THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA:

FINAL REPORT

NPS WORK ORDER NO. CA 8021-8-0002

Lawrence E. Stevens

and

Tina J. Ayers

Department of Biological Sciences, Box 5640
Northern Arizona University
Flagstaff, AZ 86011

31 December, 1995

Submitted To:

The National Biological Survey
Northern Arizona University, Box 5614
Flagstaff, AZ 86011

THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA:

FINAL REPORT

NPS WORK ORDER NO. CA 8021-8-0002

Lawrence E. Stevens

and

Tina J. Ayers

Department of Biological Sciences, Box 5640
Northern Arizona University
Flagstaff, AZ 86011

31 December, 1995

Submitted To:

The National Biological Survey
Northern Arizona University, Box 5614
Flagstaff, AZ 86011

THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA: FINAL REPORT

Lawrence E. Stevens

and

Tina J. Ayers

Department of Biological Sciences, Box 5640
Northern Arizona University
Flagstaff, AZ 86011

NPS Work Order No.:	**CA 8021-8-0002**
Starting Date:	**15 June, 1992**
Duration:	**27 Months**
Date of Final Report:	**31 December, 1995**
Funding Amount:	**$262,410.00**
Supported by:	**The Bureau of Reclamation** **Glen Canyon Environmental Studies Program** **P.O. Box 22459** **Flagstaff, AZ 86002-2459**
Submitted To:	**The National Biological Survey** **Northern Arizona University, Box 5614** **Flagstaff, AZ 86011**

IA. COOPERATIVE AGREEMENT: CA 8021-8-0002

NAME: THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA: FINAL TECHNICAL AND ADMINISTRATIVE REPORTS

PRINCIPAL INVESTIGATORS: LAWRENCE E. STEVENS AND TINA J. AYERS

GOVERNMENT TECHNICAL REPRESENTATIVE: DR. PETER G. ROWLANDS

SHORT TITLE OF WORK: FINAL TECHNICAL AND ADMINISTRATIVE REPORTS

STARTING DATE: 15 JUNE, 1992

DURATION: 27 Months

DATE OF FINAL REPORT: 31 DECEMBER, 1995

FUNDING AMOUNT: $262,410.00

SUPPORTED BY: The Bureau of Reclamation
Glen Canyon Environmental Studies Program
P.O. Box 22459
Flagstaff, AZ 86002-2459

SUBMITTED TO: The National Biological Survey
Northern Arizona University, Box 5614
Flagstaff, AZ 86011

SPECIFIC RESPONSES TO NBS REVIEW COMMENTS

We thank the National Biological Service (NBS) for taking the time to review the draft final report of the Interim Flows vegetation monitoring project. We document our responses to the NBS comments below.

* The format for the report was the standard format at the time of writing, and has been used on numerous previous reports. We took specific care to outline management impacts for each section so that concerned managers could understand options and potential strategies.

* We have included more detail on our methods.

* We opted for the use of scientific names all the way through. Specific terms like "xylem water potential" and "inundation frequency" are not jargon, but describe physiologically and ecologically relevant phenomena.

* We do not presume that "more and larger marshes are...better" for Grand Canyon. We do recognize wetlands as rare and threatened habitats in the Southwest which support endangered species (which should interest the NBS), and have specifically identified these patterns in numerous other reports and publications. Perhaps new NBS editors should review the existing literature.

* After reviewing the taxonomy of Equisetum, and recognizing that two spellings of the epithet have been widely published, the Ecological Society of America recommended spelling this species hyemale.

* We have endeavored to use place names as river miles (English units), but conduct our analyses using metric terms.

* We have re-edited the bibliography section and changed "Pierces Ferry" (the original, correct spelling) to the incorrect "Pearces Ferry" (apparently a USGS misspelling of the original). Also, we renumbered the appendices.

* We reformatted and re-fonted the entire text.

* Table 2.03 is now Table 2.01. The mean total basal area (cm^2/m^2) of 52.9 means there was, on average 52.9 cm^2 of clonal wet marsh basal cover/m^2. The term "sd" refers to 1 standard deviation around the mean.

* The NBS reviewer may be aware that vegetation assemblages are not always pure stands, and that riparian and even upland plant species occasionally are found in Grand Canyon marshes.

* Delivery of specimens to the Grand Canyon's collection has always been planned in these vegetation monitoring projects.

* Gooddings willow were relatively common at individual sites (e.g., Lees Ferry) during the pre-dam period. While a few Fremont cottonwood saplings occurred in the river corridor (particularly prior to 1982), the present crop may actually become a reproductively successful population, a condition which could result in substantial changes in corridor vegetation.

* Citing soon-to-be-published literature as In press is a standard practice in the scientific literature.

* Coyote will has been classified by the U.S. Fish and Wildlife Service as a wetland obligate species in the Southwest, and our data clearly and unequivocally demonstrate that coyote willow is useful as a marsh indicator species.

* We have done our best to correct typographic errors in our species list, and we synthesized the numbering system used in the text and analyses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

We wish to thank the office and staff of the National Park Service at Grand Canyon National Park and the National Biological Survey at Northern Arizona University for their support through the course of this project. We thank Mr. David L. Wegner and his staff at the Bureau of Reclamation Glen Canyon Environment Studies Office for their enthusiastic support of this project, and particularly Mr. Chris Brod for topographic mapping assistance. We thank Ms. Lisa Kearsley (National Park Service, Grand Canyon) for logistical support, field mapping assistance and help with the MIPS analyses of aerial photographs. We acknowledge the excellent logistical support provided by the office and field staff of O.A.R.S., Inc. M. Kearsley was responsible for data management and quality control, as well as some field crew leadership. We deeply appreciate the enthusiastic assistance of our field and office staff, including: A. Autenreith, D. Bechtel, K. Buck, G. Dayton, A. Holm, M. Gregg, J. Hazel, H. Mayes, M. Moran, D. Northcutt, R. Scott, D. Silva, G. Sponenburgh, J. Star, B. Venable, R. Weber and A. Wilson. Ms. M. Etter contributed innumerable hours of diligent assistance with data entry and ERDAS, and volunteered her time most nobly. We were also assisted by numerous NPS volunteers, to whom we owe a large debt of gratitude.

ABSTRACT

THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION IN THE COLORADO RIVER DOWNSTREAM FROM GLEN CANYON DAM, ARIZONA:

1994 FINAL REPORT

ABSTRACT

This report evaluates the effects of interim flows from Glen Canyon Dam on riparian vegetation in the Colorado River corridor in Grand Canyon National Park. Initiated in August, 1991, interim flows criteria were designed to protect fluvial ecosystem resources as the Bureau of Reclamation Environmental Impact Statement is completed. Thus, a report of no change or improvement of resource conditions signifies that the purposes for which interim flows were established are being achieved.

We documented short-term (3-yr) and longer-term (5-10 yr) effects of interim flows on the riparian vegetation in this system. Interim flows have permitted a rapid, downslope shift in fluvial marsh and riparian vegetation. Compositional changes related to increased drought stress are taking place on a longer-term basis in marshes and on other previously colonized lower riparian zone habitats. Under interim flows, previously established marshes not subjected to scour by tributary flooding decreased in area, while new marshes have become established throughout the river corridor. Mainstream marshes downstream from the Little Colorado River were partially scoured by combined flows of 1000 m^3/s from Little Colorado River floods and mainstream flows in early 1993. The three short pulses of flooding scoured the lowest lying marsh vegetation and aggraded return current channels, demonstrating that planned floods conducted as short pulses of flows just above power plant capacity may negatively affect riparian vegetation development in this system.

Our specific conclusions include the following.

1) The 1993 marsh inventory revealed that wet marsh (cattail/reed) patch density/km between Lees Ferry and Diamond Creek increased 3.5-fold over the 1991 total (n=253); however, total estimated fluvial wet marsh area decreased 22% from 9.0 ha to 7.03 ha. Areal losses were related to scour downstream from the Little Colorado River by the January-February 1993 floods, with marsh area losses of up to 90 percent in some narrow reaches. In contrast, the unflooded section of the river upstream from the Little Colorado River exhibited a very slight gain (0.3%) in marsh area during this period. Additional but smaller marshes have developed as a result of flooding impacts and interim flows effects. If these developing marshes are permitted to grow, marsh area can be expected to increase again dramatically; however, planned flooding will undoubtedly scour most of these new marshes, as well as much of the other "new dry" zone vegetation, from the river corridor.

2) Comparison of MIPS analysis of marsh area at 24 sites between 1988 and 1994 reveals a great increase in fluvial marsh area through time up to 1992; however, overall marsh area declined significantly between 1992 and 1993 as a result of Little Colorado River flooding and probably also because of decreased inundation frequency of marsh vegetation at higher stage elevations. These analyses suggest that interim flows are having the hypothesized effect of reducing marsh area and concentrating marsh growth along channel margins and return current channel (RCC) mouths.

3) Wet marsh cover above the maximum interim flows stage (566 m^3/s) has decreased through the interim flows period, and composition has shifted towards dominance by woody phreatophytes (especially Salix exigua).

4) Silt-rich, low-slope shoreline habitats between the 425 and 566 m^3/s stages (protected from daily inundation) have undergone primary colonization by wet marsh taxa during the interim flows period. Colonization occurred through clonal expansion of existing marsh stands in return current channel mouths and by primary colonization of reattachment point and channel margin settings.

5) Flooding of the Little Colorado River during the January and February 1993 demonstrated that short-duration (ca 5-day) flows of maximum powerplant discharge (950 m^3/s) aggrade RCCs, increasing the baselevel and further reducing inundation frequency. Short-term floods are therefore unlikely to reactivate scour of RCC's, limiting the utility of such events in restoration of RCC habitats. Higher magnitude and/or longer duration flows are required to reform RCC habitats. However, such floods will eliminate increased marsh cover that has developed at low (425-566 m^3/s) stages. The result of coupling an interim flows regime with planned mainstream and erratic tributary floods is likely to reduce fluvial marsh cover in this system.

6) Measurement of xylem water potential (XWP) and stem growth of Salix exigua growing along a moisture/elevational gradient at four sites was conducted to evaluate the effects of interim flows on water relations of a marsh indicator species. Measurements were taken at four sites during the pre-dawn and midday hours during low-, medium- and high-flow months in 1992 and 1993. We hypothesized that monthly flow volume would be negatively correlated with Salix xylem water potential, and that measurement of this parameter could be used as an effective monitoring method, as proposed by Stromberg et al. (1993). Willow XWP studies support the contention that interim flows have increased moisture stress on high bar locations: a) S. exigua growth was negatively correlated with stage elevation, stem age, stem length and basal area; b) temperature and relative humidity varied in relation to stage elevation, between day and night, between months in 1993 and between sites (over distance downstream from Glen Canyon Dam; and c) temperature and humidity-adjusted willow xylem water potential (XWP) varied by time of day, between study sites and between months; d) Log_n-transformed S. exigua annual stem growth was positively correlated with log_n-transformed distance downstream and with both mean monthly pre-dawn and mean mid-day adjusted XWP values, and was negatively correlated with log_n-transformed ramet age. We found that nearly 70 % of the variance in willow XWP was attributable to temperature and relative humidity.

Implementation of selective withdrawal at Glen Canyon Dam to warm the Colorado River may influence growth rates and patterns of riparian plant dominance.

7) Controlling on-going invasions of non-native plants varies between species, with some species (e.g., Erianthus ravennae) that can be controlled relatively easily, and others (e.g. Lepidium latifolium) that may not.

8) MIPS analyses of 1991 and 1994 aerial photographs at six study areas revealed that although the overall cover of riparian vegetation at most study sites is static or increasing, the distribution of vegetation is shifting within sites. Sandbar riparian and wetland vegetation is concentrating between the 566 and 900 m^3/s stages, and previously established S. exigua in high bar locations is dying back.

9) Relative axis 1 DECORANA species scores on long-term quadrats in the lower riparian zone were lower in 1993 relative to 1992 scores, reflecting a gradual shift during interim flows towards sand bar species that are more drought tolerant. This was also supported by changes in individual species mean and sum basal areas on long-term quadrats in several lower riparian zone geomorphic settings.

10) The "new dry" zone, lying between the interim flows maximum flow stage (566 m^3/s stage) and the "normal operations" stage (ca. 900 m^3/s stage), is being quickly and actively colonized by riparian plants, particularly herbs, clonal phreatophytes and perennial grasses, with higher density but lower diversity on fine-grained (silty fine sand) substrata, as compare to cobble and boulder substrata.

11) GIS related mapping of five long-term study areas was completed and has been contributed to the GCES GIS database. We found support for the dynamic equilibrium hypothesis, the intermediate disturbance hypothesis and a geomorphic environments hypothesis, all of which combined helped explain patterns of plant diversity at these sites.

CHAPTER I

INTRODUCTION

CHAPTER I:

INTRODUCTION

PROBLEM STATEMENT

Riparian vegetation is structurally adjusted and evolutionarily adapted to the flooding frequency of the river system in which it occurs (Odum 1981, Nilsson 1984, Day et al. 1988, Hupp 1988, Auble et al. 1994). By altering the frequency, magnitude, duration and seasonal timing of flooding disturbance, flow regulation dramatically influences riparian vegetation (Stevens et al. 1995).

Discharge from Glen Canyon Dam affects riparian vegetation along the Colorado River downstream in Glen Canyon National Recreation Area and in Grand Canyon National Park (Clover and Jotter 1944, Carothers et al. 1979, Stevens and Waring 1988, Stevens 1989, Stevens et al., 1995). These effects include altered establishment and developmental trajectory of marsh and other shoreline plant communities by influencing erosion of alluvial sediment deposits, seed dispersal and seedling establishment, water relations of streamside plants, and the population dynamics of exotic plant species. Riparian habitat is widely recognized as supporting high levels of biodiversity and for its high levels of bioproductivity. In the Southwest, riparian habitat comprises less than 0.5 percent of the landscape (Simcox and Zube 1985), but supports more than 50 percent of the species in the landscape. At least 5,000 species (plants, invertebrates and vertebrates) rely on desert riparian habitats in Grand Canyon National Park. Grand Canyon National Park established maintenance of riparian vegetation diversity in the Colorado River corridor as a primary management objective (U.S. Bureau of Reclamation 1995:56).

On 1 August, 1991, the Secretary of the Interior initiated preliminary interim flows criteria on discharge from Glen Canyon Dam, a test program of reduced maximum flows and reduced fluctuation in the Grand Canyon (Fig. 1.01). Interim flows were designed to limit dam-related sediment losses and mitigate resource degradation, thereby allowing fluvial ecosystem processes to proceed unaffected by dam operations and in accord with the National Park Service management objectives until the Environmental Impact Statement Record of Decision and long-term monitoring program are implemented.

Interim flows consist of low-, medium-, and high-volume months, with low flows during the spring and late fall, moderate flows in June, September and November, and high flows during mid-summer and mid-winter. Interim flows have a minimum flow of 141.5 m^3/s (5,000 cfs), a maximum discharge of 566 m^3/s (meters^3 per second) (20,000 cfs, cubic feet per second), a reduced range of daily fluctuation, and reduced up-ramping and down-ramping rates. This change in flow regime was implemented in November, 1991 and strongly affected flow parameters downstream (Fig 1.02).

The interim flows regime has exposed an additional belt of shoreline to plant colonization between the pre- and post- interim flows maximum discharge (566 to 900 m^3/s stages), and has reduced hourly and daily flow fluctuations. Our monitoring efforts are related to understanding the impacts of reduced inundation frequency at upper stage elevations and the extent and rate of colonization of the new shoreline habitat. A finding of no change in vegetation resource states signifies that the purposes for which interim flows were established are being achieved.

CHAPTER I:

INTRODUCTION

PROBLEM STATEMENT

Riparian vegetation is structurally adjusted and evolutionarily adapted to the flooding frequency of the river system in which it occurs (Odum 1981, Nilsson 1984, Day et al. 1988, Hupp 1988, Auble et al. 1994). By altering the frequency, magnitude, duration and seasonal timing of flooding disturbance, flow regulation dramatically influences riparian vegetation (Stevens et al. 1995).

Discharge from Glen Canyon Dam affects riparian vegetation along the Colorado River downstream in Glen Canyon National Recreation Area and in Grand Canyon National Park (Clover and Jotter 1944, Carothers et al. 1979, Stevens and Waring 1988, Stevens 1989, Stevens et al., 1995). These effects include altered establishment and developmental trajectory of marsh and other shoreline plant communities by influencing erosion of alluvial sediment deposits, seed dispersal and seedling establishment, water relations of streamside plants, and the population dynamics of exotic plant species. Riparian habitat is widely recognized as supporting high levels of biodiversity and for its high levels of bioproductivity. In the Southwest, riparian habitat comprises less than 0.5 percent of the landscape (Simcox and Zube 1985), but supports more than 50 percent of the species in the landscape. At least 5,000 species (plants, invertebrates and vertebrates) rely on desert riparian habitats in Grand Canyon National Park. Grand Canyon National Park established maintenance of riparian vegetation diversity in the Colorado River corridor as a primary management objective (U.S. Bureau of Reclamation 1995:56).

On 1 August, 1991, the Secretary of the Interior initiated preliminary interim flows criteria on discharge from Glen Canyon Dam, a test program of reduced maximum flows and reduced fluctuation in the Grand Canyon (Fig. 1.01). Interim flows were designed to limit dam-related sediment losses and mitigate resource degradation, thereby allowing fluvial ecosystem processes to proceed unaffected by dam operations and in accord with the National Park Service management objectives until the Environmental Impact Statement Record of Decision and long-term monitoring program are implemented.

Interim flows consist of low-, medium-, and high-volume months, with low flows during the spring and late fall, moderate flows in June, September and November, and high flows during mid-summer and mid-winter. Interim flows have a minimum flow of 141.5 m^3/s (5,000 cfs), a maximum discharge of 566 m^3/s (meters^3 per second) (20,000 cfs, cubic feet per second), a reduced range of daily fluctuation, and reduced up-ramping and down-ramping rates. This change in flow regime was implemented in November, 1991 and strongly affected flow parameters downstream (Fig 1.02).

The interim flows regime has exposed an additional belt of shoreline to plant colonization between the pre- and post- interim flows maximum discharge (566 to 900 m^3/s stages), and has reduced hourly and daily flow fluctuations. Our monitoring efforts are related to understanding the impacts of reduced inundation frequency at upper stage elevations and the extent and rate of colonization of the new shoreline habitat. A finding of no change in vegetation resource states signifies that the purposes for which interim flows were established are being achieved.

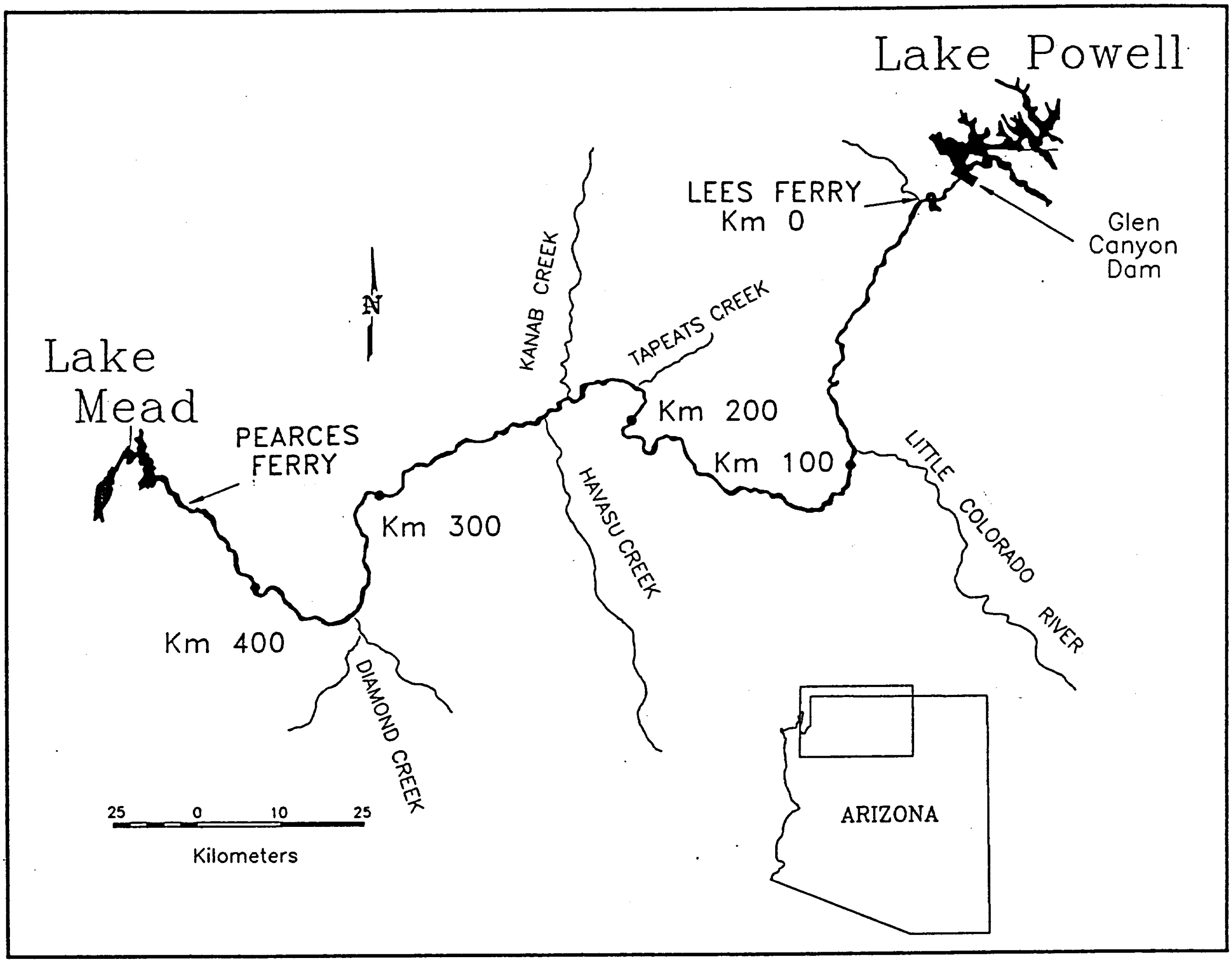


Figure 1.01: General map of the Colorado River downstream from Glen Canyyon Dam, Arizona.

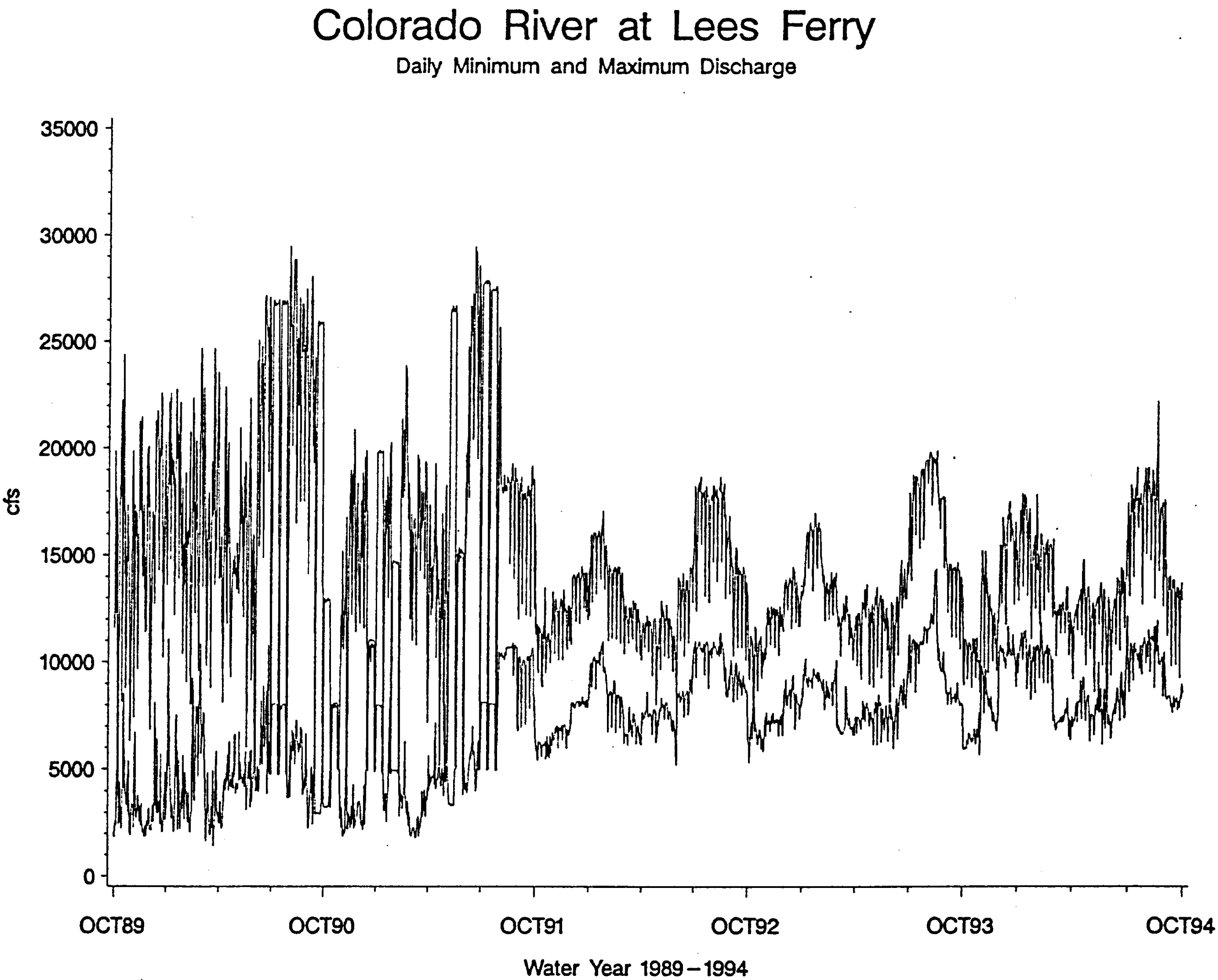


Figure 1.02: Flows from Glen Canyon Dam from October 1989 through October, 1994 measured at the U.S. Geological Survey guaging station at Lees Ferry, Arizona.

OBJECTIVES

The purpose of this study was to determine whether interim flows limited the impacts of Glen Canyon Dam operations on riparian vegetation resources in the Grand Canyon. We monitored the effects of interim flows on riparian vegetation composition and structure from 1992 to 1994, using comparably collected data from the Glen Canyon Environmental Studies Phase II program (Patten 1990). This study describes interim flows effects on the rate and trajectories of the riparian plant community development, fluvial/terrestrial ecosystem interactions, population changes in exotic plant species, and the risk status of endemic species.

Our specific objectives included the following.

1. Monitor the effects of interim flows from Glen Canyon Dam on the distribution, extent and development of fluvial marshes along the Colorado River from Glen Canyon Dam to Diamond Creek.

2. Monitor the effects of interim flows from Glen Canyon Dam on the distribution and development of other new high water zone plant assemblages between Glen Canyon Dam and Diamond Creek.

3. Prepare monitoring data for inclusion into the GCES/NPS GIS database.

In addition, we provide information on the effects of Little Colorado River flooding in January-February, 1993 on marsh and lower riparian zone vegetation. These observations are relevant to on-going discussions regarding the role of planned flooding as a management strategy in this system.

METHODS AND STRUCTURE OF THIS REPORT

We conducted 11 research river trips from June 1992 to June 1994 during low-, medium-, and high-flow months through the Colorado River in Grand Canyon National Park between Lees Ferry and Diamond Creek, in accord with our proposed schedule (Table 1.01; Fig. 1.01). Staffing and equipment costs on these trips were borne by this project, and logistics were provided by O.A.R.S., Inc. and by personal contributions of equipment. Research river trips staff included of several Northern Arizona University (NAU) staff and NPS personnel, and hiring protocol for field and laboratory assistants conformed to that required by the NAU Human Resources Department. We were assisted by numerous volunteers who were supported through the Volunteers In Parks Program at Grand Canyon National Park.

Riparian vegetation research in GCES Phase II focused on species diversity and variation in riparian vegetation associated with typical geomorphic settings at sites studied by Stevens and Ayers (1993) during GCES Phase II, and additional sites were used to address other study objectives (Table 1.02; Appendix A).

Included with this report is an administrative summary documenting the expenditures associated with this project. This project was initiated later than anticipated, but we were able to accomplish the prescribed research, monitoring and reporting on schedule.

Table 1.01: Research river trips summary, 1993 to 1994.

TRIP DATES	PURPOSE OF TRIP	# NAU STAFF	# VIP'S (HRS WORK)	FEDERAL & OTHER STAFF
14-29 Aug, 1992	Quadrat and transect reestablishment	5	5 (640)	2
16 Sep-2 Oct, 1992	Census marsh transects	8	2 (272)	9
16 Oct-2 Nov, 1992	Complete censusing	8	8 (1152)	6
12-23 March, 1993	Priority site mapping	1	3 (288)	0
4-20 May, 1993	Spring marsh and trib monitoring, mapping, XWP[1], surveying	7	14 (1904)	3
2-14 June, 1993	Mapping, light measurement XWP, tributary plots wrap-up	3.5	6 (624)	2
8-19 July, 1993	Mapping, light measurement XWP	3	6 (576)	2
8-24 Sept, 1993	Mainstream plot monitoring, marsh inventory, mapping, XWP, surveying	5	7 (952)	7
1-20 Oct, 1993	XWP	1	1 (53)	0
29 Oct-14 Nov, '93	Fall marsh monitoring, mapping, XWP wrap-up, productivity wrap-up	7	7 (952)	4
15 Apr-1 May, 1994	Marsh censuses	5	7 (1088)	7
26 May-9 Jun, 1994	Mapping	1	4 (480)	2

[1] XWP = Xylem water potential studies

Table 1.02: Study sites in the Colorado River corridor, Grand Canyon National Park.

MILE/ SIDE*	TYPE OF STUDY SITE	USE IN THIS STUDY
0.0R*	Mapping	Veg. Mapping
0.7R	Paria River Tributary	LT[1] Tributary Quads
8.0L	LTS**	LT Quads
8.0L	Badger Cr. Tributary	LT Tributary Quads
19.9L	Marsh	LRZ[2] Marsh MIPS Analysis
20.5R	North Cyn. Tributary LTS	LT Tributary Quads
26.0R	Marsh	Off-river MIPS Control Site
30.0L	30 Mile Cyn. Tributary	LT Tributary Quads
31.5R	LTS	LT Quads
31.8R	Vaseys Tributary LTS	LT Tributary Quads
37.0L	Marsh	LRZ Marsh MIPS Analysis
43.1L	Marsh, Mapping	Marsh Transects, Veg. Mapping, LRZ, MIPS, XWP[3]
47.0R	Saddle Cyn. Tributary	LT Tributary Quads
50.0L	Marsh, XWP	LRZ Marsh MIPS Analysis, XWP
51.3L	Marsh, Mapping, LTS	LT Quads, LRZ Marsh MIPS Analysis, Veg.Mapping
51.6L	Marsh, Mapping	LRZ Marsh MIPS Analysis, Veg. Mapping
51.9R	Little Nankoweap Cyn. Tributary	LT Tributary Quads
52.2R	Nankoweap Cr. Tributary	LT Tributary Quads
53.0R	Marsh	LRZ Marsh MIPS Analysis
55.5R	Marsh, Mapping	LRZ Marsh MIPS Analysis, Veg. Mapping,
61.0	Mapping	Veg. Mapping
61.0R	Little Colorado R. Tributary	LT Tributary Quads
64.7R	Carbon Cr. Tributary	LT Tributary Quads
68.2R	Mapping, LTS	LT Quads, Veg. Mapping
71.0L	Marsh, Mapping, LTS	LT Quads, LRZ Marsh MIPS Analysis, Veg. Mapping
76.5R	Marsh	Off-river MIPS Control Site
98.0R	Crystal Cr. Tributary	LT Tributary Quads
103.9R	LTS	LT Quads
106.0L	Serpentine Cyn. Tributary	LT Tributary Quads
109.0R	Shinumo Cr. Tributary	LT Tributary Quads
119.0R	LTS	LT Quads
122.1R	122-Mile Cyn. Tributary	LT Tributary Quads
122.1R	LTS, Mapping	LT Quads, Veg Mapping

Table 1.02 (continued)

MILE/ SIDE*	TYPE OF STUDY SITE	USE IN THIS STUDY
122.8L	Marsh, Mapping, LTS	LT Quads, LRZ Marsh MIPS Analysis, Veg. Mapping
126.0L	126 Mile Cyn. Tributary	LT Tributary Quads
133.5R	Tapeats Cr. Tributary	LT Tributary Quads
136.0L	Deer Cr. Tributary	LT Tributary Quads
136.5R	Marsh	LRZ and Off-river Control MIPS Sites
137.0R	LTS, Mapping	LT Quads, Veg Mapping
143.5R	LTS, Mapping	LT Quads, Veg Mapping
143.5R	Kanab Cr. Tributary	LT Tributary Quads
145.0L	LTS	LT Quads
148.0L	Matkatamiba Cr. Tributary	LT Tributary Quads
157.0L	Havasu Cyn. Tributary	LT Tributary Quads
166.0	Mapping	Veg. Mapping
171.5L	Marsh, XWP	LRZ Marsh MIPS Analysis, XWP
171.5L	Mohawk Cyn. Tributary	LT Tributary Quads
172.1L	LTS	LT Quads
179.5L	Marsh, XWP	Off-river Control MIPS Analysis
182.7R	LTS	LT Quads
194.1L	Marsh, LTS, Mapping, XWP	LRZ Marsh MIPS, LT Quads, Veg Mapping, XWP
198.0R	Marsh	LRZ Marsh MIPS Analysis
198.5R	Parashant Cyn. Tributary	LT Tributary Quads
209.0	Mapping	Veg. Mapping
213.0R	LTS	LT Quads
219.9R	LTS	LT Quads
220.0R	220 Mile Cyn. Tributary	LT Tributary Quads
225.0R	Marsh	LRZ Marsh MIPS Analysis
225.7L	Diamond Cr. Tributary	LT Tributary Quads

* Left or Right side of the river, looking downstream
[1] LT - Long-term quadrat studies
[2] LRZ - lower riparian zone ($<1,275$ m^3/s)
[3] XWP - xylem water potential studies

Specific Objectives

Objective 1: Interim flow effects on mainstream marshes.

We used two approaches to pursue this objective. This first component of study consisted of investigation of fluvial marsh development from system-wide to local/microsite spatial scales, following the protocols established by Stevens and Ayers (1993) and Stevens et al. (1995). These results are presented in Chapter II.

a) We conducted a comprehensive field inventory of fluvial marshes between Lees Ferry and Diamond Creek in 1993 and compared the results with those of Stevens and Ayers (1992) and Stevens et al. (1995). These data allowed us to compare changes in fluvial marsh distribution and cover in relation to the geomorphic reaches (Schmidt and Graf 1990) from 1991 to 1993 (Table 1.02; Fig. 1.01; Appendices B, C).

b) To relate marsh cover changes to pre-interim flow conditions, we examined 1988, 1990, 1991 and 1992 aerial still- and video- photography of 20 fluvial and 4 spring-fed marshes using MIPS analysis (Table 1.02; Fig. 1.01). The spring-fed marshes were located in close proximity to the river, but upslope of interim flow stages, and therefore serve as controls against which to evaluate change in fluvial marsh cover.

c) A total of 8 study sites were used for detailed marsh studies: 43L, 51L, 56R, 71L, 123L, 172L, 194L, 213L (Table 1.02; Figs. 1.01, 1.03). Transect topography and marsh species composition and basal area were monitored at permanently georeferenced sites used by Stevens et al. (1995) during GCES Phase II.

The second form of analysis of interim flow impacts entailed analysis of drought stress responses of a marsh indictor species, Salix exigua, and these results are presented separately in Chapter 3. Four marsh study sites were selected to examine plant moisture stress in Salix exigua. This species was selected as an indicator of marsh responses to interim flows because it widely co-occurs with marsh taxa, such as Typha spp. and Phragmites australis. Closure of the 51L site for Southwest willow flycatcher (Empidonax trailii extimus) protection precluded use of that site for Salix studies, forcing us to use 50L marsh as a nearby substitute.

Objective 2: Interim flow effects on other riparian vegetation.

We pursued this objective through several avenues, which are presented in Chapter 4.

a) We continued to collect and identify plant species from the river corridor and surrounding xeric uplands (Appendix A). Specimens are currently housed in the Northern Arizona University Deaver Herbarium and vouchers are being prepared for transfer to Grand Canyon National Park. Because plant diversity in Grand Canyon is now rather well known, we focused our attention on the distribution of rare, endemic, non-native and selected indicator species.

