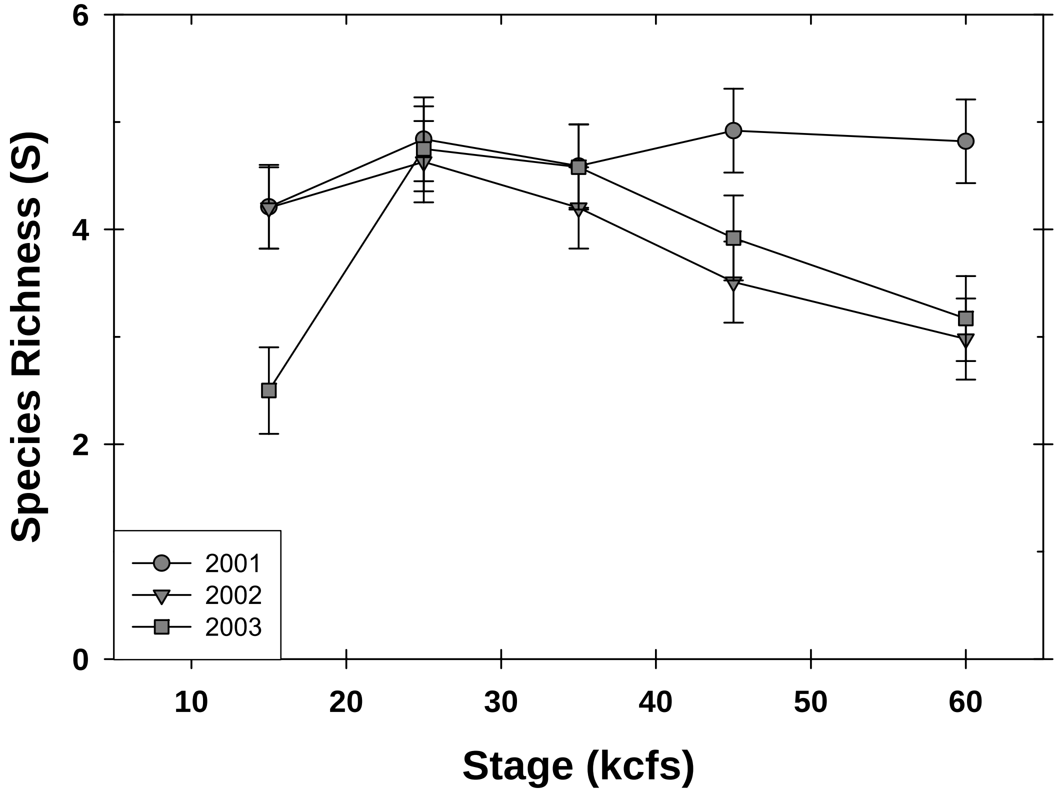


Figure Dyn-3. Species richness in five stage zones in 2001 and 2002, and changes between years. Vertical bars represent +/- 1 s.e.

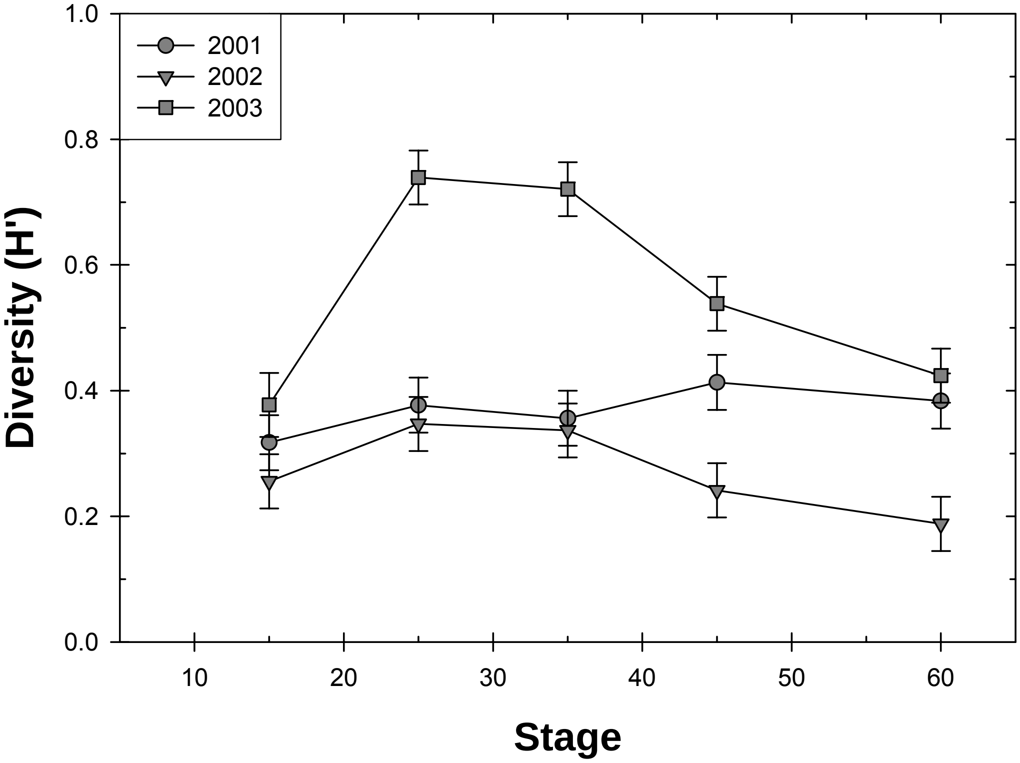


Figure Dyn-4. Shannon diversity (H') in five elevation zones between 2001 and 2003. Vertical bars represent +/- 1 s.e.

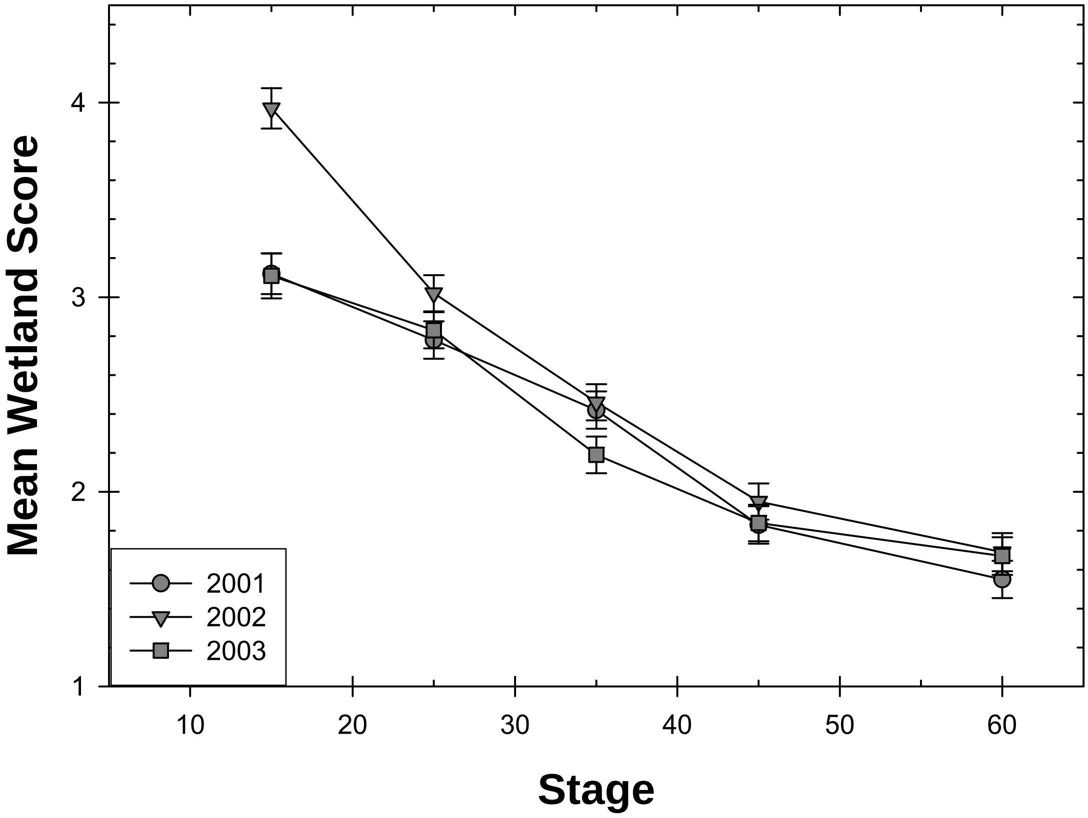


Figure Dyn-5. Wetland indicator scores in five elevation zones between 2001 and 2003. Higher scores represent more wetland affiliation. Vertical bars represent +/- 1 s.e.

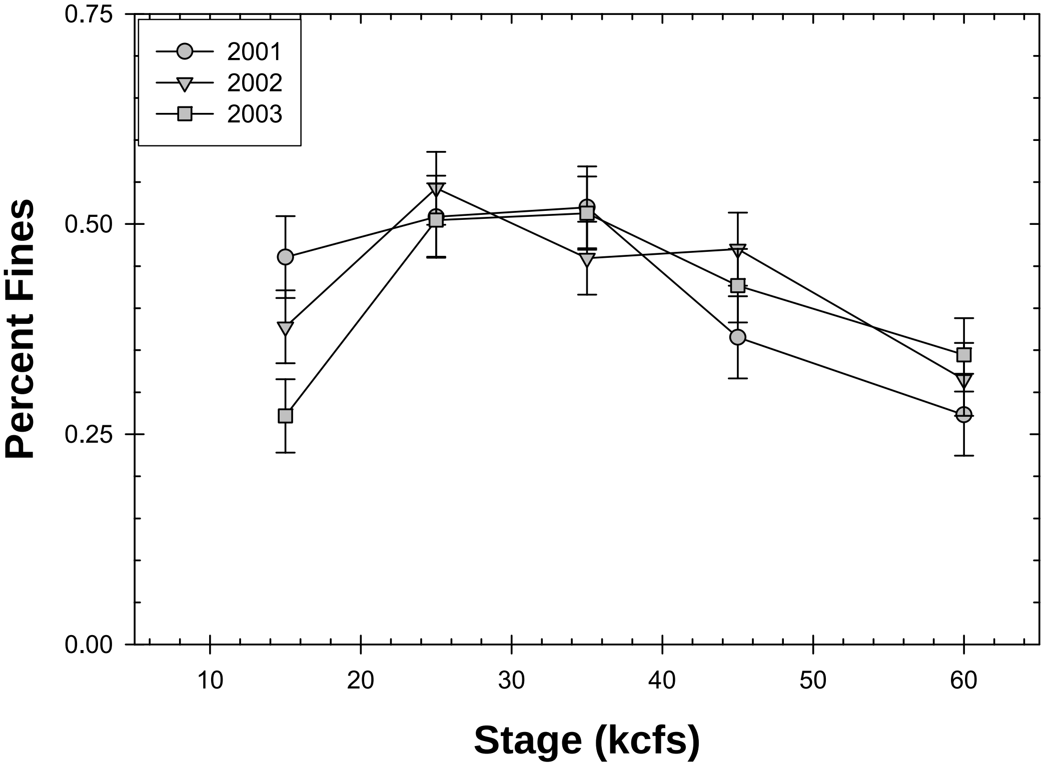


Figure Dyn-6. Soil texture changes between 2001 and 2003 in five elevation zones. Data represent the percent of points at the stage zone covered by sand or finer sediments. Vertical bars represent +/- 1 s.e.

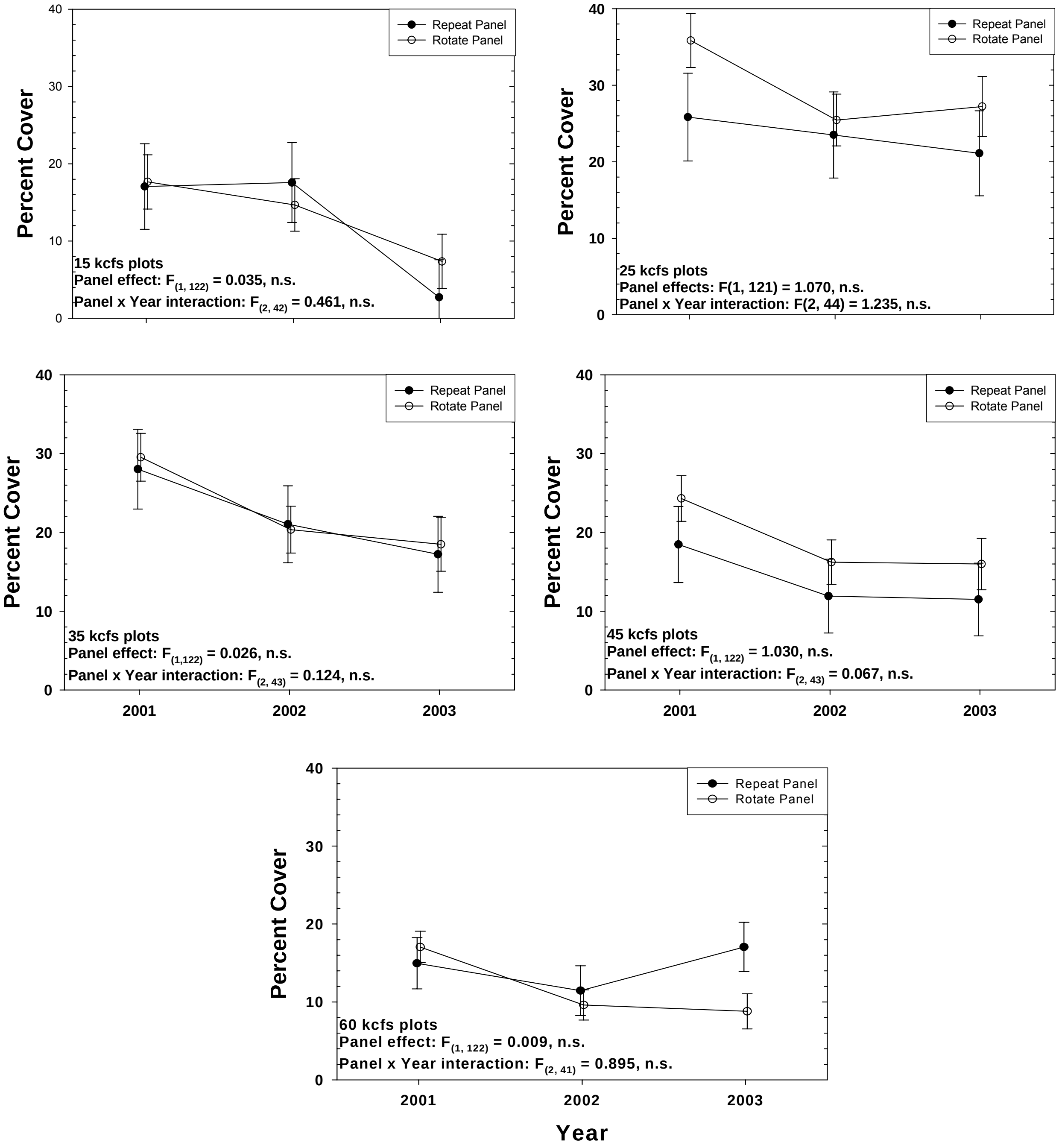


Figure Dyn-7. Vegetative cover in the five stage elevation plots in panels visited each year (repeat panels) and those visited only once between 2001 and 2003 (rotate panels). Vertical bars represent ± 1 s.e.

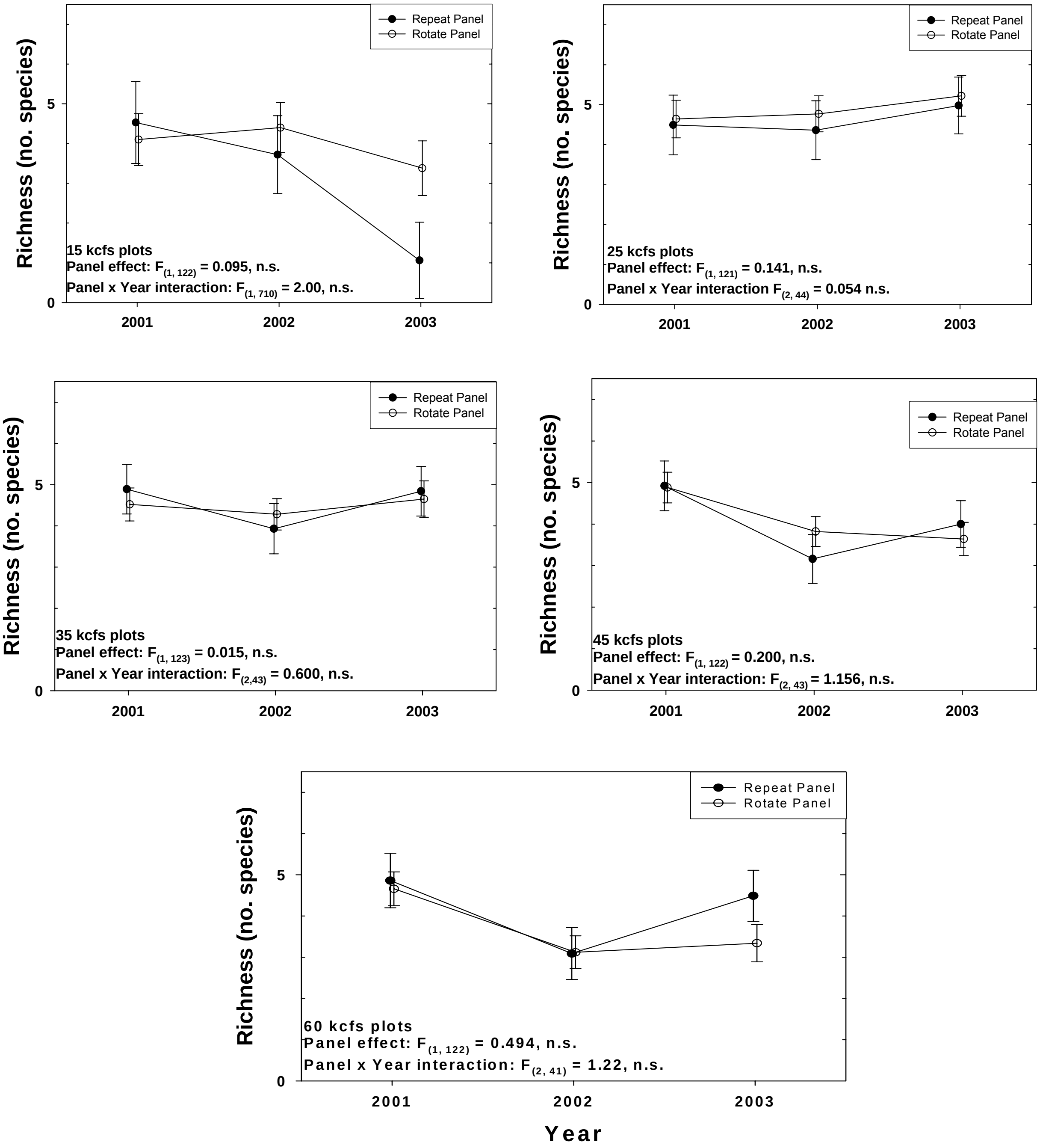


Figure Dyn-8. Species richness in plots at the 5 stage elevations in the plots visited each year (repeat panels) and plots visited only once between 2001 and 2003 (rotate panels). Vertical bars represent ± 1 s.e.

PART IV

RECOMMENDATIONS FOR IMPROVED INVENTORY AND MONITORING METHODS

Michael J. C. Kearsley
David C. Lightfoot
and
Sandra L. Brantley

The methods used for this inventory and monitoring project were developed and tested over the three-year course of our survey. Some aspects, including study site selection and bird sampling methods, were dictated by GCMRC in the Request for Proposals and in subsequent meetings or memoranda afterwards. Many of these and our own methods proved useful in addressing our research questions, while others proved problematic. There were also several aspects of the field and analytic work that we did not anticipate, including logistical or methodological problems, and findings that were inconsistent with predictions from the literature. We explain these and make recommendations for potential solutions.

There are two major parts of this section. The first is a description of problems and potential solutions regarding specific elements of the inventory and monitoring that were encountered. We begin with design problems and then proceed through issues with sampling the taxonomic groups in the same sequence as they were presented in the preceding pages. The second part is a set of overall recommendations for future long-term monitoring of Grand Canyon terrestrial riparian corridor biotic resources in response to dam operation, based on the findings of our three-year inventory and monitoring study and other previous research.

General TEM Project Survey/Sampling Problems

Sampling patches versus habitats. The lack of a GIS base map from which to select study sites hampered our ability to generalize the conclusions that we made from our "patches" to the entire riparian area in the river corridor. Our conclusions are valid for the set of areas defined as historically surveyed sites and places which appeared to be historically surveyed sites on aerial photographs based on vegetation extent and density. However, it is not yet possible to discuss the number of breeding birds, arthropods, lizards or small mammals or the status of vegetation density in the entire river corridor because we have been sampling points in a non-random way. Our finding of the Southwest willow flycatcher in a "non-traditional" site is a case in point; by restricting the set of possible sampling localities, one restricts the amount of information available.

In the future, GCMRC should consider taking a different approach to sampling such that sampling points are determined in a random manner. As with the vegetation dynamics sampling, potential sites would then have to be visited beforehand to eliminate those sites that would yield no data (e.g., cliffs, steep rocky areas) about changes in habitat quality or the abundance of wildlife. And rather than focus on patches of vegetation that look distinct to trained human observers, sampling could be done in 100 – 200 m segments of new high water zone and adjacent old high water zone vegetation. From this kind of sample, it would be possible to scale up to the entire river corridor and would allow for statistically defensible conclusions. Such an approach may be logistically difficult relative to number and frequency of river trips, and problematic for fixed-point samples like mammal traps and pitfall traps in an integrated monitoring setting.

Trip- versus site-driven sampling. For several of the faunal surveys contained in this project, the time available to sample within a site was not always adequate. First, for some taxa, particularly small mammals, a single night at a site often does not yield an adequate sample of the richness and abundance of the individuals present. Second, arthropod survey crews needed to break down gear and move to the next site in time to set up survey equipment by early evening (4:30 – 5:00 pm) so that mid-day sampling was precluded in any of the sites. Third, the conditions during some days were inappropriate for sampling, such as when cold, rainy or windy conditions kept the cold-blooded species inactive and the breeding birds quiet and less prone to fly. As a result, estimates of the abundance for some taxa were probably below actual numbers during some site visits. To address all of these problems, we recommend sampling sites for 2 to 3 consecutive days when faunal sampling is planned.

Vegetation

Vegetation volume / habitat sampling. Our initial plan was to measure only woody vegetation volume as had been done in bird studies, and attempt to relate these measures to other taxonomic groups. Although it reliably predicted an upper limit on the density of breeding birds in our sites, it failed as a measure of overall habitat for other taxonomic groups. Only herpetofauna were marginally related to TVV, and the relationship was negative in that case. By collecting data on herbaceous species, plus measuring vegetative cover in broad cover classes along the integrated sampling transects, we were better able to link vegetation to the mammals and invertebrates. In the future, other measures of habitat quality for mammals and herpetofauna, such as substrate texture and coarse- and fine woody debris should also be measured. Such measures would likely change with different river flow regimes.

By measuring vegetation volume of woody species, we were able to link the amount of vegetation in terrestrial habitats to dam operations. Previous links were anecdotal, and usually related to unusual events such as the mid-1980s high flows or major flooding from the Little Colorado River. Here the connection was made to parameters of daily flow, which should be more useful to water managers who need to plan releases a year in advance.

The number of sites visited each year for vegetation volume was set by factors other than the characteristics of the vegetation. We visited at least 65 bird sites per year because a power analysis on trends in breeding bird abundance (J. Spence, Glen Canyon NRA, unpublished data) showed that this was an appropriate number for estimating bird densities. The number of integrated monitoring sites where TVV was measured was set at 14 per trip by logistical constraints. In both cases we were able to detect between-year differences in vegetation volume.

Although it is tempting to rely on the smaller number of sites from the integrated monitoring patches, for the sake of generality it would be better to sample more sites on a yearly basis. The integrated monitoring sites were more homogeneous in terms of size and vegetation density than the larger population of bird patches, so there was less between-site variation in vegetation density to mask any between-year differences. To derive more broadly applicable trends in vegetation volume, we recommend that the larger number of less homogeneous sites be surveyed in any future studies with goals to measure habitat characteristics.

Vegetation volume sampling needs to be linked more directly to the hydrograph. During this project, it was separated into broad hydrologic zones, but was a source of higher variability in the bird patches. Much of the difference between trends in our vegetation volume estimates in bird patches and TEM sites was related to higher variability in bird patches because we ranged across the entire 25,000 to 80,000 cfs zone rather than being limited to a tighter area around faunal transects. The new stage-discharge model in the GCMRC GIS could be used to narrow the bands surveyed for vegetation volume. Non-emergency releases from the dam are limited to 60,000 cfs, so areas above this point are not really part of the "new high water zone" area.

Vegetation dynamics studies. The vegetation dynamics surveys have yielded useful information on trends in plant abundance and their connection to the hydrograph and precipitation patterns at different stage elevations. After three years of surveys, we detected a slight negative effect of increased flow on cover and plant species richness. This was likely an artifact of not having enough variation in flow and precipitation parameters or not enough time for trends to fully develop. With another year of sampling (2004), we detected a stronger and more statistically significant positive effect of flow on cover and species richness above the 25 kcfs elevation (M. Kearsley, unpublished data). Having an extra year of surveys with high spring and summer flows allowed us to detect this effect.

Because the sampling plan was spatially balanced and probability based, we can extend conclusions about the behavior of vegetation in study plots at different stage elevations to vegetation at those elevations throughout the river corridor. More importantly, we can extend the conclusions about the relationship between vegetation measures and the hydrograph to the river corridor as a whole.

The number of samples (60 per year) has been adequate to detect change as shown by power analysis by N. Scott Urquhart (N.S. Urquhart and M. Kearsley, MS in prep) examining the levels of components of variation found in the system including year effects, site effects, trend effects and error. The results showed that this sampling plan is able to detect a 2% per year trend in vegetative cover at the 25 kcfs stage elevation after 15 years with a probability of 75%. At 5% per year, that time is shortened by roughly half. Thus if cover measures 35% in the 25 kcfs plots, we would conclude that a drop to 25% cover was statistically significant after 7 – 15 years (5% of 35% per year for 7 years or 2% of 35% per year for 15 years). The detection probabilities are even higher for changes in species richness; based on an average of 5 species per plot, we would be able to detect a drop to four species per plot after 10 years with a probability of roughly 85%.

The rotating panel design has been helpful in minimizing investigator impacts on the sites. We were not able to detect differences in investigator impacts between the "rotate" panels, visited once in three years, and the "repeat panels" that were visited every year. Those visited yearly did not lose cover or richness due to erosion and trampling, nor did they significantly increase in richness due to the introduction of seeds on investigators' footwear. The statistical power gained from adding the "repeat" panel to a rotating panel setup will allow us to detect trends in the vegetation sooner than would be possible under a strictly rotating setup or a fully random setup.

Arthropods

Arthropod survey sampling schedule. One major problem with the arthropod surveys was that the number and timing of surveys undoubtedly meant that we were not able sample all of the potential species relative to inventory. Our surveys did not completely coincide with times of the year when different species were active. Most arthropod species are short-lived, many less than 30 days for the adult stage, which is the life stage needed for proper identification. Ideally, inventory work should be conducted throughout the year, but logistic restrictions limit trips to only a few per year. In contrast to inventory, we recommend that future arthropod monitoring studies focus on the spring/early summer season, when arthropod abundance and richness tend to be high. In relation to integrated research, that also is the time of year when breeding birds rely on arthropods as a food resource.

Plant-dwelling arthropod sampling. Quantitative vegetation foliage sweep-net sampling for plant-dwelling arthropods was designed to provide a standardized sample from a volume of vegetation measuring 2 m in all directions from the person taking the sample standing on the ground at the sampling point. The intention was for all samples across hydrologic zones and sites to represent a comparable standardized volume with reference to the ground. We now believe that this method was somewhat flawed in that we did not adequately sample foliage arthropods in situations where the vegetation canopy was greater than 2 m in height, such as in large tamarisk or mesquite stands. In large stands, 2 m sample areas consisted mostly of subcanopy woody branches rather than green foliage. Since most foliage arthropods occur on the leafy foliage rather than woody branches, sweep samples from tall woody vegetation probably missed many of the foliage arthropods. Although the method used was good to standardize a volume of space, we recommend modifying the method to sample a standardized volume of "green foliage vegetation." However, such an approach will be more difficult to standardize between sampling points, because vertical sample location selection becomes more subjective and prone to bias. There are additional problems with sampling at various heights while maintaining consistency in sweep net function. Use of ladders and/or long-handled nets may help, but are problematic in that such sampling is still not comparable to a person standing on the ground, and is time consuming and difficult to perform. Another approach is to sample a "cylinder" of vegetation volume from the ground to the top of the canopy, but then stand height becomes a confounding covariate, sample volumes need to be standardized, and more effort is required to collect the samples. We recommend that attempts to develop a sampling procedure following the above possibilities should be explored for future foliage arthropod sampling methods.

Plant-dwelling arthropod taxonomy. The plant arthropods were represented by a large number of taxa representing many groups where identification to the genus and species level are very difficult and time consuming. Diptera, Hemiptera and Homoptera in particular were represented by many species, and there currently are no taxonomic experts available to identify many of those taxa. We recommend that long-term ecological monitoring studies need not identify all taxa to the family, genus, or species level. Some arthropod orders are relatively small, and the taxa are ecologically similar, such as Homoptera. Other large orders are represented by families that are ecologically very different (e.g., Coleoptera and Diptera). Some genera and species are distinct and easily identified (e.g. most Odonata, and some Coleoptera, Orthoptera, and Lepidoptera). A good sampling strategy should employ variable taxonomic ranks for arthropods depending upon abundance and ease of identification. Some taxa can readily be monitored at the species level, and others meaningfully monitored at the order level. Expert arthropod biologists should be employed to make the decisions as to what taxa to monitor, and which taxonomic ranks are appropriate for those taxa, given the goals of monitoring.

Chironomid midges. We did not quantify chironomid midge numbers or species composition in our study because of the tremendous amount of time that would be required. However, given that midges do represent a direct link between aquatic river productivity and the terrestrial riparian environment, we recommend that future monitoring studies consider sampling midges with Malaise traps. As mentioned above for plant arthropods, midges need not be identified to genus or species (of which there are many in the Colorado River) to provide valuable information on potential biomass and nutrient transport from the aquatic to the terrestrial system.

Herpetofauna

Herpetological surveys. The Protocols document within the Request for Proposals for this project stipulated that herpetological surveys would be conducted at all bird patches. This precluded reasonable results based on the ectothermic nature of the reptiles. In order to sample all the sites, the surveyors had to leave camp early and visit several sites before the sun reached the beach and warmed substrates sufficiently for lizards to be active. Hence, many of the April / May surveys were conducted on beaches where lizards were likely present, but none were documented because they were not yet active. In September during fall surveys of the second and subsequent years, the herpetofauna survey crew remained in camp with the arthropod crew until late morning. Although fewer sites could be surveyed, this allowed a more thorough search to be conducted in each site surveyed. In addition, it allowed for conditions to be more consistent among all surveys. Herpetofauna surveys within each of the hydrologic zones across all sites lacked time standardization. We did not spend the same amount of time surveying for herpetofauna in each zone at each site. We did standardize herpetofaunal surveys for patch size, but future surveys also should consider rigorous time standardization (equal time per zone over all sites, at the same times of day) as well. We recommend that future monitoring studies consider reptile sampling for a minimum of two days so that all diurnal environmental/thermal conditions will be available for surveys.

Birds

Point count versus walking survey data. The physical layout of vegetation in the riparian corridor in narrow bands of new- and old high water zones often made it difficult to survey birds in a traditional fixed-radius 50-meter manner. It was the unusual site that had enough depth of vegetation to allow even a single, full plot. Furthermore, the point count method consistently detected fewer individual birds and fewer species of birds in comparisons of the two methods within the same sites.

We used both walking surveys and point counts in the fieldwork. The former generated better estimates of bird species richness in our sites for trend analysis and were comparable to data from three previous studies (Brown 1989, Sogge et al. 1997, Spence 2000), which used this same method. Point counts may allow better comparison of current data to previously collected data in which point count methods were used and are likely a more consistent and more quantitative method. In addition, we may be able to detect long-term trends in bird populations on a regional scale by including distance estimation parameters in our data collection. During walking counts and point counts on the June trip, we began to record the estimated distance in meters from the observer to the bird. Distance estimation techniques (Buckland et al. 1993, 2001; Fancy 1997) are being used throughout National Parks in the Western United States to estimate density of birds. We recommend that transect walking counts with observer to bird distance measures, be used for future monitoring studies.

Efficacy of nest searching. Nest searching did not appear to be an effective means to determine changes in abundance and composition of nesting birds within and between OHWZ and NHWZ patches across time. Due to the time limitation for nest searches at each site, only the most conspicuous nests were found. For example, the highest numbers of nests located during both field trips in 2001 were those of Black-chinned Hummingbirds (13 nests). During the 2001 surveys, we had a total of 94 detections for this species. Black-chinned Hummingbirds build fairly conspicuous, open cup nests (Ehrlich et al.1988) and are very territorial (i.e., they will “buzz” an intruder). Locating these nests poses little difficulty for nest searchers with limited time. Lucy’s Warblers, however, build well-concealed nests, usually in cavities (Erhrlich et al. 1988), which are difficult to find. Though Lucy’s Warblers were the most common species detected during surveys (690), only six Lucy’s Warbler nests were located during both field trips.