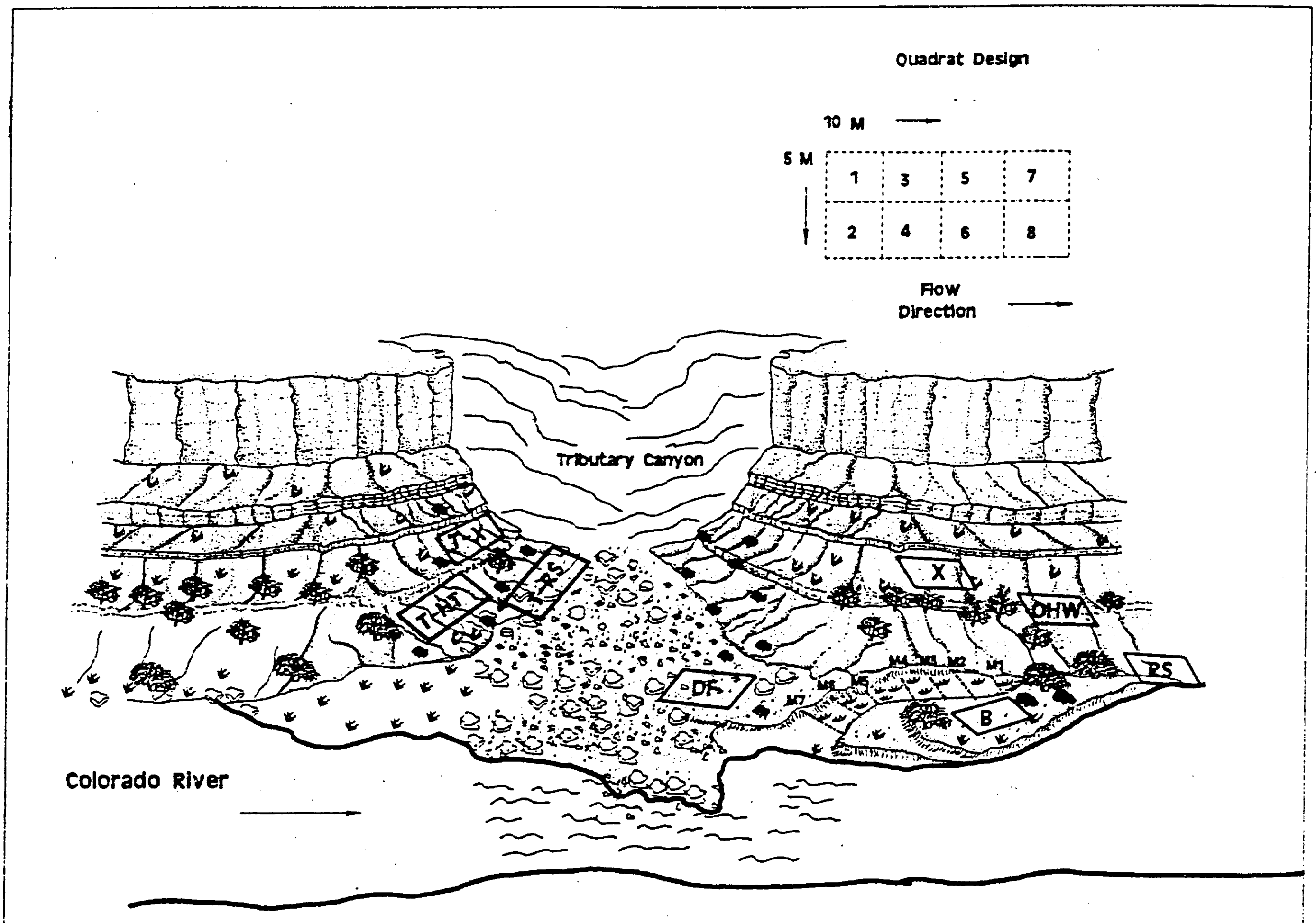


Figure 1.03 Diagram showing quadrat location in six geomorphic settings at a typical tributary mouth/recirculation zone along the Colorado River in the Grand Canyon, Arizona. Mainstream quadrats included xeric (X), old high water (OHW), debris fan (DF), riparian strip (RS, channel margin), bar platform (B, general beach), and a series of 1.0 m-wide fluvial marsh belt transects (M) in the return current channel.

b) We analyzed vegetation cover on low level aerial photographs of selected study sites (Table 1.02) taken in late July, 1991. We compared vegetation cover in several geomorphic settings with June 1994 aerial photographs of these same study sites.

c) Twenty study areas were selected and established in Grand Canyon under the GCES Phase II program (Table 1.02; Figs. 1.01; Appendix D). Each study area contained 5 m x 10 m permanent quadrats in the following geomorphic environments: marsh (where possible), bar platform, channel margin and debris fan habitats (Fig. 1.03). We were advised by Grand Canyon National Park during proposal development to avoid monitoring upper riparian and desert zone quadrats during this study. These results are presented in Chapter IV.

d) To increase the sample size of study plots, we also measured vegetation cover on two randomly selected 5 m x 10 m quadrats in fine and coarse substrata in the "new dry" and "new high water" zones, respectively, through the geomorphic reaches (Schmidt and Graf 1990). We were particularly interested in the germination success of Tamarix and other perennial and weed species on a system-wide basis.

Objective 3. Prepare data for inclusion into the GCES/NPS GIS database.

We compiled the above data for inclusion into the GCES database in Lotus 123 format. In addition, we mapped topography, geomorphology, soil particle size and plant species distribution at five permanent study sites, including 43L, 56R, 68R, 123L and 209L (Table 1.02, Fig. 1.01). These data were incorporated into the GCES GIS and were analyzed to determine the relationships between geomorphology, plant diversity and the distribution of plant associations. These results are presented in Chapter 5.

We summarize the results of each of the above subobjectives and contribute our perspectives on management considerations in Chapter 6. We list the publications and presentations given on this project in Appendix E.

CHAPTER II

THE EFFECTS OF INTERIM FLOWS ON THE DISTRIBUTION AND DEVELOPMENT OF FLUVIAL MARSHES

CHAPTER II:

THE EFFECTS OF INTERIM FLOWS ON THE DISTRIBUTION AND DEVELOPMENT OF FLUVIAL MARSHES

INTRODUCTION

Fluvial marshes are diverse, productive patches of wetland vegetation that develop along rivers. Along the Colorado River in the Grand Canyon, fluvial marshes develop in low velocity geomorphic environments where inundation frequency is high and soils are silty, particularly return current channels (RCCs; Stevens and Ayers 1993). System-wide, reach-based and local/microsite spatial scale differences influence the interpretation of marsh vegetation cover and compositional changes in the Colorado River corridor in Grand Canyon National Park between Lees Ferry and Diamond Creek, Arizona (Stevens et al. 1995). At the inception of interim flows, marsh assemblages were found to be non-randomly distributed, with increased marsh cover in wide reaches, but increased density of smaller marshes with distance downstream (Stevens et al. 1995). Marshes provide cover and food resources for numerous avifaunal and wildlife species, including migrant and breeding waterfowl, Empidonax trailii extimus, Geothlypis trichas, Castor canadensis, and Odocoileus hemionus. We monitored cover and composition of fluvial marshes from 1991 through 1993, the first two years of interim flows.

METHODS

Study Design

Because of the overwhelming influence of geomorphology on marsh distribution and composition, we monitored fluvial marsh development at several spatial scales, including: a system-wide inventory of marsh distribution and cover; a reach-based analysis of serial aerial photographs of selected marshes; and local-scale and microsite monitoring of 1.0 m^2 plots and topography (Tables 1.01, 1.02), as described below.

We conducted a comprehensive field inventory of fluvial marshes between Lees Ferry and Diamond Creek after the methods of Stevens et al. (1995). Stevens recorded all marsh patches, their composition and estimated size, during two river trips in the autumn of 1993. These data were compared with Stevens 1991 inventory of fluvial marshes between Lees Ferry and Diamond Creek (Stevens et al. 1995). All marshes were identified as to location, side of the river, composition, and estimated length and width (multiplied together to estimate area). Stevens focused his 1993 inventory on Juncus spp./Scirpus spp./Typha spp./Phragmites australis marshes, and did not record Equisetum spp. patches, which have become so numerous and large in this system that they cannot be reliably inventoried with this method. These data also allowed us to compare changes in fluvial marsh distribution from 1991 to 1993 in relation to Schmidt and Graf's (1990) 11 geomorphic reaches.

We tested the accuracy of area estimation by comparing estimated and measured lengths and widths of 27 marshes of different sizes in the river corridor. Area estimates were strongly positively correlated with ground-truthed measurements:

$$A_e = 0.844A_m - 1.467$$
$$(r^2 = 0.992, F_{1,25} = 3319.7, p < 0.00001)$$

where A_e (m^2) is estimated length (m) * estimated width (m) and A_m is the measured length * measured width. Our length estimates were slightly more accurate than width estimates:

$$L_e = 0.914L_m + 0.055$$
$$(r^2 = 0.988, F_{1,25} = 2134.545, p < 0.00001)$$

$$W_e = 0.863W_m + 0.057$$
$$(r^2 = 0.931, F_{1,25} = 350.113, p < 0.00001)$$

where L_e, L_m, W_e and W_m are estimated and measured length and width, respectively.

This inventory procedure provides an effective, cost-efficient, system-wide estimate of developing marsh area, provided it is consistently performed by individuals who are thoroughly trained and are intimately familiar with the river corridor; however, as other observers take over monitoring in 1994 and subsequently, we doubt that any conclusive data can be generated using this method until sufficient between-year replication can be evaluated for the observers involved.

To assess changes in the area of individual fluvial marshes between years in more detail, we examined serial video- and still image aerial photographs from the Bureau of Reclamation for 20 lower riparian zone (LRZ), and four adjacent, but off-river, spring-fed marshes (off-river) using the Map and Image Processing System (MIPS; Table 1.02). The LRZ marshes were distributed throughout the river corridor, and were selected on the basis of distribution within geomorphic reaches established by Schmidt and Graf (1990). The four off-river marshes constituted a set of control sites against which to evaluate changes in wetland vegetation not induced by dam operations. Photograph series included: 28 May, 1988 (still photography, variable flow); 4-5 June, 1990 (still photography, constant 142 m^3/s); July 28-29, 1991 (video, constant 142 m^3/s); 10-11 October, 1992 (still photography, constant 142 m^3/s); 28-31 May, 1993 (still photography, constant 227 m^3/s), 1 June, 1994 (still photography, constant 227 m^3/s). Several of these marshes were under study by Stevens in 1984-1986, providing additional background data on marsh development (Stevens et al. 1995). The 1991 video imagery was collected immediately prior to implementation of interim flows on 1 August, 1991, and therefore provides a good baseline for the analysis of interim flows effects.

During interim flows, discharge rarely, if ever, exceeded the maximum interim flows limit of 566 m^3/s; however, the Little Colorado River (LCR) generated three large (ca. 10-yr return frequency events) in January and February, 1993. These floods increased mainstream river discharge to approximately 935 m^3/s (33,000 cfs) for several weeks and scoured newly established vegetation from low-lying portions of channel margins and sand bars. The total duration of flood peaks was less than 5 d, but mainstream flows remained above 700 m^3/s for nearly a month. The May, 1993 photograph series was taken three months after recession of these 10-year floods, and therefore provides information on flood impacts, with controls above the LCR having no flood effects.

Marsh area was mapped at approximately 1:4,800 scale from the photographs and scanned into MIPS. Two or more ground control points that were identifiable on all photographs were measured in the field, and the data were transferred to MIPS. Plan view area measurements of marshes were then calculated. Precision tests revealed that standard deviations were 1.85% of the mean for three sets of six replicated measurements on single, complex polygons. Video images were digitized directly off the MIPS screen. Mean marsh area was calculated for LRZ marshes by pooling all fluvial marsh sizes. Areas of the 20 LRZ and the four adjacent off-river (spring-fed) marshes were analyzed using the nonparametric Friedman test with years as treatments and marshes as blocks.

We monitored the topography of pre-established belt transects in the seven detailed study site marshes in the fall of 1992 and 1993, and compared results with our 1991 baseline data (Tables 1.01, 1.02). One site (71L, Cardenas Marsh) was not sampled in 1992 because of southwest willow flycatcher nesting. These marsh plots were topographically surveyed at 1.0 m intervals on a biannual schedule from 1992 to 1994, using the standard electronic land surveying protocol of the GCES Program. These data have been compiled into the GCES information management system, and have been related to inundation frequency changes at these sites. Because these plots are georeferenced in relation to local and, where possible, GCES GIS geographic control, these data form a useful long-term baseline against which to measure future change in marsh topography and composition.

We monitored the basal area of all species occurring in the large, stratified (by elevation), random 1.0 m x 1.0 m plots in belt transects on the seven study sites used by Stevens et al. (1995). Fifty-one (where possible) 1.0 m^2 plots were selected from each study site, and unvegetated plots were subsequently excluded, providing an initial group of 307 randomly selected 1.0 m^2 plots (Fig. 2.01). We estimated the number and mean basal diameter of species with exceptionally great stem density. Springtime (April/May) data have also been compiled, but provide relatively little information that can be related to marsh changes. The reason for this is that perennial marsh vegetation is deciduous, and newly emerging ramets of Typha, Phragmites, Scirpus and other taxa poorly represent the dominance of these species on the plots during the spring months. Therefore, we focused our analyses on autumn census data. We classified marsh vegetation associations using TWINSPAN (Hill 1979) on the 1991 matrix data. We constructed a matrix of the total basal area of each of 76 plant taxa that occurred in these plots in 1991 to classify distinctive associations. Seedlings are particularly difficult to distinguish and several groups were pooled, including: Sonchus asper and Lactuca serriola and seedling Bromus spp. grasses.

Plot data provided an assessment of microscale marsh community dynamics on these long-term, georeferenced belt transect plots. We compared the mean basal area/m^2 of dominant marsh species for autumn censuses between years on each site using graphical and simple linear regression techniques. Plot data for 1991, 1992 and 1993 were also compared using species loading scores derived from detrended correspondence analysis (DECORANA, Ter Braak 1992). We ranked the species loading scores for the first three axes in each year, and compared the ranked scores for each axis over the three years using a Friedman test, with species as blocks (SYSTAT, Wilkinson 1991). Species with high factor loading scores on axis 1 occur in frequently inundated sites (Stevens et al. 1995), whereas those with high scores on axis 2 occur on soils with finer texture. This ranked analysis provides a conservative evaluation of marsh change through time.

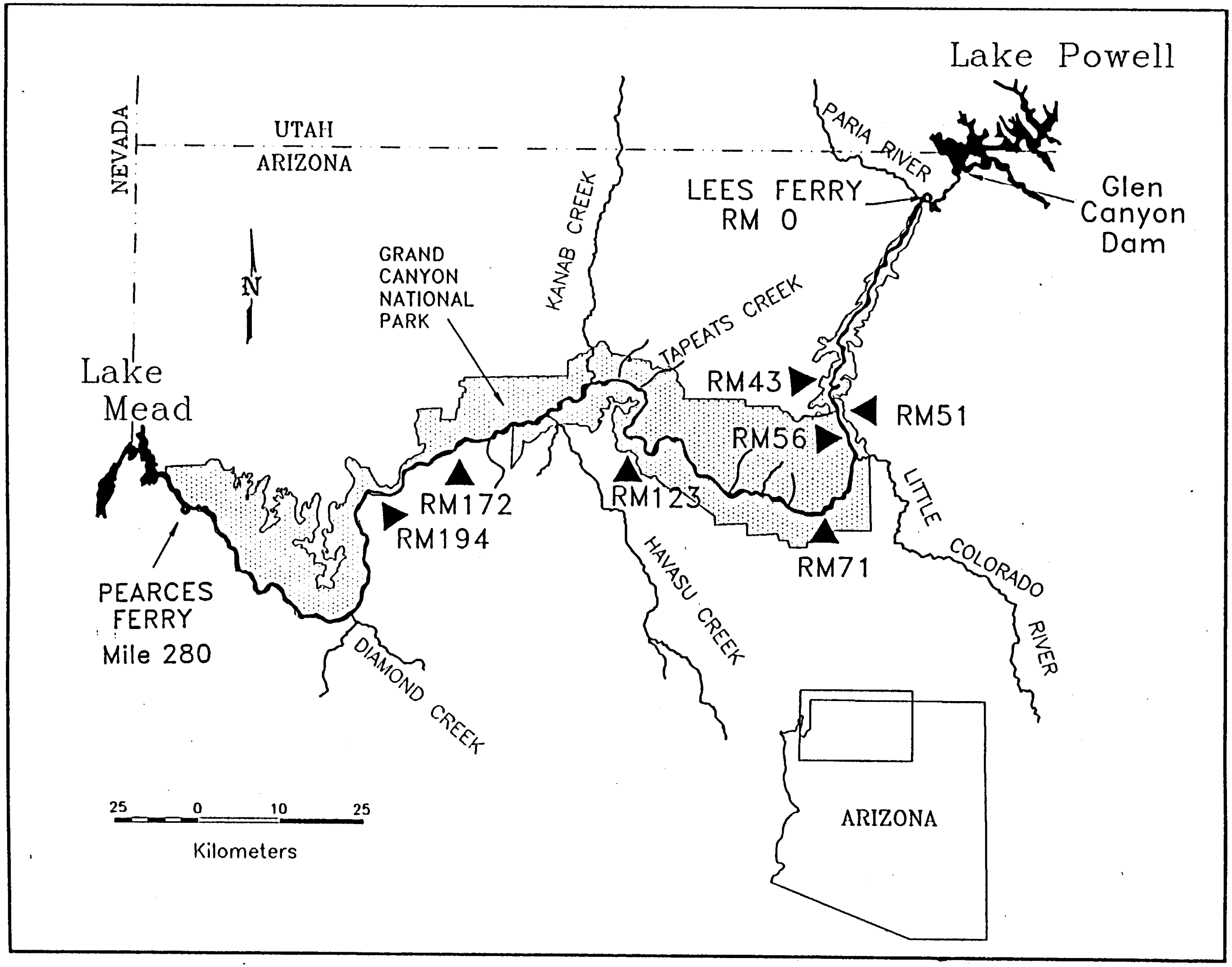


Figure 2.01: Map of seven study marshes on which marsh transects were monitored.

RESULTS

Classification

Marsh plant associations used in the following description of historical marsh development were derived from TWINSPAN analyses of the plots data. The first TWINSPAN division distinguished a wet marsh assemblage and a phreatophyte/dry marsh assemblage (Table 2.01). The second TWINSPAN division of the wet marsh vegetation distinguished a cattail/reed association (Typha domingensis, Phragmites australis, Juncus spp.) from a non-clonal herbaceous horseweed/Bermuda-grass association (Conyza canadensis, Cynodon dactylon). The phreatophyte/dry marsh group separated a woody perennial tamarisk/arrowweed (Tamarix ramosissima, Pluchea sericea) association from a dry marsh horsetail/willow (hybrid Equisetum and Salix exigua) association. A minor xeric/upland component was also noted within the tamarisk/arrowweed assemblage. In this report we focused on the marsh associations.

TWINSPAN may also prove to be useful as a monitoring tool in itself. Although not presented here changes in the classification scheme between years may be used to illustrate changes in dominance of indicator species. Therefore, we intend to continue improving marsh classification at periodic intervals.

Fluvial Marsh Inventory

Our 1993 inventory revealed 895 wet marsh patches (7.0 ha) in the lower riparian zone of the Colorado River between Lees Ferry and Diamond Creek, not including 33 marshes (3.5 ha) associated with tributary mouths or springs (Table 2.02). Wet marsh patch density/km increased 3.5-fold over the 1991 system-wide total (253); however, estimated marsh area decreased from 9.0 ha in 1991. The great increase in wet marsh density/km reflects the large number of small, wet marsh patches that are presently colonizing channel margin and low velocity habitats colonizing throughout the river corridor. Despite this large increase in marsh density, total marsh area decreased between inventories. The reaches downstream from the LCR had been scoured by the January-February 1993 floods decreased in area most strongly, with marsh area losses of up to 90 percent in some narrow reaches. In contrast, the four unflooded reaches upstream from the LCR exhibited a slight gain in marsh area.

MIPS Analysis of Aerial Photographs

Fluvial marsh area increased significantly from 1988 through 1992, and then decreased significantly in 1993. Friedman $T_{5,55} = 37.345$, $p < 0.001$. The critical rank sum difference between years (11.3) demonstrated the following pattern for 12 mainstream marshes for which all years were represented:

$$1988 < 1990 < 1991 < 1992 > 1993 = 1994$$

with rank sum values for 1988, 1990, 1991, 1992, 1993 and 1994 of 12, 30, 45.5, 62, 48.5 and 54, respectively (Table 2.03). Marsh area increased between 1988 and 1990, a period of nearly

Table 2.01: Four marsh plant associations derived from TWINSPAN analysis of 307 1.0 plots in 7 fluvial marshes, and associated mean inundation frequency, mean soil texture, mean total basal area (cm2/m2) and mean species richness/m2.

MARSH ASSOCIATION	MEAN INUNDATION FREQUENCY (n, 1 sd)	MEAN SOIL TEXTURE	MEAN TOTAL BASAL AREA (cm2/m2) (1 sd)	SPECIES RICHNESS (S/m2) (1 sd)
1. CLONAL WET MARSH (CATTAIL/REED) Typha domingensis, Phragmites australis, Juncus torreyana, Carex aquatilis, Equisetum arvense, Scirpus validus, Agrostis stolonifera, Echinochloa crus-galli, Veronica anagallis-aquatica	0.54 (50, 0.251)	silty loam	52.9 (80.931)	4.6 (2.914)
2. NONCLONAL WET MARSH (HORSEWEED) Conyza canadensis, Polygonum aviculare, Cynalon dactylon, Melilotus alba, M. officinale	0.17 (43, 0.170)	loamy sand	14.7 (14.554)	4.9 (2.320)
3. WOODY PHREATOPHYTE (TAMARISK/ARROWWEED) Tamarix ramosissima, Pluchea sericea, Alhagi camelorum, Artemisia ludoviciana, Aster spinosus, Baccharis salicifolia, Bromus rubens, Centaurium calycosum, Epilobium adenocaulon, Erigeron divergens, Gnaphalium chilense, Gutierezzia sarothrae, Hordeum jubatum, Oenothera hookeri, O. pallida, Salix gooddingii, Salsola iberica, Sonchus asper, Sporobolus cryptandrus, Sporobolus contractus, Xanthium stromarium	0.16 (68, 0.197)	sand	39.9 (86.812)	4.5 (2.465)

Table 2.01 (continued)

MARSH ASSOCIATION	MEAN INUNDATION FREQUENCY (n, 1 sd)	MEAN SOIL TEXTURE	MEAN TOTAL BASAL AREA (cm2/m2) (1 sd)	SPECIES RICHNESS (S/m2) (1 sd)
4. DRY MARSH (HORSETAIL/WILLOW) Hybrid Equisetum, Salix exigua, Ambrosia sp., Andropogon glomeratus, Artemesia dracunculus, Aster subulatus, Baccharis emoryi, Bromus tectorum, Bromus wildenowii, Chrysothamnus nauseosus, Corispermum nitidum, Dicoria brandegei, Elymus canadensis, Juncus sp., Lepidium latifolium, Muhlenbergia asperifolia, Plantago lanceolata, Plantago major, Polypogon monspeliensis, Solidago canadensis, Sporobolus flexuosus, Taraxacum officinale	0.18 (146, 0.194)	sand	16.4 (19.456)	4.7 (2.459)

Table 2.02: Geomorphic characteristics and 1991 and 1993 lower riparian zone fluvial marsh inventory in 11 reaches of the Colorado River between Lees Ferry and Diamond Creek, Grand Canyon National Park, Arizona, excluding marshes associated with springs or tributaries. Reach descriptions follow Schmidt and Graf (1990). One sd for mean area data is included parenthetically.

REACH	RCH LENGTH (KM)*	MEAN RCH WIDTH (M)**	1991 MARSH No/km	1993 MARSH No/km	MEAN 1991 MSH AREA (HA)	MEAN 1993 MSH AREA (HA)	1991 MSH CVR (HA/KM)	1993 MSH CVR (HA/KM)	1991 TOTAL MSH AREA (HA)	1993 TOTAL MSH AREA (HA)
Permian Reach	17.7	85.3 W	.51	2.32	.10 (.120)	.02 (.029)	.04	.04	.71	.67
Supai Gorge	18.5	64.0 N	.22	1.73	<.01 (.010)	<.01 (.005)	<.01	<.01	.05	.06
Redwall Gorge	28.0	67.1 N	.07	3.25	.01 (.015)	<.01 (.002)	<.01	<.01	.08	.10
Lower Marble Canyon	34.6	106.7 W	1.88	6.94	.05 (.118)	.01 (.069)	.08	.08	2.76	2.78
Furnace Flats	25.4	118.9 W	1.18	2.56	.04 (.060)	.01 (.003)	.04	.03	1.02	.73
Up. Granite Gorge	64.8	57.9 N	.05	0.14	.02 (.018)	<.01 (.013)	<.01	<.01	.06	.06
Aisles Reach	12.2	70.1 N	.16	0.33	.02 (.014)	<.01 (.002)	<.01	<.01	<.01	<.01

Table 2.02 (continued)

REACH	RCH LENGTH (KM)*	MEAN RCH WIDTH (M)**	1991 MARSH No/km	1993 MARSH No/km	MEAN 1991 MSH AREA (HA)	MEAN 1993 MSH AREA (HA)	1991 MSH CVR (HA/KM)	1993 MSH CVR (HA/KM)	1991 TOTAL MSH AREA (HA)	1993 TOTAL MSH AREA (HA)
Mid. Granite Gorge	23.0	64.0 N	.04	1.22	.08 (-)	<.01 (.019)	<.01	<.01	.13	.13
Muav Gorge	32.0	54.9 N	.19	1.34	.01 (.015)	<.01 (.018)	<.01	<.01	.13	.13
Lower Canyon Reach	86.6	94.5 W	1.34	3.72	.03 (.034)	<.01 (.016)	.04	.03	3.46	2.32
Low. Granite Gorge	18.7	73.2 N	.75	1.07	.04 (.046)	<.01 (.004)	.03	<.01	.56	<.01
TOTALS OR GRAND MEANS	362.8	79.0 -	.70	2.47	.04 (.071)	0.008 (0.039)	.02	.02	8.99	7.03

* Distance downstream from Lees Ferry, Arizona
** Reported by Schmidt and Graf (1990): N = narrow reach; W = wide reach.

Table 2.03: MIPS analysis of marsh area change of 20 fluvial and 4 off-river marshes between 1988 and 1993 in the Colorado River corridor in Grand Canyon National Park, AZ

MILE/ SIDE*	DEPOSIT TYPE**	SITE TYPE***	MARSH AREA (HA) 1988	1990	1991	1992	1993	1994
-6.5R	RCC	F	0.176	0.251	---	0.270	0.307	0.416
19.9L	RCC	F	0.000	0.006	---	0.007	0.001	0.002
25.5R	CM	F	0.002	0.010	0.005	0.011	0.019	0.341
25.5R	SPRING	OR	0.017	0.011	0.018	0.023	0.025	0.007
43.1L	RCC+BP	F	0.013	0.041	0.060	0.068	0.065	0.057
50.0L	RCC+BP	F	0.011	0.176	0.315	0.499	0.510	0.524
51.2L	RCC+BP	F	0.023	0.181	0.294	0.401	0.421	0.554
51.4L	RCC+BP	F	---	0.101	0.111	0.181	0.180	0.209
53.0R	SD+RCC	F	---	0.148	0.157	0.205	0.196	0.317
55.5R	BP	F	0.063	0.493	0.788	1.090	0.987	1.158
71.1L	RCC+BP	F	---	0.283	0.334	0.426	0.397	0.362
76.5R	CM	F	0.009	0.029	0.091	0.123	0.100	0.081
76.5R	SPRING	OR	0.305	0.330	0.279	0.366	0.334	0.286
122.8L	RCC	F	0.000	0.023	0.067	0.070	0.015	0.017
136.5R	CM	F	0.017	0.063	0.087	0.154	0.093	0.230
136.5	SPRING	OR	0.567	0.651	0.669	0.590	0.590	0.625
171.5L	RCC+BP	F	---	0.036	0.073	0.143	0.105	0.013
172.1L	RCC+BP	F	0.009	0.167	0.178	0.222	0.074	0.160
179.4L	SPRING	OR	0.970	0.914	1.002	0.992	1.098	1.198
194.1L	RCC+BP	F	0.006	0.124	0.265	0.373	0.409	0.636
198.0R	RCC+BP	F	0.010	0.071	0.173	0.232	0.173	0.004
213.0L	RCC+BP	F	0.000	0.022	0.107	0.168	0.058	0.072
225.2R	RCC+BP	F	0.008	---	0.091	0.166	0.133	---

* Side looking downstream
** CM - channel margin deposit; RCC - return current channel, RCC+BP - return current channel + bar platform; SPRING - spring source.
*** F - Fluvial marsh, OF - Off River marsh

"normal operations", and between 1991 and 1992 as interim flows exposed new habitat for colonization; however, marsh area decreased between 1992 and 1993. This overall decrease in area was largely the result of January-February, 1993 LCR floods. Ten of 11 marshes below the Little Colorado River decreased in area from 1992 to 1993 (Table 2.02). In addition, 5 of 9 mainstream marshes upstream from the LCR confluence decreased in size during the same interval. Marshes upstream from the LCR were not scoured by tributary flooding, and the loss of cover there was attributed to the change in flow regime. Additional colonization of newly exposed habitats continued throughout the system in 1994, with seven of nine upstream marshes and five of nine downstream marshes increasing in area. The off-river marshes exhibited no significant change in area between 1988 and 1994 ($T_{4,15} = 6.0$, $\underline{p} = 0.536$; Table 2.03).

Marsh Plots

Topography: Interim flows stabilized the topography of return current channel (RCC) marshes which have been under observation since 1991; however, 1993 LCR flooding resulted in aggradation of RCC habitats. Repeated surveys of the marsh study sites established by Stevens and Ayers (1993) in GCES Phase II revealed insignificant changes in topography from Fall 1991 to Spring 1994 for sites upstream from the LCR (Figs. 2.02 - 2.08); however, the 1993 LCR floods inundated RCC marshes downstream from the Little Colorado River for a period of more than a month, and resulted in aggradation of these habitats. Topographic data from the Forester, 172 Mile and 194 Mile marshes reveals this pattern, with an increase in RCC floor baselevel of approximately 20 cm between Fall 1992 and Spring 1993 surveys.

Composition Changes: Marsh plots data revealed both a gradual loss of previously established marsh cover and a rapid increase in cover in the newly stabilized shoreline between the 566 and 900 m^3/s stages that are presently protected from scour by interim flows. Gradual reduction in basal cover of Typha, Scirpus and other characteristic clonal marsh taxa at stage elevations above the 566 m^3/s (the interim flows maximum) stage occurred at the previously established marshes under study (Fig. 2.09, Appendices B, C). These characteristic taxa are gradually being replaced by grasses, dry marsh taxa and woody phreatophytes, particularly Salix exigua and Phragmites. For example, the basal cover of Typha, Scirpus spp. and other wet marsh taxa lying above the 566 m^3/s stage in RCC marshes at Miles 43, 51, 123, 172, 194 and 213 has been reduced, while the cover of Salix and Phragmites increased (Appendix C).

In contrast to gradual decreases above the 566 m^3/s stage, wet marsh taxa have rapidly colonized newly protected RCC mouth habitats at Miles 43L, 51L, 56R, 71L and 194L (Chapter 4, this report) below the 566 m^3/s stage. These are sites in which pre-interim flows marshes were well established in RCC settings (Stevens et al. 1995) and where RCC mouths are low gradient. Clonal expansion of vegetation from RCCs has expanded down the mouths and out onto the newly exposed shoreline habitats. Sites with steep RCC mouths (123L and 172L) have not supported expansion of wet marsh vegetation.

Sand bars with gently sloping faces at the current reattachment point have undergone primary colonization by wet marsh taxa between the approximate 400 and 600 m^3/s stages. This process has been observed at the 43L, 51L, 56R, 68R, 123L, 172L and 194L sites. Sites with steep eroding cutbanks at the reattachment point (e.g., 71L and 213L) do not support new reattachment point marshes. The primary colonization process is therefore strongly influenced

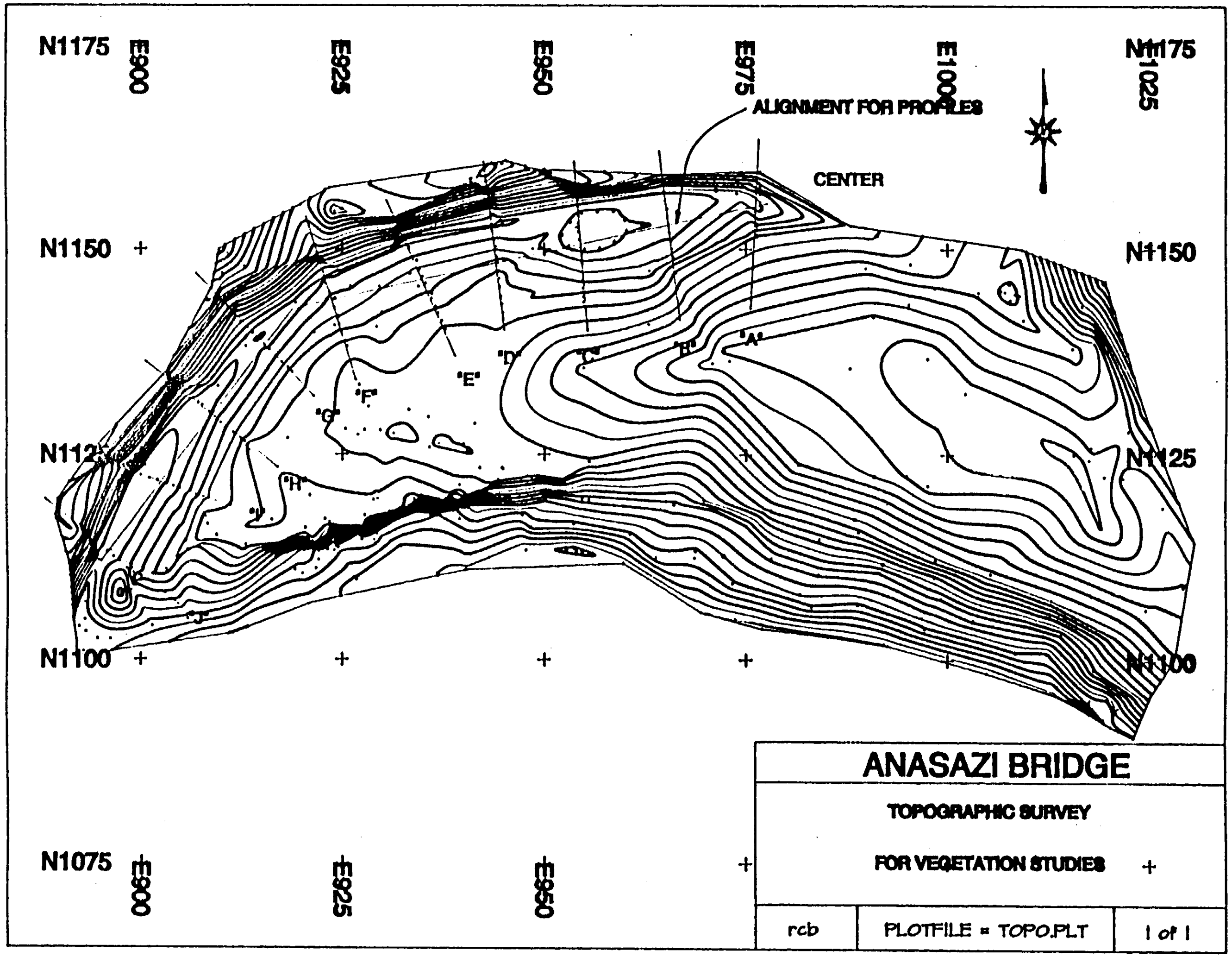


Figure 2.02A: Topographic map of the Mile 43L (Anasazi Bridge) marsh study site, showing transect locations.

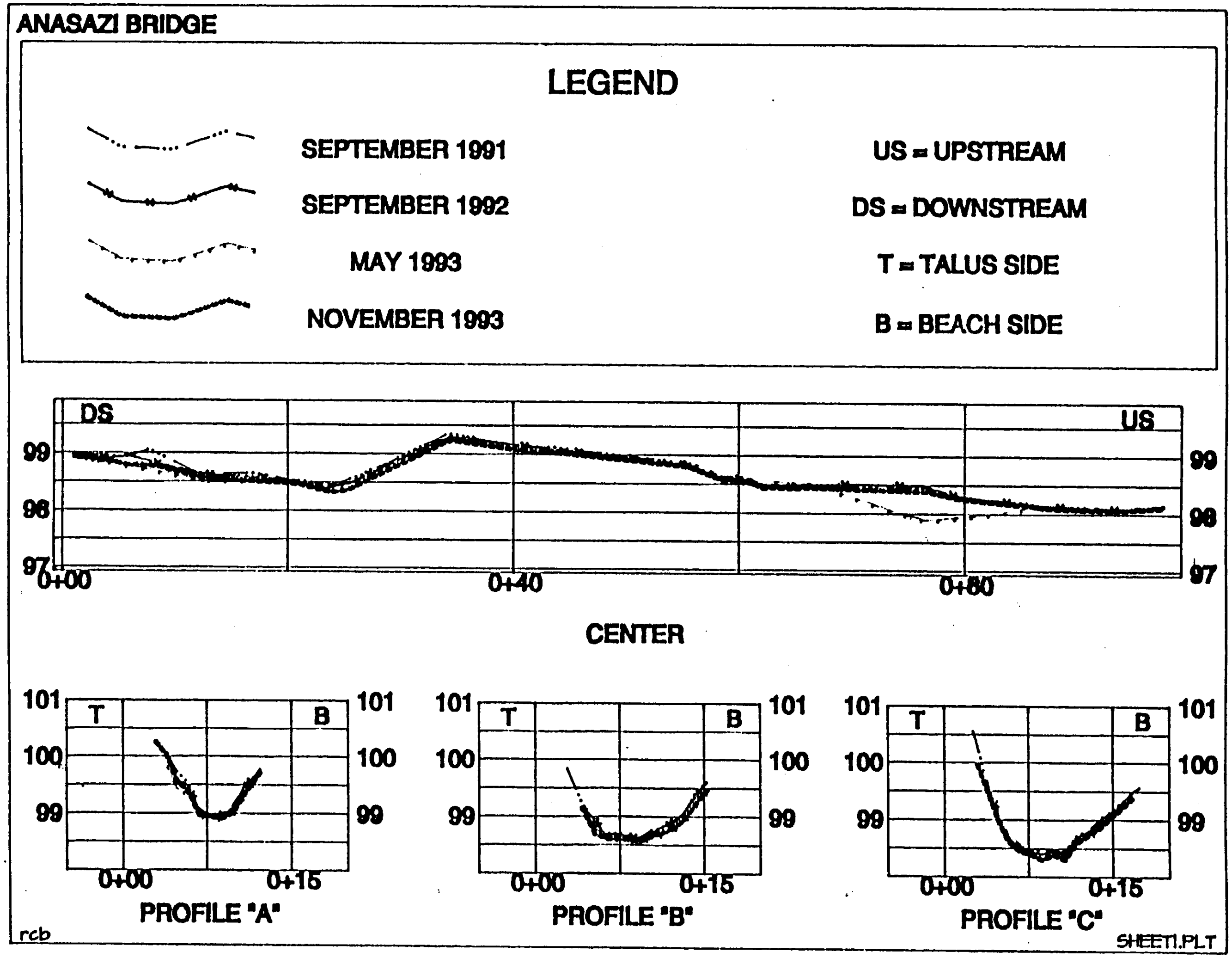


Figure 2.02B: Surveyed profiles of marsh transects at the Mile43L (Anasazi Bridge) marsh study site, 1991-1993.