In 2002 and 2003, we implemented territory mapping consistent with Sogge et al. (1997) and quantified breeding bird behavior as described in the Arizona Breeding Bird Atlas Handbook (Corman 1994). Territory mapping is an effective method to estimate numbers of territories (indicating a nesting pair) for each bird species detected within each patch without actually observing the nest. Walking surveys and territory mapping have proven to be successful in tacking long-term trends in bird abundance (Holmes and Sherry 2001). The addition of territory mapping and breeding bird criteria to our data for examining numbers of breeding birds by behavior may be the most practical way to assess breeding bird abundance and composition.

Southwestern Willow Flycatcher issues. We recommend that persons conducting willow flycatcher surveys be familiar with all flycatcher songs and calls and not be completely reliant on a “fitz-bew” response to song playbacks. Solitary pairs of willow flycatchers may not respond to the standard “fitz-bew” song. At site RM 50.4L, an established breeding site, the “fitz-bew” tape was played numerous times for a two-hour period, and no “fitz-bew” response was detected. In visiting the site mid-July that year, we found a willow flycatcher nest and a pair of flycatchers (presumably the same pair found in early June) feeding two fledged offspring. We speculate that solitary pairs of flycatchers not breeding in a “semi-colonial” fashion typical of the species may not be responsive to song playbacks due to lack of intra-specific interactions. In areas where willow flycatcher numbers are low and solitary pairs exist, such as along the Colorado River in Grand Canyon, it would be possible to miss breeding flycatchers if surveyors are not trained to recognize all songs and calls.

As described above, our discovery of the pair of flycatchers was based solely upon the "creet" and interaction call vocalizations and visual identification by expert observers (Robert Mesta - USFWS, Peter Bichier Garrido - Smithsonian Institute, Helen Yard - USGS/GCMRC avian ecologist). The birds did not respond to the "fitz-bew" tape even when played numerous times. The pair of breeding Southwestern Willow Flycatchers discovered at a new location in Grand Canyon (RM 28.3L) was found by auditory detection of other calls ("creet," "weoo" interaction calls) described by Sedgewick (2000). RM 28.3L had never been included in past bird surveys. Finding willow flycatchers at the site was coincidental with a general bird survey. This clearly demonstrates the importance of surveying randomly selected sites. Additionally, future surveys of random and deliberately selected vegetation patches on the lower end of the river (RMs 180–225) may be valuable in detecting flycatchers. Known flycatcher nesting sites are documented below RM 225 in Lake Mead (pers. comm. T. Koronkiewicx, 2004, SWCA Environmental Consultants). Flycatchers may migrate up river from those nesting sites at some point in the future.

Difficulty in flycatcher detections along the river in Grand Canyon may also be based on limited site visitations and timing of surveys. Surveys in May are valuable in detecting migratory flycatchers and early male arrivals establishing territories. The June survey period (also a time of territory establishment, nest building and egg laying) may be especially important in detecting the birds in Grand Canyon. Flycatchers are known to have lower song rates later in the breeding cycle (while caring for nestlings and fledglings) and during this time may be highly secretive as a way to protect their offspring.

Careful consideration should be given regarding any removal of non-native vegetation along the Colorado River in Grand Canyon. Removal of non-natives, such as tamarisk, then replanting with native vegetation is not necessarily "good" for potential flycatcher habitat. A high mean number of flycatcher nests in Central Arizona were found in tamarisk (49) when compared with native Goodding's willow (0.4), Velvet mesquite (0.8) with the highest number of nests surprisingly located in snags (116.8) (Allison et al. 2003). Studies in other flycatcher breeding habitat in the Southwest have revealed similar results, therefore the removal of non-native vegetation should be scrutinized (Whitfield et al.2003).

<u>Bird survey methods and timing</u>. If future bird censuses are conducted, we recommend one of three methods: spot mapping, 50m fixed-width line transects, or 10-minute fixed radius point counts (50 m). Aerial photographs for all sites are available from GCMRC. Spot mapping is time intensive and sites would need two visits by observers for accuracy. If time is an issue, we recommend either fixed-width walking transects (50m boundaries), or 10-minute fixed radius point counts. Five-minute unbounded point counts required in the original Request for Proposals used in this study revealed low numbers of birds when compared to walking transects. Walking transect methods used in the current study could then be used to compare future data.

To maximize breeding bird counts and assessments, future studies may consider conducting field trips during the optimal breeding season (between May and July). April and early May surveys during the current study revealed large numbers of wintering and migratory bird species that do not necessarily breed in Grand Canyon. Chronologically, birds arrive on the lower end of the river first (coming up from southern wintering locations) then migrate up river and establish territories in breeding locations around mid-May, then nest through late June-early July (Brown 1989). Information on nest outcomes and fledglings would reveal better results if conducted June through the end of July.

Avian productivity. To assess avian productivity, we recommend the Breeding Bird Atlas data collection method described by Corman (1994), which was carried out over several years (seven or more). Bird productivity estimates in Grand Canyon are especially difficult due to limited access to sites, logistical constraints, and expense. More accurate population estimates of birds to determine regional trends would be possible but would take numerous days of visitation at the same sites using the same methods of collecting census data, finding nests, determining nest outcomes and other parameters (Holmes and Sherry 2001). A carefully designed study to assess avian productivity would require an enormous effort and a large amount of funding which may not be feasible.

Mammals

Mammal specimen vouchering. The severe restrictions placed on our ability to voucher small mammals created problems in terms of the perceived validity of the work. Field identification, based on gross external morphology, could not verify species identification. During the 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 would represent a new record for the Park and a range extension for the species. Without more extensive collections, the results will continue to be inconclusive. We recommend better support for vouchering reference mammal specimens for future inventory and monitoring research in Grand Canyon.

Multiple night sampling for rodents. We were able to trap rodents for only one night per site visit, which was likely not adequate to sample all rodent species and individuals. Survey rodent sampling is usually conducted for at least three consecutive nights, animals are marked, and recapture rate is used to evaluate adequacy of sampling. We were not able to do this with one night of trapping. We recommend that future monitoring studies should allow for three consecutive nights of rodent trapping.

Summary recommendations for future long-term monitoring studies of for the effects of dam operation on terrestrial riparian biota of Grand Canyon.

Study site selection. The sites chosen for this inventory and monitoring study were large vegetation patches that had previously served as bird study sites. Therefore, the results of our inventory and monitoring study only can be applied to such sites. If future monitoring of the riparian corridor of Grand Canyon is intended to represent the entire riparian corridor, then monitoring sites should be randomly chosen from all possible such locations in the canyon. We recommend that random or stratified random sampling be used to locate future monitoring sites. Within this structure, the site selection method should be determined by the goals and purpose of monitoring studies.

Intensity, replication, and appropriate vegetation and faunal elements for long-term monitoring. Based on our findings and recommendations, we propose two different types of future biotic monitoring scenarios; one that emphasizes extensive spatial replication of study sites throughout the riparian corridor for vegetation and birds; and the other that emphasizes intensive monitoring of other animals, by allowing more intensive sampling at fewer sites.

Sampling intensity. Spence (unpublished data) and Kearsley and Urquhart (MS in prep.) conducted power analyses revealing that the appropriate numbers of study sites per year were 65 for bird surveys, and 60 for vegetation dynamics. If the goal of a long-term monitoring program is to assess bird and vegetation responses to river fluctuation over the entire Grand Canyon corridor, then a series of about 60 randomly located sites is appropriate. Some level of arthropod sampling, such as quick sweep-net samples of vegetation could be incorporated into such a design with an emphasis on measuring biomass of functional groups rather than enumeration of all taxa present. However, more intensive sampling such as pitfall taps or Malaise traps, and more extensive vegetation arthropod sampling, and sampling for mammals and reptiles would have to be limited to some subset of about 10-20 such sites per year, allowing for 2-3 sampling days per site. That subset of sites should all be part of the larger set of vegetation/bird sites for integration purposes.

Sampling for animals at a subset of sites would need to be conducted on separate trips from the more extensive and rapid vegetation and bird sampling trips. The most serious problem with the design of our three-year study was that one day/night per study site was not adequate to sample most animal groups. In particular, reptiles and mammals should be sampled for two-three days/nights in order to obtain appropriate representation of all species present at a site. Plant-dwelling arthropods should be sampled from the tops of the vegetation canopy, requiring the use of ladders or other methods that would take considerably more time than the simple sweep-net approach used in this study. Ground, plant, and night-flying arthropod sampling from 16 hours at each of 14 sites did produce data that adequately demonstrated water zone differences in species composition and abundance, and annual differences that we could attribute to variation in rainfall. However, reptile and rodent sampling data did not reveal such strong patterns, probably largely due to the inadequacy of one day/night sampling periods.

During our three-year study, we sampled in the spring (April/May), mid summer (June/July), and autumn (September). If sampling must be limited to one season per year, then late spring/early summer is preferable, because the flora and fauna of the riparian corridor have Mojave Desert affinities with peak productivity during that time and because it may allow better demonstration of links between vegetation, breeding birds and these other taxa.

Biological taxa to be studied. Based on data in this report and our experiences during this project, we recommend that most emphasis in future monitoring be directed towards vegetation, breeding birds and one or more subsets of the arthropods that we have sampled. Surveys of small mammals and herpetofauna yielded variable results, and they would likely need to be sampled of multiple days within a single year. Useful inventory information has been gained from surveying them, but specific information needs would need to be identified relative to abundances in order to justify long-term monitoring.

Vegetation. Vegetation volume responds to flow parameters. Thus, decisions about flow during winter and early spring months will have direct and measurable effects on energy flow through terrestrial food webs and recreational values through aesthetics and vegetation encroachment on campsites. Similarly, vegetation cover during fall surveys is also affected by flow parameters, and presents an opportunity to study the effects of spring and summer flow regimes on plant abundance and species richness.

Arthropods. As primary consumers, arthropods represent a link between vegetation and higher trophic levels. Correlation analysis revealed many positive relationships arthropod taxa and the density of specific plant types. Because it is a quantitative method, we recommend that ground-dwelling arthropods be surveyed in future monitoring programs using pitfall traps. Ground arthropod taxa can and should be identified and tabulated to at least the family rank for isopods, crickets, ants, ground beetles, spiders and darkling beetles. And even though they were not selected for quantitative analysis during this study, we recommend that chironomid midges with aquatic life cycle stages be sampled using Malaise traps, given the long history of aquatic foodbase studies in Grand Canyon showing links between flow parameters and aquatic invertebrates. There will be many other species present in the Malaise traps, but these can be set aside for future processing until there is the need and funding to identify them and / or quantify their abundance. Midges should be identified only to the family rank, saving considerable time, and still providing data for a river based food resource to terrestrial birds. Consideration should be made for the inclusion of plant-dwelling arthropods, since they provide food for breeding birds. However, identification of plant arthropod taxa should be limited to important functional/ecological groups such as caterpillars, beetles, flies, and spiders. As with the midges, the pooling of many taxa will save time, and still provide valuable ecological information about arthropod abundance, and food resources for birds. The inventory results of our study now provide valuable information on the actual species that represent those groups.

Breeding birds. Although breeding bird densities did not respond directly to flow parameters, they are strongly correlated with vegetation density and many breeding bird species are regarded by Tribal Stakeholders as traditional cultural properties. In addition, data from the three years covered by this study showed a consistent decline in breeding bird densities that could not be explained on the basis of sampling changes. We see this as a compelling reason to determine if bird densities have continued to drop in the years since then. We recommend that decisions regarding Southwestern Willow Flycatcher monitoring be left to the federal Fish and Wildlife Service, since endangered species monitoring generally serves a different and more specific set of research goals and sampling protocols than general terrestrial biotic community monitoring.

See Table Rec-1 for a summary of our recommended sampling schedules taxa, and methods for future biological monitoring of the terrestrial riparian corridor.

Literature Cited

Allison, L. J., C. E. Paradzick, J. W. Rourke, and T. D. McCarthey. 2003. A characterization of vegetation in nesting and non-nesting plots for Southwestern willow flycatchers in Central Arizona. *In* Sogge, M. K., B. E. Kus, S. J. Sferra, and M. J. Whitfield, (editors). Ecology and conservation of the willow flycatcher. Studies in Avian Ecology No. 26:81-90.

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.

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.

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

Ehrlich, P. R., D. S. Dobkin and D. 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.

Holmes, R. T. and T. W. Sherry. 2001. Thirty-year bird population trends in an unfragmented temperate deciduous forest: Importance of habitat change. Auk 118:589-609.

Rothstein, S. I., B. E. Kus, M. J. Whitfield, and S. J. Sferra. 2003. Recommendations for cowbird management in recovery efforts for the Southwestern willow flycatcher. *In* Sogge, M.K., B. E. Kus, S.J. Sferra, and M.J. Whitfield, (editors). Ecology and conservation of the willow flycatcher. Studies in Avian Ecology No. 26:157-167.

Sedgewick, J. A. 2000. Willow Flycatcher (*Empidonax traillii*). *In* A. Poole and F. Gill, (editors). The Birds of North America, No 533. The Academy of Natural Sciences, Philadelphia, PA and the American Ornithologists' Union, Washington, DC.

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. 2000. Summary of the 1996-1999 Avian monitoring program along the Colorado River from Glen Canyon Dam to Upper Lake Mead. Unpublished report submitted to Grand Canyon Monitoring and Research Center. National Park Service, Resource Management Division, Glen Canyon NRA. Pp 20.

Whitfield, M., J., M. K. Sogge, S. J. Sferra, and B. E. Kus. 2003. Ecology and behavior-Introduction. *In* Sogge, M. K., B. E. Kus, S. J. Sferra, and M. J. Whitfield, (editors). Ecology and conservation of the willow flycatcher. Studies in Avian Ecology No. 26:53-55.

*******Possible Spence/Urquhart refs
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. Pages 71-85 *in* V. Barnett and K. F. Turkman, editors. Statistics for the environment. John Wiley and Sons, New York.

Urquhart, N. S., G. T. Auble, J. G. Blake, D. T. Bolger, T. Gerrodette, S. G. Leibowitz, D. C. Lightfoot, and A. H. Taylor. 2000. Report of a peer review panel on terrestrial aspects of the Biological Resources Program of the Grand Canyon Monitoring and Research Center. June 23, 2000. U.S. Department of the Interior, Grand Canyon Monitoring and Research Center. Flagstaff, AZ. 49 pp.

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.

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.

Spence, J. R. 2000. Summary of the 1996-1999 Avian monitoring program along the Colorado River from Glen Canyon Dam to Upper Lake Mead. Unpublished report submitted to Grand Canyon Monitoring and Research Center. National Park Service, Resource Management Division, Glen Canyon NRA.

Table Rec-1. Recommended survey schedule, taxa, and methods for future biological monitoring of the terrestrial riparian corridor in Grand Canyon.

Annual survey schedule			
Trip (timing)	Group	Survey Methods	Output
Spring 1 (Early May) 14 days	Breeding Birds	Point counts with distance sampling	Breeding bird density
	Vegetation	Vegetation volume for all patches	TVV: woody, herbaceous.
Spring 2 (Late May / Early June) 14 days	Breeding Birds	Point counts with distance sampling	Breeding bird density
Spring 3 (Late May) 18 days	Arthropods	Pitfall traps Malaise traps Sweep net (with ladders)	Ground-dwelling and day-active flying insects, specifically midges. Caterpillars, beetles, spiders, flies (identified to those functional groups only)
Spring 4 (Late June / Early July)	Breeding Birds	Point counts with distance sampling	Breeding bird density
Fall 14 days	Vegetation	Vegetation transects with elevation.	Cover, species richness, percent exotics by stage elevation

Appendix A

List of plant species encountered

Taxonomy follows that of the USDA PLANTS database (http://plants.usda.gov)

Family	Species	CommonName
Equisetaceae		
	Equisetum arvense L.	horsetail
	Equisetum ×ferrissii Clute (pro sp.)	Scouring rushl
Pteridaceae		
	Adiantum capillus-veneris L.	maidenhair fern
	Cheilanthes eatonii Baker	Eaton's lip fern
Ephedraceae		
	Ephedra nevadensis S. Wats.	Nevada mormon tea
	Ephedra torreyana S. Wats.	Torrey mormon tea
	Ephedra viridis Coville	mormon tea
Agavaceae		
	Agave utahensis Engelm.	century plant
	Yucca angustissima Engelm. ex Trel.	fine leaf yucca
Cyperaceae		
	Carex aquatilis Wahlenb.	Sedge
	Cladium californicum (S. Wats.) O'Neill	Sawgrass
	Eleocharis rostellata (Torr.) Torr.	Spikerush
	Schoenoplectus acutus (Muhl. ex Bigelow) A.& D. Löve	Bulrush
	Schoenoplectus pungens (Vahl) Palla	common threesquare
Juncaceae		
	Juncus sp.	Rush
	Juncus articulatus L.	jointed rush
	Juncus balticus Willd.	wire rush
	Juncus bufonius L.	toad rush
	Juncus ensifolius Wikstr.	Rush
	Juncus nevadensis S. Wats.	Nevada rush
	Juncus tenuis Willd.	slender rush
	Juncus torreyi Coville	Rush
Liliaceae		
	Nolina microcarpa S. Wats.	Beargrass
Poaceae		
	Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	indian ricegrass
	Achnatherum speciosum (Trin. & Rupr.) Barkworth	desert needlegrass
	Agropyron sp.	wheatgrass
	Agrostis sp.	Bentgrass
	Agrostis stolonifera L.	Redtop
	Andropogon gerardii Vitman	sand bluestem
	Andropogon glomeratus (Walt.) B.S.P.	bushy beardgrass
	Aristida adscensionis L.	six-weeks three-awn
	Aristida arizonica Vasey	Arizona threeawn
	Aristida purpurea Nutt. var. nealleyi (Vasey) Allred	blue three-awn
	Bothriochloa barbinodis (Lag.) Herter	cane bluestem
	Bothriochloa laguroides (DC.) Herter	silver beardgrass
	Bouteloua aristidoides (Kunth) Griseb.	six-weeks needle grama
	Bouteloua curtipendula (Michx.) Torr.	side oats grama
	Bouteloua eriopoda (Torr.) Torr.	black grama
	Bouteloua trifida Thurb.	red grama
	Bromus catharticus Vahl	rescue grass
	Bromus japonicus Thunb. ex Murr.	Japanese chess

Family	Species	CommonName
Poaceae	Bromus rigidus Roth	ripgut brome
	Bromus rubens L.	foxtail chess
	Bromus sp.	brome
	Bromus tectorum L.	cheatgrass
	Cynodon dactylon (L.) Pers.	bermuda grass
	Dasyochloa pulchella (Kunth) Willd. ex Rydb.	fluff grass
	Distichlis spicata (L.) Greene	desert saltgrass
	Elymus canadensis L.	Canada wild rye
	Elymus elymoides (Raf.) Swezey ssp. elymoides	squirrel tail
	Elymus trachicaulis (Link) Gould ex. Shinners	slender wheatgrass
	Elymus trachycaulus (Link) Gould ex Shinners	slender wheatgrass
	Eragrostis sp.	lovegrass
	Eragrostis cilianensis (All.) Vign. ex Janchen	stink grass
	Hesperostipa comata (Trin. & Rupr.) Barkworth	needle and thread
	Hordeum jubatum L.	foxtail barley
	Imperata brevifolia Vasey	satintail
	Leymus simplex (Scribn. & Williams) D.R. Dewey	alkali wildrye
	Lollium arundinaceum (Schreb) S.J. Darbyshire	tall fescue
	Muhlenbergia asperifolia (Nees & Meyen ex Trin.) Parodi	scratch grass
	Muhlenbergia porteri Scribn. ex Beal	bush muhly
	Panicum capillare L.	witch grass
	Panicum obtusum Kunth	vine mesquite
	Pascopyrum smithii (Rydb.) A. Löve	western wheatgrass
	Paspalum dilatatum Poir.	dallisgrass
	Phragmites australis (Cav.) Trin. ex Steud.	fiesta flower
	Piptatherum miliaceum (L.) Coss.	smilo grass
	Pleuraphis jamesii Torr.	galleta
	Pleuraphis rigida Thurb.	big galleta
	Poa sp.	bluegrass
	Poa fendleriana (Steud.) Vasey	mutton grass
	Poa pratensis L.	Kentucky bluegrass
	Polypogon monspeliensis (L.) Desf.	rabbitfoot grass
	Polypogon viridis (Gouan) Breistr.	waterbent
	Saccharum ravennae (L.) L.	ravenna grass
	Schizachyrium scoparium (Michx.) Nash	little bluestem
	Schizachyrium scoparium (Michx.) Nash	little bluestem
	Sporobolus sp.	dropseed
	Sporobolus airoides (Torr.) Torr.	alkali sacaton
	Sporobolus contractus A.S. Hitchc.	spike dropseed
	Sporobolus cryptandrus (Torr.) Gray	sand dropseed
	Sporobolus flexuosus (Thurb. ex Vasey) Rydb.	mesa dropseed
	Sporobolus giganteus Nash	giant dropseed
	Tridens muticus (Torr.) Nash	slim tridens
	Vulpia octoflora (Walt.) Rydb.	six-weeks fescue
Typhaceae		
	Typha domingensis Pers.	narrowleaf cattail
Apocynaceae		
	Apocynum cannabinum L.	hemp dogbane

Family	Species	CommonName
Asclepiadaceae	Funastrum cynanchoides (Dcne.) Schlechter	climbing milkweed
Asteraceae	Acourtia wrightii (Gray) Reveal & King	brownfoot
	Ambrosia acanthicarpa Hook.	annual burrweed
	Ambrosia dumosa (Gray) Payne	white bursage
	Artemisia dracunculus L.	Drummond rock cress
	Artemisia filifolia Torr.	sand sagebrush
	Artemisia ludoviciana Nutt.	Louisiana sage
	Artemisia tridentata Nutt.	big sagebrush
	Baccharis brachyphylla Gray	short-leaved baccharis
	Baccharis emoryi Gray	Emory baccharis
	Baccharis salicifolia (Ruiz & Pavón) Pers.	baccharis
	Baccharis sarothroides Gray	broom baccharis
	Baccharis sergiloides Gray	waterweed
	Bebbia juncea (Benth.) Greene	chuckwalla's delight
	Brickellia atractyloides Gray	spiny brickellbush
	Brickellia californica (Torr. & Gray) Gray	pachaba
	Brickellia longifolia S. Wats.	longleaf brickellbush
	Chloracantha spinosa (Benth.) Nesom	spiny aster
	Cirsium sp.	thistle
	Conyza canadensis (L.) Cronq.	horseweed
	Dicoria sp.	twinbugs
	Dicoria canescens Gray	desert dicoria
	Dicoria canescens Gray ssp. brandegeei (Gray) Kartesz,	single seed dicoria
	Encelia farinosa Gray ex Torr.	white brittlebush
	Encelia frutescens (Gray) Gray	rayless encelia
	Eriastrum Woot. & Standl	woolystar
	Ericameria nauseosa (Pallas ex Pursh) Nesom & Baird	rabbitbrush
	Erigeron sp.	fleabane
	Erigeron divergens Torr. & Gray	spreading fleabane
	Erigeron lobatus A. Nels.	fleabane
	Euthamia occidentalis Nutt.	western goldentop
	Gutierrezia sp.	snakeweed
	Gutierrezia sarothrae (Pursh) Britt. & Rusby	broom snakeweed
	Hymenopappus sp.	hymenopappus
	Isocoma acradenia (Greene) Greene	alkali goldenbush
	Isocoma drummondii (Torr. & Gray) Greene	
	Lactuca sp.	lettuce
	Machaeranthera canescens (Pursh) Gray	hoary tansyaster
	Machaeranthera gracilis (Nutt.) Shinners	slender goldenweed
	Machaeranthera pinnatifida (Hook.) Shinners	spiny goldenweed
	Pleurocoronis pluriseta (Gray) King & H.E. Robins.	arrowleaf
	Pluchea sericea (Nutt.) Coville	arroweed
	Porophyllum gracile Benth.	pore-leaf, odora
	Pseudognaphalium stramineum (Kunth) W.A. Weber	cudweed
	Psilostrophe sparsiflora (Gray) A. Nels.	greenstem paperflower
	Solidago canadensis L.	Canada goldenrod
	Sonchus asper (L.) Hill	spiny-leaved sow thistle
	Sonchus oleraceus L.	common sow thistle
	Stephanomeria parryi Gray	desert straw
	Stephanomeria pauciflora (Torr.) A. Nels.	brownplume wirelettuce

Family	Species	CommonName
Asteraceae	Symphotrichium subulatum (Michx.) Nesom	saltmarsh aster
	Taraxacum officinale G.H. Weber ex Wiggers	common dandelion
	Thymophylla pentachaeta (DC.) Small var. pentachaeta	fetid marigold
	Trixis californica Kellogg	trixis
	Xanthium strumarium L.	common cocklebur
	Xylorhiza tortifolia (Torr. & Gray) Greene	mohave aster
Boraginaceae		
	Cryptantha Lehm ex G. Don	cryptantha
	Lappula occidentalis (S. Wats.) Greene	stickseed
	Tiquilia canescens (DC.) A. Richards.	shrubby coldenia
	Tiquilia latior (I.M. Johnston) A. Richards.	hispid coldenia
Brassicaceae		
	Arabis drummondii Gray	Drummond rock cress
	Cardamine parviflora L.	sand bittercress
	Descurainia pinnata (Walt.) Britt.	yellow tansy mustard
	Draba cuneifolia Nutt. ex Torr. & Gray	Whitlow grass
	Lepidium fremontii S. Wats.	desert alyssum
	Lepidium latifolium L.	perennial pepperweed
	Lepidium montanum Nutt.	peppergrass
	Rorippa nasturtium-aquaticum (L.) Hayek	watercress
	Stanleya pinnata (Pursh) Britt.	prince's plume
Cactaceae		
	Echinocereus engelmannii (Parry ex Engelm.) Lem.	Englemann hedgehog
	Echinocereus triglochidiatus Engelm.	claretcup cactus
	Ferocactus cylindraceus (Engelm.) Orcutt var. cylindraceus	California barrel cactus
	Mammillaria grahamii Engelm. var. grahamii	Arizona fishhook
	Opuntia acanthocarpa Engelm. & Bigelow	buckhorn cholla
	Opuntia basilaris Engelm. & Bigelow	beavertail cactus
	Opuntia engelmannii Salm-Dyck	cactus apple
	Opuntia erinacea Engelm. & Bigelow ex Engelm.	mojave prickly pear
	Opuntia phaeacantha Engelm.	desert prickly pear,
Celastraceae		
	Mortonia scabrella Gray	sandpaper bush
Chenopodiaceae		
	Atriplex canescens (Pursh) Nutt.	four wing saltbush
	Atriplex confertifolia (Torr. & Frém.) S. Wats.	shadscale
	Salsola tragus L.	Russian thistle
	Suaeda suffrutescens S. Wats.	seepweed
Crossosomataceae		
	Glossopetalon spinescens Gray var. aridum M.E. Jones	greasebush
Elaeagnaceae		
	Elaeagnus angustifolia L.	Russian olive
Euphorbiaceae		
	Chamaesyce arizonica (Engelm.) Arthur	spurge
Fabaceae		
	Acacia greggii Gray	catclaw acacia
	Alhagi maurorum Medik.	camelthorn
	Astragalus sp.	milkvetch
	Cercis orbiculata Greene	California redbud
	Glycyrrhiza lepidota Pursh	wild licorice
	Medicago sativa L.	alfalfa

Family	Species	CommonName
Fabaceae	Melilotus officinalis (L.) Lam.	white sweet clover
	Melilotus sp.	sweetclover
	Parryella filifolia Torr. & Gray ex Gray	dunebroom
	Prosopis glandulosa Torr.	honey mesquite
	Psoralidium lanceolatum (Pursh) Rydb.	lemon weed
	Psorothamnus fremontii (Torr. Ex Grey) Barnaby var. fremontii	Fremont's dalea
	Quercus turbinella Greene	shrub live oak
Gentianaceae		
	Centaurium calycosum (Buckl.) Fern.	Buckley's centaury
	Centaurium exaltatum (Griseb.) W. Wight ex Piper	centaury
Lamiaceae		
	Hedeoma nana (Torr.) Briq.	dwarf mock pennyroyal
	Hedeoma oblongifolia (Gray) Heller	mock pennyroyal
	Mentha arvensis L.	field mint
Malvaceae		
	Sphaeralcea ambigua Gray	desert mallow
	Sphaeralcea grossulariifolia (Hook. & Arn.) Rydb.	globe mallow
Nyctaginaceae		
	Abronia elliptica A. Nels.	sand verbena
	Boerhavia wrightii Gray	spiderling
	Mirabilis multiflora (Torr.) Gray	Colorado four o'clock
Onagraceae		
	Camissonia multijuga (S. Wats.) Raven	frost-stem suncup
	Epilobium ciliatum Raf. ssp. ciliatum	willowweed
	Oenothera caespitosa Nutt.	evening primrose
	Oenothera elata Kunth	Hooker evening primrose
	Oenothera pallida Lindl.	pale evening primrose
Orobanchaceae		
	Orobanche ludoviciana Nutt.	Louisiana broomrape
Plantaginaceae		
	Plantago lanceolata L.	narrowleaf plantain,
	Plantago major L.	common plantain
	Plantago ovata Forsk.	woolly plantain
	Plantago patagonica Jacq.	woolly indianwheat
Polemonaceae		
	Gilia sp.	gilia
	Phlox sp.	phlox
Polemoniaceae		
	Ipomopsis aggregata (Pursh) V. Grant	ipomopsis
Polygonaceae		
	Eriogonum deflexum Torr.	skeleton weed
	Eriogonum inflatum Torr. & Frém.	desert trumpet
	Eriogonum sp.	buckwheat
	Polygonum lapathifolium L.	willow smartweed
	Polygonum sp.	knotweed
Rhamnaceae		
	Ziziphus obtusifolia (Hook. ex Torr. & Gray) Gray	greythorn
Rosaceae		
	Fallugia paradoxa (D. Don) Endl. ex Torr.	Apache plume
	Purshia mexicana (D. Don) Henrickson	cliffrose

Family	Species	CommonName
Rubiaceae		
	Galium stellatum Kellogg	desert bedstraw
Salicaceae		
	Populus fremontii S. Wats.	Fremont cottonwood
	Salix exigua Nutt.	coyote willow
Scrophulariaceae		
	Castilleja linariifolia Benth.	long leaf paintbrush
	Mimulus cardinalis Dougl. ex Benth.	scarlet monkeyflower
	Veronica americana Schwein. ex Benth.	speedwell
	Veronica anagallis-aquatica L.	water speedwell
Solanaceae		
	Datura wrightii Regel	sacred thorn-apple
	Lycium andersonii Gray	Anderson thornbush
	Lycium pallidum Miers	rabbit thorn
	Nicotiana alata Link & Otto	jasmine tobacco
	Solanum americanum P. Mill.	American nightshade
	Solanum elaeagnifolium Cav.	silverleaf nightshade
Tamaricaceae		
	Tamarix ramosissima Ledeb.	tamarisk
Ulmaceae		
	Celtis laevigata Willd. var. reticulata (Torr.) L. Benson	net-leaf hackberry
Verbenaceae		
	Aloysia wrightii Heller ex Abrams	Wright lippia
Viscaceae		
	Phoradendron californicum Nutt.	desert mistletoe
Zygophyllaceae		
	Larrea tridentata (Sessé & Moc. ex DC.) Coville	creosotebush

Appendix B

List of arthropod taxa encountered

Taxonomy follows sources listed in text on pages 65.