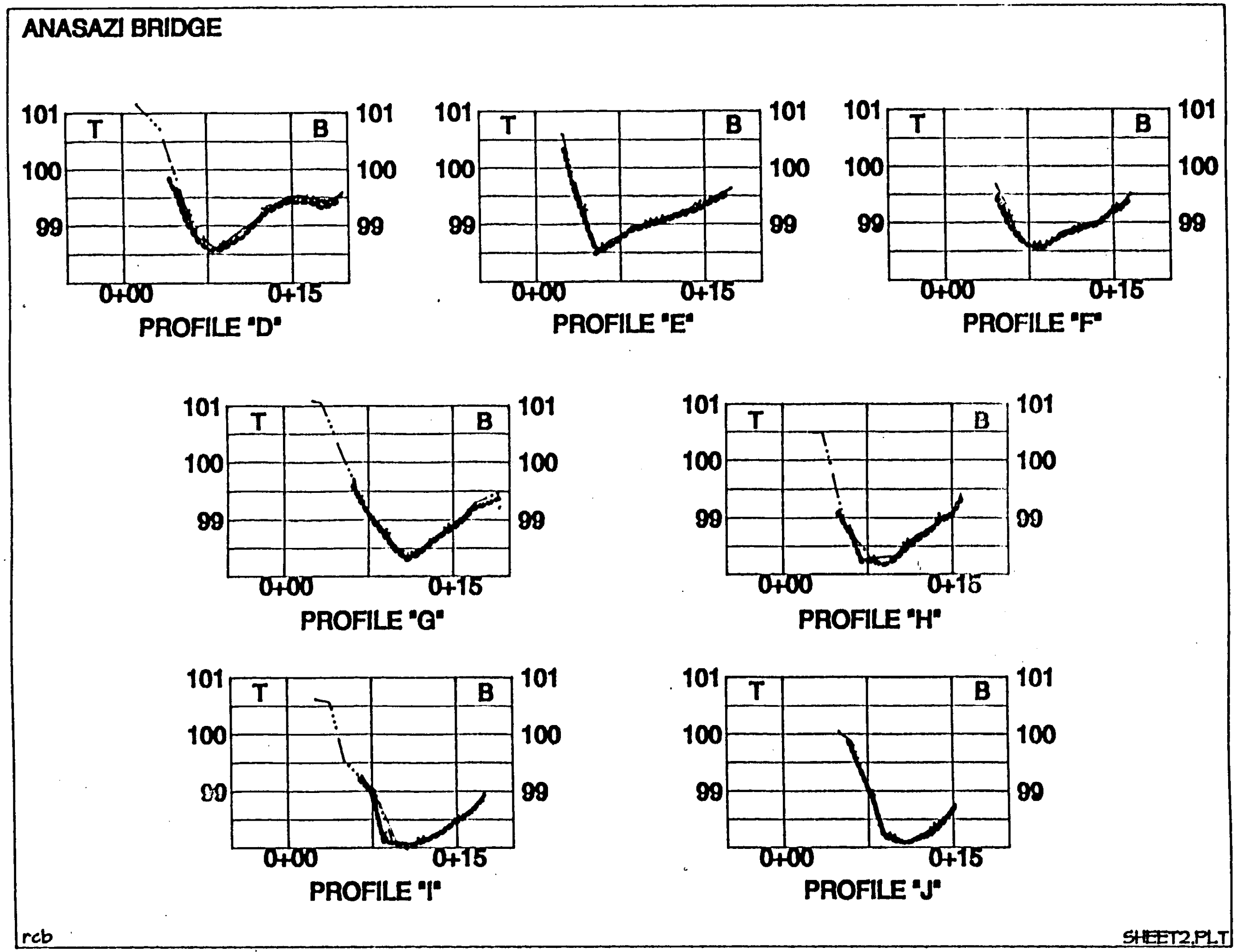


Figure 2.02B: Profiles of marsh transects at the Mile 43L (Anasazi Bridge) marsh study site, 1991-1993 (cont'd).

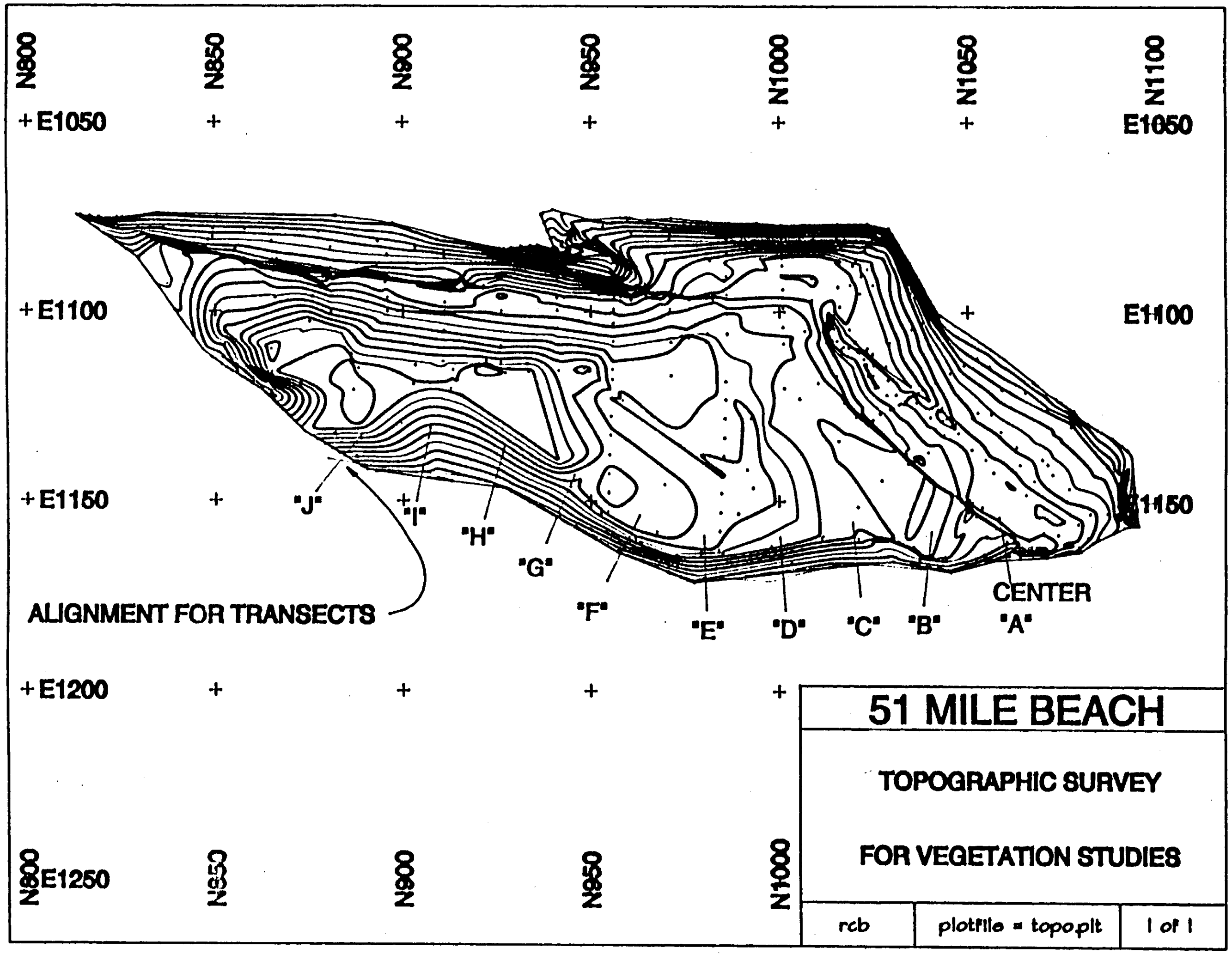


Figure 2.03A: Topographic map of the Mile 51L marsh study site, showing transect locations.

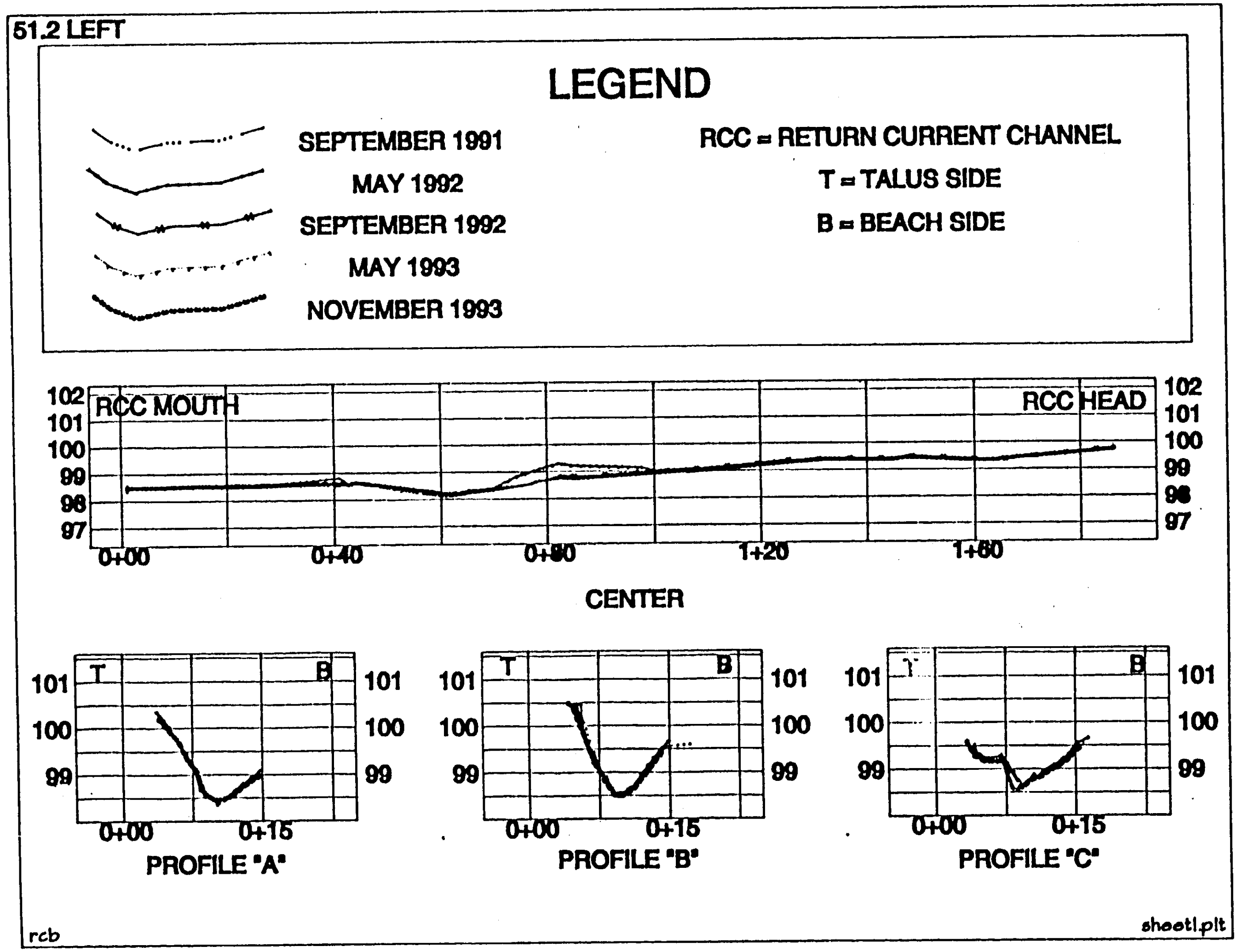


Figure 2.03B: Surveyed profiles of marsh transects at the Mile51L marsh study site, 1991-1993.

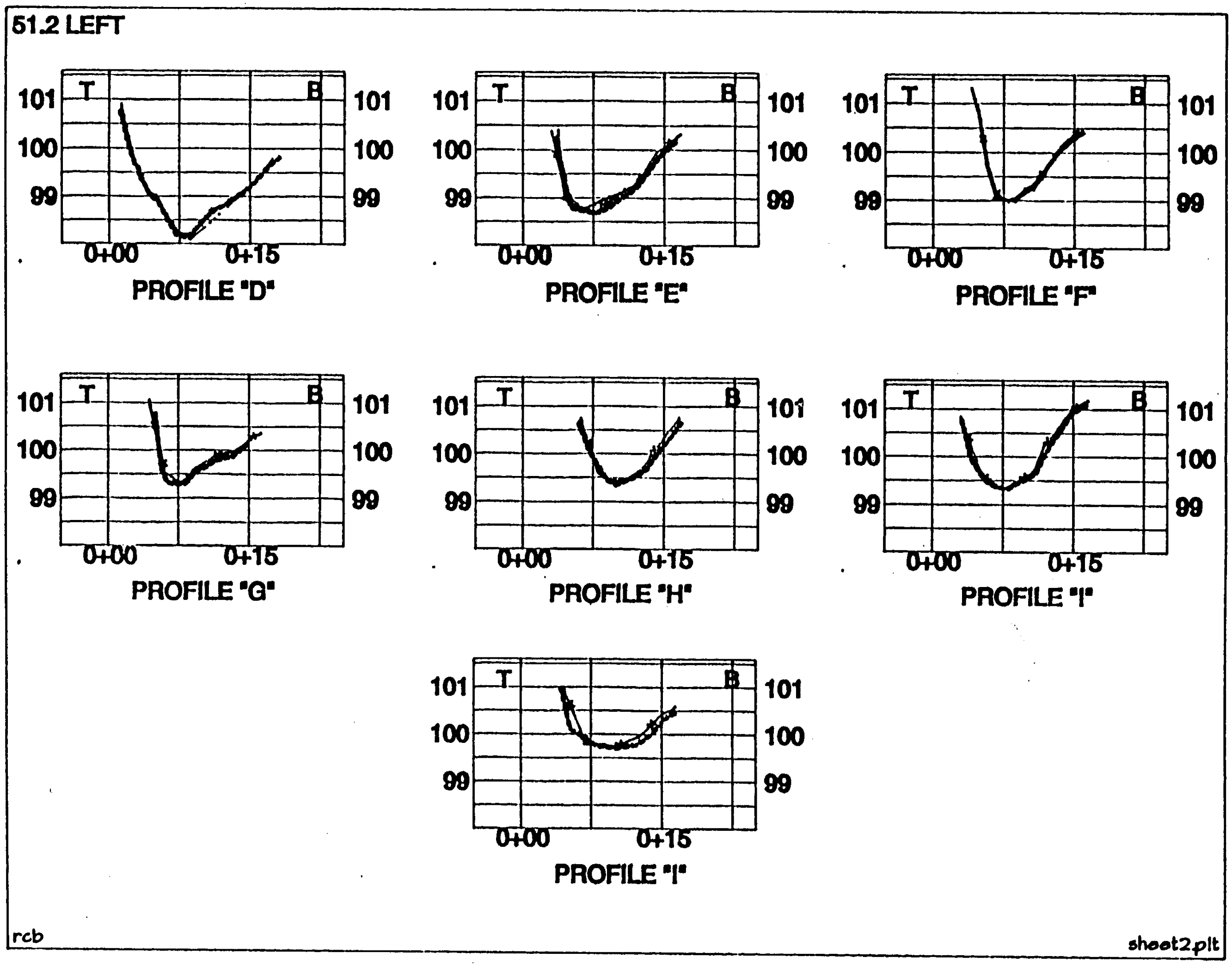


Figure 2.03B: Surveyed profiles of marsh transects at the Mile51L marsh study site, 1991-1993 (cont'd).

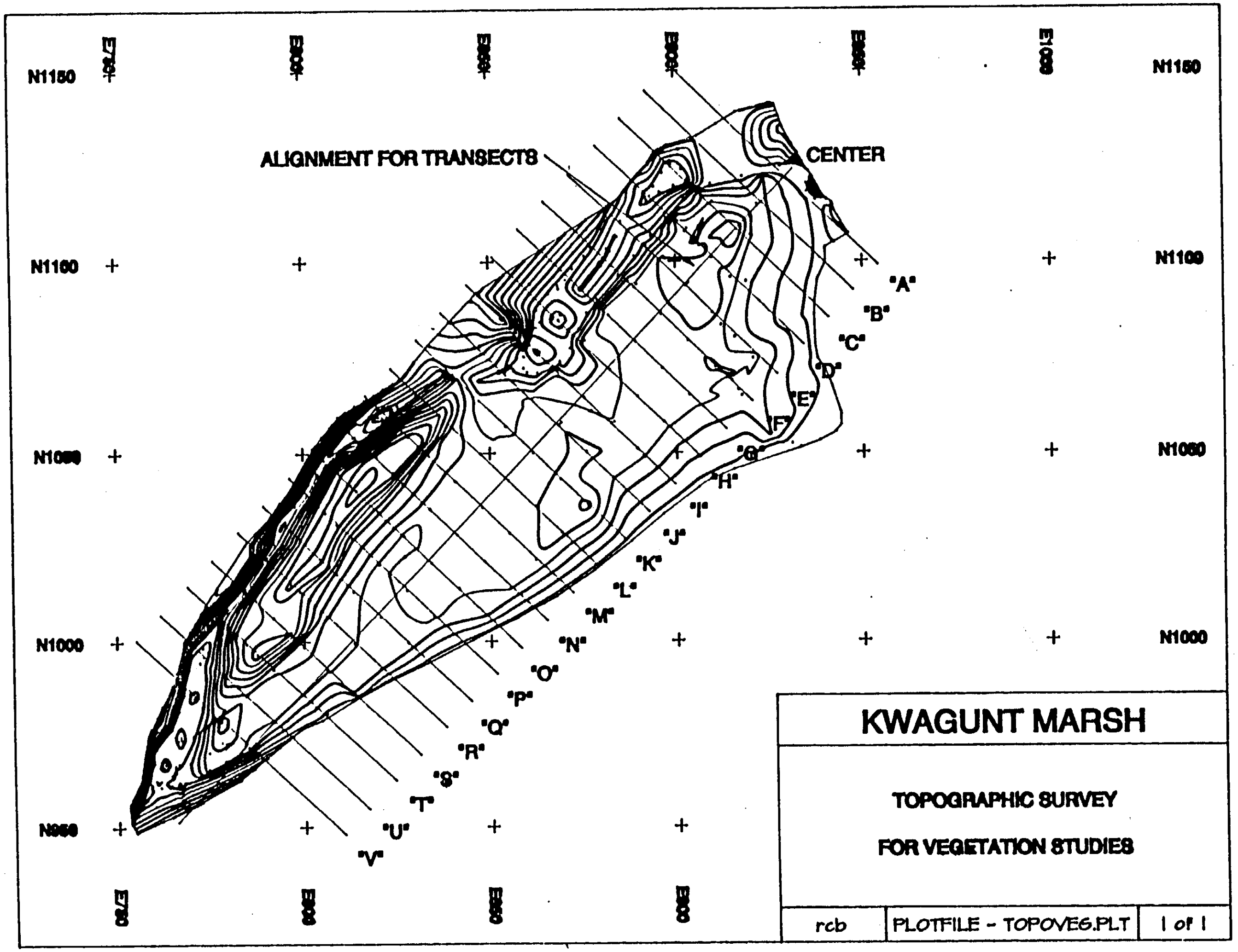


Figure 2.04A: Topographic map of the Mile 56R marsh study site, showing transect locations.

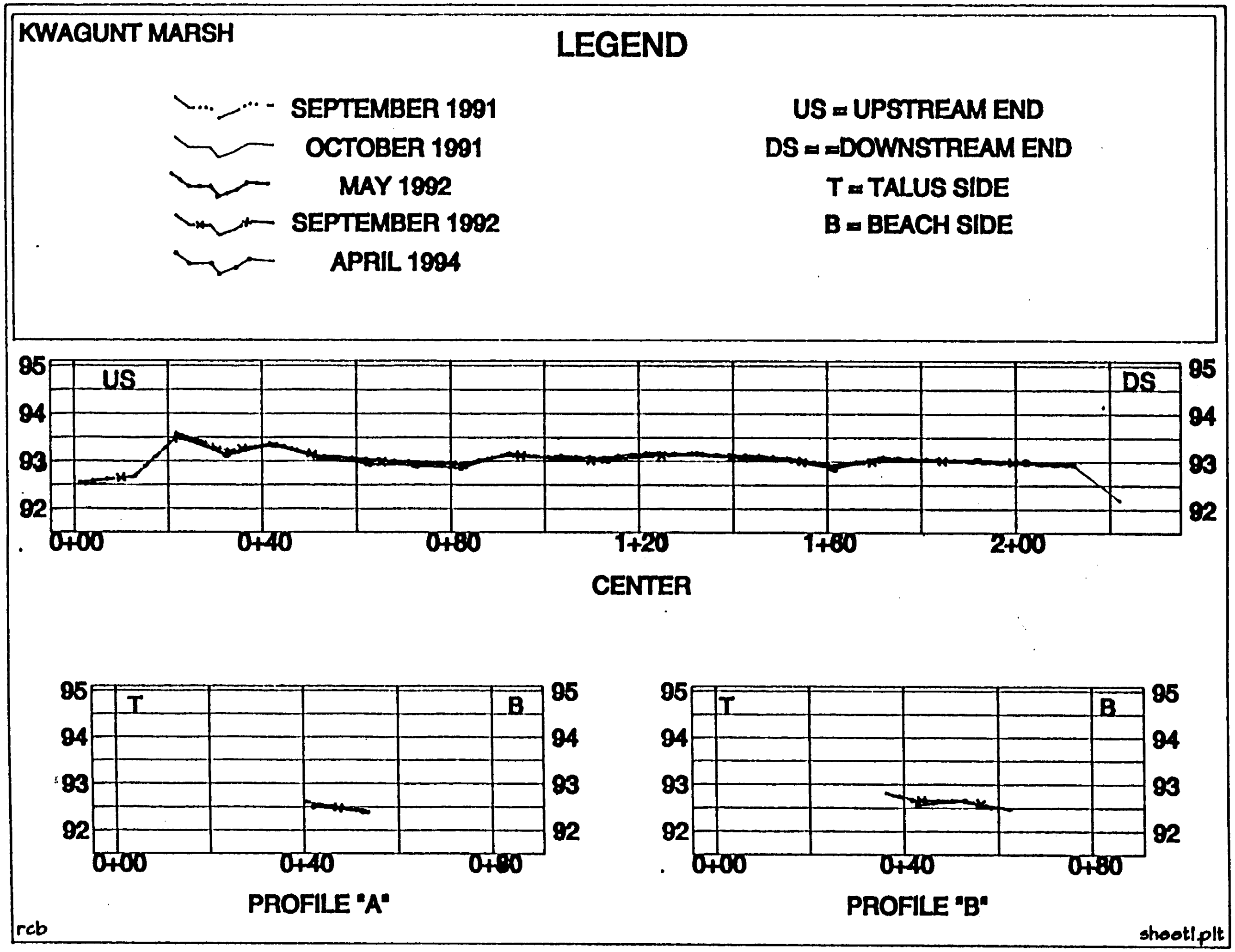


Figure 2.04B: Surveyed profiles of marsh transects at the Mile 56R marsh study site, 1991-1993.

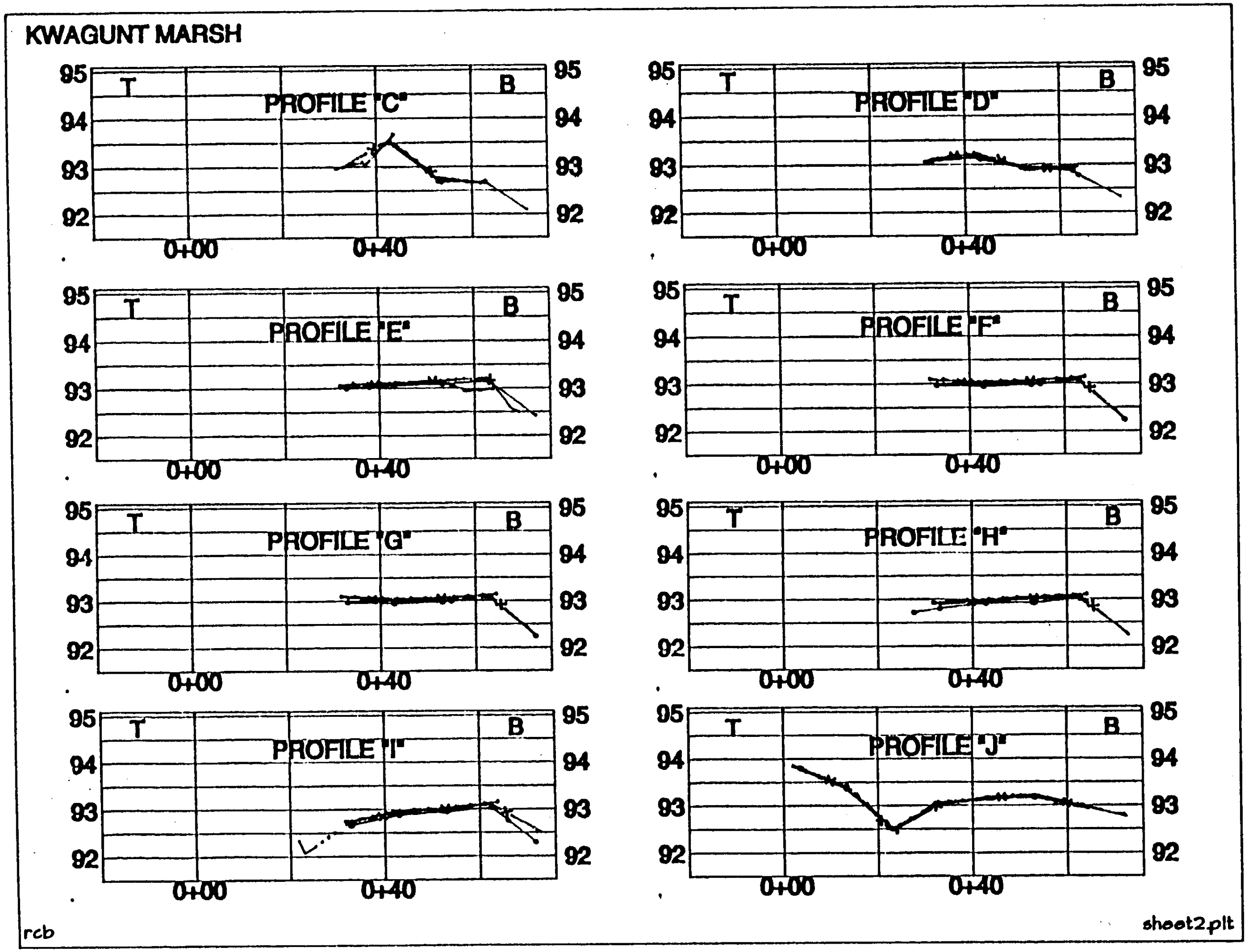


Figure 2.04B: Surveyed profiles of marsh transects at the Mile 56R marsh study site, 1991-1993 (cont'd).

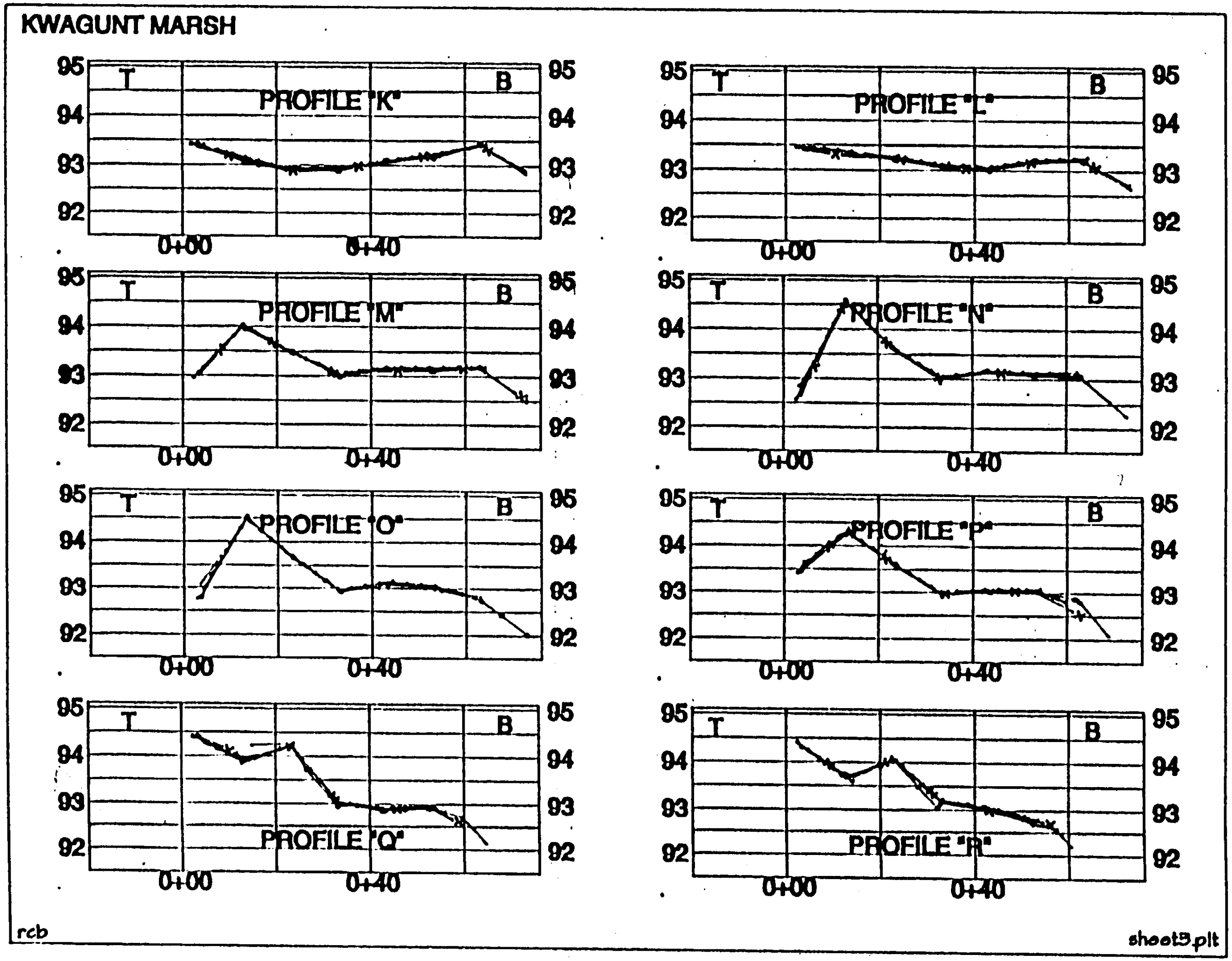


Figure 2.04B: Surveyed profiles of marsh transects at the Mile 56R marsh study site, 1991-1993 (cont'd).

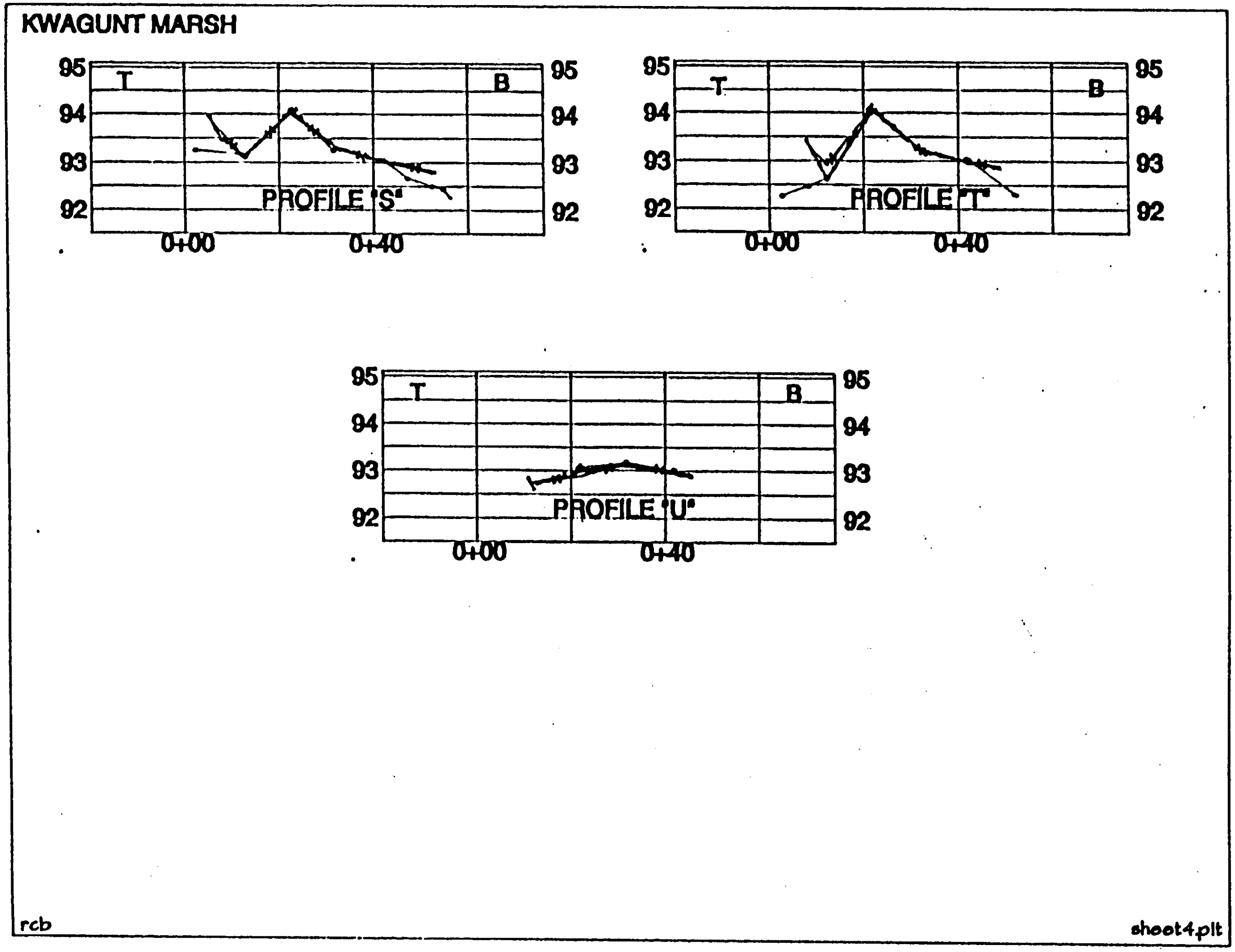


Figure 2.04B: Surveyed profiles of marsh transects at the Mile 56R marsh study site, 1991-1993 (cont'd).

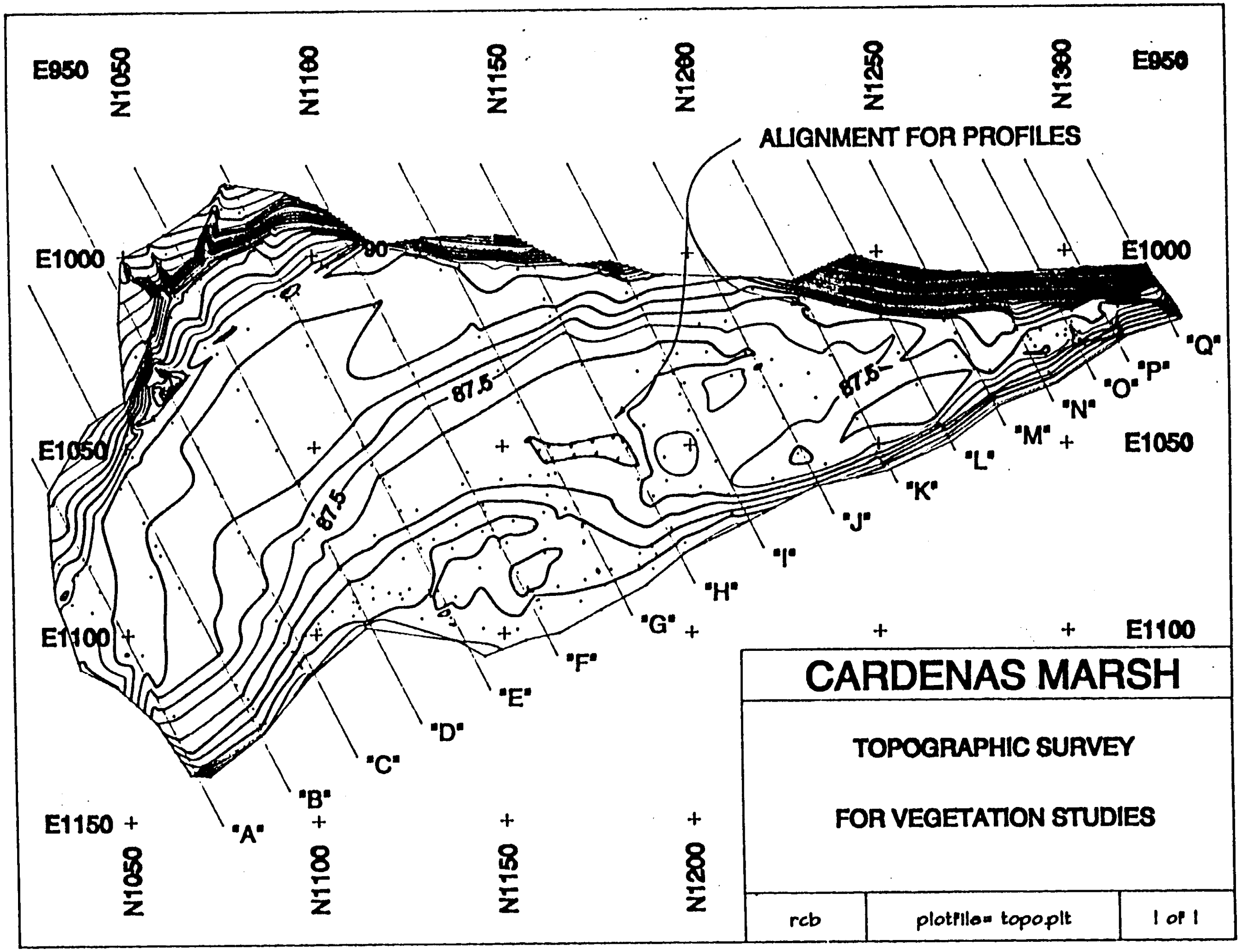


Figure 2.05A: Topographic map of the Mile 71L marsh study site, showing transect locations.