TAXA (Phylum Arthropoda)					**WATER ZONE**		
CLASS	**ORDER**	**FAMILY**	**GENUS**	**SPECIES**	**SHOR**	**NHWZ**	**OHWZ**
Chilopoda	Lithobiomorpha	Henicopidae	Lamyctes	fulvicornis	x		
		Lithobiidae	unknown genus	sp.1	x		
Diplopoda	Polydesmida	Polydesmidae	unknown genus	sp.1			x
Malacostraca	Isopoda	Armadilliidae	Armadillidium	vulgare	x	x	
		Porcellionidae	Porcellio	laevis	x	x	
Arachnida	Ixodida	Ixodidae	Dermacentor	variabilis		x	
	Mesostigmata	unknown family	unknown genus	sp.1		x	
	Oribatei	unknown family	unknown genus	sp.1		x	
	Prostigmata	Anystidae	unknown genus	sp.1	x	x	x
		Bdellidae	unknown genus	sp.1	x		
		Erythraeidae	unknown genus	sp.1	x	x	x
	Araneae	Anyphaenidae	Anyphaena	californica	x		
			Anyphaena	pacifica		x	
		Araneidae	Larinia	sp.1	x		
			Metepeira	arizonica	x		x
		Caponiidae	Tarsonops	systematicus			x
		Clubionidae	Cheiracanthium	inclusum		x	
			unknown genus	sp.1	x		
		Corinnidae	Castianeira	sp.1	x		
			Meriola	decepta	x		
		Dictynidae	Mallos	pallidus		x	x
		Gnaphosidae	Cesonia	gertschi	x	x	
			Drassyllus	insularis	x		
			Gnaphosa	californica			x
			Gnaphosa	clara			x
			Haplodrassus	sp.1		x	
			Herpyllus	hesperolus	x		
			Micaria	sp.1		x	
			Micaria	jeanae			x
			Scopodes	bryantae	x		
			Zelotes	anglo	x		
		Linyphiidae	unknown genus	sp.1	x		x
		Liocranidae	Agroeca	trivittata	x		
			Neoanagraphis	chamberlini	x		
		Lycosidae	Arctosa	littoralis	x	x	
			Pardosa	vadosa	x		
			Schizocosa	celerior	x	x	
			Trochosa	sp.1	x		
		Mimetidae	Mimetus	hesperus			x
		Oecobiidae	Oecobius	isolatus			x
		Oxyopidae	Oxyopes	scalaris		x	x
		Philodromidae	Apollophanes	texanus		x	
			Ebo	sp.1	x	x	x

		Pholcidae	Physocyclus	sp.1		x	
			Psilochorus	sp.1	x	x	x
		Salticidae	Platycryptus	sp.1	x		
			Sassacus	sp.1	x		
			Sitticus	sp.1		x	
			unknown genus	sp.1	x		
		Selenopidae	Selenops	sp.1		x	
		Sicariidae	Loxosceles	deserta	x	x	x
		Tetragnathidae	Tetragnatha	versicolor	x		
		Theraphosidae	Aphonopelma	sp.1		x	
		Theridiidae	Euryopis	sp.1			x
			Latrodectus	hesperus		x	
			Steatoda	fulva		x	x
			Steatoda	transversa	x		
			unknown genus	sp.1	x	x	x
		Thomisidae	Misumenops	californicus		x	x
			Tmarus	sp.1		x	x
			Xysticus	lassanus	x		
	Opiliones	Ceratolasmatidae	Hesperonemastoma	pallidimaculosum	x	x	
	Pseudoscorpiones	unknown family	unknown genus	sp.1		x	x
	Scorpiones	Buthidae	Centruroides	exilicauda	x	x	x
		Iuridae	Hadrurus	spadix		x	x
		Vaejovidae	Paruroctonus	becki			x
			Serradigitus	harbisoni group			x
			Serradigitus	subtilimanus	x		
			Vaejovis	confusus group			x
	Solifugae	Eremobatidae	Eremobates	sp.1	x	x	x
Insecta	Collembola	Entomobryidae	unknown genus	sp.1	x	x	x
		Hypogastruridae	unknown genus	sp.1	x		
		Isotomidae	unknown genus	sp.1	x		
		Sminthuridae	unknown genus	sp.1	x	x	x
	Archaeognatha	Machilidae	Mesomachilis	sp.1	x	x	x
			Mexomachilis	sp.1			x
		Meinertellidae	Machilinus	aurantiacus		x	
	Zygentoma	Lepismatidae	Lepisma	sp.1		x	x
	Odonata	Aeshnidae	Anax	junius	x	x	
		Calopterygidae	Hetaerina	americana	x		
		Libelluidae	Libellula	comanche	x		
		Libelluidae	Libellula	saturata	x	x	
			Pachydiplax	longipennis	x		
			Sympetrum	corruptum	x	x	
		Gomphidae	Progomphus	borealis	x		
		Coenagrionidae	unknown genus	sp.1	x		
			unknown genus	sp.2	x		
	Phasmatodea	Heteronemiidae	Parabacillus	hesperus			x

Mantodea	Mantidae	Litaneutria	minor			x
		Stagmomantis	californica			x
Orthoptera	Acrididae	Aeoloplides	tenuipennis			x
		Cibolacris	parviceps			x
		Melanoplus	herbaceus		x	
		Melanoplus	cinereus			x
		Orphulella	pelidna	x	x	
		Parapomala	pallida	x	x	x
		Poecilotettix	longipennis			x
		Psoloessa	texana			x
		Schistocerca	nitens		x	x
		Schistocerca	shoshone	x	x	
		Trimerotropis	pallidipennis	x	x	x
	Romalidae	Tytotthyle	maculata			x
	Gryllidae	Cycloptilium	comprehendens			x
		Eunemobius	carolinus	x		
		Gryllus	alogus	x	x	
		Gryllus	undesc. sp. 1			x
		Gryllus	undesc. sp. 2		x	
		Oecanthus	californicus		x	
		Oecanthus	rileyi		x	
	Rhaphidophoridae	Ceuthophilus	sp.1			x
	Tettigoniidae	Ateloplus	coconino		x	x
		Capnobotes	fuliginosus	x	x	x
		Insara	elegans			x
	Tetrigidae	Paratettix	mexicanus	x		
	Tridactylidae	Ellipes	minutus	x		
Dictyoptera	Blatellidae	Blatella	vaga	x		
	Blattidae	Blatta	lateralis	x		
	Polyphagidae	Arenivaga	sp.1	x	x	x
Isoptera	Rhinotermitidae	Reticulitermes	sp.1	x	x	
Psocoptera	unknown family	unknown genus	sp.1		x	
Hemiptera	Anthocoridae	Orius	sp.1	x		
	Berytidae	Pronotacantha	annulata	x	x	x
		Jalysus	sp.1			x
	Coreidae	Leptoglossus	sp.1			x
		Narnia	snowi	x		
	Corixidae	unknown genus	sp.1		x	x
	Cydnidae	Amnestus	sp.1	x	x	x
		Dallasiellus	californicus		x	
		Melanaethus	crenatus	x	x	x
		Tominotus	conformus	x		
	Lygaeidae	Geocoris	sp.1	x	x	
		Lygaeus	kalmii	x		
		Neacoryphus	sp.1			x

	Nysius	sp.1	x	x	x
	Nysius	sp.2	x		x
	Ochrimnus	sp.1	x	x	x
	Pachybrachius	sp.1			x
	unknown genus	sp.2			x
	unknown genus	sp.3			x
	unknown genus	sp.8	x		
	unknown genus	sp.24		x	x
	unknown genus	sp.30	x	x	x
	unknown genus	sp.32			x
Miridae	Phytocoris	sp.1	x	x	x
	Phytocoris	sp.2		x	x
	Phytocoris	sp.3	x	x	x
	Phytocoris	sp.4		x	x
	Phytocoris	sp.5	x		x
	Psallus	sp.1	x		x
	Tropidosteptes	sp.1			
	unknown genus	sp.1		x	
	unknown genus	sp.3			x
	unknown genus	sp.4			x
	unknown genus	sp.5			x
	unknown genus	sp.6			x
	unknown genus	sp.7			x
	unknown genus	sp.8		x	x
	unknown genus	sp.9			x
	unknown genus	sp.10			x
	unknown genus	sp.11		x	
	unknown genus	sp.12			x
	unknown genus	sp.13	x	x	
	unknown genus	sp.14	x		
	unknown genus	sp.15		x	
	unknown genus	sp.16	x		
	unknown genus	sp.17	x		
	unknown genus	sp.18			x
	unknown genus	sp.19	x		x
	unknown genus	sp.19			x
	unknown genus	sp.20	x		
	unknown genus	sp.21			x
	unknown genus	sp.34	x	x	x
	unknown genus	sp.35	x	x	x
	unknown genus	sp.36	x	x	x
	unknown genus	sp.37	x	x	x
	unknown genus	sp.39	x		x
	unknown genus	sp.40	x	x	
	unknown genus	sp.41			x

	unknown genus	sp.42	x		
	unknown genus	sp.43	x		
	unknown genus	sp.45			x
	unknown genus	sp.48	x	x	x
	unknown genus	sp.49	x	x	x
	unknown genus	sp.50	x	x	x
	unknown genus	sp.51	x	x	x
	unknown genus	sp.52	x	x	x
	unknown genus	sp.54	x	x	x
	unknown genus	sp.55	x	x	x
	unknown genus	sp.57			x
Nabidae	Dolichonabis	sp.1	x		
Notonectidae	Notonecta	sp.1			x
Pentatomidae	Brochymea	parva			x
	Chinavia	hilaris		x	
	Chlorochroa	sayi	x	x	x
	Mecidea	sp.1		x	x
	Pitedia	sp.1			x
	Tepa	sp.1			x
	Thyanta	custator	x	x	x
	Thyanta	pallidoverens	x		x
Phymatidae	Phymata	salicis	x		
Reduviidae	Apiomeris	sp.1			x
	Emesaya	incisa		x	x
	Oncochephalus	geniculatus		x	
	Pselliopus	sp.1		x	
	Rasahus	biguttatus	x		
	Reduvius	senilis			x
	Sinea	rileyi		x	
	Stenolemoides	arizonensis		x	
	Zelus	socias	x	x	x
	Zelus	renardii		x	
	unknown genus	sp.1			x
	unknown genus	sp.2	x		
	unknown genus	sp.3	x		
	unknown genus	sp.14			x
Rhopalidae	Arhyssus	sp.1		x	x
	Harnostes	reflexus			x
	Leptocoris	sp.1		x	x
	Liorhyssus	hyalinus			x
	unknown genus	sp.33	x	x	x
Saldidae	Saldula	sp.1	x		
	Saldula	sp.2	x		
Tingidae	unknown genus	sp.1		x	x
	unknown genus	sp.2	x		x

		unknown genus	sp.25	x		x
Homoptera	Acanaloniidae	unknown genus	sp.1			x
	Aphididae	unknown genus	sp.1	x	x	x
	Cercopidae	unknown genus	sp.1		x	x
	Cicadellidae	Aceratagallia	sp.1	x	x	
		Aceratagallia	sp.2		x	x
		Aceratagallia	sp.3			x
		Aceratagallia	sp.4			x
		Coelidia	sp.1			x
		Idiocerus	sp.1		x	x
		Idiocerus	sp.2			x
		Nionia	palmeri		x	
		Opsius	stactogalus	x	x	
		unknown genus	sp.1		x	
		unknown genus	sp.2	x		
		unknown genus	sp.3	x	x	
		unknown genus	sp.4	x		x
		unknown genus	sp.5		x	
		unknown genus	sp.6		x	
		unknown genus	sp.7		x	x
		unknown genus	sp.10	x		
		unknown genus	sp.11	x		
		unknown genus	sp.12			x
		unknown genus	sp.13			x
		unknown genus	sp.14		x	x
		unknown genus	sp.16			x
		unknown genus	sp.17	x	x	
		unknown genus	sp.18			x
		unknown genus	sp.20	x	x	x
		unknown genus	sp.21		x	
		unknown genus	sp.22		x	
		unknown genus	sp.23		x	
		unknown genus	sp.24	x		
		unknown genus	sp.28			x
		unknown genus	sp.29	x		
		unknown genus	sp.30			x
		unknown genus	sp.31	x		
		unknown genus	sp.34	x	x	x
		unknown genus	sp.35	x		
		unknown genus	sp.36	x		
		unknown genus	sp.37			x
		unknown genus	sp.38	x		
		unknown genus	sp.41			x
		unknown genus	sp.42			x
		unknown genus	sp.43			x

		unknown genus	sp.44	x		
		unknown genus	sp.45	x		
		unknown genus	sp.46		x	
		unknown genus	sp.47			x
		unknown genus	sp.48			x
		unknown genus	sp.49	x		
		unknown genus	sp.50		x	
		unknown genus	sp.51	x		
		unknown genus	sp.52		x	
	Cicadidae	Diceroprocta	apache	x	x	x
	Cixiidae	Oliarus	complectus	x	x	
		Oliarus	sp.1	x		
		unknown genus	sp.3	x		
		unknown genus	sp.5	x		x
		unknown genus	sp.6	x		
		unknown genus	sp.7	x		
	Delphacidae	unknown genus	sp.1	x		x
		unknown genus	sp.1	x		
		unknown genus	sp.2	x		
		unknown genus	sp.2		x	
		unknown genus	sp.3		x	
		unknown genus	sp.4		x	
	Psyllidae	unknown genus	sp.1		x	
		unknown genus	sp.2		x	
		unknown genus	sp.3	x		x
Thysanoptera	Thripidae	Frankliniella	sp.1	x	x	x
Neuroptera	Chrysopidae	Chrysopa	sp.1	x	x	x
		Eremochrysa	sp.1	x	x	x
	Conioptergidae	unknown genus	sp.1	x	x	x
		unknown genus	sp.2	x	x	x
	Corydalidae	Corydalus	sp.1			x
	Hemerobiidae	Hemerobius	sp.1	x	x	x
		Micromus	sp.1	x	x	x
		Sympherobius	sp.1	x	x	x
		unknown genus	sp.1	x	x	x
		unknown genus	sp.2	x	x	x
		unknown genus	sp.3	x		x
	Mantispidae	unknown genus	sp.1	x	x	x
		unknown genus	sp.2	x	x	x
	Myrmeleontidae	unknown genus	sp.1	x	x	x
		unknown genus	sp.2	x	x	x
		unknown genus	sp.3	x	x	x
		unknown genus	sp.4	x	x	x
		unknown genus	sp.5			x
		unknown genus	sp.6			x

		unknown genus	sp.7	x	x	x
		unknown genus	sp.8	x		x
		unknown genus	sp.9	x	x	x
	Raphididae	unknown genus	sp.1		x	
Coleoptera	Anobiidae	Niptus	sp.1			x
		Niptus	sp.2		x	x
	Anthicidae	Notoxus	sp.1	x	x	x
		Notoxus	calcaratus	x		
		unknown genus	sp.1		x	
		unknown genus	sp.2	x	x	x
		unknown genus	sp.3	x	x	
		unknown genus	sp.4	x		
		unknown genus	sp.5			x
		unknown genus	sp.6			x
	Bostrichidae	Apatides	sp.1			x
		Amphicerus	sp.1			x
		unknown genus	sp.1		x	x
		unknown genus	sp.2	x		x
	Buprestidae	Acmaeodera	quadrivittata	x	x	x
		Acmaeodera	sp.1	x	x	x
		Acmaeodera	gibbula			x
		Chrysobothris	octocola	x		
		Chrysobothris	merkeli	x		
		Hippomelas	sp.1	x	x	x
		Hippomelas	sp.2	x	x	
		Melanophila	sp.1	unk.	unk.	unk.
	Cantharidae	Cantharus	sp.1	x		
		unknown genus	sp.1		x	x
	Carabidae	Agonum	cyclifer	x		
		Agonum	parextimum	x		
		Amara	apacheana		x	
		Amara	harpalina		x	
		Amblycheila	schwarzi			x
		Anisodactylus	californicus	x		
		Apristus	latens	x		
		Apristus	sp.1	x		
		Bembidion	levigatum	x		
		Bembidion	rapidum	x		
		Brachinus	elongatulus	x		
		Brachinus	texanus	x		
		Bradycellus	nitidus	x		
		Bradycellus	rivalis	x		
		Calathus	opaculus	x		
		Calleida	platymaides	x		
		Calosoma	sponse		x	

	Chlaenius	leucoscelis	x		
	Chlaenius	tricolor	x		
	Cicindela	oregona maricopa	x		
	Cicindela	punctulata punctulat	x		
	Cymindis	punctigera		x	
	Discoderus	obsidianus			x
	Dyschiriodes	aratus	x		
	Elaphrus	sp.1	x		
	Elaphrus	sp.2	x		
	Elaphrus	sp.3	x		
	Nebria	sp.1	x		
	Platynus	lyratus	x		
	Rhadine	sp.1		x	
	Selenophorus	nr. semirufus		x	
	Tetragonoderus	fasciatus	x	x	
	Tetragonoderus	pallidus		x	x
Cephaloidae	unknown genus	sp.1	x	x	x
Cerambycidae	Aethecerinus	latecinctus		x	
	Anoploeurius	sp.1	x	x	x
	Malobidion	sp.1			x
	Neoclytus	magnus	x		
	Oncideres	rhodosticta			x
Chrysomelidae	Altica	sp.1			x
	Anisostena	arizonica	unk.	unk.	unk.
	Babia	sp.1	unk.	unk.	unk.
	Babia	sp.2		x	
	Coleothorpa	sp.1		x	
	Diachus	sp.1		x	
	Dibolia	sp.1		x	
	Disonycha	sp.1	x	x	x
	Glyptoscelis	sp.1		x	
	Metachroma	sp.1	x	x	x
	Monoxia	sp.1		x	
	Monoxia	sp.2			x
	Monoxia	sp.3			x
	Pachybrachis	sp.1		x	
	Pachybrachis	sp.2			x
	Paria	sp.1	x		
	Phyllotreta	sp.1		x	
	Trirhabda	sp.1		x	
	unknown genus	sp.1		x	
	unknown genus	sp.4			x
	unknown genus	sp.7		x	
Cleridae	Cymatodera	sobara		x	
	Enoclerus	quadrisignatus			x

	Lecontella	sp.1			x
	Necrobia	rufipes	x		
	Trichodes	ornatus			x
	unknown genus	sp.1			x
	unknown genus	sp.2	x	x	
Coccinellidae	Chilocorus	stigma	x	x	
	Coccinella	septemnotata	x		
	Hippodamia	convergens	x		
	Hyperaspidius	sp.1	x		
	Hyperaspidius	arcuatus	x		
	Hyperaspis	conspirens		x	
	Olla	v-nigrum	x		
	Olla	sp.2			x
	Scymnus	sp.1	x	x	x
	unknown genus	sp.1	x		
Cryptophagidae	Cryptophagus	sp.1	x		
	unknown genus	sp.2	x		
Curculionidae	Apion	sp.1			x
	Minyomerus	sp.1			x
	Scyphophorus	sp.1			x
	unknown genus	sp.2		x	x
	unknown genus	sp.3			x
	unknown genus	sp.4			x
	unknown genus	sp.6	x		
	unknown genus	sp.7	x		
	unknown genus	sp.8			x
	unknown genus	sp.9			x
	unknown genus	sp.10		x	
	unknown genus	sp.11	x		
	unknown genus	sp.12			x
	unknown genus	sp.13			x
Dermestidae	Cryptorhopalum	sp.1			x
Elateridae	Aeolus	sp.1	x	x	
	Esthesopus	sp.1	x	x	x
	Horistonotus	sp.1	x	x	x
	Melanotus	sp.1	x	x	x
	unknown genus	sp.1	x	x	x
	unknown genus	sp.2	x	x	
	unknown genus	sp.3	x	x	x
	unknown genus	sp.4	x	x	
	unknown genus	sp.5	x		
	unknown genus	sp.6	x		
Histeridae	Hetaerius	carri	x		
	unknown genus	sp.1	x	x	
Hydrophilidae	Cercyon	quisquilius	x		