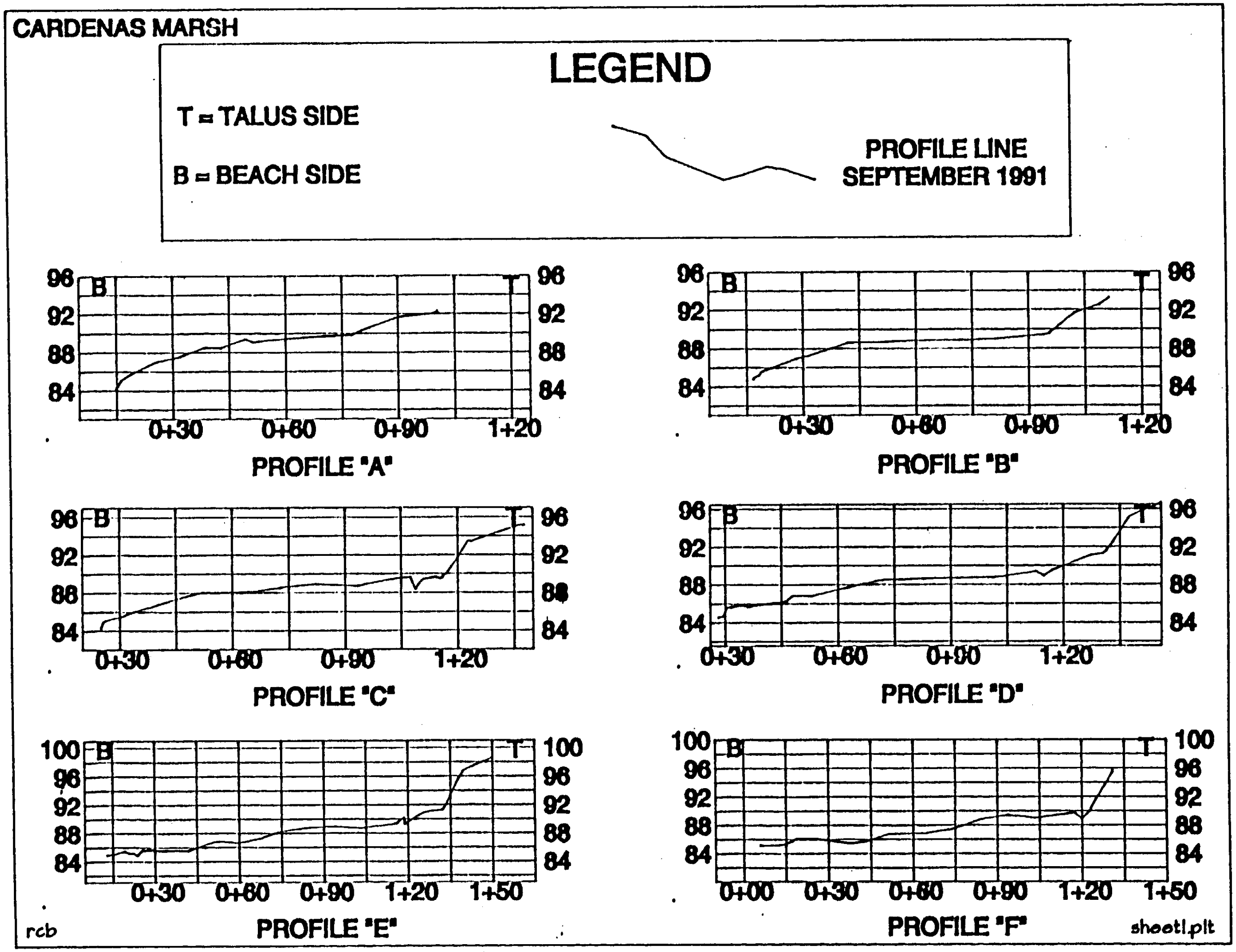


Figure 2.05B: Surveyed profiles of marsh transects at the Mile71L marsh study site.

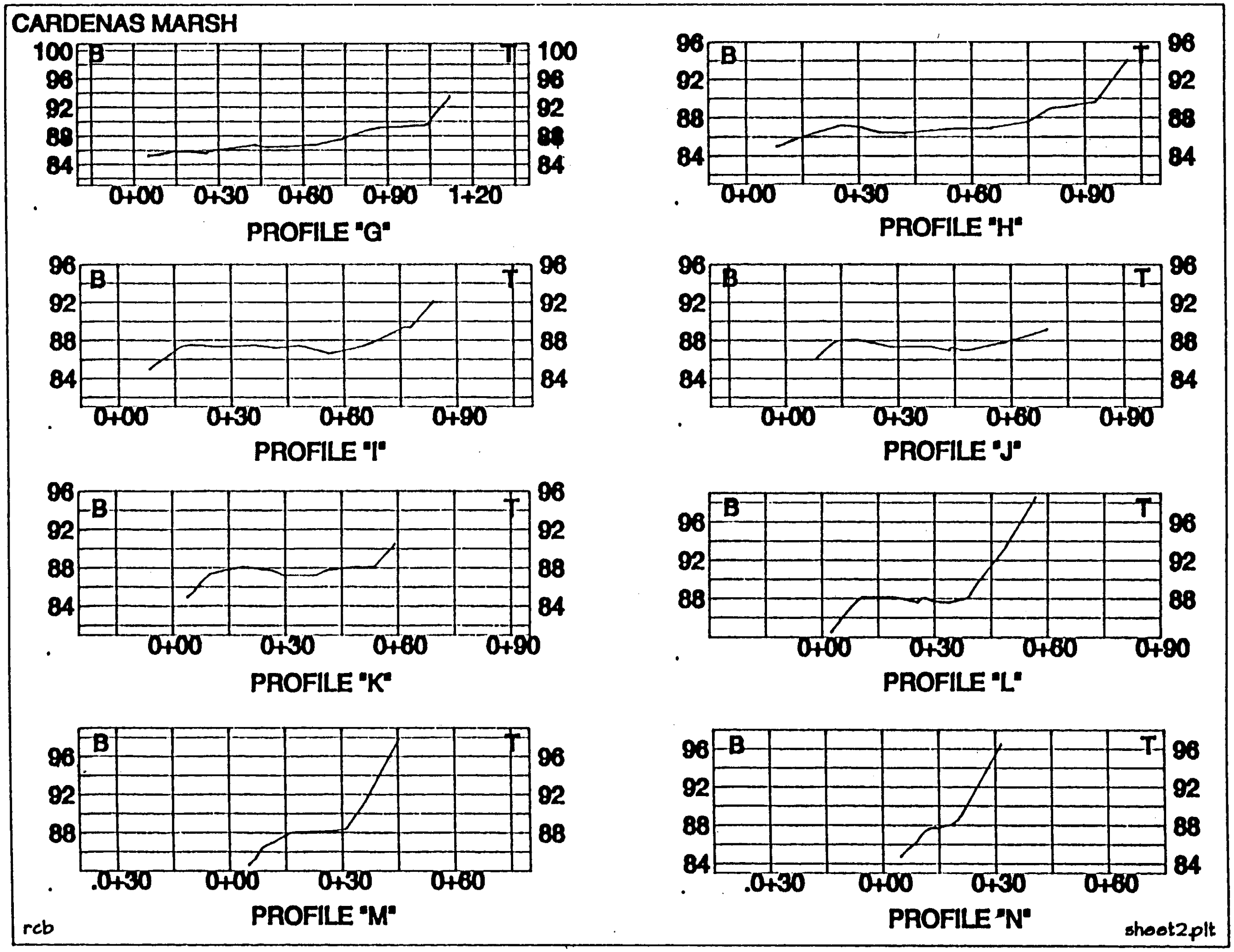


Figure 2.05B: Surveyed profiles of marsh transects at the Mile71L marsh study site, 1991-1993 (cont'd).

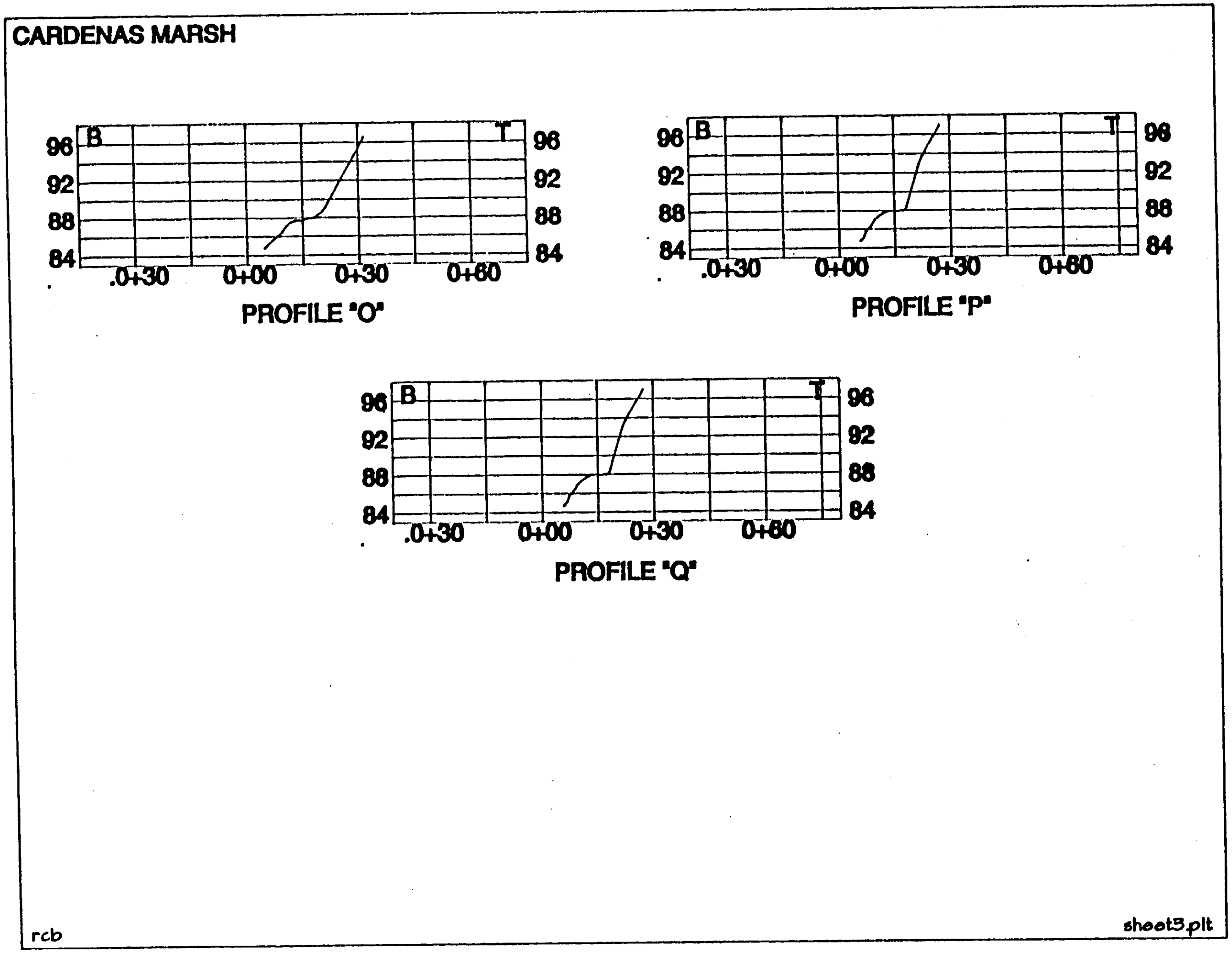


Figure 2.05B: Surveyed profiles of marsh transects at the Mile71L marsh study site, 1991-1993 (cont'd).

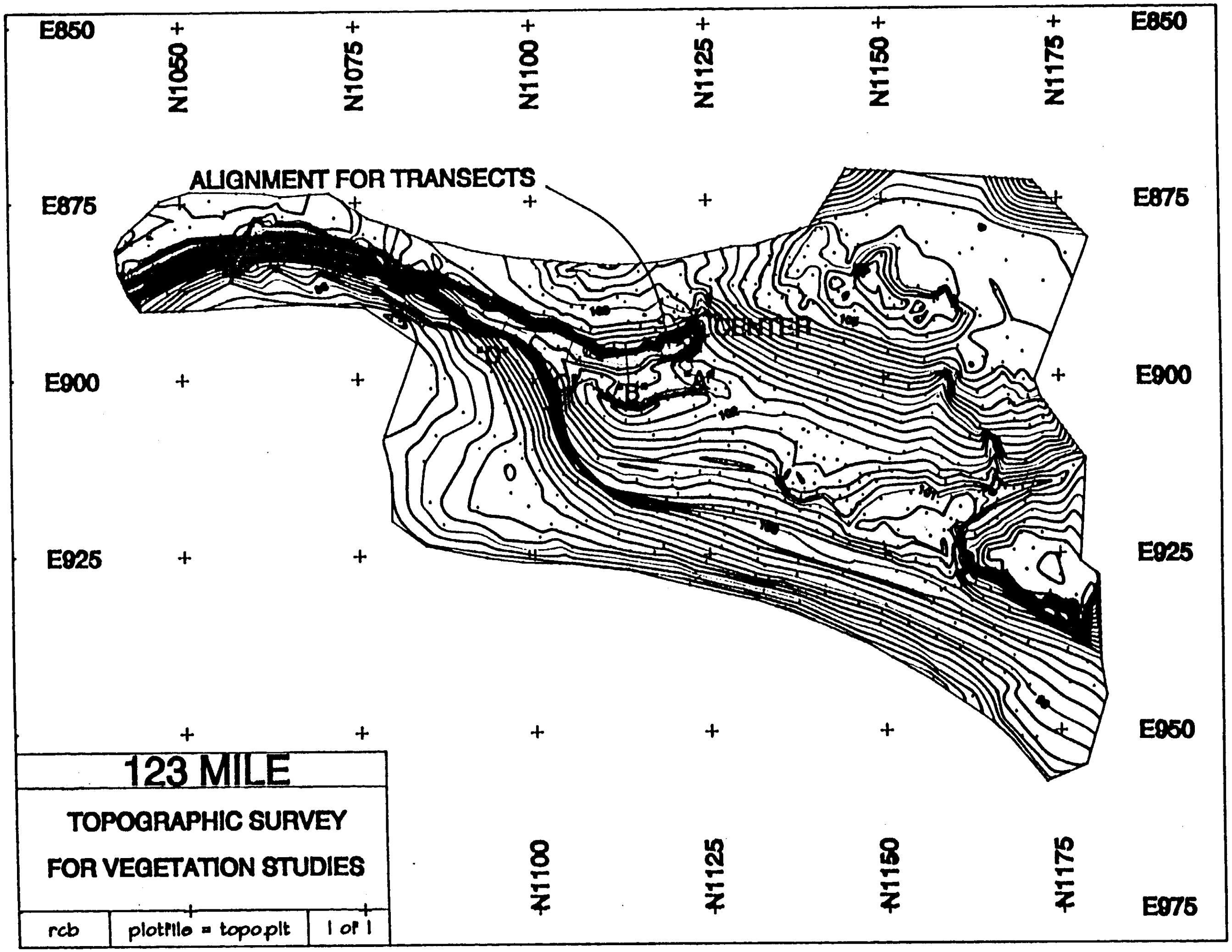


Figure 2.06A: Topographic map of the Mile 123L marsh study site, showing transect locations.

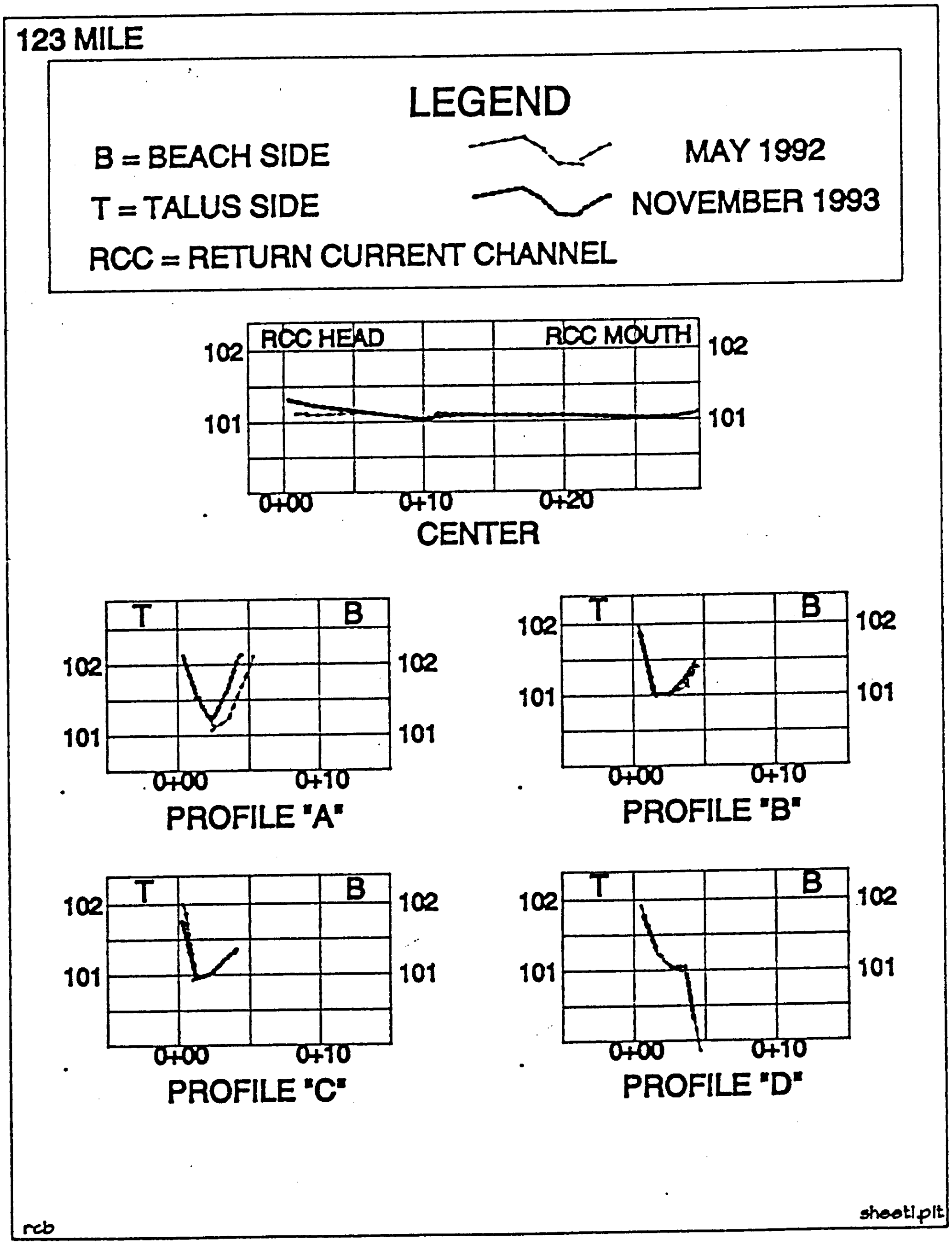


Figure 2.06B: Surveyed profiles of marsh transects at the Mile 123L marsh study site, 1991-1993.

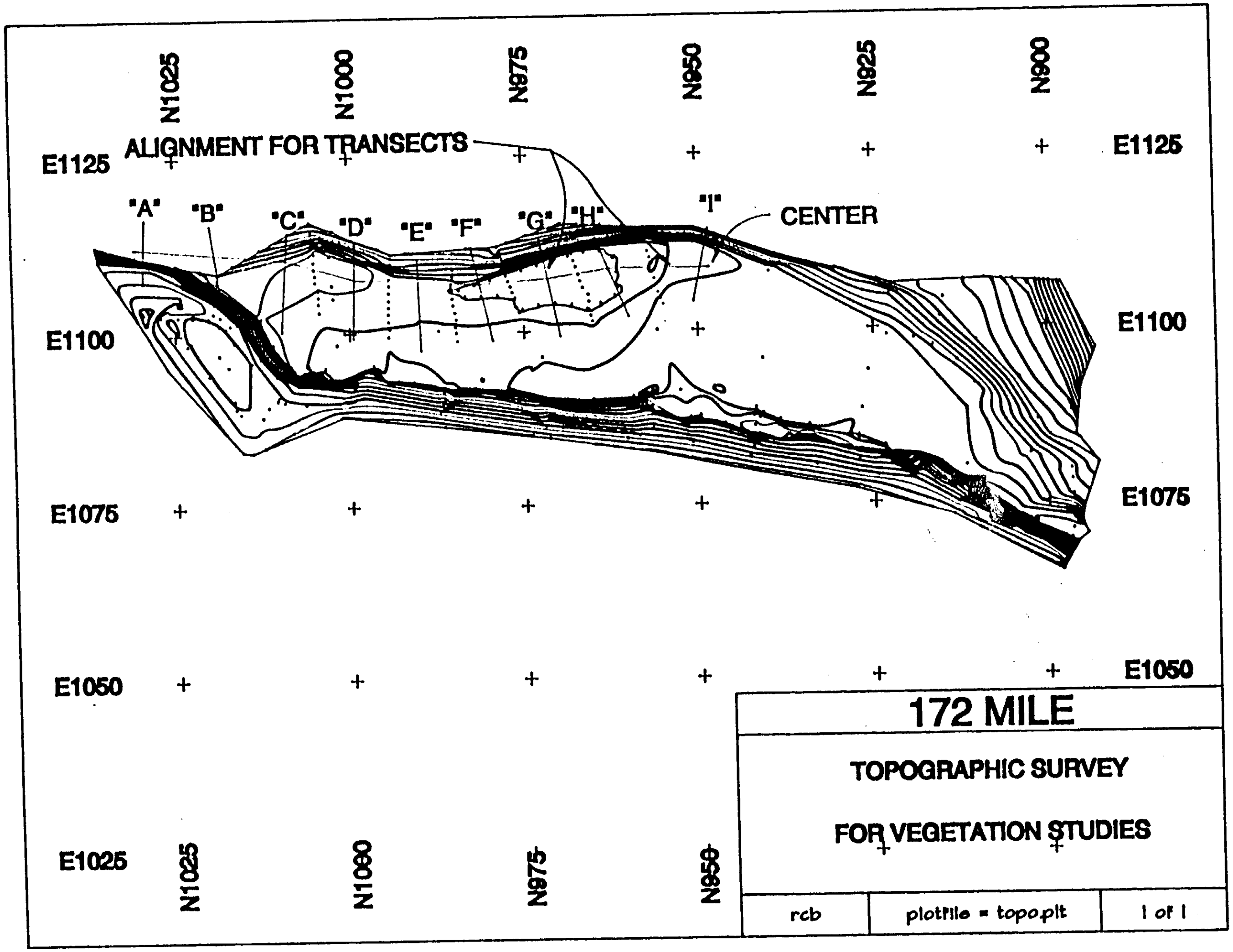


Figure 2.07A: Topographic map of the Mile 172L marsh study site, showing transect locations.

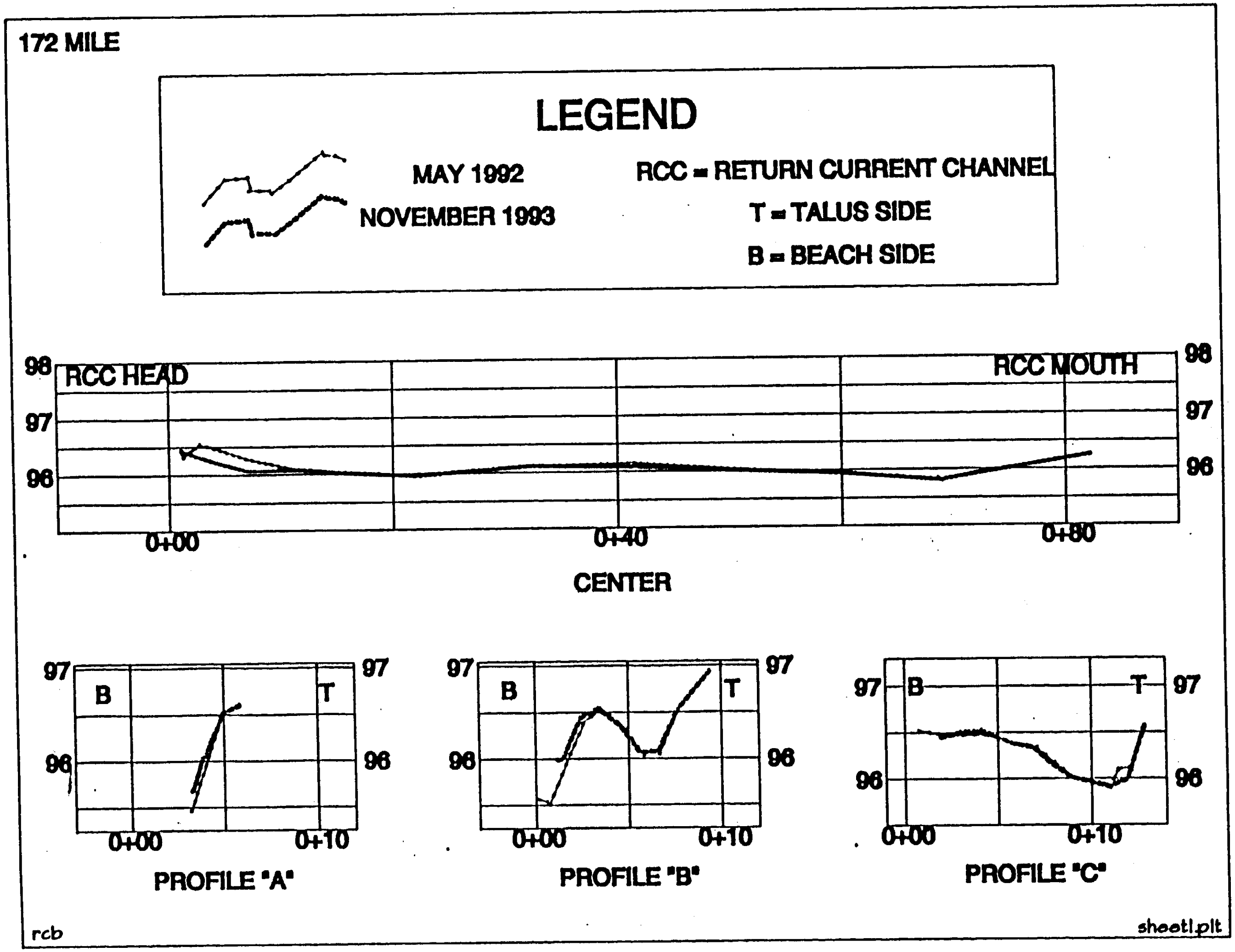


Figure 2.07B: Surveyed profiles of marsh transects at the Mile 172L marsh study site, 1991-1993.

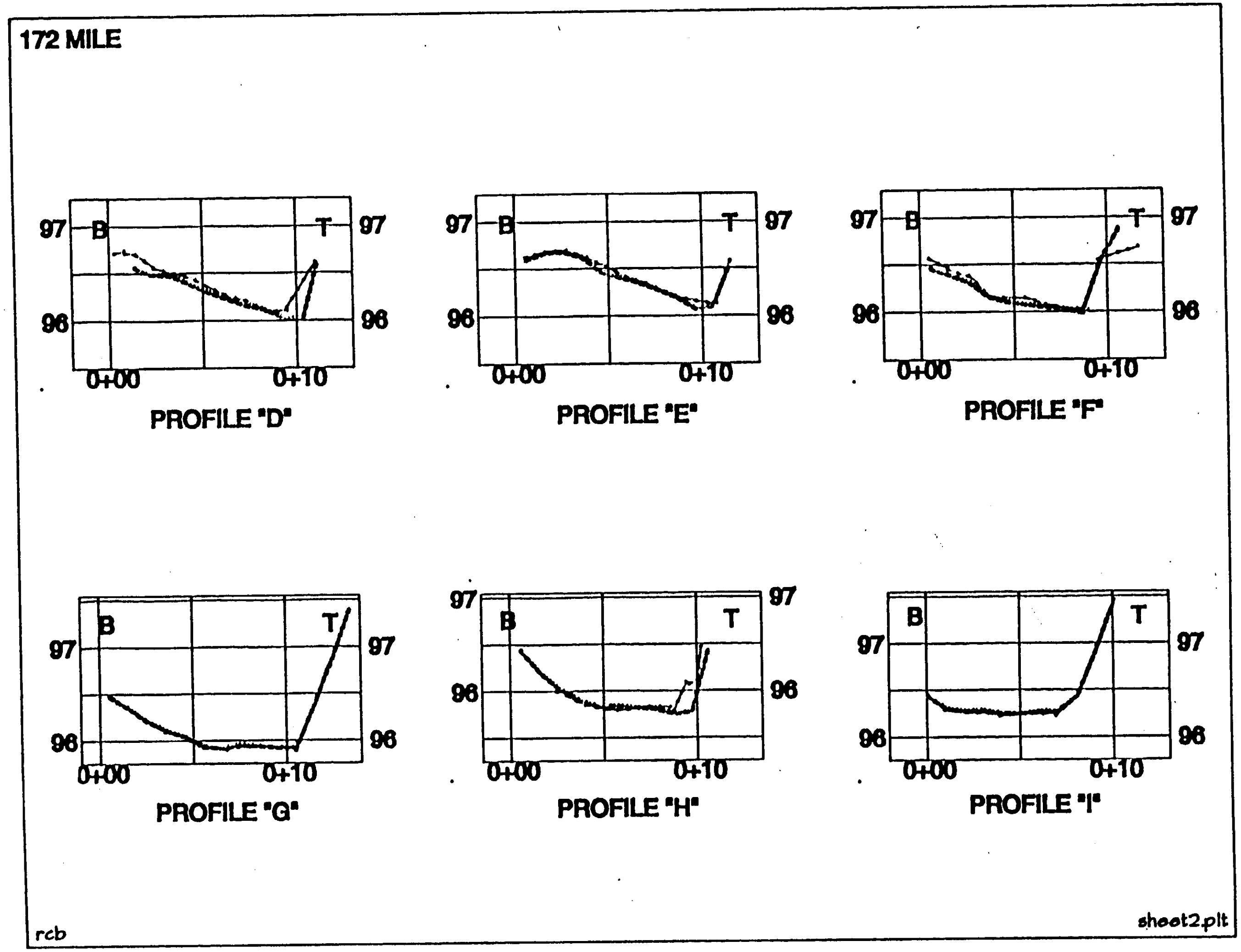


Figure 2.07B: Surveyed profiles of marsh transects at the Mile 172L marsh study site, 1991-1993 (cont'd).

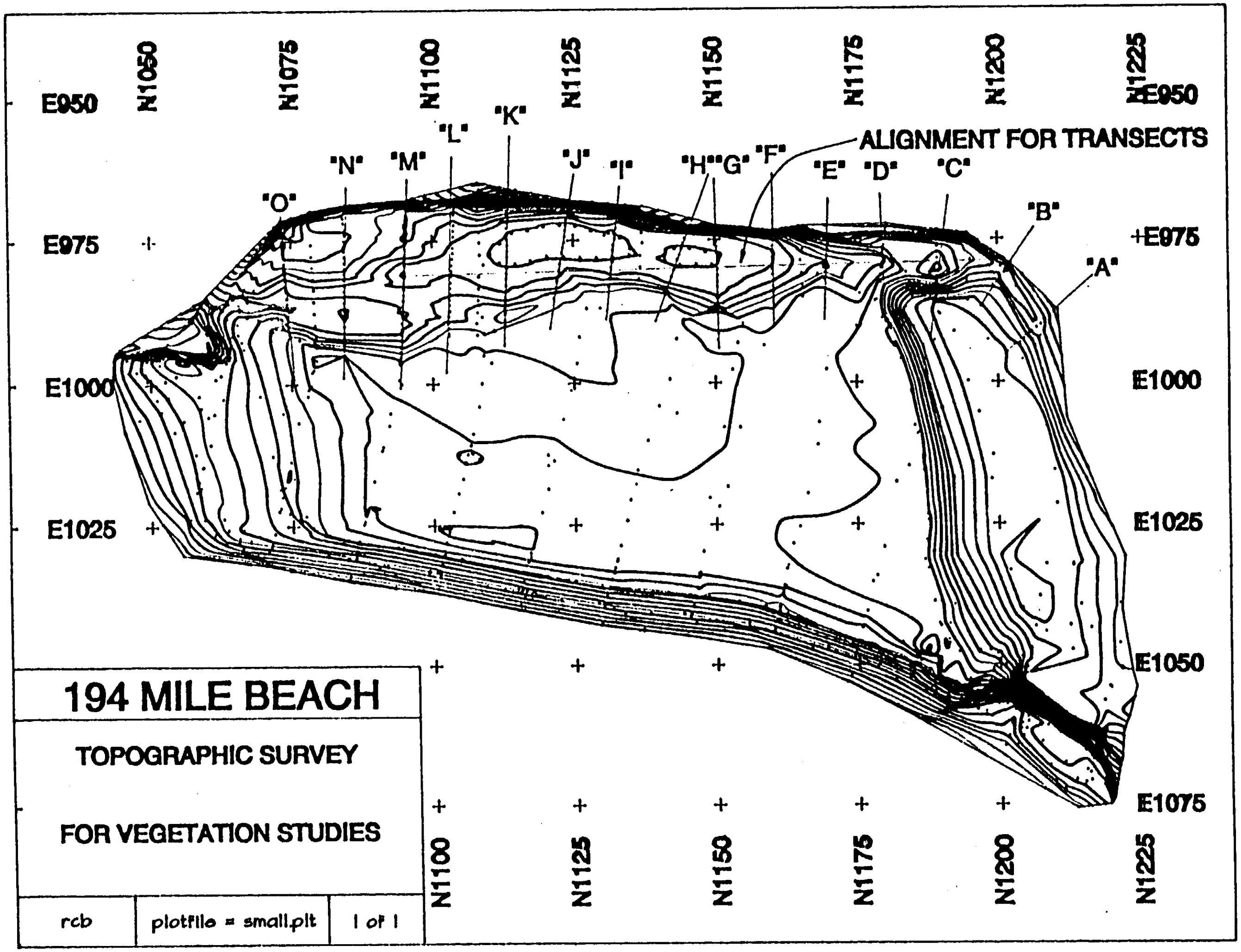


Figure 2.08A: Topographic map of the Mile 194L marsh study site, showing transect locations.

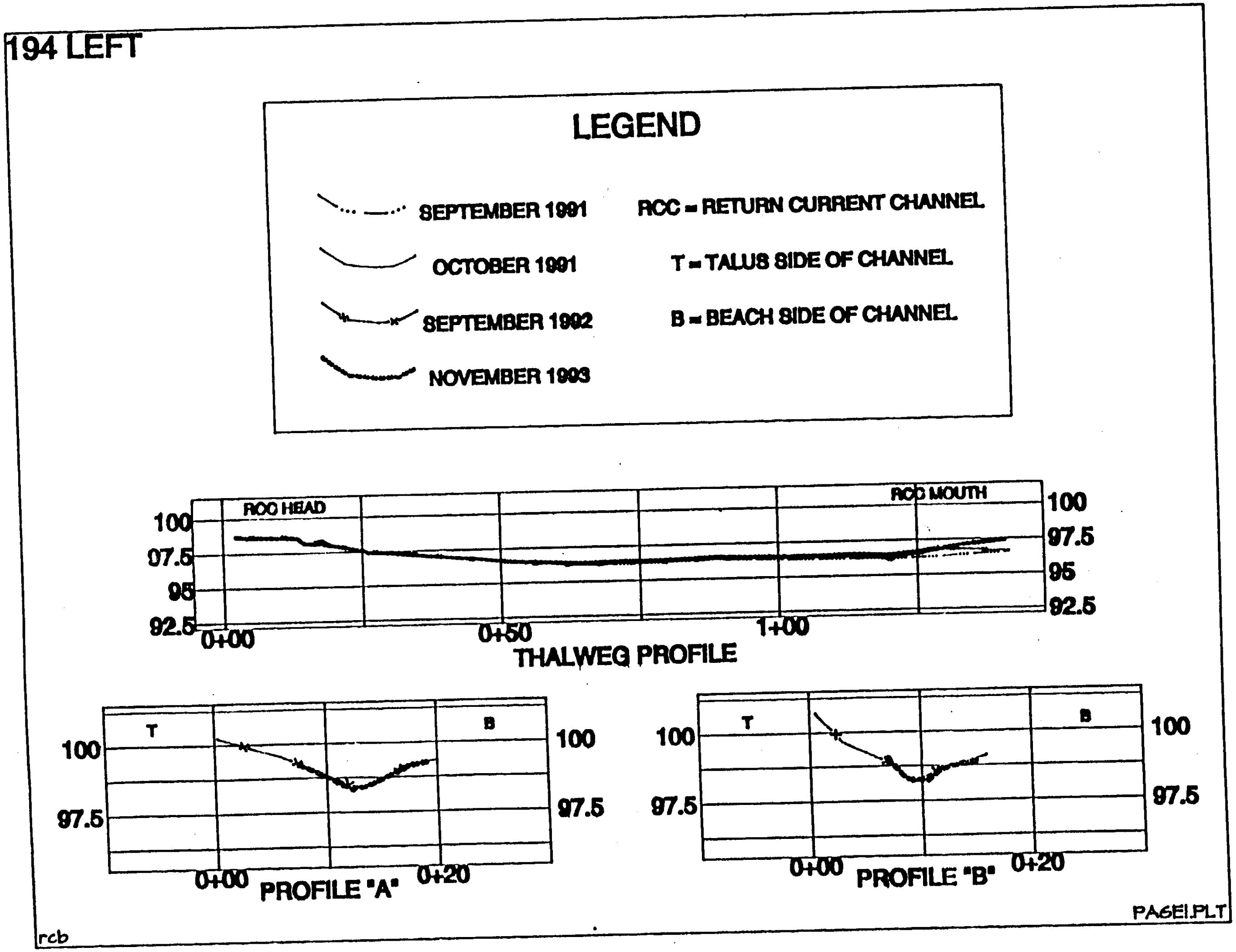


Figure 2.08B: Surveyed profiles of marsh transects at the Mile 194L marsh study site, 1991-1993.

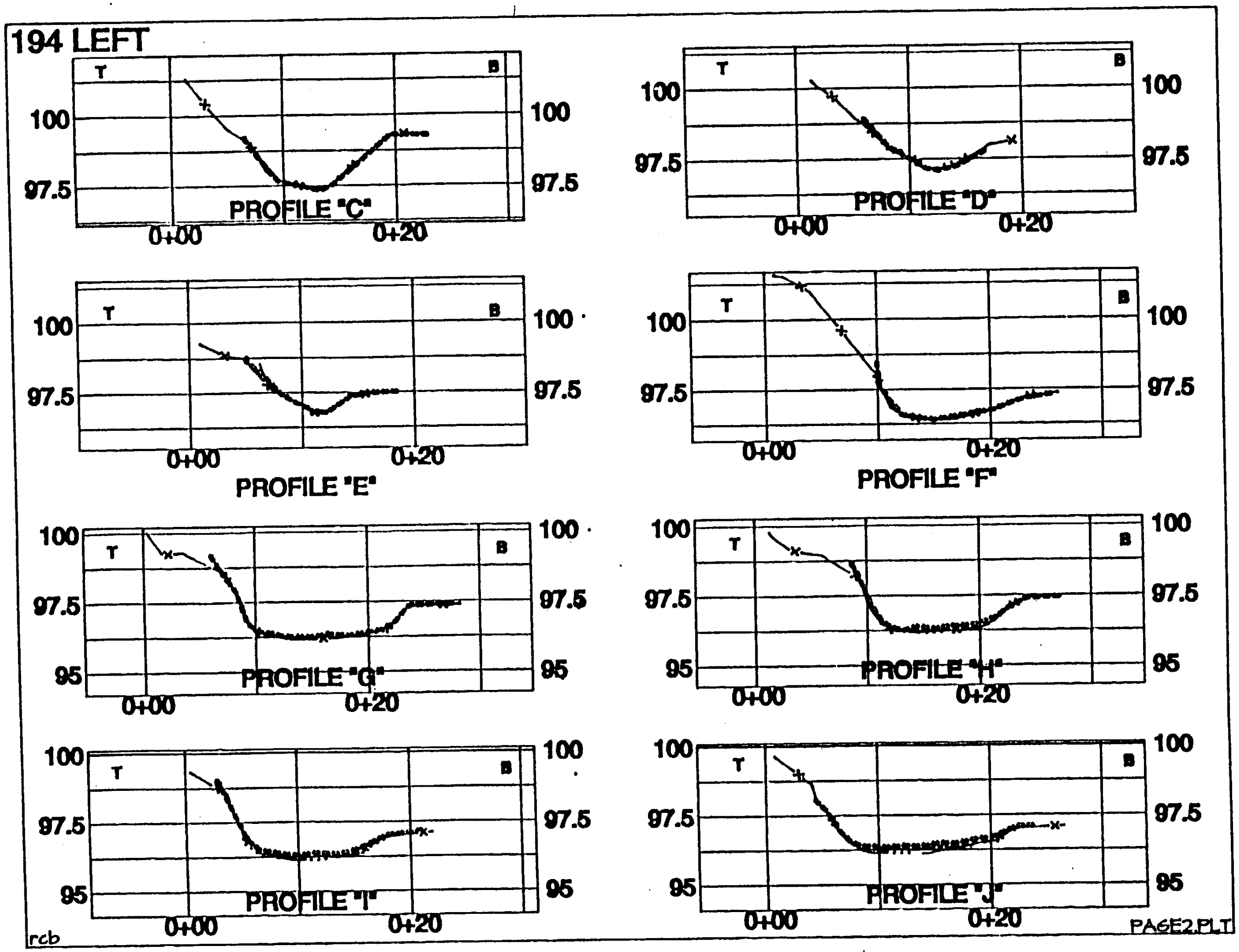


Figure 2.08B: Surveyed profiles of marsh transects at the Mile 194L marsh study site, 1991-1993 (cont'd).

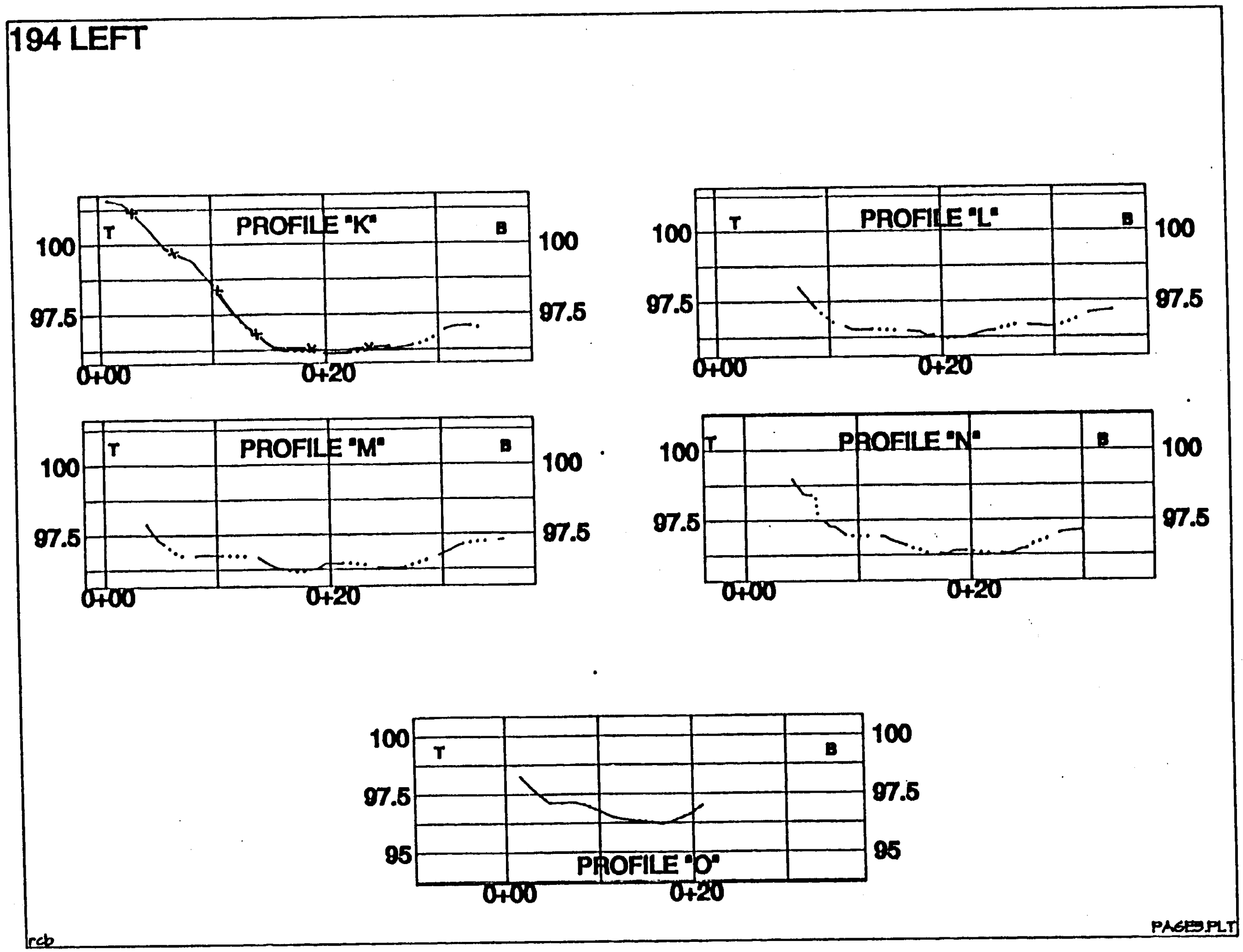


Figure 2.08B: Surveyed profiles of marsh transects at the Mile 194L marsh study site, 1991-1993 (cont'd).

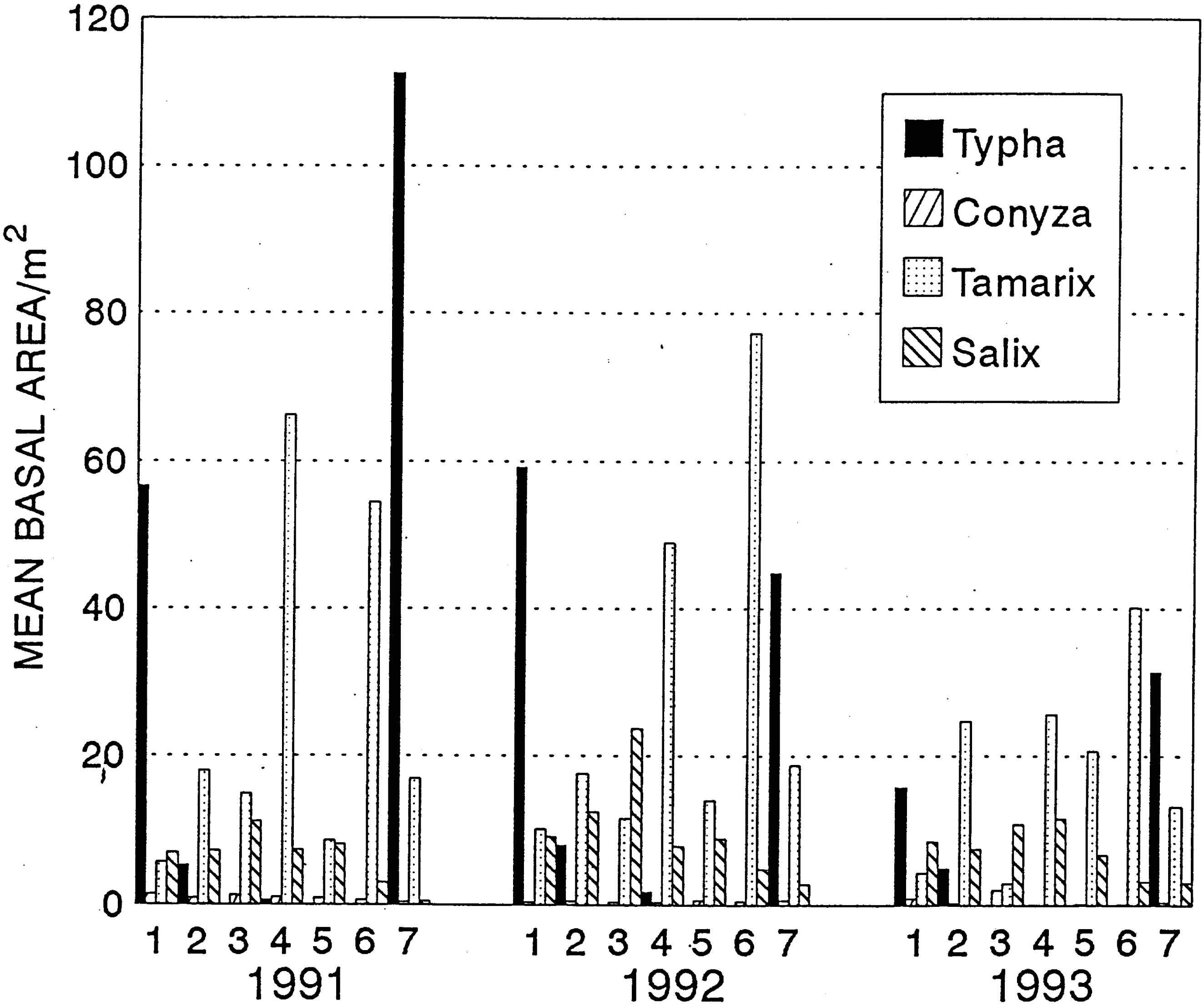


Figure 2.09: Mean basal area of four dominant marsh species at 7 study sites in 1991, 1992, and 1993.

by: 1) the presence of nearby fluvial marshes which may supply propagules, and 2) microsite slope steepness.

Ordination: Ranked axis 1 scores varied significantly between years ($t_{Friedman} = 7.36$, $p = 0.025$ for 41 species), and post hoc analysis indicated that 1991 data were significantly lower than 1992 or 1993 ($p = 0.005$; Table 2.04). Axis 2 scores varied significantly between years ($t_{Friedman} = 17.12$, $p < 0.001$), and post hoc analysis indicated that 1992 scores were significantly higher than 1991 or 1993 ($p = 0.005$), except for the wet marsh horsetail/herb assemblage. Axis 3 scores also varied significantly between years ($t_{Friedman} = 3.950$, $p = 0.049$), with 1991 scores overall significantly higher than 1992 or 1993 for wet marsh assemblages, but lower for dry marsh and upland assemblages ($p = 0.007$).

DISCUSSION

Shifts in flow regimes have affected fluvial marsh composition and distribution in this system. On the basis of GCES Phase II studies, we predicted that reduction of the range of daily flow fluctuations would result in: 1) reduced cover of previously established wet marsh taxa at stages above the interim flows maximum (566 m^3/s), which had formerly been inundated on a regular basis (e.g., upper elevation RCC habitats); and 2) increased colonization of wet marsh taxa at lower stage elevations. In addition, planned flooding may be used as a management strategy to recreate critical sandbar habitats, such as return current channels; however, uncertainties exist regarding the stage and frequency of planned floods.

Our first prediction is supported by MIPS analysis and by on site monitoring of transects. Interim flows appear to be negatively influencing fluvial marshes established prior to 1991. MIPS analyses show that marsh area increased between 1990 and 1991, a period of nearly "normal operations", and between 1991 and 1992. In contrast, 5 of 9 mainstream marshes upstream from the LCR confluence decreased in size from 1992 to 1993. Because these marshes lie upstream from the LCR, they were not scoured by flooding, reduction in area constitutes a slight negative effect of interim flows on marsh development. Many of the previously established marshes occurred in RCCs that are no longer being inundated by flow fluctuations. In agreement with our predictions, these habitats are shifting from dominance by clonal wet marsh taxa to woody phreatophytes, especially Salix exigua.

Under interim flows we observed relatively rapid colonization of channel margin habitats by wet marsh taxa, particularly Scirpus pungens, Phragmites australis and Typha spp.. This colonization is strongly dependent on geomorphic position within the eddy, with RCC mouth expansion of established clonal species and primary colonization non-clonal herbaceous taxa (e.g., Plantago spp., Conyza canadensis, Aster subulatus, etc.) of relatively flat, fine-grained habitats at the current reattachment points. Because of the low stage at which these assemblages are developing, these new marsh patches are likely to be scoured by planned floods, as proposed in the EIS.

Ordination analyses also suggest that marsh vegetation composition is changing under interim flows in response to changing microsite conditions. Axis 1 is largely associated with moisture availability (Stevens et al. 1995), and our data suggest that wet marsh species scores are increasing in basal area in wetter settings. Changes in the rank of axis 2 scores suggests that interim flows caused an initial rapid adjustment of assemblages in relation to grain sizes but this

Table 2.04: Mean ranks of DECORANA marsh plant guild factor loading scores for axes 1, 2 and 3 for 1991, 1992 and 1993 from permanent transects along the Colorado River in the Grand Canyon. Guilds are: 1 - wet marsh (cattail/reed); 2 - wet marsh (horseweed/herb), 3 - woody phreatophyte (tamarisk/arrowweed), 4 - dry marsh (horsetail/sandbar willow), 5 - upland/xeric (Mohave desertscrub). One sd and n are included.

GUILD		MEAN RANK OF DECORANA SPECIES LOADING SCORES								
		AX191	AX291	AX391	AX392	AX292	AX192	AX193	AX293	AX393
1	$\bar{x}$	18.67	23.07	17.93	57.17	33.58	52.08	31.00	25.90	41.30
	1sd	14.412	20.427	16.671	31.420	19.699	26.951	0.000	20.529	21.135
	n	15	15	14	18	18	18	10	10	10
2	$\bar{x}$	40.56	48.83	31.89	47.18	46.50	52.05	31.00	33.45	39.09
	1sd	21.700	23.997	22.262	25.063	27.613	30.970	0.000	14.166	15.300
	n	9	9	9	11	11	11	11	11	11
3	$\bar{x}$	52.79	39.82	56.06	48.71	58.46	52.19	31.00	28.75	19.19
	1sd	15.974	20.233	15.610	26.021	29.355	32.419	0.000	20.567	17.383
	n	17	17	17	24	24	24	16	16	16
4	$\bar{x}$	35.62	40.76	36.16	54.25	50.68	44.35	32.63	36.47	33.05
	1sd	18.561	19.581	19.065	24.800	26.440	24.669	12.271	17.836	13.048
	n	25	25	25	20	20	20	19	19	19
5	$\bar{x}$	46.00	41.21	43.00	38.54	49.08	46.38	31.00	24.75	17.75
	1sd	24.739	26.511	17.282	30.623	34.709	28.253	0.000	13.574	8.221
	n	7	7	7	13	13	13	4	4	4

assortative process may be slowing as interim flows proceed. As we previously reported, the distribution of fluvial marshes is dependent on microsite inundation frequency and grain size.

Our observation of aggradational changes associated with the LCR flooding events in 1993 suggest that brief, moderately high flows, coupled with a month of $\geq$ 700 m^3/s flows results in aggradation of RCCs, but are insufficient to result in redevelopment of those features. Velocities required to scour silt-rich marsh sediments are considerably higher than those required to move sand; however, stage-related velocities in RCCs are not presently known for floods and such information is critical to understanding the process of RCC development. To the extent that RCCs support highly productive, early seral stages of marsh development, as well as nursery areas for larval native fish and habitat for avifauna, we conclude that short flooding spikes of the magnitude proposed by the EIS will not be sufficient to restore these characteristic habitats in the Grand Canyon. If planned flooding is to be used as a management strategy, as proposed in the draft EIS, more study should be devoted to understanding how activation and scour of RCCs occurs. We suspect that planned high flows should be somewhat larger and probably of longer duration than those that occurred in 1993.

From these analyses we conclude that the future maintenance and development of fluvial marshes under an interim flows-style flow regime depends on the frequency of planned floods and erratic tributary flows. It is likely that continued interim flows and a regular flooding program will reduce fluvial marsh cover in this system. Continued monitoring is required to evaluate long-term changes in fluvial marsh responses to flow events in this system.

CHAPTER III

XYLEM WATER POTENTIAL OF *Salix exigua* NUTTALL, AN INDICATOR OF MOISTURE STRESS IN FLUVIAL MARSHES ALONG THE COLORADO RIVER IN THE GRAND CANYON, ARIZONA

CHAPTER III:

XYLEM WATER POTENTIAL OF *Salix exigua* NUTTALL, AN INDICATOR OF MOISTURE STRESS IN FLUVIAL MARSHES ALONG THE COLORADO RIVER IN THE GRAND CANYON, ARIZONA

INTRODUCTION

Terrestrial plant species maintain a negative xylem water potential (XWP) through the process of transpirational water loss at the leaf or stem surface (Hale and Orcutt 1987). If insufficient soil water is available to maintain water balance, XWP decreases and the plant may become stressed and alter allocation patterns, changes that may result in wilting, dieback or mortality. Each terrestrial plant species functions within its own XWP range, which varies across moisture gradients and between species (Schollander et al. 1965). Halophytes and xerophytes may be adapted to drought stress and some may operate under XWP values as low at -6.0 MPa. In contrast, riparian species are much less tolerant of drought, commonly operating the range of -0.1 to -3.0 MPa. Riparian and wetland phreatophytes require direct contact with the water table or the capillary fringe to maintain water balance, and for photosynthesis, growth and reproduction (Fenner et al. 1984, Stromberg and Patten 1991, Busch et al. 1992). Maintenance of plant water potential (XWP) is particularly important for such species in arid regions, because they are usually poorly adapted to the surrounding xeric conditions. Differences between riparian species' root architecture may influence water uptake under fluctuating groundwater conditions (Koslowski 1984). For example, Stevens and Waring (1985) observed differences in survival and recovery after flooding for riparian species with different root architectures, from deeply-rooted Prosopis glandulosa, to adventitiously-rooting Tamarix ramosissima, to clonal (rhizomatous) taxa such as Salix exigua.

Operations of Glen Canyon Dam between 1963 and 1991 permitted development of novel, biologically productive fluvial marshes along the Colorado River throughout the Grand Canyon; however, variation in flow influences these riparian plant assemblages in this system (Stevens et al. 1995). Implementation of interim flows in August, 1991 reduced daily and monthly discharge fluctuations, potentially affecting lower riparian zone vegetation in the Colorado River ecosystem. Interim flows criteria include low daily ranges and reduced monthly mean flows, particularly during May and June, when daily air temperatures are high. River stage changes are quickly translated into bankstored groundwater stage changes in the unconsolidated riverside sand bars in Colorado River sandbars in this system (Budhu 1992; Carpenter et al. 1992). Interim flows may influence marsh plant species by changing bankstored groundwater availability, altering composition and reducing productivity. Characteristic marsh species, such as cattail, are distributed in relation to soil texture and moisture availability in this system, and reduced flow fluctuation may influence these important physical gradients (Stevens et al., 1995).

In this study we evaluated the effects of interim flows and monthly changes in river flow regimes associated with Glen Canyon Dam interim flows on the XWP of a marsh indicator species (S. exigua), an ubiquitous marsh affiliate in this system. Characteristic marsh species in this system include horsetail (Equisetum spp.), sedge (Scirpus spp., Carex spp.), rush (Juncus spp.), cattail (Typha spp.) and reed (Phragmites australis). These species are herbaceous and rhizomatous, but have hollow, triangular or flat stem structures that reduce effective measurement of plant water potential using standard pressure bomb techniques (Schollander et al. 1965). However, Salix exigua is a common, woody marsh species and its xylem water potential can be readily be measured with these techniques. We measured plant water potential and stem growth of S. exigua across stage elevation gradients at four sandbars. We collected data during the pre-dawn and mid-day hours during low-, medium- and high-flow months in 1993. We hypothesized that monthly flow volume is negatively correlated with S. exigua plant water potential (XWP), and that measurement of this parameter could be used as an effective monitoring method, as proposed by Stromberg et al. (1993).

METHODS

Measurement of Plant Water Potential

Plant water potential is a measure of the amount of free energy per unit volume between matrically (soil) bound, pressurized or osmotically bound water within the plant, in comparison with that of pure water. Measurement of plant water potential was pioneered by P.F. Schollander and associates (1965) with the development of the commonly used pressure bomb method. By placing the cut stem of a plant into a chamber and pressurizing it with N_2 gas, xylem fluid is forced out of the cut stem. The pressure (as megapascals, MPa with 1 MPa = 10 bars) required to drive fluid out of the stem is a measure of XWP. XWP is a relative (species-specific and condition-specific) measure of moisture stress in plants, and the pressure bomb technique is a standard and effective means of evaluating the amount of moisture stress in field situations (Stromberg et al. 1993). Stress is an induced change in physiological processes that results in a reduction of plant growth, yield or survival (Hale and Orcutt 1987). XWP changes dramatically over the course of a day, with moderate values in the pre-dawn hours, and lower values during sunny days when transpiration is maximized. Predawn XWP measurements are conservative estimates of stress; however, mid-day values provide insight on the range in drought tolerance of a given plant species. In this study we used a PMS, Inc. Schollander-type pressure bomb, and employed the recommended protocol for preparing cut stems (PMS, Inc. Corvallis, OR).

Study Organism

XWP is nearly or wholly impossible to measure on marsh macrophytes directly because of irregular stem cross-sections (e.g. triangular stems of Scirpus and Carex, or flat stems of Typha domingensis). Therefore we selected a closely associated woody shrub that also occurred in fluvial marshes to serve as an indicator species. Salix exigua is a shallow-rooted, native, clonal willow that occupies the peripheries of Colorado River marshes throughout the Grand

Canyon. From research on S. exigua during GCES-II, XWP is known to be affected by temperature, relative humidity and somewhat on river stage. S. exigua water relations are sufficiently well known to its use as an indicator species for monitoring habitat water availability (Donovan and Ehlringer 1991, Stevens and Ayers 1993). These studies indicate that S. exigua functions in a physiologically similar range of XWP as many marsh species, but may be slightly more tolerant of chronic drought stress.

Study Area

The Colorado River in the Grand Canyon is regulated by Glen Canyon Dam, a 200 m high hydroelectric facility located 25 km upstream of Lees Ferry, Arizona (Fig. 3.01). The daily range of Colorado River fluctuations under normal dam operations is dependent on distance from Glen Canyon Dam and geomorphic reach characteristics. Under normal operations, wide reaches commonly experienced more than 2 m of daily stage change during the mid-summer months; however, interim flows have reduced daily fluctuations by half. Daily river fluctuations are translated into phreatic surface stage changes within sand bars in a complex fashion, with the amplitude of groundwater stage fluctuations decreasing with distance away from the riverside (Budhu 1992, Carpenter et al. 1992). Completion of Glen Canyon Dam in 1963 resulted in a dramatic increase in marsh vegetation (Turner and Karpiscak 1980, Stevens et al., 1995), particularly in wide reaches. Wide geomorphic reaches in this system support far greater fluvial marsh density and cover because reduced current velocity allows for deposition of alluvial sediments, and because softer parent rock provides more low-gradient surface area for colonization (Schmidt and Graf 1990, Blinn et al. 1992, Stevens and Ayers 1993, Stevens et al., 1995). By convention, locations along the river are designated by miles from Lees Ferry.

Field Study Sites

We selected four study sites at which to measure Salix exigua XWP in 1993 (Fig. 3.01): Miles 43L, 50L, 171.5L and 194L marshes (Fig. 3.01). These sites provided S. exigua populations with numerous genets distributed across stage elevations of 425 m^3/s up to 1,430 m^3/s (from the upper range of interim flows to the upper limit of the lower riparian zone; Stevens and Ayers 1993). Sand bar stratigraphy was well known at these sites (Beus and Avery 1992). Hypsometric relationships have been determined from those survey data and topographic changes have been documented. The four study sites are reattachment bars (sensu Schmidt and Graf 1990), with bar platforms inundated by flows of ca. 900 m^3/s, near the normal maximum powerplant capacity.

The Mile 43L site is a reattachment bar in an upper pool environment, composed of well-sorted fine- to medium-grained sand (Beus and Avery 1992). The upstream portions of the bar platform and the return current channel were overlaid with a 0.5 m thick deposit of silty fine sand, deposited in 1987-1989. The 1,150 m^3/s to 1,400 m^3/s terrace at the 43 Mile study site was composed of a 1.0-1.5 m thick deposit of fine to medium sand overlying a much thicker

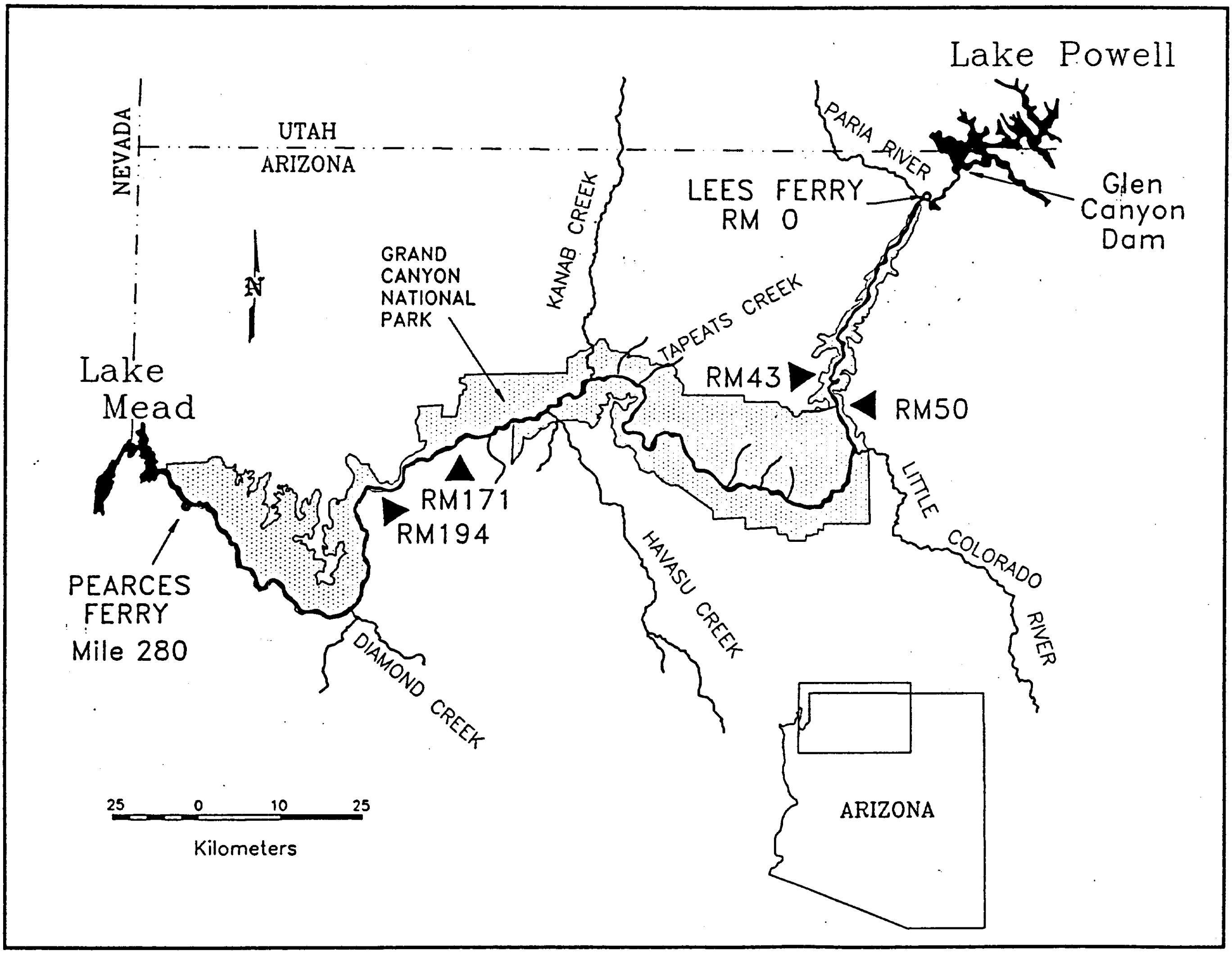


Figure 3.01: Map of <u>Salix exigua</u> xylem water potential study sites in the Grand Canyon.

silty fine sand deposit probably pre-dam in origin. The bar had been extensively reworked by flooding in 1983, with minor reworking in 1984-1986. S. exigua exists from approximately 400 to 1500 m^3/s stage elevations at this site. Stage-to-discharge relationships were generated for this site as part of the sand bar topographic studies of Beus and Avery (1992) and detailed marsh studies (Stevens et al., 1995). At the onset of interim flows, the Mile 43L marsh occupied the return current channel (RCC); however, interim flows inundate only the lower one-third of this formerly well-developed return channel. We sampled approximately 20 marked S. exigua and several random stems on distinctive terraces at the 425, 550, 700, 850 and 1,100 m^3/s stage elevations at this site. Sampling took place during pre-dawn and mid-day hours in May (low flow month), June (moderate flow month), July (high flow month), September (moderate flow month) and October (low flow month, mid-day measurements only) in 1993.

Although we initially proposed Mile 51.5L marsh as a study site, that site was closed due to suspected presence of breeding Southwest willow flycatcher. Therefore we selected the nearest comparable site as an alternative. The Mile 50L marsh provided S. exigua stems across a range of stage elevations from approximately 400 to 1,130 m^3/s stage elevations. This is a reattachment bar with a well-developed return channel that is inundated on a daily basis by all interim flows. We sampled approximately 20 marked S. exigua and several random stems on distinctive terraces at the 550, 850 and 1,100 m^3/s stage elevations at this site. Sampling took place during pre-dawn and mid-day hours in May (low flow month), June (moderate flow month), July (high flow month), September (moderate flow month) and October (low flow month, mid-day measurements only) in 1993.

The Mile 171.5L site was a reattachment bar in an upper pool environment, composed of well-sorted fine- to medium-grained sand in the wide, low gradient Lower Canyon reach. The bar surface up to the 935 m^3/s stage was inundated by flooding from the Little Colorado River in January and February, 1993, and a silty fine sand veneer of ca. 30 cm was deposited on the 566 m^3/s terrace. We sampled approximately 20 marked S. exigua and several random stems on distinctive terraces at the 425, 700, 1,100 and 1,400 m^3/s stage elevations at this site. Sampling took place during pre-dawn and mid-day hours in May (low flow month), June (moderate flow month), July (high flow month), September (moderate flow month) and October (low flow month, mid-day measurements only) in 1993.

The Mile 194L marsh exists on a well-studied reattachment bar and occupies a large return current channel (Beus and Avery 1992, Stevens et al. 1995). This site provided S. exigua stems across a range of stage elevations from approximately 400 to 1,130 m^3/s stage elevations. Initial interim flows inundated only about half of the RCC, and aggradation of ca. 0.5 m of fine silty sand took place in the RCC at this site during the January-February, 1993 Little Colorado River floods. We sampled approximately 20 marked S. exigua and several random stems on distinctive terraces at the 550, 850 and 1,100 m^3/s stage elevations at this site. Sampling took place during pre-dawn and mid-day hours in May (low flow month), June (moderate flow month), July (high flow month), September (moderate flow month) and October (low flow month, mid-day measurements only) in 1993.

Field Data Collection

Sampling was conducted during pre-dawn (midnight to first light) and mid-day (11:00 to 16:30 in full sunlight) periods. One stem was removed from each of more than 20 tagged individuals and measured for XWP before cutting and processing another stem. Temperature and relative humidity (sling psychrometer method) were recorded at the beginning and ending of sampling within each stand at each site. In addition to sampling the 20 marked plants, we also sampled three nearby randomly selected plants in each zone. We surveyed the root crown elevations of marked plants on both sites using standard electronic surveying equipment and following GCES-II land surveying protocol. We also measured nodal growth of the marked plants in 1993. Survey data are archived in the U.S. BOR GCES Information Management System (Flagstaff, Arizona).

Preliminary tests of within-plant variability revealed little difference in XWP throughout the canopies of individual S. exigua plants (Schollander et al. 1965, Stevens and Ayers 1993). Therefore, we continued the protocol of cutting lateral stems of the appropriate diameter for the pressure bomb from 1-2 m above the ground. Stevens and Ayers (1993) evaluated the effects of delayed measurement after cutting on XWP values by collecting several stems and processing samples at 1.25 minute intervals. They reported that XWP values increased at a rate of 0.03 MPa/min (depending on initial XWP level) during the first several minutes. Therefore, we continued to measure XWP on sampled stems within one minute after cutting.

We tested the effects of monthly double sampling from individually marked plants by comparing XWP levels of randomly sampled plants with marked plants in each stand during each sampling event. Comparison of mean monthly XWP values in each zone at each site revealed no significant difference between marked and random plants (Wilcoxon $Z_{47,56}$ = -1.253, $p_{2\text{-sided}}$ = 0.206). Therefore we concluded that this intensity of repeated sampling had no influence on the marked populations. We pooled random and marked stem data to describe thermal and relative humidity model influences on XWP (below).

Analyses

First we evaluated the suitability of S. exigua as an indicator species by determining the influence of stage (a negative correlate of moisture availability) on S. exigua nodal growth. We conducted a multiple stepwise linear regression analysis of annual nodal growth across stage elevation, and in response to total ramet length, basal area and stem age, at the Mile 43L willow stand in the Fall of 1992.

Temporal and spatial variability of dry bulb temperature and relative humidity were evaluated between sites using multiple analysis of covariance (SYSTAT v. 5.1, Wilkinson 1991). This MANCOVA model contained the following factors: site (a distance -related function), month in 1993, time-of-day (pre-dawn versus mid-day), an interaction term between month and time-of-day, and stage elevation (a covariate).