Lycidae	Lycus	sanguineus	x		
	unknown genus	sp.1	x		
Melandryidae	unknown genus	sp.1	x	x	x
	unknown genus	sp.2	x	x	x
	unknown genus	sp.3	x	x	x
	unknown genus	sp.4	x	x	x
	unknown genus	sp.5	x	x	x
	unknown genus	sp.6	x	x	x
Meloidae	Epicauta	tenuilineata	x	x	x
	Epicauta	sp.1	x	x	x
	Epicauta	sp.2	x	x	
	Lytta	magister	x		
	Nemognatha	nigripennis		x	x
	Nemognatha	niticula	x		
	Nemognatha	sparsa			x
	unknown genus	sp.1		x	
Melyridae	Attalus	oregonensis		x	x
	Attalus	sp.1		x	x
	Collops	grenellus	x	x	
	Collops	parvus	x		
	Trichochrous	sp.1	x	x	
	unknown genus	sp.3			x
Mordellidae	unknown genus	sp.1	x	x	x
Nitidulidae	Carpophilus	hemipterus	x	x	x
	Carpophilus	pallipennis	x		
Oedemeridae	Xanthochroina	bicolor		x	x
Phengodidae	Zarhipis	sp.1			x
Scarabaeidae	Aphodius	sp.1			x
	Aphodius	sp.2			x
	Cyclocephala	sp.1	x	x	x
	Diplotaxis	sp.1		x	
	Diplotaxis	sp.2	x	x	x
	Diplotaxis	sp.3	x	x	x
	Diplotaxis	sp.4		x	x
	Glaresis	sp.1			x
	Golbocerina	sp.1			x
	Ochodaeus	sp.1			x
	Oxygrylius	ruginasus	x	x	x
	unknown genus	sp.3		x	
	unknown genus	sp.4			x
Scraptiidae	Anaspis	rufa	x	x	
	Canifa	sp.1			x
Scydmaenidae	unknown genus	sp.1			x
	unknown genus	sp.2			x
	unknown genus	sp.3			x

	Staphylinidae	Aleocharinae	spp.	x		
		Creophilus	maxillosus			x
		Homaeotarsus	sp.1	x		x
		Philonthus	sp.1			x
		Philonthus	sp.2	x	x	x
		Stenus	sp.1	x		
		unknown genus	sp.1	x		
		unknown genus	sp.2	x		
		unknown genus	sp.3	x	x	
	Tenebrionidae	Alleculinae	sp.1		x	x
		Alleculinae	sp.2	x	x	x
		Batulini	sp.1		x	x
		Blapstinus	brevicollis	x	x	
		Blapstinus	histricus	x	x	
		Blapstinus	sulcatus	x	x	x
		Centrioptera	muricata			x
		Eleodes	extricatus	x	x	x
		Eleodes	delicata	x	x	
		Metaponium	convexicolle	x	x	x
		Micromes	sp.1			x
		Telabis	histricum	x	x	x
		Triorophus	sp.1		x	x
	Trogidae	Trox	suberosus	x		
Hymenoptera	Andrenidae	Andrena	sp.1		x	
		Perdita	spp.	x	x	x
	Anthophoridae	Centris	rhodopus		x	
		Diadasia	lutzi			x
		Diadasia	martialis			x
		Diadasia	minuta		x	
		Diadasia	rincona	x	x	x
		Melissodes	sp.1			x
		Tetraloniella	sp.1			x
		Xylocopa	californica	x	x	
		Xylocopa	tabaniformis	x		
	Apidae	Apis	mellifera	x	x	
		Bombus	morrisoni		x	
	Bethylidae	unknown genus	sp.1		x	x
		unknown genus	sp.2		x	
		unknown genus	sp.3	x		
		unknown genus	sp.4	x		
		unknown genus	sp.5		x	
		unknown genus	sp.6		x	x
	Braconidae	unknown genus	sp.1	x	x	x
		unknown genus	sp.2			x
		unknown genus	sp.3	x	x	x

	unknown genus	sp.4	x	x	x
	unknown genus	sp.5	x	x	x
	unknown genus	sp.6	x	x	x
	unknown genus	sp.7	x	x	x
	unknown genus	sp.8	x	x	x
	unknown genus	sp.9	x	x	
	unknown genus	sp.10	x	x	x
	unknown genus	sp.11		x	
	unknown genus	sp.12	x	x	x
	unknown genus	sp.13		x	x
	unknown genus	sp.14			x
Bradynobaenidae	Chyphotes	petiolaris		x	x
Chalicidae	unknown genus	sp.1	x		x
Chrysididae	unknown genus	sp.1		x	
	unknown genus	sp.2	x		
Colletidae	Colletes	daleae		x	
	Colletes	louisae		x	
	Colletes	sp.1		x	
Dryinidae	unknown genus	sp.1		v	
Formicidae	Camponotus	sp.1		x	x
	Camponotus	sp.2		x	x
	Crematogaster	depilis	x	x	x
	Cyphomyrmex	wheeleri			x
	Dorymyrmex	insana	x	x	x
	Formica	integroides	x	x	x
	Forelius	pruinosus	x	x	x
	Hypoponera	opacior	x		
	Leptothorax	muscorum	x	x	x
	Leptothorax	nevadensis	x	x	x
	Monomorium	minimum	x	x	x
	Myrmecocystus	mexicanus			x
	Myrmecocystus	romainei			x
	Paratrechina	vividula		x	x
	Pheidole	ceres	x	x	x
	Pogonomyrmex	occidentalis			x
	Pogonomyrmex	maricopa	x	x	x
	Pogonomyrmex	rugosus			x
	Solenopsis	molesta		x	
	Solenopsis	xyloni	x	x	x
Halictidae	Agepostemon	sp.	x	x	
	Agepostemon	melliventris	x	x	x
	Augochlorella	sp.	x	x	x
	Halictus	ligatus	x	x	
	Lasioglossum	sisymbria	x	x	
	Lasioglossum	sp.			x

	Sphecodes	sp.		x		x
Megachilidae	Anthidiellum	notatum		x	x	
Ichneumonidae	unknown genus	sp.1		x		
	unknown genus	sp.2				x
	unknown genus	sp.3		x		
	unknown genus	sp.4		x	x	
	unknown genus	sp.5		x	x	
	unknown genus	sp.6		x	x	
	unknown genus	sp.7		x	x	x
	unknown genus	sp.8		x	x	x
	unknown genus	sp.9		x	x	x
	unknown genus	sp.10		x	x	x
	unknown genus	sp.11		x	x	x
	unknown genus	sp.12		x		
	unknown genus	sp.13		x	x	
	unknown genus	sp.14		x	x	x
	unknown genus	sp.15			x	x
	unknown genus	sp.16		x	x	x
	unknown genus	sp.17			x	x
	Ashmeadiella	bucconis			x	x
	Ashmeadiella	meliloti		x	x	
	Ashmeadiella	prosopidis				x
	Ashmeadiella	sonora			x	
	Dianthidium	implicatum				x
	Megachile	concinna		x		
	Megachile	frugalis			x	
	Megachile	lippiae		x	x	
	Megachile	manifesta				x
Mutillidae	Acrophotopsis	curygnatha			x	
	Dasymutilla	sp.1		x		
	Dasymutilla	sp.2		x	x	
	Dasymutilla	satanus			x	x
	Odontophotopsis	melicausa		x	x	x
	Odontophotopsis	serca		x	x	x
	Odontophotopsis	mamata		x	x	x
	Odontophotopsis	erbus			x	x
	Sphaeropthalma	pallida		x	x	x
	Sphaeropthalma	helicoan		x	x	x
	Sphaeropthalma	macswaini			x	x
	Sphaeropthalma	noctivaga		x	x	x
	Sphaeropthalma	orestes		x	x	
	Sphaeropthalma	pluto			x	
	Sphaeropthalma	triangularis			x	
	Sphaeropthalma		1		x	
	Acrophotopsis	curygnatha			x	

	unknown genus	sp.1	x	x	x
	unknown genus	sp.2		x	x
Pompilidae	Agenioides	biedermani		x	
	Anopliodes	sp.1		x	
	Anoplius	lophopompilus	x		
	Anoplius	sp.1		x	
	Aporinellus	medianus			x
	Hemipepsis	ustulata ustulata	x	x	x
	Pepsis	formosa	x	x	
	Pepsis	mildei		x	
	Pepsis	pallidolimbata	x	x	
	Pepsis	thisbe	x	x	
Scoliidae	Crioscolia	alcione	x	x	
	Campsomeris	pilipes	x		
	Campsomeris	tolteca	x	x	
	Campsomeris	plumipes		x	
Pteromalidae	unknown genus	sp.1			x
	unknown genus	sp.3		x	
	unknown genus	sp.4	x		x
	unknown genus	sp.5		x	
Sphecidae	Ammophila	sp.1	x	x	x
	Bembix	melanaspis		x	
	Bembix	sp.1	x	x	
	Bembix	troglodytes	x	x	
	Cerceris	californica		x	
	Chalybion	californicum	x	x	
	Chlorion	aerarium		x	
	Eucerceris	canaliculata			x
	Liris	argentata		x	
	Microbembix	mondonta	x	x	
	Mimesa	cressonii	x		
	Palmodes	sp.1		x	x
	Philanthus	gibbosus		x	
	Pluto	sayi		x	
	Podalonia	sp.1		x	x
	Podalonia	xerophila		x	
	Prionyx	sp.1	x	x	
	Prionyx	sp.2			x
	Prionyx	fervens			x
	Prionyx	subatratus		x	
	Sceliphron	caementarium	x	x	x
	Sphecius	convallis	x		
	Sphecius	grandis	x		
	Steniolia	duplicata	x		
	Steniolia	elegans		x	

		Stictiella	formosa			x
		Stizus	occidentalis			x
		Tachysphex	sp.1	x	x	
		Tachysphex	terminatus		x	
		Tachytes	distinctus	x		
		Tachytes	fulviventris		x	
		Tachytes	sp.1	x	x	
		Trypoxylon	californicum	x		
		Xerostrictia	sp.1	x		
	Tenthredidae	unknown genus	sp.1		x	
	Tiphiidae	brachycistidine	sp.1		x	
		Myzinum	sp.1	x	x	x
		unknown genus	sp.1	x	x	x
	Torymidae	unknown genus	sp.1	x		
	Vespidae	Eumenes	bollii		x	x
		Euodynerus	pratensis	x	x	
		unknown genus	sp.1		x	
Trichoptera	Hydropsychidae	Ceratopsyche	oslari	x	x	x
Lepidoptera (moths)	Arctiidae	Cisthene	angelus	x	x	x
		Cisthene	juanita		x	x
		Cisthene	sp.1			x
		Crambidia	myrlosea	x	x	x
		Lycomorpha	sp.1		x	x
		Ectypia	clio		x	x
		Euchaetes	perlevis	x	x	x
		Euchaetes	zella	x	x	x
	Geometridae	Anacamptodes	sancta	x	x	x
		Archirhoe	neomexicana	x	x	x
		Chloraspilates	bicoloraria	x	x	x
		Chloraspilates	minima	x	x	x
		Chlorochlamys	phyllinaria	x	x	x
		Dichorda	sp.1		x	x
		Dysstroma	brunneata	x	x	x
		Elpiste	metanemaria	x	x	x
		Euacidalia	sp.1	x	x	x
		Eupithecia	annulata	x	x	x
		Eupithecia	sp.1	x	x	x
		Eusarca	sp.1	x	x	x
		Eusarca	sp.2	x	x	x
		Eusarca	tibiaria	x	x	
		Glaucina	ochrofuscaria	x	x	x
		Glaucina	sp.1	x	x	x
		Lambdina	flavilinearia	x	x	
		Lithostege	rotundata	x	x	x
		Narraga	fimetaria	x	x	x

Perizoma	custodiata	x	x	x
Pero	modesta	x		x
Pigia	multilineata	x		
Semiothisa	nigrocomma	x	x	x
Semiothisa	pallidata	x	x	x
Semiothisa	sp.1	x	x	x
Semiothisa	sp.2	x	x	x
Semiothisa	sp.3	x	x	x
Semiothisa	sp.4	x	x	x
Semiothisa	sp.5	x	x	x
Semiothisa	s-signata	x	x	x
Stenoporpia	pulchella	x	x	x
Synchlora	sp.1	x	x	x
Zenophleps	obscurata	x	x	x
unknown genus	sp.12		x	
unknown genus	sp.13		x	
unknown genus	sp.16			x
unknown genus	sp.19	x	x	x
unknown genus	sp.24	x	x	x
unknown genus	sp.27	x	x	x
unknown genus	sp.28			x
unknown genus	sp.29			x
unknown genus	sp.30	x	x	x
unknown genus	sp.34		x	x
unknown genus	sp.100		x	
unknown genus	sp.101			x
unknown genus	sp.102	x		x
unknown genus	sp.103		x	
unknown genus	sp.105	x		
unknown genus	sp.106	x	x	x
unknown genus	sp.107	x	x	x
unknown genus	sp.108			x
unknown genus	sp.109	x		x
unknown genus	sp.110	x	x	x
unknown genus	sp.111		x	x
unknown genus	sp.113	x	x	x
unknown genus	sp.115	x		
unknown genus	sp.116		x	
unknown genus	sp.117		x	
unknown genus	sp.120		x	x
unknown genus	sp.121		x	x
unknown genus	sp.122		x	x
unknown genus	sp.124	x		
unknown genus	sp.125			x
unknown genus	sp.126	x	x	x

	unknown genus	sp.127			x
	unknown genus	sp.128	x	x	
	unknown genus	sp.129			x
	unknown genus	sp.130			x
Lasiocampidae	unknown genus	sp.1	x	x	x
	unknown genus	sp.2		x	x
Noctuidae	Abagrotis	orbis	x		x
	Abagrotis	sp.1			x
	Acontia	arida	x	x	x
	Acontia	bella		x	x
	Acontia	cretata			x
	Acontia	lanceolata	x	x	x
	Acontia	sp.(new)	x	x	x
	Agrotis	ipsilon	x	x	x
	Agrotis	malefida	x		
	Aleptina	semiatra	x	x	x
	Allerastria	albicilaiata chacoensis			x
	Allerastria	albiciliatus	x	x	x
	Autographa	californica	x		x
	Azenia	virida		x	x
	Bagisara	buxea	x	x	x
	Bulia	deducta	x	x	x
	Bulia	similaris californic	x	x	x
	Caradrina	meralis	x		
	Catabena	terminellus	x	x	x
	Cataocala	babayaga	x		
	Catocala	palaeogama		x	x
	Cobubatha	dividua			x
	Condica	discistriga	x		
	Condica	sp.1	x	x	x
	Conochares	arizonae-elegantula	x	x	x
	Copablepharon	album	x	x	x
	Discestra	crotchii	x	x	x
	Discestra	mutata			x
	Discestra/Scotogramm	sp.1	x	x	
	Drasteria	pallescens	x	x	x
	Draudtia	leucorena	x	x	x
	Emarginea	percara	x	x	x
	Euscirrhopterus	gloveri	x	x	x
	Euxoa	auxiliaris	x	x	x
	Euxoa	hollemani	x		
	Euxoa	medialis	x	x	x
	Euxoa	messoria			x
	Faronta	tetera		x	x
	Grotellaforma	lactea	x	x	x

Helicoverpa	zea	x	x	x
Heliothis	phloxiphaga	x	x	x
Hemeroplanis	historialis	x	x	x
Hemeroplanis	incusalis	x	x	x
Hemieuxoa	rudens	x	x	x
Heteranassa	fraterna	x		
Heteranassa	mima	x	x	x
Hexorthodes	nipana	x	x	x
Homolagoa	grotelliformis		x	
Homorthodes	fractura			x
Homorthodes	sp.1	x	x	
Hoplolythra	discistriga			x
Lacinipolia	illaudabilis	x	x	x
Lacinipolia	quadrilineata	x	x	x
Lacinipolia	strigicollis	x	x	x
Leucania	farcta	x	x	x
Lythrodes	venatus	x	x	x
Melipotis	indomita		x	x
Melipotis	jucunda	x	x	x
Micrathetis	costiplaga	x	x	x
Neoligia	tonsa		x	x
Nocloa	aliaga		x	
Oncocnemis	major	x	x	x
Oncocnemis	pallidior		x	
Oncocnemis	pernotata		x	x
Oncocnemis	rosea		x	
Oxycnemis	fusimacula	x	x	x
Oxycnemis	gracillima		x	x
Oxycnemis	sp.1	x	x	x
Ozarba	propera	x	x	x
Paectes	abrostella		x	
Peridroma	saucia	x	x	x
Plagiomimicus	mimica	x		x
Polia	sp.1	x	x	x
Polia	sp.2	x	x	x
Protogygia	pallida	x	x	x
Protorthodes	alfkeni	x	x	x
Pseudaletia	unipuncta	x	x	x
Pseudanarta	sp.1	x	x	x
Pseudohadena	vulnerea	x	x	x
Schinia	acutilinea	x	x	x
Schinia	albafascia	x	x	x
Schinia	albafascia	x		
Schinia	buta			x
Schinia	ciliata	x	x	x

Schinia	hulstia		x	x
Schinia	intrabilis	x	x	x
Schinia	lynx			x
Schinia	miniana			x
Schinia	sexplagiata		x	x
Schinia	sp.(new)	x	x	x
Schinia	tertia	x	x	x
Sopodoptera	sp.1	x		
Spodoptera	exigua	x	x	x
Spodoptera	frugiperda		x	x
Stiria	consuela	x	x	x
Stylopoda	groteana		x	x
Synedoida	pulchra	x	x	x
Synedoida	tejonica	x	x	x
Tarachidia	cuta	x		x
Tarachidia	semiflava		x	
Tarachidia	venustula		x	x
Tathorhynchus	exsiccata	x	x	x
Toxonprucha	repentis	x	x	x
Toxonprucha	sp.1	x	x	x
Toxonprucha	volucris	x	x	x
Trichoclea	decepta	x	x	x
Trichoplusia	ni	x	x	x
Tridepia	nova	x	x	x
Tripudia	dimidiata		x	
Ulolonche	dilecta	x	x	x
Walterella	ocellata		x	
Zale	rubiata		x	
Zale	sp.1	x	x	x
Zaleops	umbrina	x	x	x
unknown genus	sp.2	x	x	x
unknown genus	sp.3	x	x	x
unknown genus	sp.6	x	x	x
unknown genus	sp.13		x	
unknown genus	sp.16		x	x
unknown genus	sp.19		x	x
unknown genus	sp.19 (sic)			x
unknown genus	sp.27	x	x	
unknown genus	sp.29	x	x	
unknown genus	sp.31			x
unknown genus	sp.35			x
unknown genus	sp.36	x	x	
unknown genus	sp.38		x	x
unknown genus	sp.42			x
unknown genus	sp.47	x	x	x

	unknown genus	sp.48	x	x	
	unknown genus	sp.51			x
	unknown genus	sp.78			x
	unknown genus	sp.93			x
	unknown genus	sp.96			x
	unknown genus	sp.97		x	
	unknown genus	sp.112		x	
	unknown genus	sp.115			x
	unknown genus	sp.119	x	x	x
	unknown genus	sp.135			x
	unknown genus	sp.136			x
	unknown genus	sp.138		x	x
	unknown genus	sp.143	x	x	x
	unknown genus	sp.144		x	
	unknown genus	sp.150		x	
	unknown genus	sp.153	x	x	x
	unknown genus	sp.154			x
	unknown genus	sp.157			x
	unknown genus	sp.159	x	x	x
	unknown genus	sp.165		x	x
	unknown genus	sp.167	x	x	x
	unknown genus	sp.200			x
	unknown genus	sp.202	x		x
	unknown genus	sp.203			x
	unknown genus	sp.204	x		
	unknown genus	sp.208			x
	unknown genus	sp.209	x		
	unknown genus	sp.210		x	x
	unknown genus	sp.211			x
	unknown genus	sp.215			x
	unknown genus	sp.217	x		x
	unknown genus	sp.229			x
	unknown genus	sp.232	x		
	unknown genus	sp.236			x
	unknown genus	sp.244	x	x	
	unknown genus	sp.245	x		
	unknown genus	sp.246		x	
	unknown genus	sp.247	x		
	unknown genus	sp.252	x		
	unknown genus	sp.255			x
	unknown genus	sp.256			x
	unknown genus	sp.257		x	
Notodontidae	unknown genus	sp.1	x	x	x
Pterophoridae	Stenoptilodes	grandis	x	x	x
	unknown genus	sp.1	x		

	unknown genus	sp.2	x	x	x
	unknown genus	sp.3			x
	unknown genus	sp.4	x		
Pyralidae	Blepharomastix	ranalis		x	
	Diastictis	fracturalis			x
	Diathrausta	reconditalis	x	x	x
	Euchromius	ocelleus	x	x	x
	Fissicrambus	sp.1	x	x	x
	Hellula	regatalis	x	x	x
	Helvibotys	helvialis	x	x	x
	Jacara	trabalis		x	x
	Loxostege	albiceralis	x	x	x
	Loxostege	allectalis			x
	Loxostege	sp.1	x	x	x
	Lygropia	octonalis	x		
	Mimorista	subcostalis	x	x	x
	Nomophila	nearctia	x	x	x
	Palpita	quadristigmalis			x
	Paragyractis	sp.1	x	x	x
	Petrophila	jaliscalis	x	x	x
	Petrophila	longipennis	x	x	x
	Pyrausta	onythesalis	x	x	x
	Spoladea	recurvalis		x	
	Stega	salutalis grisealis	x	x	x
	Stegea	sp.	x	x	x
	unknown genus	sp.1	x		x
	unknown genus	sp.2		x	x
	unknown genus	sp.3			x
	unknown genus	sp.4			x
	unknown genus	sp.5	x	x	
	unknown genus	sp.7	x	x	x
	unknown genus	sp.9	x	x	
	unknown genus	sp.10		x	x
	unknown genus	sp.11		x	x
	unknown genus	sp.12	x	x	x
	unknown genus	sp.15		x	x
	unknown genus	sp.17	x		x
	unknown genus	sp.18		x	
	unknown genus	sp.19			x
	unknown genus	sp.20		x	
	unknown genus	sp.21			x
	unknown genus	sp.22			x
	unknown genus	sp.23	x	x	x
	unknown genus	sp.25			x
	unknown genus	sp.27	x		

		unknown genus	sp.28			x
		unknown genus	sp.29		x	x
		unknown genus	sp.30	x	x	
		unknown genus	sp.31		x	x
		unknown genus	sp.32			x
		unknown genus	sp.33			x
		unknown genus	sp.35		x	
		unknown genus	sp.37	x	x	x
		unknown genus	sp.38	x	x	x
		unknown genus	sp.40	x	x	x
		unknown genus	sp.41		x	x
		unknown genus	sp.100	x	x	x
		unknown genus	sp.101	x	x	x
		unknown genus	sp.102	x	x	x
		unknown genus	sp.103		x	
		unknown genus	sp.104	x		x
		unknown genus	sp.105	x	x	x
		unknown genus	sp.106	x	x	x
		unknown genus	sp.107	x	x	x
		unknown genus	sp.108		x	
		unknown genus	sp.109	x	x	x
		unknown genus	sp.110	x		
		unknown genus	sp.111	x		
		unknown genus	sp.112		x	
		unknown genus	sp.113	x		
		unknown genus	sp.114	x		x
		unknown genus	sp.115			x
	Saturniidae	Hemileuca	neumoegeni			x
		Sphingicampa	hubbardi	x	x	x
	Sphingidae	Hyles	lineata	x	x	x
		Manduca	quinquemaculata	x		x
		Pachysphinx	modesta	x		x
		Sphinx	chersis	x		
	Tortricidae	Eucosma	sp.1	x		x
		Eucosma	sp.2			x
		unknown genus	sp.212		x	x
	unknown family	unknown genus	sp.1	x	x	x
(butterflies)	Hesperiidae	Copaeodes	aurantiaca	x	x	
		Pyrgus	communis	x		
	Libtheidae	Libytheana	bachmanii		x	
	Lycaenidae	Atlides	halesus	x		
		Brephidium	exile	x		
		Hemiargus	ceraunus	x		
		Leptotes	marina	x		
		Strymon	melinus	x		

	Nymphalidae	Asterocampa	celtis		x	x
		Chlosyne	acastus		x	
		Danaus	plexippus	x	x	
		Danaus	gilippus	x	x	
		Euptioeta	claudia	x	x	
		Junonia	coenia	x		
		Libytheana	carinenta	x	x	
		Adelpha	bredowii	x		
		Nymphalis	antiopa	x	x	
		Vanessa	cardui	x	x	
		Vanessa	atalanta	x	x	
	Papilionidae	Battus	philenor	x		
		Papilio	machaon	x		
		Papilio	multicaudatus	x	x	
	Pieridae	Anthocharis	sara	x	x	
		Colias	eurytheme	x	x	
		Colias	cesonia	x		
		Nathalis	iole	x		
		Pieris	sisymbrii	x		
		Pieris	protodice	x	x	x
		Pieris	callidice	x		
		Pontia	protodice	x	x	
	Riodinidae	Apodemia	palmeri	x	x	
		Apodemia	mormo	x		
Diptera	Anthomyiidae	unknown genus	sp.1	x		
	Apioceridae	Apiocera	intosa	x	x	
		Apiocera	parahydra		x	
	Asilidae	Efferia	albibarbis	x	x	
		Efferia	basini	x	x	x
		Efferia	imperialis			x
		Efferia	sp.1	x		
		Efferia	staminea			x
		Efferia	tricella			x
		Efferia	vertebrata		x	x
		Efferia	zonata		x	
		Laphystia	limatula	x	x	
		Laphystia	sp.1	x	x	x
		Laphystia	utahensis	x	x	
		Megaphorus	frustrus		x	x
		Polacantha	composita	x	x	x
		Proctacanthus	neamo	x	x	x
		Stenopogon	boharti		x	
	Bibionidae	Bibio	sp.1			x
	Bombyliidae	Anthrax	sp.1	x		
		Anthrax	sp.2		x	x

	Galbellula	sp.1	x		
	Geron	sp.1		x	x
	Ogcodocera	analis		x	x
	Oligodranes	sp.1		x	
	Phthiria	sp.1			x
	Phthiria	sp.2		x	
	unknown genus	sp.1		x	
	unknown genus	sp.2		x	
	unknown genus	sp.3		x	
	unknown genus	sp.4	x		x
Calliphoridae	unknown genus	sp.1	x	x	x
Chamaemyiidae	Pseudodinia	sp.1	x	x	x
Chloropidae	Thaumatomyia	sp.1	x	x	x
Culicidae	unknown genus	sp.1		x	x
Dolichopodidae	Chrysotus	sp.1	x	x	x
	Dolichopus	sp.1	x	x	x
	unknown genus	sp.1	x	x	x
Empididae	Neoplasta	sp.1	x		
	unknown genus	sp.1	x	x	
Lauxaniidae	unknown genus	sp.1	x	x	x
Muscidae	unknown genus	sp.1	x	x	x
Otitidae	Euxesta	sp.1		x	
Pipunculidae	unknown genus	sp.1	x		
Sarcophagidae	unknown genus	sp.1	x	x	
	unknown genus	sp.2	x	x	x
	unknown genus	sp.3	x	x	x
	unknown genus	sp.4		x	
Scenopinidae	Prorates	sp.1	x	x	x
Sepsidae	Sepsis	sp.1	x		x
Simulidae	unknown genus	sp.1	x	x	x
Syrphidae	Allograpta	exotica	x		
	Allograpta	obliqua			x
	Eupeodes	volucris	x	x	x
	Meliscaeva	diversifasciata		x	
	Mesograpta	marginata	x		
	Scaeva	pyrastri	x		
	Volucella	sp.1	x	x	
Tabanidae	Apatolestes	sp.1	x	x	x
Tachinidae	unknown genus	sp.1	x	x	x
	unknown genus	sp.2	x	x	x
	unknown genus	sp.3	x	x	x
Tephritidae	Trupanea	sp.1	x	x	
	unknown genus	sp.1	x		x
Therevidae	unknown genus	sp.1	x	x	x
Tipulidae	unknown genus	sp.1	x	x	x

Appendix C

List of herpetofaunal taxa encountered

Anura – Frogs and Toads

Bufo punctatus	red-spotted toad
Bufo woodhousei	Woodhouse’s toad
Hyla arenicolor	Canyon treefrog

Squamata – Lizards

Uta Stansburiana	side-blotched lizard
Cnemidophorus tigris	Western whiptail
Sceloporus magister	desert spiny lizard
Urosaurus ornatus	tree lizard
Phrynosoma platyrhinos	desert horned lizard
Sauromalus obesus	chuckwalla

Squamata – Snakes

Crotalus viridis abyssus	Grand Canyon pink rattlesnake
Crotalus mitchellii	speckled rattlesnake
Crotalus molossus	blacktail rattlesnake
Masticophis flagellum	red racer/coachwhip
Masticophis taeniatus	striped whipsnake

Appendix D

List of bird species encountered

Species List for All Birds Observed During Spring/Summer Trips, *2001, 2002, 2003

(Species in bold indicate rare/unusual sightings, though not records)

Spring/Summer Trips, *2001, 2002, 2003

Species	2001	2002	2003
American Avocet		1	1
American Coot			1
American Crow	1		1
American Kestrel		1	1
American Pipit		1	
American Redstart			1
American Robin		1	
American Widgeon		1	
Ash-throated Flycatcher	1	1	1
Bald Eagle		1	
Bell's Vireo	1	1	1
Belted Kingfisher		1	1
Bewick's Wren	1	1	1
Black-billed Magpie			1
Black-chinned Hummingbird	1	1	1
Black-chinned Sparrow		1	
Black-crowned Night Heron			1
Black-throated Gray Warbler	1	1	1
Black-headed Grosbeak	1	1	1
Black Phoebe	1	1	1
Black-throated Sparrow	1	1	1
Blue-gray Gnatcatcher	1	1	1
Blue Grosbeak	1	1	1
Blue-throated Grey Warbler	1		
Blue-throated Hummingbird			1
Blue-wing Teal		1	
Brewer's Sparrow		1	1
Broad-tailed Hummingbird		1	1
Bronzed Cowbird			1
Brown-crested Flycatcher	1	1	1
Brown-headed Cowbird	1	1	1
Bullock's Oriole			1
Bufflehead		1	
California Condor		1	1
California Gull		1	1

Canada Goose		1	1
Canyon Wren	1	1	1
Chipping Sparrow		1	1
Cinnamon Teal		1	1
Clark's Nutcracker		1	
Cliff Swallow			1
Common Goldeneye		1	1
Common Grackle	1	1	1
Common Merganser		1	1
Common Poorwill		1	
Common Raven	1	1	1
Common Yellowthroat	1	1	1
Coopers Hawk		1	1
Cordilleran Flycatcher		1	1
Costas Hummingbird	1	1	1
Crissel Thrasher			1
Dark-eyed Junco	1	1	1
Eared Grebe		1	
Eastern Kingbird			1
Empidonax sp.	1	1	1
Gadwall		1	1
Gambles Quail	1	1	1
Golden Eagle		1	1
Golden-crowned Kinglet	1		1
Great Blue Heron		1	1
Great Horned Owl		1	1
Great-tailed Grackle	1	1	1
Green Heron			1
Green-tailed Towhee		1	1
Green-wing Teal			1
Hammonds Flycatcher		1	
Hooded Oriole	1	1	1
House Finch	1	1	1
House Sparrow			1
House Wren		1	1
Indgo Bunting		1	
Killdeer			1
Lark Sparrow	1		1
Lazuli Bunting	1	1	1
Lesser Goldfinch	1	1	1
Lesser Scaup		1	1

Loggerheaded Shrike	1	1	
Louisianna Waterthrush	1		
Lucy's Warbler	1	1	1
MacGillivray's Warbler		1	1
Mallard		1	1
Marsh Wren		1	1
Mexican Spotted Owl			1
Mourning Dove	1	1	1
Northern Flicker		1	
Northern Mockingbird	1	1	1
Northern Pintail			1
Northern Rough-wing Swallow		1	1
Orange-crowned Warbler			1
Osprey			1
Painted Bunting			1
Painted Redstart			1
Peregrine Falcon	1	1	1
Phainopepla	1	1	1
Pinon Jay	1		
Plumbeous Vireo			1
Red-breasted Merganser		1	1
Redhead Duck		1	1
Red-tailed Hawk		1	1
Red-winged Blackbird		1	1
Ring-billed gull			1
Ring-necked Duck		1	1
Rock Wren	1	1	1
Rose-breasted Grosbeak		1	1
Ross's Goose		1	
Ruby-crowned Kinglet		1	1
Rufus-crowned Sparrow			1
Rufus Hummingbird		1	
Says Phoebe	1	1	1
Scott'sOriole		1	1
Scrub Jay	1	1	1
Sharp-shinned Hawk			1
Snowy Egret			1
Song Sparrow	1	1	1
Southwestern Willow Flycatcher	1	1	1
Spotted Sandpiper	1	1	1
Spotted Towhee	1	1	1

Summer Tanager	1	1	1
Townsend's Solitare		1	1
Turkey Vulture	1	1	1
Vesper Sparrow			1
Violet-green Swallow	1	1	1
Voux Swallow		1	1
Virginia Warbler		1	1
Warbling Vireo	1		1
Western Kingbird		1	1
Western Tanager		1	1
Western Wood Peewee	1	1	
White-crowned Sparrow	1	1	1
White-faced Ibis			1
White-throated Swift		1	1
Willet			1
Wilson's warbler	1	1	1
Wood Duck			1
Yellow Warbler	1	1	1
Yellow-breasted Chat	1	1	1
Yellow-rumped Warbler	1	1	1
Total species	54	101	116

*2001 - Two trips, April trip was omitted

Appendix E

List of small 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

Appendix F

Mammal Voucher Specimens

Appendix F. Mammal voucher specimen collected as part of the integrated terrestrial ecosystem monitoring of the riparian zone along the Colorado River in Grand Canyon from 2001-2003. Specimen preparations were either alcoholic (AL) or a skull plus alcoholic body (SA).