We analyzed the relationship between temperature and relative humidity on S. exigua XWP, a relationship which had previously been demonstrated as important by Stevens and Ayers (1993). We used multiple stepwise linear regression analysis of all 1993 data pooled, which revealed the following relationship:

$$\text{XWP (MPa)} = 0.23\ \text{ASPCRH} - 0.0495\ \text{T} + 0.3019 \qquad \text{(Eq. 1)}$$
$$(r^2 = 0.678,\ F_{2,2448} = 2577.7,\ p < 0.0001)$$

where ASPCRH is the arcsine-squareroot-transformed relative humidity and T is temperature (°C). Thus XWP is strongly negatively correlated with temperature at low relative humidity levels and less so at high relative humidities (Fig. 3.02). To standardize for temperature and relative humidity effects, we transformed all XWP values using Equation 1, creating an adjusted XWP value.

We analyzed adjusted XWP S. exigua using analysis of covariance (SYSTAT v. 5.1, Wilkinson 1991). The ANCOVA model contained the following factors: site (a distance-related function), month in 1993, sampling time-of-day (pre-dawn versus mid-day), an interaction term between month and time-of-day, and stage elevation (a covariate). A primary concern was whether monthly flow regime changes, unrelated to temperature and relative humidity, were correlated with adjusted S. exigua XWP.

We analyzed the effects of chronic stress on S. exigua growth by calculating the mean monthly temperature-humidity adjusted XWP value for each of 260 individually marked stems from all sites and zones in 1993. We conducted a multiple stepwise regression analysis with $\log_n$-transformed nodal growth in 1993 (measured in late September, 1993) as a response variable, and with predictor variables including: $\log_n$-transformed distance from Lees Ferry, AZ (km), $\log_n$-transformed ramet age (mm, as determined by examination of ramet node arrangement), temperature-humidity adjusted pre-dawn XWP, adjusted mid-day XWP, and $\log_n$-adjusted stage elevation.

RESULTS AND DISCUSSION

S. exigua as an Indicator Species

S. exigua nodal growth varied across stage elevation at the Mile 43L willow stand. This analysis indicated that ramet growth was strongly negatively correlated with elevation above the river, and that other factors influenced S. exigua growth, including stem age, stem length and basal area.

$$(\text{arcsine } G_{1992})^{-.5} = 9.635 - [0.079{*}E] - [0.089{*}A] - [0.199{*}\log(L)] + [0.029{*}B]$$
$$(r_2 = 0.460,\ F_{4,159} = 35.770,\ p < 0.001)$$

where G_{1992} is the percent stem growth in 1992 relative to total stem length, E is relative stage elevation (m), A is ramet age (yr), L is the total stem length (cm), and B is basal area (cm^2). From this analysis we concluded that S. exigua exhibited a strong response to moisture availability. Its dominance in and around fluvial marshes (Stevens et al., 1995) therefore makes it a good indicator of marsh drought stress.

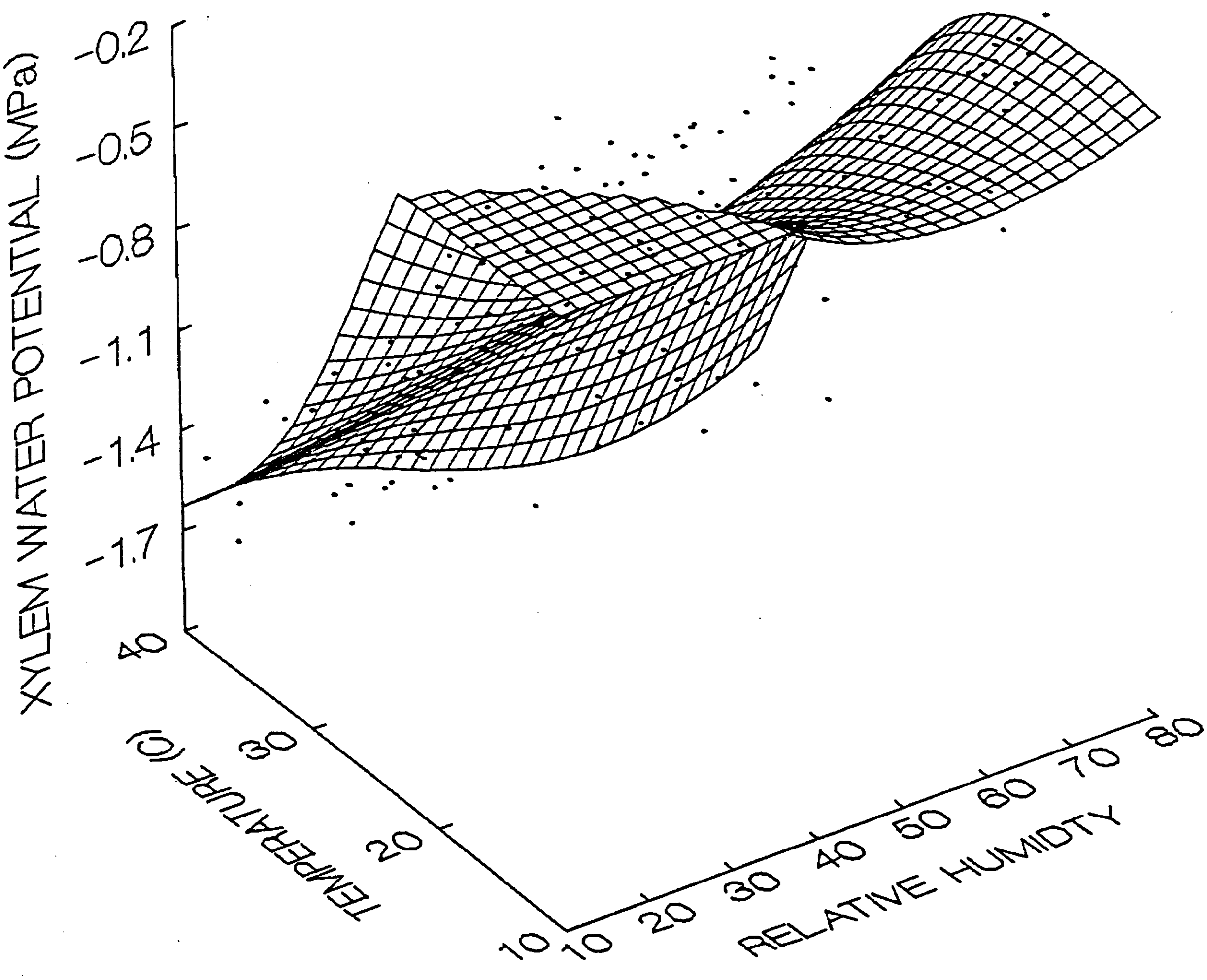


Figure 3.02: Salix exigua xylem water potential in relation to relative humidity and temperature.

Temporal and Spatial Variation in Temperature and Humidity

Temperature and relative humidity varied in relation to stage elevation, between day and night, between months in 1993 and between sites (over distance downstream from Glen Canyon Dam (overall MANCOVA Wilk's $F_{20,4930} = 233.7$, $p < 0.0001$; Table 3.01, 3.02, Fig. 3.02). Univariate MANCOVA results demonstrated that all single-factor effects were highly significant, varying, as expected, according to day versus night, between months during the summer, and and over distance downstream from Glen Canyon Dam. Air temperature was higher during the day, in mid-summer, and at the downstream-most sites. Relative humidity was higher at night, during spring and fall, after onset of the summer monsoon, and at the downstream-most sites. Interactions between time of day and month, month by site, and site by stage stage zone were also significant for temperature and relative humidity as a result of seasonal climate changes. Interaction between time of day and season were significant for temperature but not relative humidity.

Temporal and Spatial Variation in XWP

Adjusted XWP varied by time of day, between study sites and between months (Tables 3.03, 3.04). Adjusted XWP varied strongly between pre-dawn and mid-day sampling periods at all sites, typically doubling or tripling from pre-dawn to mid-day periods (A versus B in Figs. 3.03-3.06). A significant time-of-day by month interaction was attributable to increased magnitude of difference between pre-dawn and mid-day adjusted XWP during the middle of summer as compared to the spring and fall months.

Adjusted XWP varied between study sites (Tables 3.03, 3.04; Figs. 3.03-3.06). Soil texture is closely correlated with soil water retention in this system (Stevens and Ayers 1993, Stevens et al., 1995), and stratigraphic differences in soil texture varies between these sites.

Adjusted XWP varied between months at all sites (Tables 3.03, 3.04; Figs. 3.03-3.06). May and October (low flow volume months) were typically one-third to one-half of the June and July values. Given that temperature and relative humitidy effects were eliminated as an influence on XWP, this analysis reveals that monthly flow volume was exerting a significant influence on S. exigua water relations. Monthly influences are likely related to soil desiccation during the summer months.

Adjusted XWP displayed a non-significant negative correlation with stage zone (Tables 3.03, 3.04; Figs. 3.03-3.06). The lack of signicance in relation to stage zone was attributable to the adjustment of XWP for temperature and relative humidity, which vary between months and across the stage gradient (Tables 3.01, 3.02).

Salix exigua Growth

Log_n-transformed S. exigua annual stem growth (G_{1993}) was positively correlated with log_n-transformed distance downstream (D) and with both mean monthly pre-dawn (P_{am}) and mean mid-day (P_{pm}) adjusted XWP values, and was negatively correlated with log_n-transformed ramet age (A) in the stepwise linear regression analysis (Table 3.04):

Table 3.01: Summary statistics of temperature (°C), relative humidity, and mean, 1 sd and sample size of temperature-humidity adjusted Salix exigua XWP from four study sites in May, June, July, September and October, 1993.

SITE (km)	MONTH (1993)	SAMPLING TIME (PRE-DAWN 1 MID-DAY 2)	STAGE ZONE (m^3/s)	MONTHLY MEAN ADJ'D XWP (MPa)	1 SD ADJ'D XWP (MPa)	SAMPLE SIZE OF XWP MEASUREMENTS	MONTHLY MEAN % RELATIVE HUMIDITY	MEAN TEMPERATURE (°C)
69.2	5	1	425	-0.097	0.001	13	60.7	10.3
69.2	5	1	566	-0.094	0.004	19	65.7	9.6
69.2	5	1	710	-0.100	0.000	20	65.9	9.7
69.2	5	1	850	-0.097	0.001	20	62.0	10.1
69.2	5	1	990	-0.097	0.008	19	52.4	11.1
69.2	5	2	425	-0.827	0.049	12	34.4	26.4
69.2	5	2	566	-0.853	0.028	20	26.6	26.4
69.2	5	2	710	-0.778	0.002	23	28.2	25.1
69.2	5	2	850	-0.868	0.017	21	22.7	26.4
69.2	5	2	990	-1.006	0.025	23	19.5	28.5
69.2	6	1	425	-0.728	0.004	23	29.8	24.3
69.2	6	1	566	-0.759	0.006	23	23.6	24.6
69.2	6	1	710	-0.779	0.041	22	22.7	24.9
69.2	6	1	850	-0.818	0.000	24	23.1	25.6
69.2	6	1	990	-0.870	0.008	21	21.7	26.4
69.2	6	2	425	-0.897	0.038	23	27.2	27.2
69.2	6	2	566	-0.966	0.003	23	29.1	28.6
69.2	6	2	710	-1.207	0.020	22	17.3	31.5
69.2	6	2	850	-1.237	0.003	23	15.7	31.8
69.2	6	2	990	-1.063	0.020	20	19.9	29.4
69.2	7	1	425	-0.522	0.026	12	54.2	20.8
69.2	7	1	566	-0.668	0.006	23	57.6	24.4
69.2	7	1	710	-0.683	0.016	23	51.5	24.4
69.2	7	1	850	-0.656	0.054	23	53.7	23.9
69.2	7	1	990	-0.906	0.015	23	37.6	28.2
69.2	7	2	425	-1.268	0.032	23	35.6	35.0
69.2	7	2	566	-1.449	0.006	18	31.5	37.8
69.2	7	2	710	-1.458	0.012	23	30.6	37.8
69.2	7	2	850	-1.469	0.070	28	32.1	38.2
69.2	7	2	990	-1.490	0.004	23	28.8	38.1
69.2	9	1	425	-0.346	0.007	12	64.6	16.4
69.2	9	1	566	-0.338	0.003	17	71.3	15.8
69.2	9	1	710	-0.360	0.002	21	67.2	16.7
69.2	9	1	850	-0.375	0.002	22	62.4	17.2
69.2	9	1	990	-0.409	0.004	17	56.3	18.2
69.2	9	2	425	-1.083	0.044	12	32.8	31.1
69.2	9	2	566	-0.973	0.012	18	47.6	30.6
69.2	9	2	710	-1.004	0.021	22	44.4	30.8
69.2	9	2	850	-1.003	0.017	22	42.0	30.6
69.2	9	2	990	-1.654	0.002	17	13.8	38.1
69.2	10	2	425	-0.632	0.010	15	49.2	23.2
69.2	10	2	566	-0.530	0.028	20	54.8	21.0
69.2	10	2	710	-0.676	0.083	13	45.2	23.9
69.2	10	2	850	-0.732	0.007	13	36.9	24.7
69.2	10	2	990	-0.848	0.030	20	34.4	26.8
80.5	5	1	566	-0.168	0.002	20	57.0	12.4
80.5	5	1	850	-0.171	0.006	20	42.8	13.4
80.5	5	1	1130	-0.102	0.008	20	44.1	11.9
80.5	6	1	566	-0.558	0.015	23	32.7	21.3
80.5	6	1	850	-0.610	0.016	23	26.7	22.1
80.5	6	1	1130	-0.613	0.016	23	24.6	22.1
80.5	7	1	566	-0.421	0.013	23	77.7	18.1
80.5	7	1	850	-0.435	0.004	23	73.3	18.6
80.5	7	1	1130	-0.496	0.034	23	63.8	20.3
80.5	7	2	566	-1.050	0.186	23	47.9	31.9
80.5	7	2	850	-1.328	0.027	23	31.7	35.6
80.5	7	2	1130	-1.719	0.011	23	20.2	40.4
80.5	9	1	566	-0.632	0.065	16	40.0	22.8
80.5	9	1	850	-0.549	0.025	20	44.2	21.3
80.5	9	1	1130	-0.805	0.002	22	34.1	26.0
80.5	9	2	566	-1.501	0.077	17	20.6	36.8
80.5	9	2	850	-1.355	0.024	15	23.8	34.9
80.5	10	2	566	-0.712	0.025	13	44.9	24.7
80.5	10	2	850	-0.638	0.027	15	49.3	23.3
80.5	10	2	1130	-0.557	0.013	14	59.9	21.8

Table 3.01 (continued)

SITE (km)	MONTH (1993)	SAMPLING TIME (PRE-DAWN 1 MID-DAY 2)	STAGE ZONE (m^3/s)	MONTHLY MEAN ADJ'D XWP (MPa)	1 SD ADJ'D XWP (MPa)	SAMPLE SIZE OF XWP MEASUREMENTS	MONTHLY MEAN % RELATIVE HUMIDITY	MEAN TEMPERATURE (°C)
276.0	5	1	425	-0.425	0.013	12	79.9	18.2
276.0	5	1	710	-0.446	0.010	20	77.9	18.9
276.0	5	1	1130	-0.462	0.000	21	75.9	19.4
276.0	5	1	1420	-0.462	0.000	11	75.9	19.4
276.0	5	2	425	-0.814	0.019	12	45.6	26.9
276.0	5	2	710	-0.866	0.045	19	45.8	28.1
276.0	5	2	1130	-0.816	0.003	23	55.0	27.8
276.0	5	2	1420	-0.991	0.042	12	39.2	30.0
276.0	6	1	425	-0.538	0.043	19	42.6	21.0
276.0	6	1	710	-0.532	0.009	23	37.5	20.8
276.0	6	1	1130	-0.589	0.018	22	37.4	21.9
276.0	6	1	1420	-0.598	0.026	14	35.9	22.1
276.0	6	2	425	-1.603	0.010	12	16.5	37.8
276.0	6	2	710	-1.584	0.009	12	18.9	37.9
276.0	6	2	1130	-1.790	0.000	11	12.9	40.0
276.0	6	2	1420	-1.783	0.010	13	15.3	40.4
276.0	7	1	425	-0.634	0.011	17	44.1	23.1
276.0	7	1	710	-0.566	0.001	24	65.8	22.2
276.0	7	1	1130	-0.661	0.029	24	62.4	24.5
276.0	7	1	1420	-0.708	0.033	16	59.2	25.5
276.0	7	2	425	-1.169	0.006	19	48.0	34.9
276.0	7	2	710	-1.233	0.027	25	42.0	35.3
276.0	7	2	1130	-1.365	0.022	23	32.6	36.4
276.0	7	2	1420	-1.364	0.017	15	37.8	37.2
276.0	9	1	425	-0.360	0.020	20	41.9	17.4
276.0	9	1	710	-0.344	0.006	26	45.5	16.9
276.0	9	1	1130	-0.385	0.011	24	38.7	17.9
276.0	9	1	1420	-0.418	0.009	13	33.9	18.6
276.0	9	2	425	-1.269	0.024	9	21.0	33.0
276.0	9	2	710	-1.259	0.024	29	20.5	32.8
276.0	9	2	1130	-1.438	0.018	21	13.9	34.7
276.0	9	2	1420	-1.292	0.066	7	17.6	32.9
276.0	10	2	425	-0.547	0.005	13	45.2	21.3
276.0	10	2	710	-0.524	0.000	15	49.8	20.8
276.0	10	2	1130	-0.602	0.013	22	43.0	22.4
276.0	10	2	1420	-0.629	0.000	14	39.1	22.8
312.1	5	1	566	-0.404	0.011	19	70.2	17.8
312.1	5	1	850	-0.380	0.002	21	74.4	16.9
312.1	5	1	1130	-0.376	0.001	21	80.3	16.5
312.1	5	2	566	-0.900	0.037	20	63.6	30.8
312.1	5	2	850	-0.986	0.039	20	45.3	30.6
312.1	5	2	1130	-1.206	0.008	20	26.5	32.6
312.1	6	1	566	-0.567	0.016	18	44.0	21.7
312.1	6	1	850	-0.695	0.025	20	37.7	24.0
312.1	6	1	1130	-0.738	0.012	23	34.6	24.7
312.1	6	2	566	-1.252	0.056	20	31.9	34.2
312.1	6	2	850	-1.354	0.030	22	27.7	35.4
312.1	6	2	1130	-1.044	0.006	24	30.4	30.1
312.1	7	1	566	-0.505	0.025	24	76.5	20.8
312.1	7	1	850	-0.612	0.029	21	57.7	23.1
312.1	7	1	1130	-0.785	0.000	25	50.4	26.7
312.1	7	2	566	-1.067	0.000	23	52.9	33.3
312.1	7	2	850	-1.091	0.018	21	47.2	33.1
312.1	7	2	1130	-1.350	0.073	25	34.6	36.4
312.1	9	1	566	-0.167	0.013	18	63.0	11.8
312.1	9	1	850	-0.207	0.008	19	60.4	13.1
312.1	9	1	1130	-0.357	0.009	23	32.7	17.5
312.1	9	2	566	-1.285	0.021	20	19.3	33.1
312.1	9	2	850	-1.160	0.025	20	26.4	31.8
312.1	9	2	1130	-1.598	0.007	22	11.8	36.8
312.1	10	2	566	-0.616	0.057	4	45.1	22.7
312.1	10	2	850	-0.560	0.028	19	44.7	21.5
312.1	10	2	1130	-0.787	0.007	20	30.3	25.4

Table 3.02: MANCOVA table of temperature (T°C) and arcsine-squareroot transformed relative humidity (ASRH) responses to month, time-of-day (pre-dawn versus mid-day), study site location (distance from Glen Canyon Dam), stage zone, and all two-way interactions at four _Salix exigua_ XWP study sites along the Colorado River in the Grand Canyon.

SOURCE	WILKS LAMBDA	APPROXIMATE F-VALUE (df)	p	SIGNIFICANCE OF RESPONSE VARIABLES pT°C	p_{ASRH}
Overall Model	0.264	$233.664_{20,4930}$	< 0.001	< 0.001	0.004
Time-of-Day (T)	0.882	$165.209_{2,2465}$	< 0.001	< 0.001	< 0.001
Month (M)	0.943	$74.373_{2,2465}$	< 0.001	< 0.001	< 0.001
Stage Zone (Z)	0.998	$2.715_{2,2465}$	0.066	< 0.090	0.023
Site (S)	0.817	$275.252_{2,2465}$	< 0.001	< 0.001	< 0.001
<u>2-WAY INTERACTIONS</u>					
T*M	0.962	$48.327_{2,2465}$	< 0.001	< 0.001	< 0.001
T*Z	0.999	$0.687_{2,2465}$	0.503	0.804	0.422
T*S	0.996	$4.910_{2,2465}$	0.007	0.032	0.509
M*Z	0.999	$0.548_{2,2465}$	0.578	0.300	0.639
M*S	0.719	$480.978_{2,2465}$	< 0.001	< 0.001	< 0.001
Z*S	0.997	$3.790_{2,2465}$	0.023	0.017	0.013

Table 3.03: Mean monthly temperature-humidity adjusted *S. exigua* XWP values in relation to 1993 annual stem growth at four locations along the Colorado River in the Grand Canyon, Arizona.

SITE (km)	STAGE (m3/s)	MEAN RAMET AGE (1 sd) (yr)	MEAN ADJ'D PRE-DAWN XWP (1 sd) (MPa)	MEAN ADJ'D MID-DAY XWP (1 sd) (MPa)	MEAN NODE 1993 GROWTH (1 sd) (mm)	n
69.2	425	8.8 (2.683)	-0.27 (0.164)	-0.92 (0.080)	170.20 (155.811)	5
69.2	565	9.7 (0.825)	-0.48 (0.075)	-1.01 (0.082)	142.14 (166.002)	14
69.2	710	9.3 (1.380)	-0.49 (0.061)	-1.08 (0.054)	168.85 (64.036)	20
69.2	850	8.9 (1.997)	-0.51 (0.074)	-1.13 (0.057)	97.30 (76.013)	20
69.2	990	8.8 (2.502)	-0.61 (0.170)	-1.19 (0.092)	85.43 (149.378)	21
80.5	565	9.6 (1.383)	-0.42 (0.030)	-1.11 (0.169)	112.21 (77.566)	19
80.5	850	10.0 (0.224)	-0.44 (0.014)	-1.18 (0.123)	292.65 (106.065)	20
80.5	1130	10.0 (0.000)	-0.50 (0.045)	-1.40 (0.295)	57.63 (64.207)	19
275.9	425	1.1 (0.289)	-0.54 (0.070)	-1.22 (0.213)	1106.67 (206.546)	12
275.9	710	8.4 (2.468)	-0.47 (0.059)	-1.09 (0.128)	285.76 (248.565)	25
275.9	1130	10.0 (0.000)	-0.54 (0.057)	-1.13 (0.147)	230.52 (84.843)	21
275.9	1420	9.5 (1.732)	-0.60 (0.038)	-1.19 (0.098)	165.08 (63.736)	12
312.1	565	10.0 (0.000)	-0.43 (0.051)	-1.10 (0.056)	560.28 (232.995)	18
312.1	850	8.7 (2.164)	-0.48 (0.029)	-1.05 (0.073)	624.00 (426.022)	18
312.1	1130	2.1 (2.810)	-0.59 (0.090)	-1.21 (0.093)	1738.00 (599.240)	22

Table 3.04: Multiple linear regression analysis of S. exigua annual nodal growth (mm) in response to mean temperature-humidity adjusted pre-dawn and mid-day XWP, study site distance from Glen Canyon Dam, stand stage elevation, and ramet age at four study sites along the Colorado River in the Grand Canyon.

SOURCE	**T-STATISTIC**	**p (2-TAIL)**
Log_n (Distance)	10.472	< 0.001
Log_n (Ramet Age)	-9.167	< 0.001
Adj'd XWP (Pre-dawn)	2.642	< 0.009
Adj'd XWP (Mid-day)	3.361	< 0.001

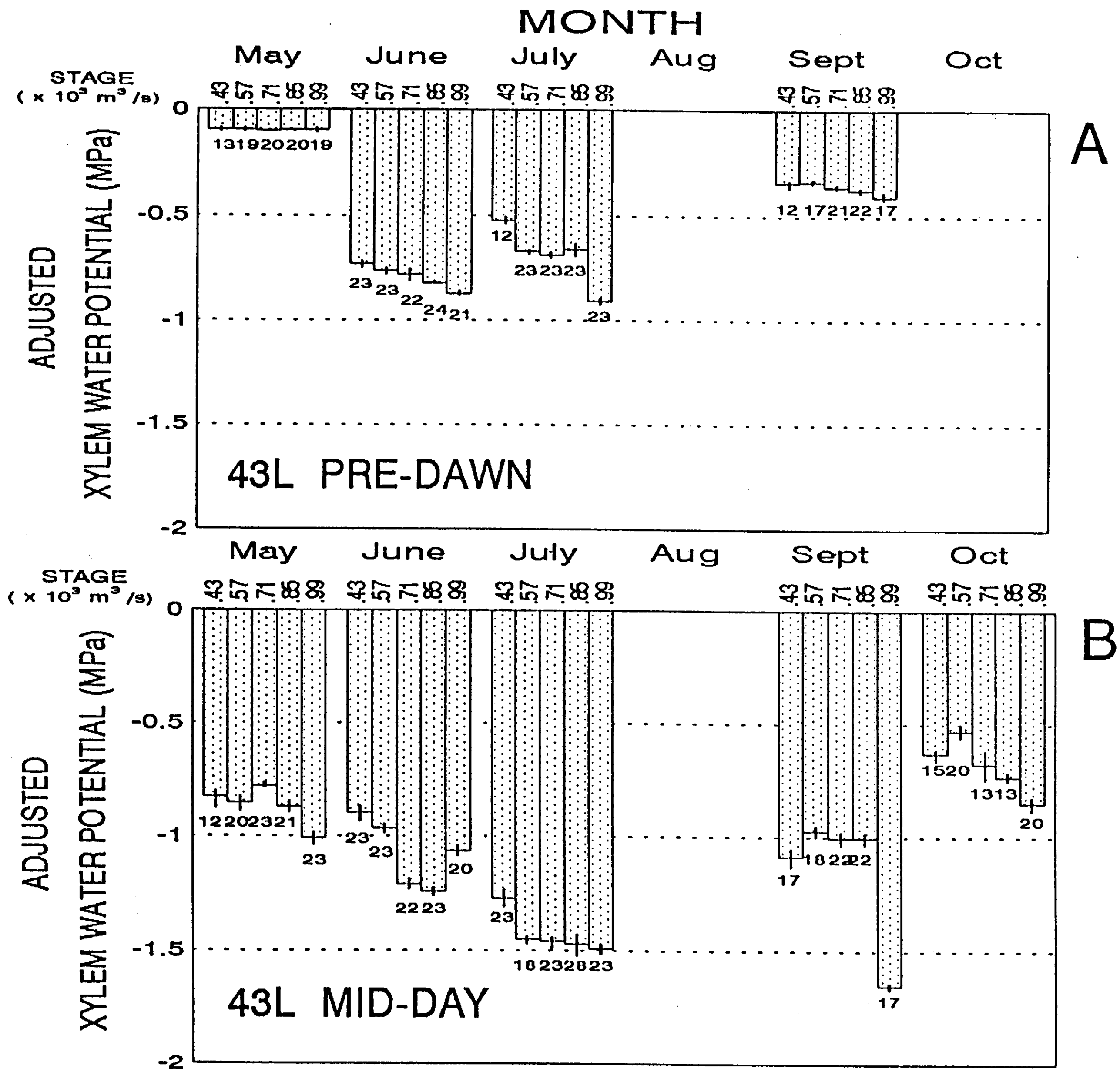


Figure 3.03: Salix exigua xylem water potential at five stage elevations at the Mile 43L site in 1993 during (A) pre-dawn and (B) mid-day periods.

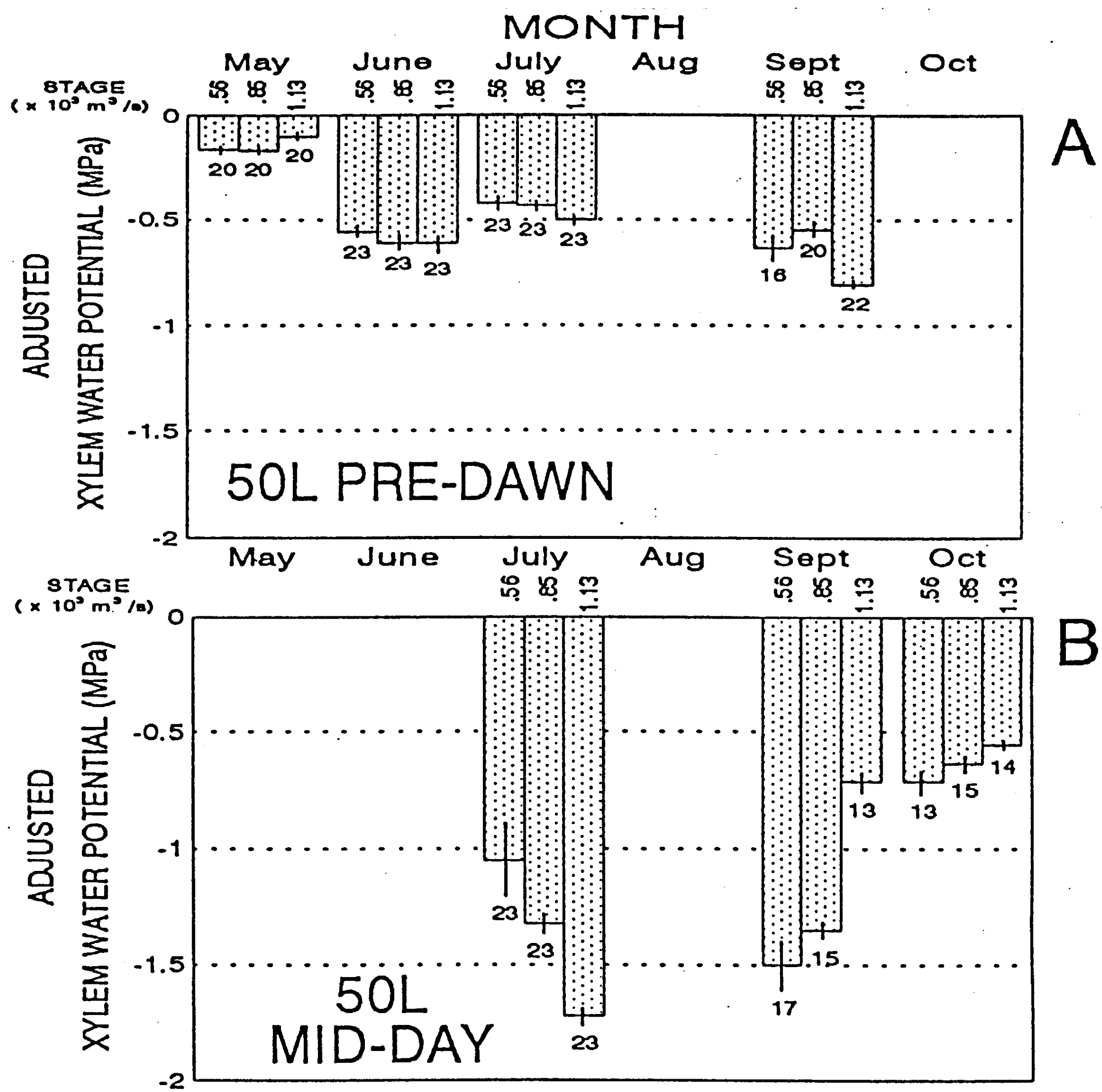


Figure 3.04: Salix exigua xylem water potential at three stage elevations at the Mile 50L site in 1993 during (A) pre-dawn and (B) mid-day periods.

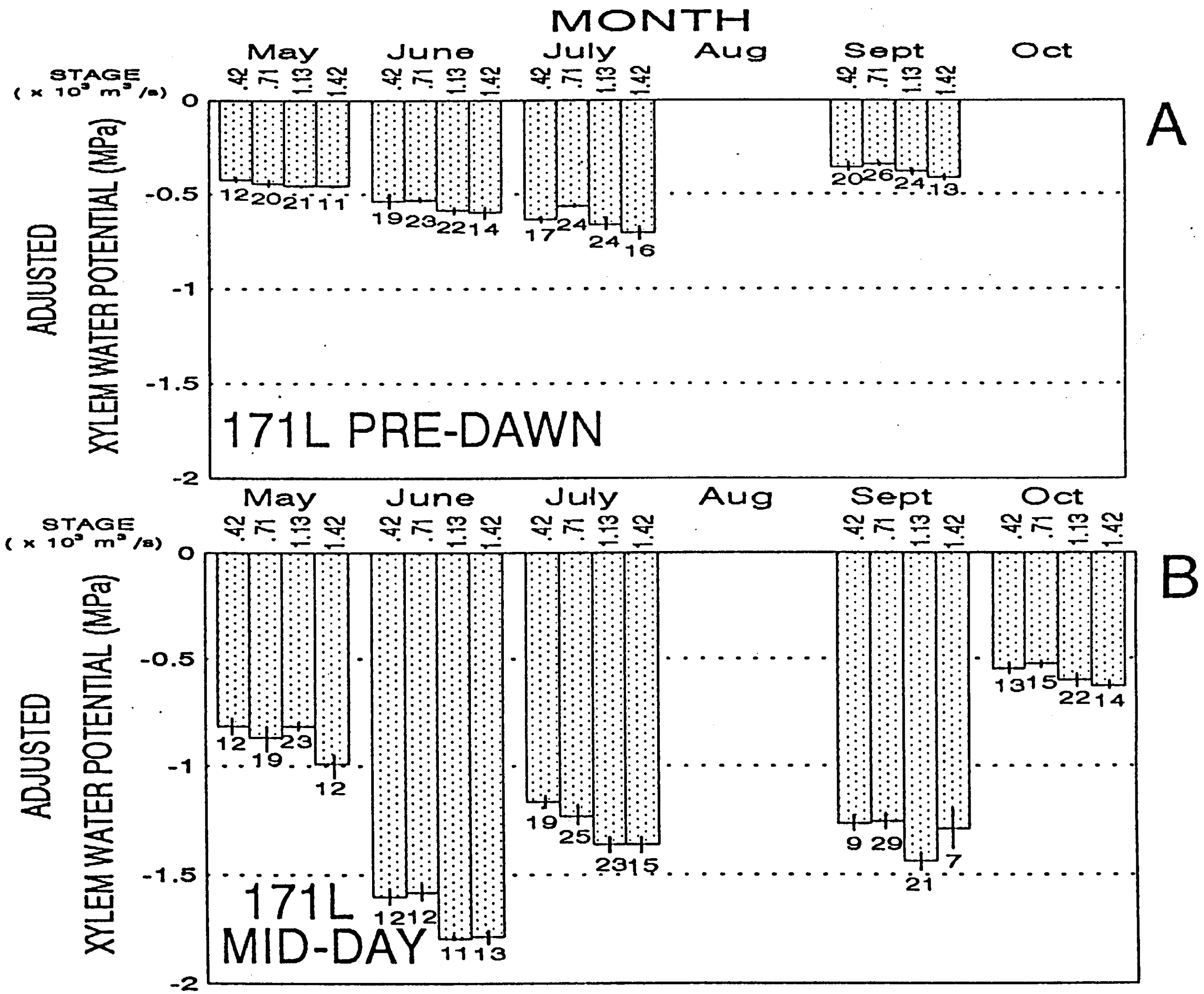


Figure 3.05: <u>Salix exigua</u> xylem water potential at four stage elevations at the Mile 171L site in 1993 during (A) pre-dawn and (B) mid-day periods.