Field Number	Species	River Mile	River Side	Date	Nature of Preparation	Note
1	Peromyscus crinitus	43.1	L	2-May-01	SA	
2	Peromyscus crinitus	46.7	R	3-May-01	SA	
3	Neotoma lepida	46.7	R	3-May-01	SA	
4	Peromyscus boylii	46.7	R	3-May-01	SA	
5	Peromyscus eremicus	46.7	R	3-May-01	SA	
6	Peromyscus eremicus	46.7	R	3-May-01	SA	
7	Peromyscus eremicus	46.7	R	3-May-01	SA	
8	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 07
9	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 07
10	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 07
11	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 07
12	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 07
13	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 06
14	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 06
15	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 06
16	Peromyscus eremicus	46.7	R	3-May-01	AL	Embryo of # 06
17	Peromyscus crinitus	46.7	R	3-May-01	AL	Embryo of # 02
18	Peromyscus crinitus	46.7	R	3-May-01	AL	Embryo of # 02
19	Peromyscus crinitus	46.7	R	3-May-01	AL	Embryo of # 02
20	Peromyscus crinitus	46.7	R	3-May-01	AL	Embryo of # 02
21	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
22	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
23	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
24	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
25	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
26	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
27	Peromyscus crinitus	43.1	L	2-May-01	AL	Embryo of # 01
28	Peromyscus boylii	54.4	L	4-May-01	SA	
29	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28
30	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28
31	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28
32	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28
33	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28
34	Peromyscus boylii	54.4	L	4-May-01	AL	Embryo of #28

35	Neotoma albigula	65.3	L	5-May-01	SA	
36	Neotoma albigula	65.3	L	5-May-01	AL	Embryo of #35
37	Neotoma albigula	65.3	L	5-May-01	AL	Embryo of #35
38	Neotoma albigula	65.3	L	5-May-01	AL	Embryo of #35
39	Neotoma lepida	74.1	R	6-May-01	SA	
40	Peromyscys eremicus	122.8	L	8-May-01	SA	invert. pitfall casualty
41	Peromyscys crinitus	166.5	L	10-May-01	SA	
42	Chaetodipus intermedius	166.5	L	10-May-01	SA	
43	Chaetodipus intermedius	166.5	L	10-May-01	SA	
44	Neotoma lepida	174.5	R	12-May-01	SA	
45	Neotoma albigula	194	L	13-May-01	SA	
46	Perognathus formosus	202	R	15-May-01	SA	
47	Neotoma albigula	209	L	16-May-01	SA	
48	Perognathus formosus	46.8	R	30-Aug-01	SA	
49	Neotoma albigula	65.3	L	1-Sep-01	SA	
50	Pipistrellus hesperus	93.2	L	3-Sep-01	SA	
51	Pipistrellus hesperus	122.8	L	4-Sep-01	SA	
52	Chaetodipus intermedius	194	L	9-Sep-01	SA	
53	Dipodomys ordii	-0.4	R	26-Apr-02	SA	
54	Reithrodontomys megalotis	46.7	R	30-Apr-02	SA	
55	Reithrodontomys megalotis	204.5	R	11-Sep-02	AL	
56	Peromyscus eremicus	51.5	L	5-May-03	AL	
57	Peromyscus eremicus	51.5	L	5-May-03	AL	

Appendix G

Mammals of the Grand Canyon Region

Mammals of the Grand Canyon (i.e., vicinity of the Colorado River from Glen Canyon Dam to Pierce Ferry on Lake Mead), including adjacent rims and plateaus. Species of possible occurrence are indicated with "P". Distribution north or south of the Colorad

Taxon	Bailey 1935-Grand Canyon NP, Monument & adjacent area	Hoffmeister 1971-Grand Canyon	Suttkus et al. 1978-Riparian Zone	Hoffmeister 1986-within 20 km of Colorado River	Drost et al. 2000-Bats along Colorado River	Current Study	Other	North	South	Rim-conifer woodland and/or forest	Rim-non-forested	Canyon sides	Tonto Plateau and other benches	Inner Gorge desertscrub	Riparian	Record	Status	Notes
ORDER INSECTIVORA (insectivores)																		
Family Soricidae (shrews)																		
Notiosorex crawfordi desert shrew	x	x		x				x	x		x		x	x	P	V		
Sorex merriami Merriam's shrew		x		x				x	x	x						V		
Sorex nanus dwarf shrew		x		x				L		x						V		
ORDER CHIROPTERA (bats)																		
Family Phyllostomidae (New World leaf-nosed bats)																		
Choeronycteris mexicana Mexican long-tongued bat					x										*	R	A	Record based on captured migrating juvenile.
Family Vespertilionidae (vesper bats)																		
Antrozous pallidus pallid bat	x	x	x	x	x	x		x	x		x	x	x	x	x	V		
Corynorhinus townsendii Townsend's big-eared bat	P	x	x	x	x			x	x		x	x	x	x	x	V		Distribution is associated with caves.
Eptesicus fuscus big brown bat	x	x		x	x			x	x	x					*	V		
Euderma maculatum spotted bat		P			x	x		p	p	x		x			*	R		
Idionycteris phyllotis Allen's big-eared bat		P		x	x			x	x	x		x			*	V		
Lasiurus cinereus hoary bat	P	x		x	x			L		x					*	V		
Lasiurus blossevilli western red bat		x		x	x			x	x						x	V		Only two records are avaialble, both from Bright Angel Creek.
Lasionycteris noctivagans silver-haired bat	x	x		x	x			L		x					*	V		Bailey (1935) and Drost et al. (2000) reported a specimen from the south rim.
Pipistrellus hesperus western pipistrelle	x	x	x	x	x	x		x	x	x	x	x	x	x	x	V		
Myotis californicus California myotis	x	x	x	x	x	x		x	x		x	x	x	x	x	V		
Myotis ciliolabrum western small-footed myotis	P	x		x	P			x	x	x					P	V		
Myotis evotis long-eared myotis	x	x		x				L		x						V		Bailey (1935) reported a record from the south rim.
Myotis occultus Arizona myotis	x	x							x	x						R		Based on single report from south rim Bailey (1935).
Myotis thysanodes fringed myotis	x	x	x	x	x			x	x	x					*	V		
Myotis volans long-legged myotis	x	x		x				x	x	x						V		
Myotis yumanensis Yuma myotis	x	x	x	x	x			x	x		x	x	x	x	x	V		
Family Molossidae (free-tailed bats)																		
Eumops perotis western bonneted bat					x							x	x	x	x	R		
Nyctinomops macrotis big free-tailed bat		P		x	x	x		x	x			x			*	V		
Tadarida brasiliensis Brazilian free-tailed bat	x	x	x	x	x			x	x		x	x	x	x	x	V		
ORDER LAGOMOROPHA (pikas, hares, and rabbits)																		
Family Leporidae (hares and rabbits)																		
Lepus californicus black-tailed jackrabbit	x	x	x	x		x		x	x	x	x			x	x	V		Reported near river only at Lee's Ferry and Scorpion Island.
Lepus townsendii white-tailed jackrabbit		P		?				x			x					R	Q	
Sylvilagus audubonii desert cottontail		x		x		x		x	x	x	x				x	V		Riparian record could be *S. nuttallii* .
Sylvilagus floridanus eastern cottontail				x					r	x						V		Known from a single specimen collected at Pine Springs in Prospect Valley.
Sylvilagus nuttallii mountain cottontail	x	x		x				x	r	x	x					V		Primarily occurs on the north rim (Kaibab Plateau). A juvenile specimen tentatively identified as *S. nuttalii pinetis* was reported from atypical deserscrub habitat at Page on south rim. Bailey (1935) reported this species was commonly observed on the so

ORDER RODENTIA (rodents)																		
Family Sciuridae (squirrels)																		
Ammospermophilus harrisii Harris's antelope squirrel			x	x					r					x	*	V		Known only from Scorpion Island in the upper end of Lake Mead.
Ammospermophilus leucurus white-tailed antelope squirrel	x	x	x	x		x		x	x		x		x	x	x	V		
Cynomys gunnisoni Gunnison's prairie dog	x	x		x					x		x		x			V		
Neotamias cinereicollis gray-collared chipmunk	P								x	x							Q	Although Bailey (1935) thought the species should occur on the south rim, the nearest records are from vicinity of San Francisco Peaks and the species has not been observed or documented on the south rim.
Neotamias dorsalis cliff chipmunk	x	x		x				x	x	x	x	x	x			V		Bailey (1935) reported observations from Phantom Ranch.
Neotamias rufus Hopi chipmunk	x			x					r	x	x					V		Known from a single specimen collected in east near Page. Also called N. quadrivittatus and N. hopiensis.
Neotamias minimus least chipmunk	x	x		x				L		x						V		
Neotamias umbrinus Uinta chipmunk	x	x		x				x		x						V		
Sciurus aberti Abert's squirrel	x	x		x				x	x	x						V		The "Kaibab squirrel" of the north rim is a well differentiated subspecies of Abert's squirrel (S. a. kaibabensis).
Spermophilus lateralis golden-mantled ground squirrel	x	x		x				L	+	x						V		A single specimen from the south rim is regarded as introduced.
Spermophilus spilosoma spotted ground squirrel	x	x		x					x		x					V		
Spermophilus variegatus rock squirrel	x	x	x	x		x		x	x	x	x	x	x	x	x	V		
Tamiasciurus hudsonicus red squirrel	x	x		x				L		x						V		
Family Geomyidae (pocket gophers)																		
Thomomys bottae Botta's pocket gopher	x	x		x				x	x	x	x					V		
Thomomys talpoides northern pocket gopher	x	x		x				L		x						V		
Family Heteromyidae (pocket mice and kangaroo rats)																		
Chaetodipus intermedius rock pocket mouse	x	x	x	x		x			x		x	x	x	x	x	V		
Dipodomys merriami Merriam's kangaroo rat			x	x				L			x		x		*	V		Known only from vicinity of Vulcan's Throne in Toroweap Valley, Scorpion Island, and Sand Point.
Dipodomys micropus chisel-toothed kangaroo rat	x			x				x	+		x					V		Hardy (1949) reported it southeast of river near Navajo Bridge, which is regarded as an introduction.
Dipodomys ordii Ord's kangaroo rat	x	x		x		x		x	x		x			x	*	V		Known in riparian habitat only in vicinity of Lees Ferry.
Perognathus amplus Arizona pocket mouse			x	x					r					x	*	V		Known only from Scorpion Island in the upper end of Lake Mead and vicinity of Pierce Ferry.
Perognathus flavescens plains pocket mouse	P			x					x		x					V		Also called *P. apache.*
Perognathus flavus silky pocket mouse	P	x		x					x	x	x					V		
Perognathus formosus long-tailed pocket mouse	P	x	x	x		x		x			x	x	x	x	x	V		
Perognathus longimembris little pocket mouse	x			x				L	+		x		x			V		Two specimens from the vincinity of Page (south of river) are regarded as introduced.
Perognathus parvus Great Basin pocket mouse				x				x		x	x					V		
Family Castoridae (beavers)																		
Castor canadensis American beaver	x	x	x	x		x		x	x						x	V		

Family Muridae (mice, rats, and voles)																		
Subfamily Sigmodontinae																		
Neotoma albigula western white-throated woodrat	x	x	x	x		x			x	x	x	x	x	x	x	V		
Neotoma cinerea bushy-tailed woodrat	x	x		x				x	r	x						V		Primarily occurs in conifer forests on north rim (Kaibab Plateau). A single specimen of *N.c. arizonae* was collected from Lees Ferry on the south side of the river.
Neotoma lepida desert woodrat	x	x	x	x		x		x	x	x	x	x	x	x	x	V		
Neotoma mexicana Mexican woodrat	x	x		x					x	x						V		
Neotoma stephensi Stephens's woodrat	x	x		x					x	x						V		
Onychomys leucogaster nothern grasshopper mouse	x	x		x				x	x		x		x			V		
Onychomys torridus southern grasshopper mouse				x				r	r				x	x		V		Specimens have only been collected from near Vulcans Throne on the north side and Pierce Ferry on the south side.
Peromyscus boylii brush mouse	x	x	x	x		x		x	x		x	x	x	x	x	V		
Peromyscus crinitus canyon mouse	x	x	x	x		x		x	x			x	x	x	x	V		
Peromyscus eremicus cactus mouse	x	x	x	x		x		x	x		x		x	x	x	V		
Peromyscus maniculatus deer mouse	x	x	x	x				x	x	x	x		x	x	x	V		
Peromyscus truei pinon mouse	x	x	x	x				x	x	x					*	V		
Reithrodontomys megalotis western harvest mouse	x	x	x	x		x		x	x	x	x				x	V		
Subfamily Murinae																		
Mus musculus house mouse		x		x							x					V	I	
Subfamily Arvicolinae																		
Microtus longicaudus long-tailed vole	x	x		x				x		x						V		
Microtus mogollonensis Mogollon vole	x	x		x					x	x						V		Previously called *M. mexicanus.*
Ondatra zibethicus common muskrat				x												R	Q	Report based on drawing of footprints taken near mile 200.
Family Erethizontidae (New World porcupines)																		
Erethrizon dorsaturn North American porcupine	x	x		x						x	x					V		
ORDER CARNIVORA (Carnivores)																		
Family Canidae (dogs, foxes, and wolves)																		
Canis latrans coyote	x	x	x	x		x		x	x	x	x		x	x	x	V		
Canis lupus gray wolf	x	x						x	x	x	x					R	E	
Urocyon cinereoargenteus common gray fox	x	x	x	x		x		x	x	x	x	x	x	x	x	V		
Vulpes macrotis kit fox						?	x				x					R		
Family Ursidae (bears)																		
Ursus americanus black bear	x	x		x				x	x	x						R		More common on the south rim.
Ursus arctos grizzly bear	x	x		x				x	x	x	x					V	E	
Family Procyonidae (raccoons, ringtails, and coatis)																		
Bassariscus astutus ringtail	x	x	x	x		x		x	x			x	x	x	x	V		
Procyon lotor northern raccoon	x	x		x		x		x	x						x	R		
Family Mustelidae (weasels, otters, and badgers)																		
Lontra canadensis northern river otter	x	x		x				x	x						x	R	E?	
Mustela erminea ermine							x	x		x								
Mustela frenata long-tailed weasel	x	x		x				x	x	x						V		
Taxidea taxus American badger	x	x		x				x	x	x	x		x			V		
Family Mephitidae (skunks)																		
Spilogale gracilis western spotted skunk	x	x	x	x		x		x	x			x	x	x	x	V		
Mephitis mephitis striped skunk	x	x		x				x	x	x						V		
Family Felidae (cats)																		
Lynx rufus bobcat	x	x		x		x		x	x	x	x	x	x	x	x	V		
Panthera onca jaguar	x	x		x					x	x	x	?	?	?	?	R	E	
Puma concolor mountain lion	x	x		x		x		x	x	x	x	x	x	x	x	V		

ORDER PERISSODACTYLA (odd-toed ungulates)																	
Family Equidae (horses and asses)																	
Equus asinus feral ass		x	x	x				x	x		x		x	x	x	R	I	
Equus caballus feral horse				x							x					R	I	
ORDER ARTIODACTYLA (even-toed ungulates)																	
Family Cervidae (deer and relatives)																	
Cervus canadensis wapiti		P		x					x	x						R		The native subspecies was extirpated. Contemporary populations are the result of introductions.
Odocoileus hemionus mule deer	x	x	x	x		x		x	x	x	x		x	x	x	V		
Family Antilocapridae (pronghorns)																	
Antilocapra americana pronghorn	x	x		x					x		x		x			V		
Family Bovidae (cattle, sheep and relatives)																	
Bos bison bison	x			x				r			x					R	I	There is an introduced population in Houserock Valley.
Capra hircus goat						x									*		I	It is unknown if this was a domestic or feral goat.
Ovis canadensis bighorn sheep	x	x	x	x		x		x	x			x	x	x	x	V		