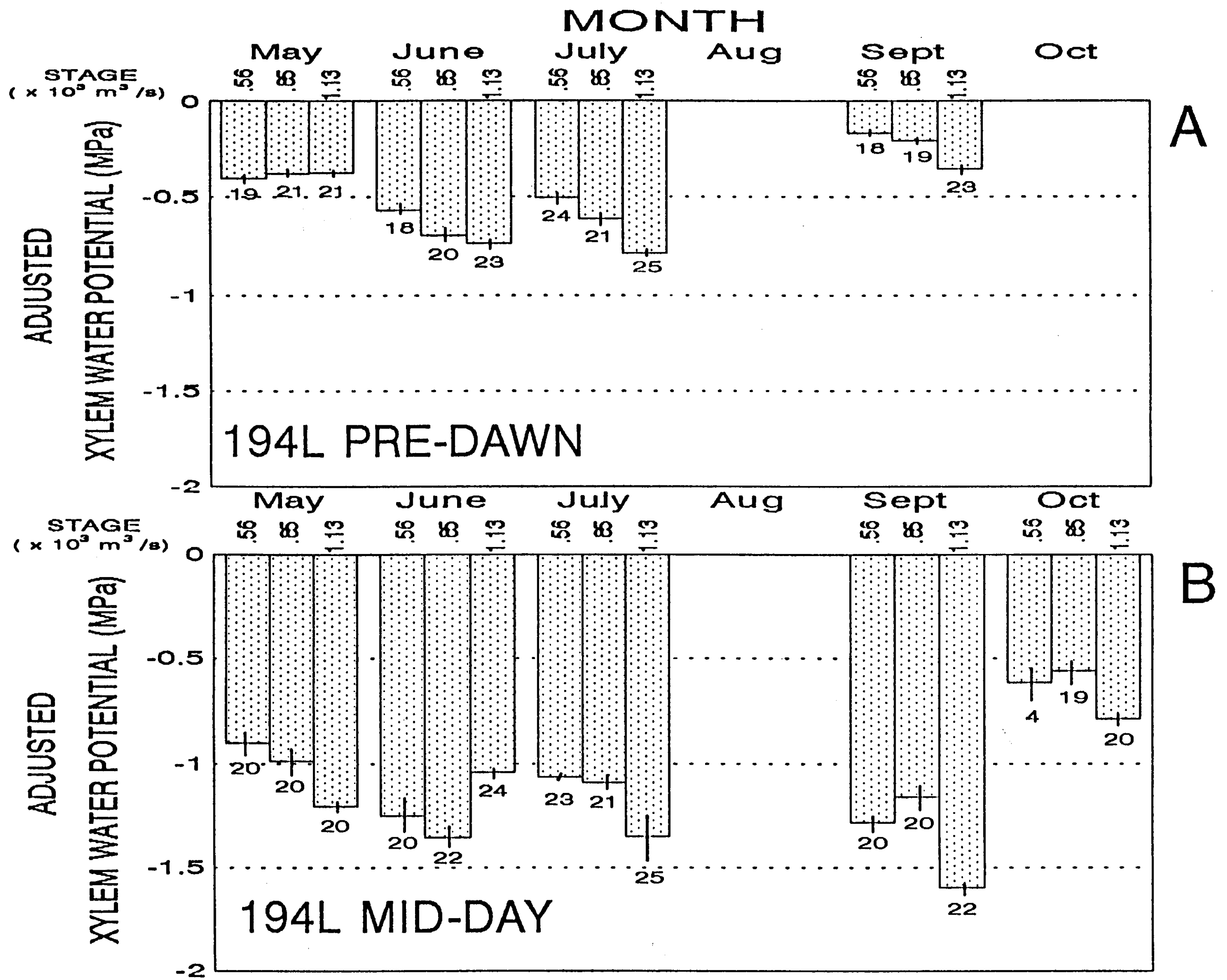


Figure 3.06: <u>Salix exigua</u> xylem water potential at three stage elevations at the Mile 194L site in 1993 during (A) pre-dawn and (B) mid-day periods.

$$\log_n(G_{1993}) = 4.432 + [0.949*\log_n(D)] - [0.794*\log(A)] + [1.810*P_{am}] + 1.282*P_{pm}$$
$$(\text{adjusted } r^2 = 0.540, F_{4,254} = 76.747, p < 0.0001)$$

S. exigua growth was positively correlated with distance downstream ($p < 0.001$) as an artifact of beaver pruning activity at the lowermost site. First year stems are the most rapidly growing, and both the middle and high zone willow stands at Mile 194 marsh were attacked by beaver in 1991 or 1992. This is evidenced by the comparatively young ages of willow ramets in those stands (Table 3.03). Distance-related differences in ramet growth were not apparent between the other stands.

As expected, S. exigua growth was negatively correlated with ramet age ($p < 0.001$). This effect is commonly observed in all dendrochronological studies, where annular ring width typically decreases precipitously during the first phases of growth, and annual nodal growth decreases proportionately during maturation of the ramet in S. exigua and in other willows (Price 1989).

S. exigua growth was positively correlated with mean monthly pre-dawn and mid-day XWP values ($p = 0.009$ and 0.001, respectively). Because both measures were strongly correlated with annual stem growth, the mid-day XWP values are easier to obtain and demonstrated a stronger correlation with nodal growth. For this reason we suggest that if XWP analysis is continued to be used as a monitoring technique for vegetation in this system, only mid-day values are needed.

The non-significance of stage elevation effects in this model was attributable to adjustment of XWP values for thermal and relative humidity effects.

CONCLUSIONS

Overall the relationship between chronic XWP patterns and willow growth indicates that measurement of XWP may serve as a useful, although labor-intensive, monitoring technique in this riparian system. The operating range of XWP for S. exigua range between -0.1 and -2.1 MPa, with the latter value near the wilting point for this species. S. exigua pre-dawn and mid-day XWP values obtained in 1991 during the final "normal operations" flows in the Mile 43 return current channel marsh were approximately half those of the values reported during this study (Stevens and Ayers 1993). These data support the contention that several features of interim flows (e.g. reduced flow magnitude and reduced daily inundation frequency) are increasing moisture stress in previously established Colorado River marshes.

While S. exigua can tolerate prolonged chronic moisture stress through architectural modification (e.g. extending running or tap roots to lower stage elevations) under interim flows, other marsh species may not be able to do so (Stevens et al., 1995). Typha spp., which are capable of withstanding relatively long (ca. 3-5 yr) periods of low flows in this system, is not capable of altering its architecture sufficiently to cope with long-term desiccation of RCC marshes. The longer-term (>3 yr) shift to an interim flows scenario in this system will therefore result in loss of characteristic marsh vegetation in the RCC marshes where they dominated prior to 1991. We have documented increased marsh development in RCC mouths and in channel margin environments at many sites; however, the new marsh patches will be extremely susceptible to scour during planned flood flows and should probably be considered as ephemeral. This conclusion is supported by the loss of herbaceous cover in the "New Dry" zone following flooding from the Little Colorado River in January and February, 1993.

From this analysis of S. exigua we conclude that the distinctive patterns of XWP in S. exigua document a change in water availability that supports compositional and structural shifts of previously established fluvial marsh assemblages documented in Chapter 2 (this report). Changes in environmental conditions are likely to gradually foster increased dominance by woody species and a concomitant reduction of cover by fluvial marsh assemblages.

CHAPTER IV

THE EFFECTS OF INTERIM FLOWS ON NON-MARSH VEGETATION

CHAPTER IV:

THE EFFECTS OF INTERIM FLOWS ON NON-MARSH VEGETATION

INTRODUCTION

Non-marsh vegetation in the Colorado River corridor has also dramatically increased during post-dam time (Carothers et al., 1979; Turner and Karpiscak 1980; Johnson 1991), and recent studies in this system have begun to document the role of geomorphology on variation in regulated river riparian vegetation composition and distribution (Stevens and Ayers 1993). In this component of the riparian vegetation monitoring project we used remote and ground-based techniques to monitor the changes in riparian vegetation cover across local, reach-based and system-wide spatial scales. We continued to compile information on the distribution of native and non-native plant species throughout the river corridor (e.g., Ayers et al. 1994). We conducted an analysis of paired, low-level aerial photographs of the vegetation cover on six large reattachment bars taken in July, 1991 and June, 1994. We censused established long-term 5m x 10m study quadrats located throughout the river corridor. These quadrats were situated in the characteristic geomorphic settings (channel margin, bar platform and debris fan) associated with each of 20 large tributary confluences (Fig. 1.03), and study areas were distributed in relation to the geomorphic reaches of the river (Schmidt and Graf 1990). We also assessed the distribution of riparian vegetation in the newly protected "new dry" zone lying between the 566 and 900 m^3/s stages by making stops at predetermined, random locations throughout the river corridor in 1992 and 1993.

METHODS

Plant Species Inventory

In our continuing efforts to refine the plant species inventory of the Colorado River corridor in the Grand Canyon, we collected and identified novel plant species as they were encountered. Specimens are presently housed in the Deaver Herbarium at Northern Arizona University and vouchers will be delivered to the NPS. In addition to inventory collecting, we have continued to search for listed or candidate plant species in the riparian corridor. We have also documented changing distributions of several critical native species (e.g. Salix gooddingii and Populus fremontii) and non-native species (e.g., Erianthus ravennae, Eragrostis curvula and Lepidium latifolium), and examined Tamarix ramosissima (= T. pentandra) recruitment.

Photogrammetric Analysis of Selected Study Sites

Low-level aerial photography of selected sandbars, including six of our study areas, was conducted on a biweekly basis during the GCES Phase II test flows period. The final aerial photogrammetry flight was conducted in late July, 1991 at a discharge of 142 m^3/s, immediately prior to the implementation of the first phase of interim flows. We used these 1:2,000 July 30-31, 1991 (Bureau of Reclamation black and white) aerial photographs of six vegetation study areas as the starting condition for sand bar vegetation under interim flows, and compared vegetation cover on them with that on Bureau of Reclamation aerial photographs (1:4800 true color) images taken in early June, 1994 during a constant discharge of 226 m^3/s. The six study areas are: 43.1L, 51.2L, 55.6R, 122.7L, 172.1L and 194.1L (Fig. 2.01). All sites included large, vegetated reattachment bars and initially supported developing return current channel marshes. The first three sites were upstream from the Little Colorado River (LCR) confluence and the latter three sites were downstream, allowing us to evaluate the influences of the LCR floods in January-February, 1993.

The 1991 photographs typically consisted of several images of each study site. Each image was scanned into a Tagged Image File Format (TIFF). TIFF files were imported into ERDAS and rectified using 10-15 named ground control points (GCP) on each image. GCPs were surveyed in the field according to GCES survey protocol. The rectified photo images were then "stitched" together to form a single composite image of each site. These images were exported into Map Image Processing System (MIPS) and the cover of channel margin, sand bar and marsh vegetation were digitized, using the scale established from the surveyed GCPs. The 1994 aerial photographs (one per study area) were scanned into MIPS and ground-truthed distances between ground control points were used to calibrate vegetation cover measurements.

We then compared changes in the cover of four vegetation types between 1991 and 1994 using MIPS: 1) return current channel marsh vegetation, 2) newly established low-stage marshes, 3) bar platform vegetation (predominantly Salix exigua and Tamarix ramosissima), and 4) peripheral channel margin vegetation (predominantly T. ramosissima). Stage-to-discharge relationships have been established at these six sites (Stevens et al., 1995), and were used to quantify elevational distribution of digitized vegetation patches. Vegetation composition is well known on all study areas because all are used for marsh and long-term quadrat studies. The vegetation of all six study areas was examined on the ground between April and June, 1994, and vegetation composition was mapped in detail at the Miles 43.1L, 55.5R and 122.7L study sites in early summer, 1994 (Chapter 5. this report).

Long-term Quadrats

Long-term study quadrats were established during GCES-II. Twenty mainstream study areas and 24 tributary control sites established in Grand Canyon during the Glen Canyon Environmental Studies Program Phase II (Stevens and Ayers 1993) were monitored in 1992 and 1993 (Tables 1.01, 1.02). Each study area contains a 5m x 10m permanent quadrat in each of the following geomorphic environments: bar platform, channel margin and debris fan habitats (Fig. 1.03). These quadrats in the mainstream lower riparian zone provide a consistent database for monitoring dam discharge impacts on riparian vegetation development in this system.

All annual and perennial plant species were identified in each quadrat. Basal area of all species were measured or, in the case of extremely high stem density, estimated. Substratum texture was recorded using relative grain size classes, and location (by convention as distance downstream from Lees Ferry, with named locations designated by river mile), azimuth, dip angle and percent ground and shrub cover were measured. Data were analyzed with SYSTAT (Wilkinson 1990), with subsequent analysis through DECORANA (Hill 1979).

To provide a conservative assessment of compositional change, we relativized species factor loading scores in samples space for seven groups of wetland/riparian plant species. These groups included the four marsh assemblages described in Chapter 2 (this report): 1) clonal wet marsh; 2) herbaceous non-clonal wet marsh; 3) bar platform; 4) dry marsh; as well as 5) upper alluvial terrace; 6) rocky channel margin; and 7) xeric (desert) species. Plant species identifying numbers and group designations are included in Appendices A and B. We used nonparametric Mann-Whitney tests, coupled with serial-Bonferroni tests (Rice 1989), to evaluate changes in relative factor loading scores for the first three DCA axes from 1992 to 1993.

Colonization of Newly Exposed Habitats

To gain insight into diversity and stem density patterns in the "new dry" (ND) and "new high water" (NHW) zones in coarse versus fine sediments, we conducted reach-based random stops throughout the river corridor in 1992 and 1993. Randomly selected 5m x 10 m quadrats were situated along the river corridor in the lower riparian zone in these two zones in coarse (cobble or breccia) or fine (silt-sand) substrata. Eight quadrats chosen in each of 9 geomorphic reaches. We merged Schmidt and Graf's (1990) Supai and Redwall reaches, and the Aisles and Middle Granite Gorge reaches because they were paired, adjacent short, narrow reaches. Because data from the ND and bar platform long-term quadrats had been collected in the same manner and were not significantly different from the random stops data (univariate $F_{2,98}$ = 1.538), we combined the two data sets. To reduce the number of response variables, we categorized plant basal area data by architectural growth forms (herbaceous, woody clonal phreatophytes, woody non-clonal phreatophytes, perennial grasses and annual species).

Densities of individual perennial plants were counted in three life stages: seedling, sapling and mature plants. For clonal phreatophytes, such as S. exigua and Tessaria sericea, separate stems were counted as individual plants because ramets can exist independently of the genet root mass. Substratum texture was recorded using relative grain size classes (Stevens and Ayers 1993), and river location, azimuth, dip angle and percent ground and shrub cover were measured. These random stops provided a measure of the representativeness of the quadrats database, as well as a larger data set with regard to non-native species distribution and from which to evaluate reach-based vegetation patterns.

We also established, surveyed and censused a 5 m x 10 m "new dry" quadrat at each study area where interim flows protected a relative flat portion of the bar platform from inundation (Fig. 1.02). These "new dry" quadrats lie between the 566 m^3/s and 890 m^3/s stages. The new dry zone quadrats established in our study areas were devoid of vegetation at the inception of interim flows, as determined from direct observation and close-level aerial photographs taken in July, 1991.

We pooled random stops data with the long-term quadrats data from these zones into one data set. Statistical analyses were performed using MANCOVA and Pearson correlation analyses (SYSTAT, Wilkinson 1991).

RESULTS AND DISCUSSION

Species Diversity

We include a list of all plant species collected and localities in the river corridor (Appendix A). This list and associated collections add 37 new species records for Grand Canyon National Park in 13 families and 32 genera (Ayers et al. 1994). Of these, 27 are native, while 10 are non-native. The new reports include nine grasses, two rushes, one shrub and 25 herbaceous dicots. Six of the herbaceous dicots and four grasses are non-native. Eight records are new to the Phillips et al. (1987) checklist of Grand Canyon plants.

Non-native Plant Species

Studies of colonization (below) suggest that the highly disturbed river channel margin serves as an avenue for invasion of non-native taxa. A total of 120 plant species were identified in the set of 60 quadrats censused in 1993 (below). Fifteen (12.5 percent) of these species were non-native. The proportion of all non-native species in the lower riparian zone is 1.7-fold higher than that of the long-term quadrats as a whole (Stevens and Ayers 1993). Stevens and Ayers (1993) documented the presence of several new and potentially invasive non-native plant species in this river ecosystem, including Erianthus ravennae and Lepidium latifolium, and Eragrostis curvula was found in 1993. These species are highly invasive and pose a threat to the integrity of the developing native riparian vegetation. Some of these non-native species are relatively easily controlled, whereas other species are not.

Erianthus ravennae **(Ravenna grass):** Following completion of GCES II research, we assisted the NPS develop and implement a control program of the large (2-3 m tall), highly invasive European bunchgrass, Erianthus ravennae, in the river corridor. This mechanical control program was conducted with 6 student volunteers from Prescott College (Prescott, Arizona) in March, 1993 and April, 1994 who helped remove approximately 2,500 plants. River equipment was donated by commercial outfitters, especially Canyon R.E.O. of Flagstaff, AZ. Numerous E. ravennae plants were removed from the upper Grand Canyon, and all mature E. ravennae plants were removed from the lower Grand Canyon upstream from Diamond Creek. Plant root masses were excavated, the grass bunches removed and killed by desiccation. Subsequent visits over the past year to sites at which control efforts were undertaken revealed that mechanical control was highly effective, with recruitment or regrowth at less than 3 percent of the sites. Nearly all inflorescences on remaining plants were removed in autumn, 1994, thereby limiting seed dispersal during the present winter.

E. ravennae is presently restricted to a single large population at Lees Ferry, a few scattered individuals in the Permian and Marble Canyon reaches, a small population at Tanner Rapid (Mile 68), and approximately 65 plants at Cardenas Creek (Mile 71L). We recommend that the NPS complete removal of this species, continue to monitor the system for further establishment, and continue to interact with Glen Canyon National Recreation Area to eliminate the source population of this potentially dominant non-native grass. Such a program can easily accomplished with volunteer labor, and therefore conducted at very low cost. Although not part of our contract, we gladly contributed to this effort because it demonstrates that at least some non-native plant invasions can be controlled in Grand Canyon in a low-cost fashion.

Other Non-native Grass and Herb Species: Other non-native species are not as easily controlled as E. ravennae, and the prospects for control are limited. Lepidium latifolium is a clonal herbaceous weed that blooms in spring and fall, produces abundant seed and occupies a wide range of shoreline habitats. This species has expanded its range through the entire river corridor during the period of our analyses (1990 to the present). We recommend that the NPS examine the life history and synecology of this species in an effort to understand its potential long-term effects on this ecosystem. Similarly, Eragrostis curvula is quickly becoming established throughout the river corridor and may not be readily controlled.

***Tamarix ramosissima* (Tamarisk) Recruitment:** T. ramosissima seedling establishment is intimately related to flooding in the Colorado River corridor (Stevens 1989); however, little T. ramosissima recruitment occurred following the January/February, 1993 LCR floods. Numerous new, flood-laid, fine alluvial bars were deposited downstream from the LCR after these floods. The new sediment deposits underwent 2.5 months of desiccation before the peak release of Tamarix ramosissima seeds (late April through June). As a result of this desiccation, few dense Tamarix seedling beds became established along the river. Tamarix seedling beds ("lawns") were noted at 122.1R, 194.2L, and in a few other locations, but overall Tamarix germination was not appreciably higher than in other years, as demonstrated by the random stops data (below). However, it is not presently known how rapidly sandbar surfaces desiccate following flooding. Such information would increase management flexibility in planning high release events.

Endemic and Listed Species

We located two small populations of Flaveria mcdougalli (McDougall's flaveria, a Grand Canyon endemic and candidate threatened Asteraceae species) that occur below the 3000 m^3/s flow stage (the pre-dam 10-yr flood stage) along the Colorado River. These two populations occur in south-facing seeps at Miles 148R and 166.5R. In both instances, the Flaveria populations have colonized from higher elevations down into the riverside spring environments. In both cases, the Flaveria populations are well established in the higher elevations of the springs. Although several Flaveria would be inundated during flows in excess of approximately 1,400 m^3/s, the overall populations at these sites would not be threatened by releases of less than 3000 m^3/s.

Indicator Species

We observed increased establishment and survival of Populus fremontii in the lower riparian zone throughout the Colorado River corridor in the Grand Canyon. More than 100 P. fremontii presently exist in the narrow reaches, particularly downstream from Phantom Ranch. Increased P. fremontii recruitment has occurred during interim flows, and although occasional ecesis was observed prior to interim flows, widespread recruitment was not observed during our observation of this system (1974 to the present). The increased establishment of P. fremontii in narrow reaches is probably a reflection of reduced beaver herbivory in these swift, rocky reaches. If the P. fremontii recruits survive to reproductive age in these reaches, we foresee potentially large changes in the riparian plant assemblage in this system. Increased P. fremontii cover would greatly increase potential wildlife habitat.

Gooddings willow (Salix gooddingii) was the most common native pre-dam tree species in the pre-dam river corridor. This species is highly susceptible to beaver predation and requires flood-deposited, silt-rich alluvial soils for ecesis. The intensity of beaver depredation and lack of recruitment have resulted in a general decline in the S. gooddingii population in Grand Canyon. Although this species is abundant on newly exposed silt deposits in upper Lake Mead, most of that population will perish when Lake Mead reaches full pool. Consequently, the persistence of this tree willow is uncertain along the Colorado River. The declining status of this species in the mainstream corridor suggests the need for additional study.

Aerial Photograph Analyses

Remote sensing/aerial photogrammetry allowed us to document changes in the extent of riparian and wetland vegetation cover since the inception of interim flows in selected study areas. Analyses of the low-level 1991 and 1994 aerial photographs of 6 study sites (Figs. 4.01 to 4.06) reveals that total sand bar vegetation cover is changing slightly under interim flows, but substantial changes are occurring between the four geomorphic environments examined, and above and below the LCR (Table 4.01).

1) At present, sandbar vegetation has colonized down to the ca. 425 m^3/s stage at all sites. Vegetation cover at sites above the LCR increased on low-lying portions of sand bars (Table 4.01). All study sites examined revealed expansion of herbaceous vegetation into lower stage elevations. Expansion of low-lying bar platform vegetation (predominantly dry marsh grasses and wet marsh herbs) was dramatic at 55.5R, increasing from 0.64 ha to 0.93 ha between 1991 and 1994 below the 900 m^3/s stage (Fig. 4.03A and B). Analogous large increases in low-lying vegetation cover occurred at Mile 51.5L (Fig. 4.02A and B). Increases in cover at low stages were less dramatic at Miles 43.1L because of the generally steep bar faces (Fig. 4.01A and B).

Low-lying vegetation cover at sites downstream from the LCR was less than that at upstream sites, largely because of scouring during January-February, 1993 (Table 4.01; Chapter II, this report); however, marsh vegetation at the mouths of the Mile 194.1L return current channel (RCC) increased dramatically, despite the short-duration scouring flows (Fig. 4.06 A and B). We attribute this rapid increase in cover at this site to survival of clonal Typha spp. and Scirpus spp. during aggradation in the RCC, and subsequent rapid clonal expansion.

2) Vegetation cover has decreased slightly in previously established return current channel (RCC) marshes. In 1991 the Mile 43L site (Fig. 4.01A) supported a developing RCC marsh that has largely been dewatered by interim flows. Marsh composition in the upper portions of this RCC shifting to dominance by Salix exigua (Chapter 2, this report), and Typha and other clonal marsh species are declining in cover. Similar changes were noted at the other sites except Mile 51.2L and 55.5R (Figs. 4.03A and B; Table 4.01), which have RCCs that have remained open and large under interim flows.

43.1 Mile, 1991

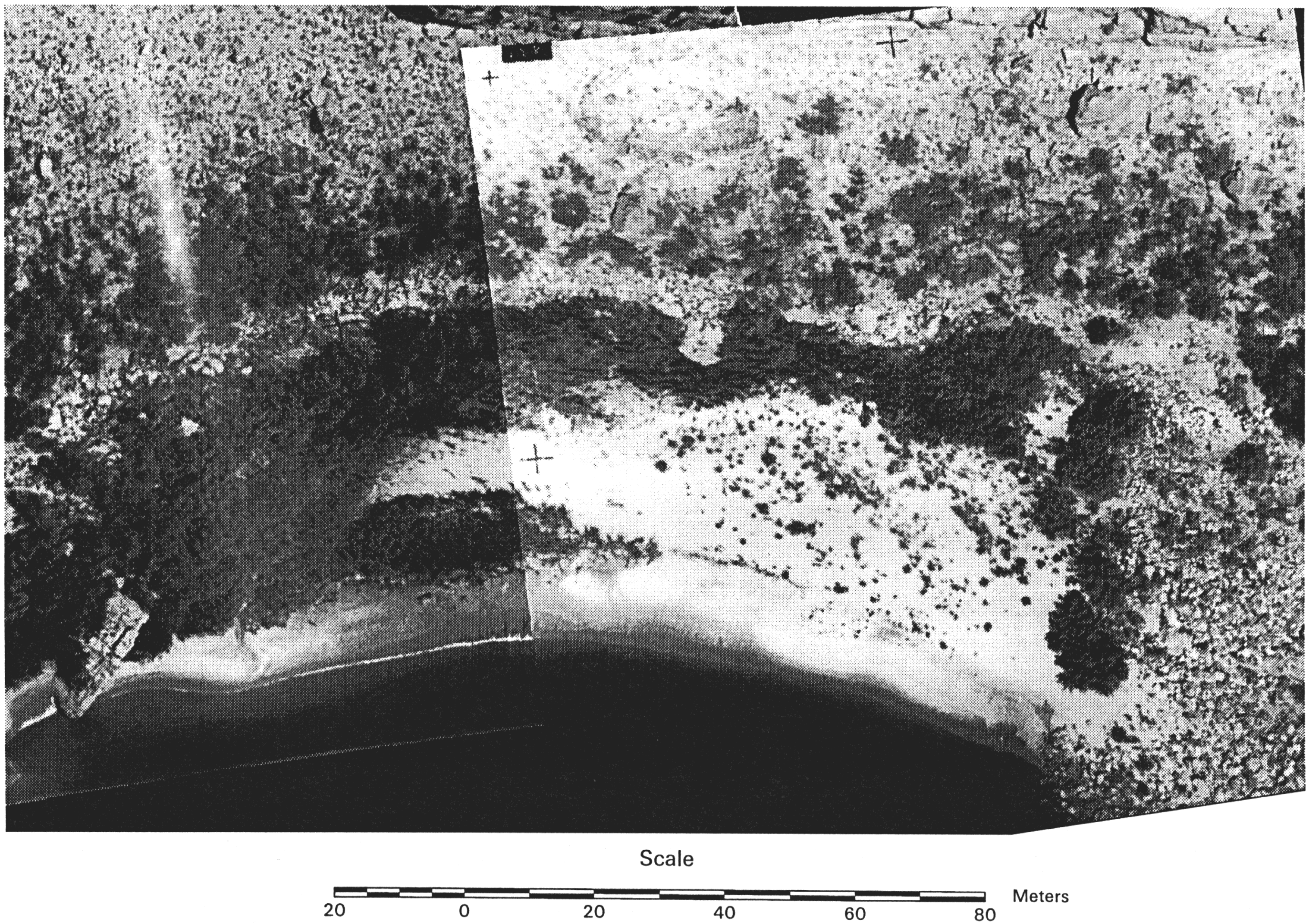


Figure 4.01A: Rectified low-level aerial photogrammetric image of the 43.1L study area in late July, 1991.

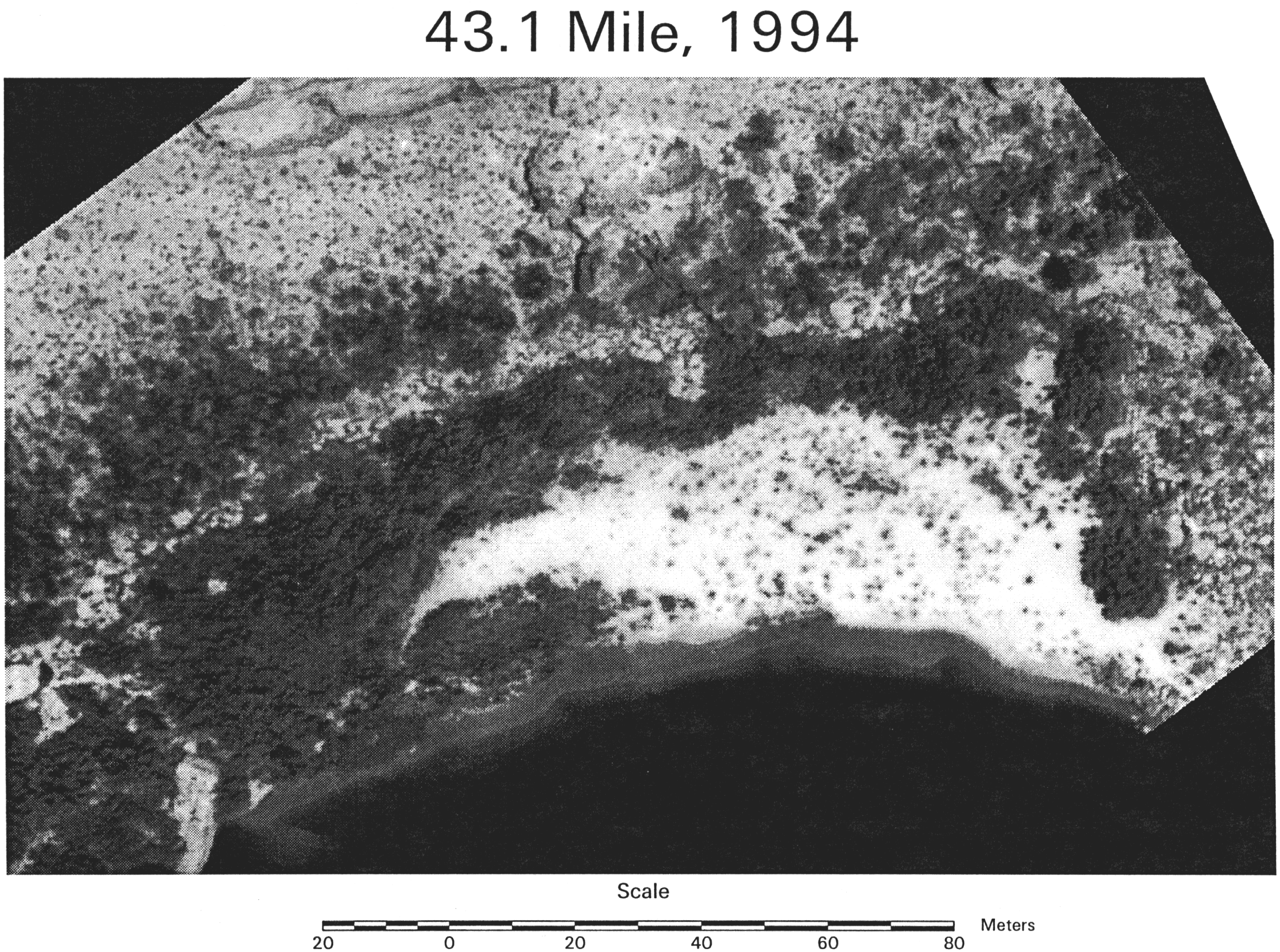


Figure 4.01B: Low-level aerial photograph of the 43.1L study area in early June, 1994.

51.2 Mile, 1991

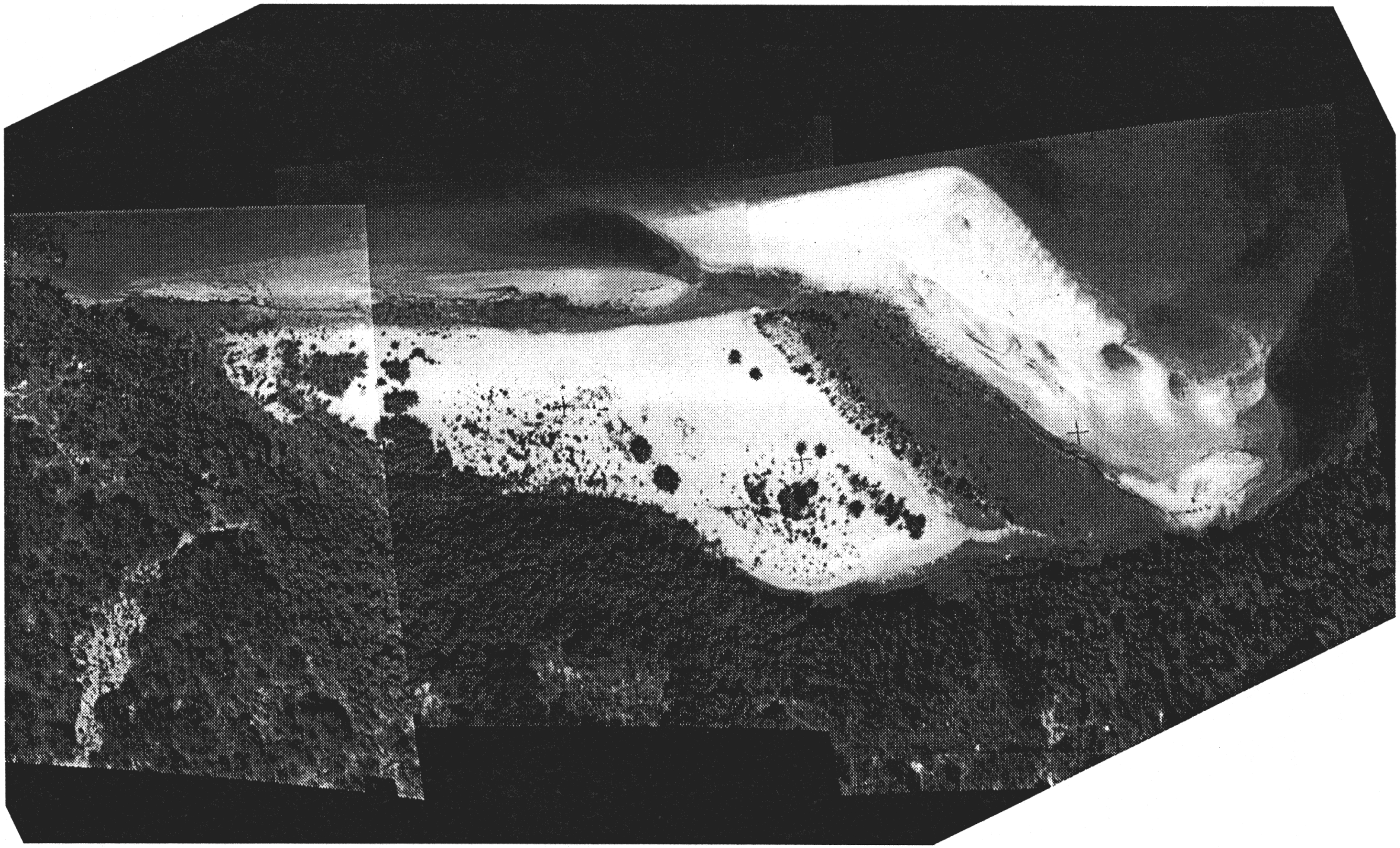


Figure 4.02A: Rectified low-level aerial photogrammetric image of the 51.2L study area in late July, 1991.

51.2 Mile, 1994

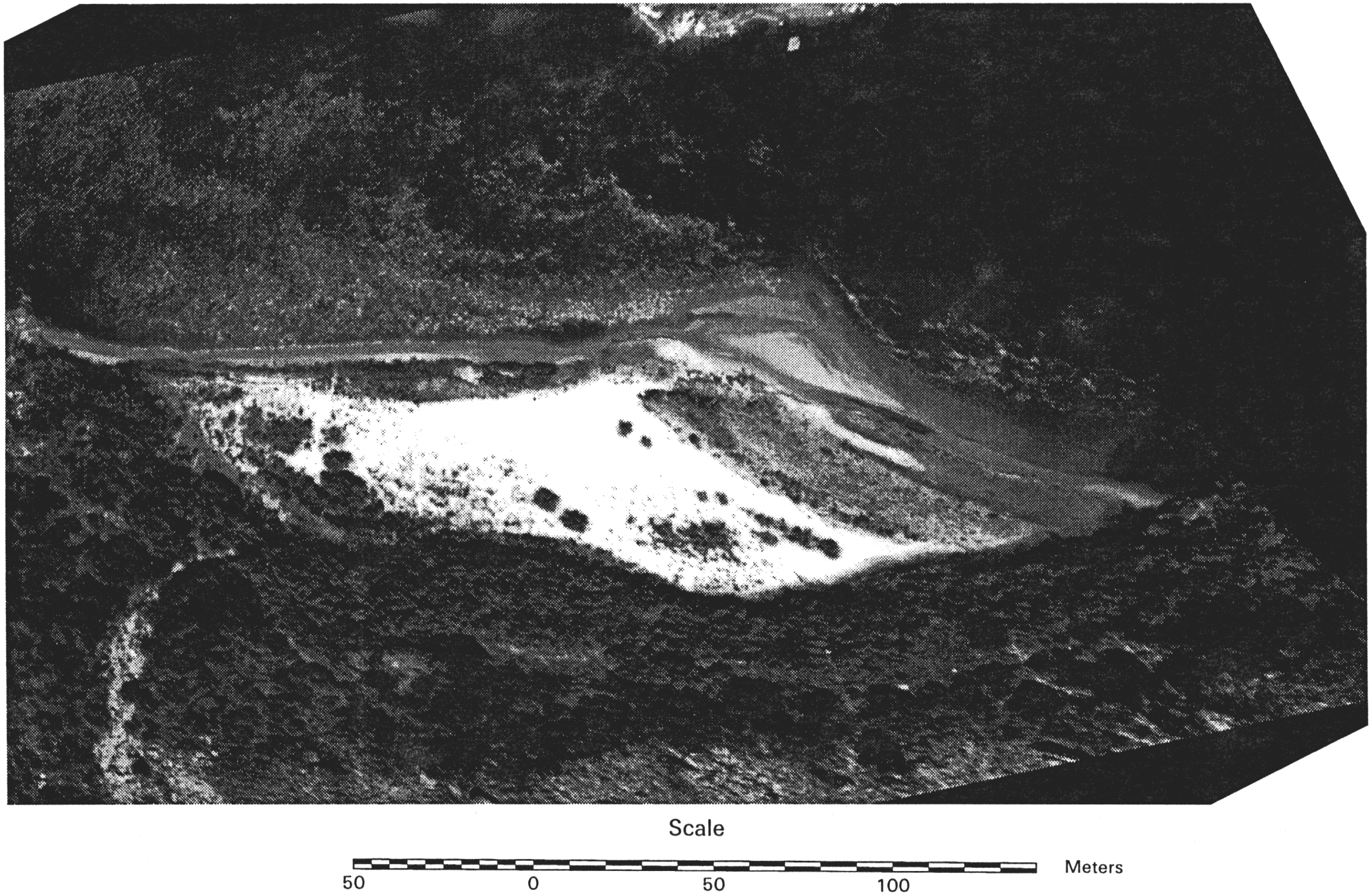


Figure 4.02B: Low-level aerial photograph of the 51.2L study area in early June, 1994.

55.5 Mile, 1991

Figure 4.03A: Rectified low-level aerial photogrammetric image of the 55.5R study area in late July, 1991.

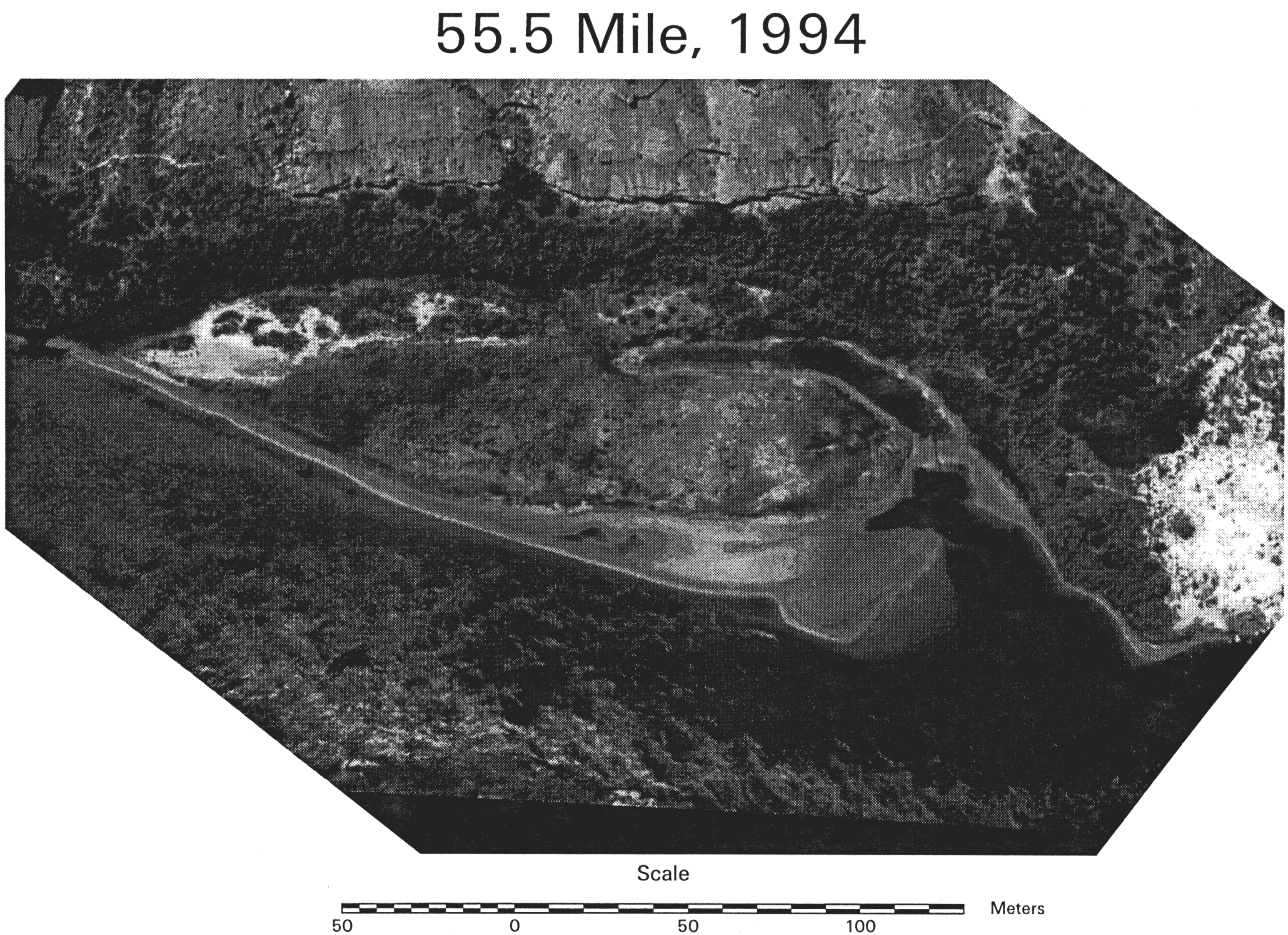


Figure 4.03B: Low-level aerial photograph of the 55.5R study area in early June, 1994.

122.7 Mile, 1991

Figure 4.04A: Rectified low-level aerial photogrammetric image of the 122.7L study area in late July, 1991.

122.7 Mile, 1994

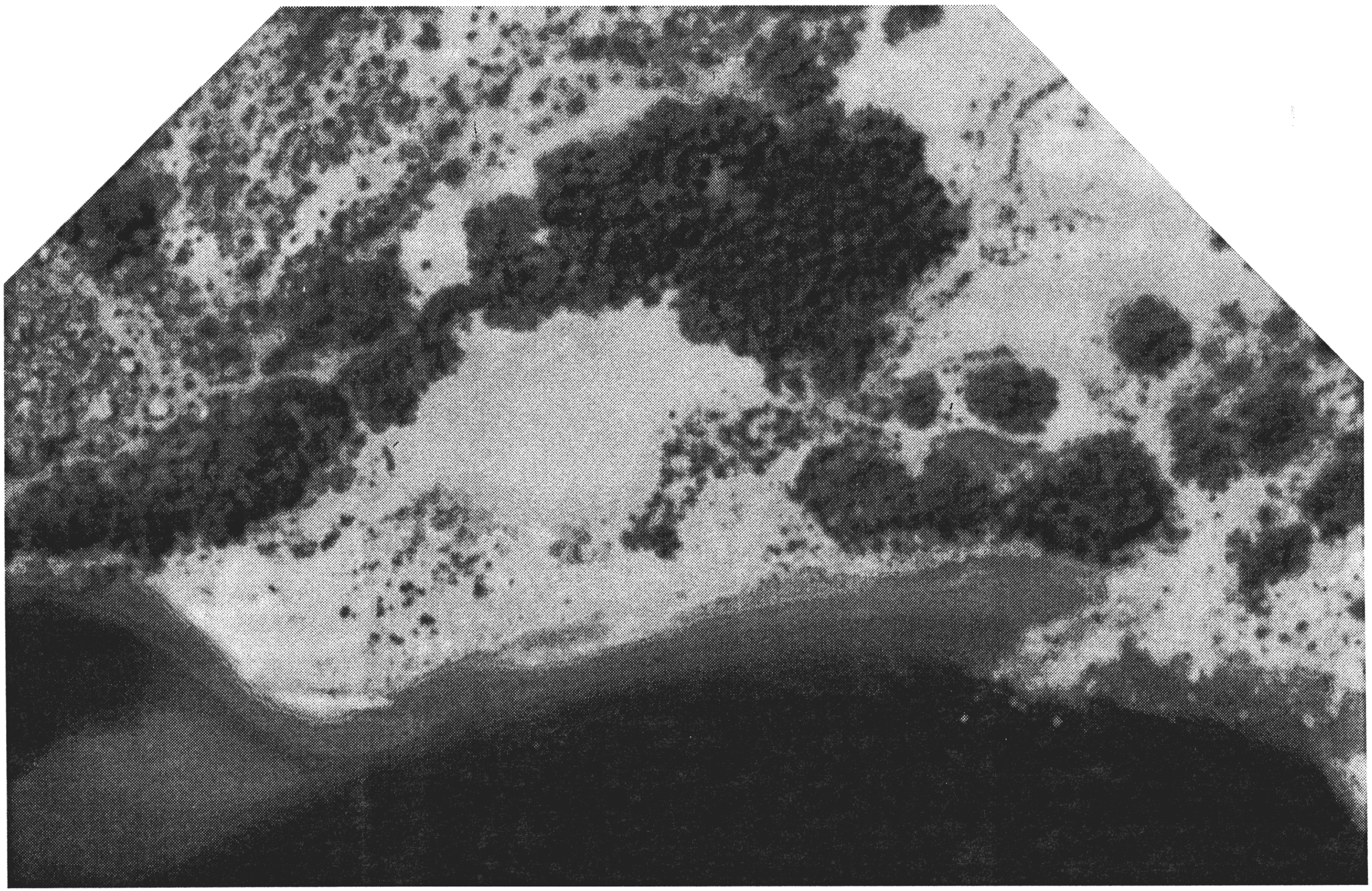


Figure 4.04B: Low-level aerial photograph of the 122.7L study area in early June, 1994.

172.3 Mile, 1991

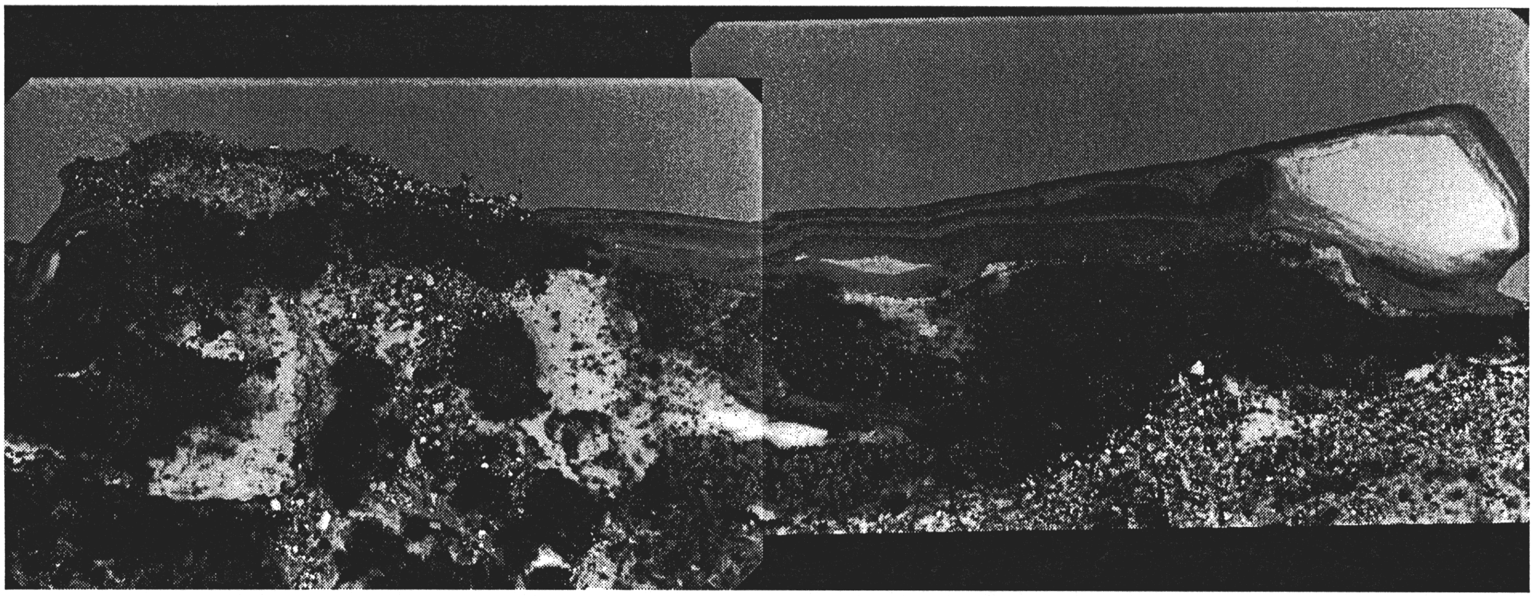


Figure 4.05A: Rectified low-level aerial photogrammetric image of the 172.1L study area in late July, 1991.

172.3 Mile, 1994

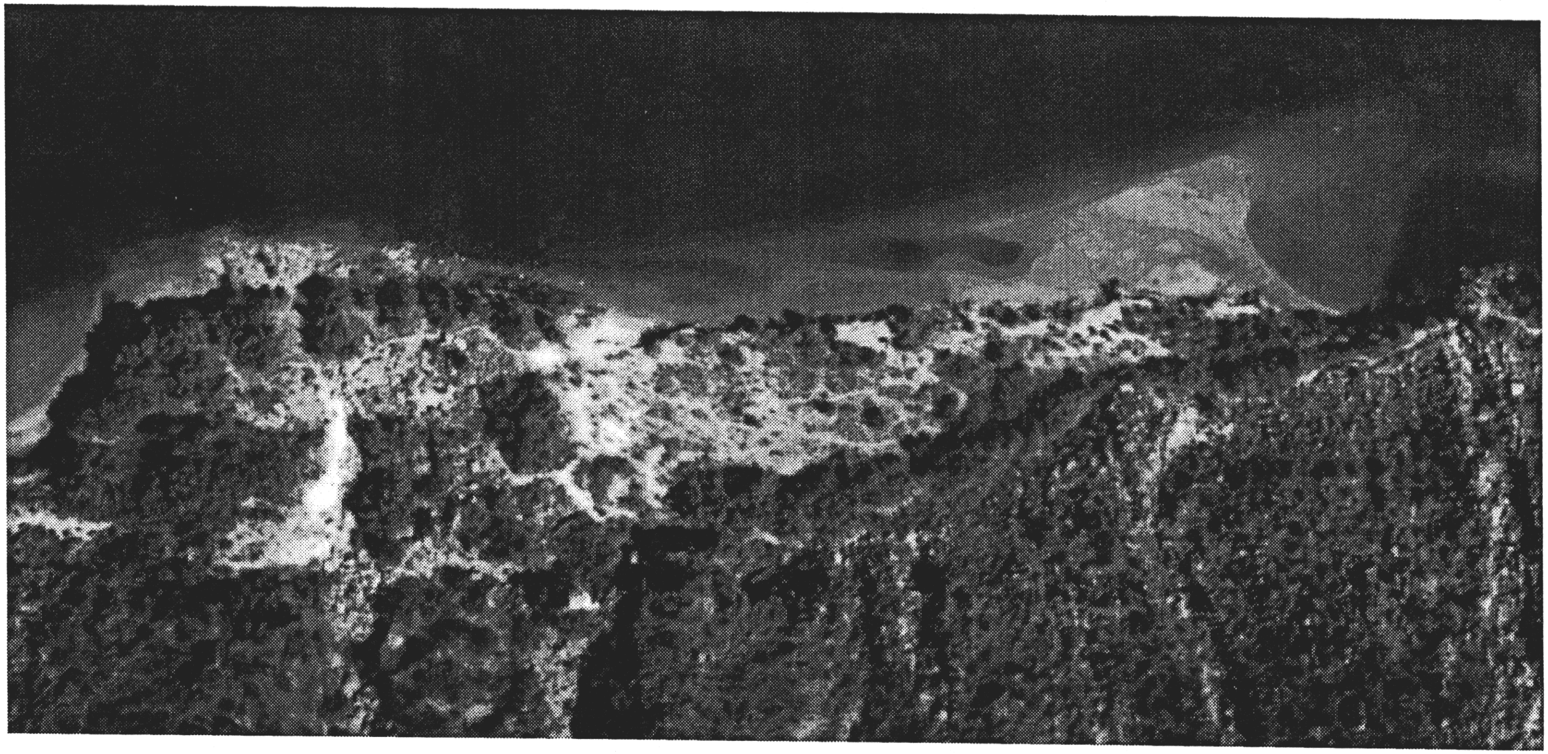


Figure 4.05B: Low-level aerial photograph of the 172.1L study area in early June, 1994.

194 Mile, 1991

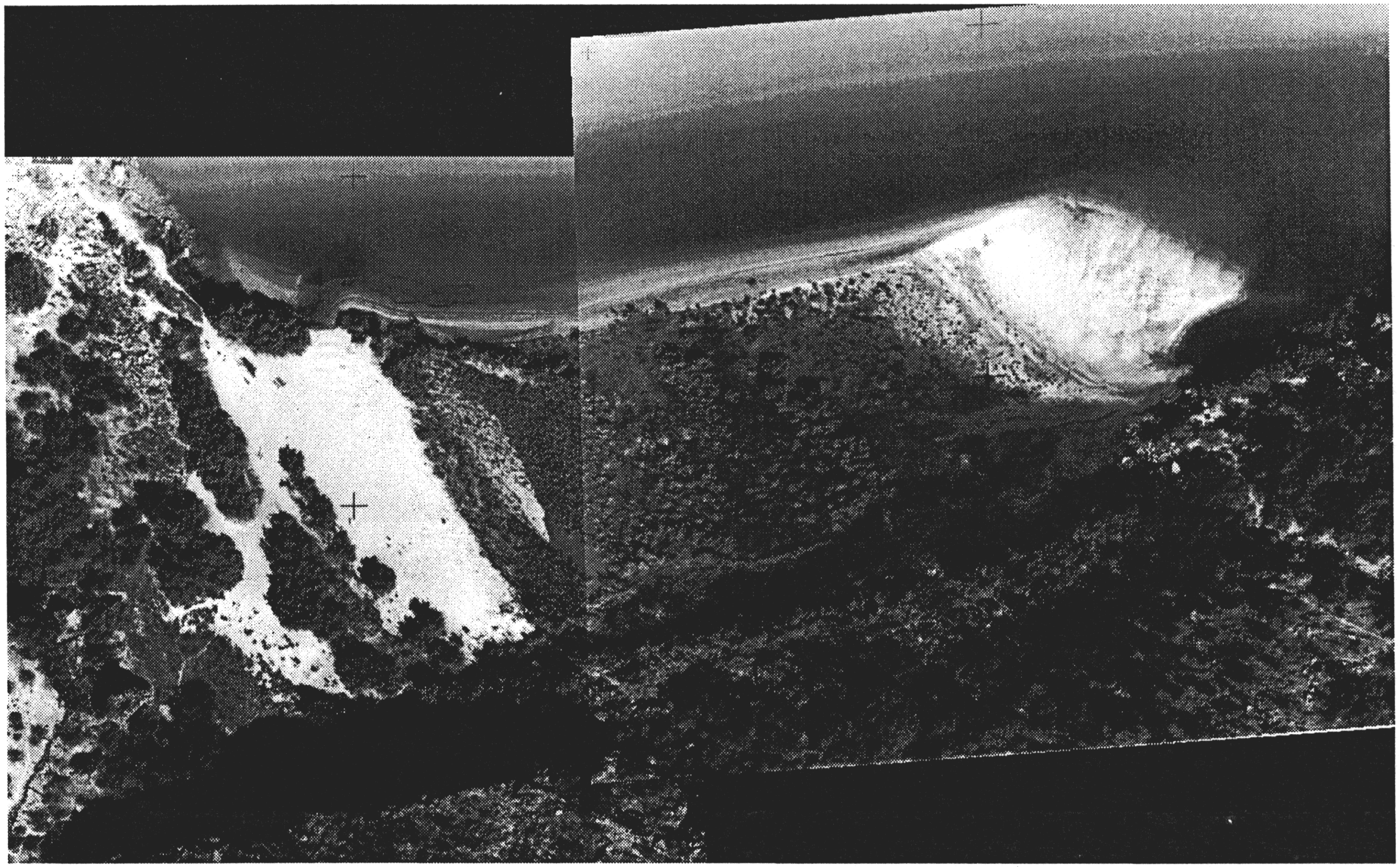


Figure 4.06A: Rectified low-level aerial photogrammetric image of the 194.1L study area in late July, 1991.

194 Mile, 1994

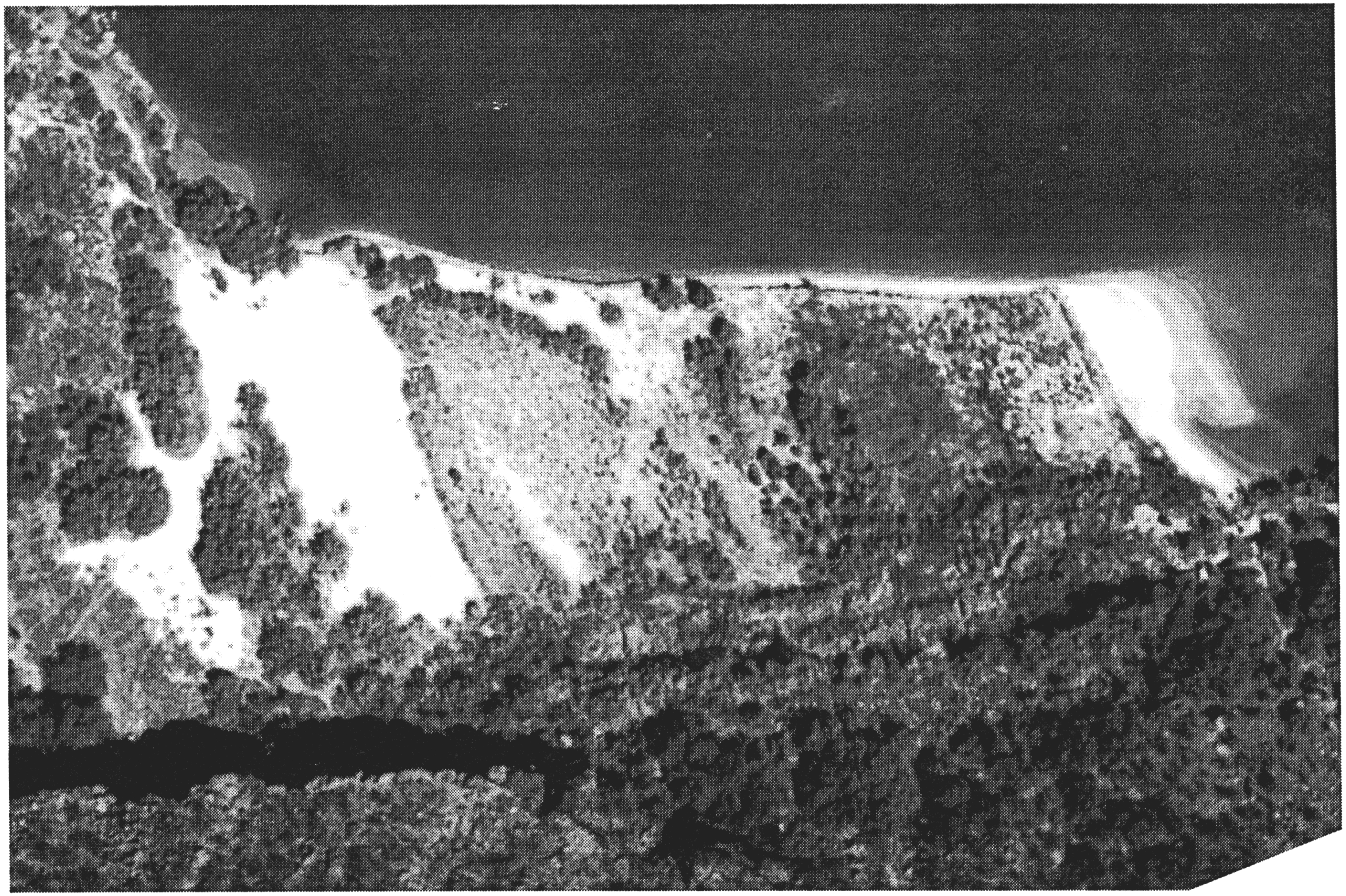


Figure 4.06B: Low-level aerial photograph of the 194.1L study area in early June, 1994.

Table 4.01: Summary of vegetation cover in 1991 and 1994 in four geomorphic settings at six study sites through the Colorado River corridor in the Grand Canyon, Arizona. Habitats include: BP - bar platform, CM - channel margin, ND - "new dry" (566 - 900 m^3/s stage) marsh, and RCC - return current channel (previously associated marshes). BP and ND cover was combined at the 172.1L study site because the two habitats could not be reliably separated on the 1991 photographs. Where shadows on photographs prevented differentiation between geomorphic settings, vegetation cover types were combined (e.g., BP + ND at 55.5R).

MILE/ SIDE	HABITAT	1991 AREA (m^2)	1994 AREA (m^2)
43.1L	RCC	296	205
	CM	3095	3913
	BP	1637	712
	ND	0	277
	TOTAL	5028	5107
51.2L	RCC	636	993
	CM	7464	7948
	BP	2316	5399
	ND	253	2273
	TOTAL	10669	16613
55.5R	RCC	78	487
	CM	6543	4912
	BP+ND	6372	9315
	TOTAL	12993	14714
122.7L	RCC	64	22
	CM	1347	1438
	BP	807	901
	ND	0	57
	TOTAL	2218	2418
172.1L	CMBP	1234	1099
	BP	1028	983
	ND	0	40
	TOTAL	2262	2122
194.1L	RCC	1483	1186
	CM	1827	1768
	BP	6157	6037
	ND	0	197
	TOTAL	9467	9188

Vegetation cover in previously established RCC marshes among study areas downstream from the LCR has decreased extensively, in comparison with upstream study areas (Table 4.01). Little herbaceous clonal marsh vegetation remains in the RCCs at the 122.7L (Fig. 4.04 A and B) and 172.1L (Fig. 4.05 A and B) study areas, and some decrease in cover occurred in the Mile 194L RCC marsh (Table 4.01; Figs. 4.06 A and B). We attribute these changes to reduction in inundation frequency in these RCCs, and to aggradation of new sediment during the 1993 LCR floods (Chapter 2, this report).

3) Upper elevation sandbar platform Salix exigua cover has decreased at some sites, while Tamarix ramosissima cover at higher stage elevations has not changed appreciably. S. exigua cover dominates the upper bar platform at Mile 43L, and has decreased from 0.16 ha to 0.07 ha from 1991 to 1994 (Table 4.01; Figs. 4.01A and B). Willow dieback has been observed at Miles 43.1L, 51.2L and 194.1L during this study (see Chapter 3, this report). These changes are likely related to increased desiccation stress resulting from lowered sandbar water tables under interim flows.

Relatively little scour of established, woody vegetation took place on the study sites downstream from the LCR, as reflected in the limited change of bar platform or channel margin vegetation at those sites (Table 4.01). Previously established T. ramosissima cover on upper bar platforms appears to be approximately equivalent at most sites. Stevens and Ayers (1993) demonstrated that T. ramosissima operates under significantly lower plant water potential range than does S. exigua. These observations and data suggest that interim flows permits T. ramosissima maintain dominance on upper bar surfaces, while S. exigua gradually shifts in position, with clonal expansion at lower stage elevations and die back at upper bar platform locations.

4) Channel margin vegetation, which is strongly dominated by T. ramosissima, also displayed slight increases in cover during interim flows (Table 4.01). We have not been able to distinguish S. exigua from T. ramosissima on 1991 aerial photographs, preventing detection of compositional changes there, and long-term quadrat data (below) do not demonstrate strong compositional changes. Using aerial photographs, we cannot detect vegetation changes on the near-vertical portions of channel margin habitats lying between the 566 and 900 m^3/s stages. Random stops (below) and observations demonstrate that this zone has been colonized by annual and clonal herbs; however, these habitats are not being regularly monitored.

Long-term Quadrat Analyses

The long-term study quadrats, which are dominated by woody phreatophytes, reveal gradual changes during interim flows. We compiled mean basal area/m^2 for each species on each site in 1992 and 1993 to illustrate the present status of riparian vegetation (Appendices B, D1, D2). Channel margin, bar platform and debris fan long-term quadrats exhibited high variance but little substantive differences in mean basal area of established dominants. Increases in mean basal cover of clonal phreatophytic Tessaria sericea (e.g. on debris fan plots) and some perennial grasses (e.g. Muhlenbergia asperifolia in debris fans) were noted, and these species share a common life history trait of being rather drought tolerant. In contrast, the basal cover of dominant phreatophytes, such as Salix exigua and Tamarix ramosissima changed little over these two years (Appendices D1, D2). To further explore changes in species composition on lower riparian zone long-term quadrats, we divided species into life history groups (Appendix A), according to designations presented in Chapter II (this report) and life history information presented in Phillips et al. (1987) and Kearney and Peebles (1960).

We analyzed basal area changes between years using relative DECORANA factor loading scores for species in samples space from 60 quadrats surveyed in 1992 and 1993 (Table 4.02). Axis 1 eigenvalues were 0.868 and 0.559 for 1992 and 1993, respectively; axis 2 eigenvalues were 0.633 and 0.436 for 1992 and 1993, respectively; axis 3 eigenvalues were 0.575 and 0.343 for 1992 and 1993, respectively. Relative DECORANA axis 1 scores decreased significantly for most life history groups from 1992 to 1993 (Mann-Whitney $p < 0.05$ for 5 of 7 life history groups; Tables 4.03, 4.04). Previous studies have demonstrated that DECORANA axis 1 is strongly positively correlated with moisture availability in this system (Stevens and Ayers 1993, Stevens et al. 1995). Thus a decrease in relative axis 1 scores signifies a compositional shift towards plant species that are more drought tolerant. This was corroborated by the increase in Terraria sericea and perennial bunch grasses in lower riparian zone settings. In contrast, little compositional shift has occurred in different grain-sized environments, associated with DECORANA axis 2, as demonstrated by few shifts among life history groups (Table 4.04).

The vegetation change resulting from interim flows appears to be a desiccation of the previously established riparian vegetation, as was demonstrated in the marshes (Chapter II, this report). Additional changes are probably occurring, but these may require several more years of monitoring to be manifest. As discussed in our remote sensing studies (above), this shift will likely be related to gradual decreasing dominance of previously established clonal, woody Salix exigua, maintenance of drought resistant Tamarix ramosissima, and increased presence of xeric perennial grasses, particularly Sporobolus spp. on the high bar locations, and increases in dominance of willow closer to the water's edge. Although short-term influences of planned floods can be readily monitored, the long-term role of interim operations with rare, planned high flows on gradual dominance shifts will be difficult distinguish until numerous years of data have been compiled and analyzed.

"New Dry" Zone versus "New High Water" Zone Vegetation

1992: Analysis of 105 "new dry" zone (ND, 566 to 900 m^3/s) and "new high water" (NHW, 900 to 1700 m^3/s) zone bar platform quadrats through the Colorado River corridor in 1992 suggested that the ND zone had been quickly colonized by riparian vegetation. The ND zone quadrats established in our study areas were devoid of vegetation at the inception of interim flows, as determined from direct field observations and inspection of low-level aerial photographs taken in mid-summer, 1991. By fall, 1992 no significant differences existed in mean plant basal area or stem density on long-term quadrats in these two zones ($F_{1,21} = 2.979$, $p = 0.099$), and the ND zone exhibited comparable basal areas of all assemblages except woody non-clonal phreatophytes when compared to the bar platform zone in 1992.

Analysis of the randomly selected study quadrats and the ND and NHW long-term quadrats together revealed that ND zone quadrats supported equivalent species densities but somewhat higher stem densities in fine-grained substrata, as compared to NHW zone quadrats (Fig. 4.07 A and B). Fine-grained habitats supported lower species densities but higher stem densities than did coarse substrata (cobble/boulder habitats; Fig. 4.07A and B), a finding in

Table 4.02: Factor loading scores of plant species from long-term study quadrats for three DECORANA axes, 1992-1993. Data are based on log-transformed plant species basal cover/50 m^2 in quadrats space. Species identifying numbers and life history group designations are described in Appendix B, and basal area data are presented in Appendices D1 and D2.

SPP			DECORANA AXIS VALUES, 1992 AND 1993				
IDNO	GROUP	AX192	AX292	AX392	AX193	AX293	AX393
201	4	4.0479	3.3296	-.7684	.1573	1.5474	.3549
1	7	3.9999	2.5791	4.0727	1.3522	3.5704	.2845
209	4	4.1384	1.3211	.8540	5.7093	-.8648	.9704
212	7	-.4350	2.5405	2.2734	.2547	2.5892	1.7544
3	3	3.7453	1.2128	3.1298	4.2230	4.1588	2.1104
222	3	4.1384	1.3211	.8540	1.7473	1.2273	-.9851
5	3	3.8402	5.6372	1.3912	2.6368	-.2856	1.8956
6	6	3.4742	1.9358	2.7586	2.6074	.6686	2.5645
227	7	3.9790	3.5462	4.8221	1.5296	2.6045	.6994
96	7	3.6841	2.7128	.9385	1.3278	-.0489	-1.4435
7	3	3.8336	2.5229	.3924	2.6965	2.5760	-.3205
237	3	3.9348	3.7850	.9844	2.6368	-.2856	1.8956
10	6	4.0520	2.2638	4.0119	2.8462	4.1440	1.1239
244	6	3.5320	5.3428	2.1280	.7130	3.1325	2.2757
11	3	3.7139	1.2163	2.4991	4.0624	1.4033	2.4625
248	6	3.8354	3.7082	-.1554	.3508	1.6986	.5241
252	7	3.7929	4.6016	2.3070	1.9564	2.2444	1.8534
256	6	2.6005	4.1883	1.8257	1.1705	1.6119	1.1581
259	3	3.9374	2.0202	4.4868	4.1206	3.1395	-.0328
12	3	3.5814	1.7196	2.4129	1.5535	3.1549	1.6006
14	2	4.0739	1.7918	2.3297	5.4621	-.7787	.9872
17	1	3.7524	1.2706	2.9811	3.8505	.1091	3.1380
601	5	3.8625	1.4224	.2768	.6024	.1649	2.2533
21	4	3.9849	1.9054	.9506	-1.4019	2.5573	2.2790
22	2	3.6571	1.7687	2.1430	3.6037	-.0470	.2706
602	7	3.5578	4.1242	.6924	1.3278	-.0489	-1.4435
603	7	3.9086	4.2185	2.6660	.4886	1.7842	.6535
23	2	3.8827	1.4633	3.7121	3.4341	4.2538	2.0237
287	6	3.3384	1.2856	2.0354	2.8201	.2841	3.3733
24	4	3.7603	3.8025	2.2005	1.2518	2.7552	3.6267
294	7	3.8364	5.6385	1.5409	.9540	3.0506	1.6166
291	6	3.2566	5.3765	2.8583	.2547	2.5892	1.7544
25	1	3.6481	4.5181	3.4784	1.5300	2.1556	.4763
298	7	3.4537	3.4296	2.9441	2.7613	2.8711	1.6369
301	7	3.8119	3.1941	.2378	2.0117	2.5288	3.7822
300	7	3.9086	4.2185	2.6660	1.7827	1.2431	2.8961
305	7	3.4732	5.0496	2.7788	.3458	1.6676	3.8427
29	4	3.6745	1.7556	1.7513	5.5816	5.1566	1.0969
604	7	3.9086	4.2185	2.6660	1.9564	2.2444	1.8534
31	3	-.4349	2.5480	2.2747	.2547	2.5892	1.7544
313	99	3.6562	4.8150	2.4656	1.5694	1.9201	3.6112
124	7	3.6395	1.5595	2.1051	5.3881	2.6706	3.7375
324	5	3.4542	2.8308	.9297	2.0304	.0036	-.8079
72	3	3.6350	2.6192	2.5591	1.1215	1.6210	1.6343
33	3	3.4953	4.5207	1.6542	.9535	.6488	3.5714
71	3	3.9418	4.4241	1.2958	1.8132	3.0251	2.3448
34	7	2.8773	4.5927	1.8089	.9707	2.5889	.7690
129	3	3.8593	2.9764	3.6840	2.1887	3.6997	2.4309
339	7	3.4537	3.4296	2.9441	2.7613	2.8711	1.6369
484	7	4.1198	2.3973	4.4403	1.1731	2.8070	1.9362
37	3	3.7524	1.2706	2.9811	4.7297	-.4020	1.9002

Table 4.02 (continued)

SPP IDNO	GROUP	AX192	AX292	AX392	AX193	AX293	AX393
		DECORANA AXIS VALUES, 1992 AND 1993					
39	4	3.7524	1.2706	2.9811	4.1206	3.1395	-.0328
40	1	3.6868	2.5455	.8236	4.1206	3.1395	-.0328
361	99	4.0563	2.0298	2.9067	1.4488	3.2086	1.6279
367	7	4.0190	3.7330	2.3241	2.7613	2.8711	1.6369
368	7	3.4537	3.4296	2.9441	.4979	2.6110	1.9307
44	2	3.5018	4.2839	1.1617	-.2040	1.6457	-1.8592
374	6	3.7469	1.6777	2.1677	2.7989	2.7408	.9090
45	4	4.0556	1.6729	2.0968	.3709	1.0348	-.0582
389	6	4.0479	3.3296	-.7684	1.0256	1.1780	3.5580
46	3	3.9086	4.2185	2.6660	-.8005	2.1231	4.1875
397	7	3.2566	5.3765	2.8583	2.7613	2.8711	1.6369
401	7	4.0485	1.4490	.2829	.3709	1.0348	-.0582
403	3	3.6639	4.2407	3.4639	4.1206	3.1395	-.0328
49	1	3.6483	.9021	1.9561	5.0454	-.6022	1.2046
51	4	4.1384	1.3211	.8540	1.8316	3.9118	.7964
417	6	4.0436	3.0301	4.6190	1.6108	1.3819	2.4339
53	4	3.8863	2.8108	-.0414	2.2016	1.5413	.3794
95	5	3.9553	4.0298	1.4100	2.6769	2.0271	1.8245
427	6	3.6093	3.5906	2.4712	4.2207	.0000	2.5163
54	4	3.7530	.5528	2.0723	.5992	2.3783	1.3299
99	6	3.8796	4.4091	3.0856	1.2391	.2808	1.8641
59	2	3.5593	2.4057	1.7799	2.6368	-.2856	1.8956
505	6	3.8047	2.5915	1.3604	.2547	2.5892	1.7544
389	4	3.7686	2.0389	.8315	4.1445	3.2482	.0176
448	7	3.7966	3.4974	.0546	4.0775	1.8294	1.2946
61	3	3.9567	2.7842	4.2411	2.7017	2.0201	3.2811
62	3	3.9324	2.7874	1.8265	.6217	1.3883	.1143
63	3	3.7210	4.2505	3.3586	1.5401	3.0135	3.2030
447	3	4.1160	2.8161	4.3676	2.0110	1.7944	3.6636
101	7	3.5578	4.1242	.6924	-.1574	1.5335	-1.84
454	5	3.8982	2.6583	.0981	1.2391	.2808	1.8641
456	6	3.9887	4.1894	.2573	.6426	1.6101	2.3292
64	4	3.6868	2.5455	.8236	2.8448	1.4110	1.8237
65	3	2.9668	2.2644	2.1411	4.6481	3.5729	2.8898
66	3	3.6454	-.0424	1.9947	.3709	1.0348	-.0582
461	7	3.2697	5.3875	2.8331	2.0823	2.3310	1.3195
463	7	3.9086	4.2185	2.6660	1.4254	2.2229	1.4811
70	99	3.7569	2.7598	2.1098	.1573	1.5474	.3549
74	1	3.5578	4.1242	.6924	1.1199	2.1169	4.3157

Table 4.03: Mean 1992 and 1993 relative DCA scores for 7 groups of wetland/riparian plant species along the Colorado River in Grand Canyon. Life history groups include: 1) clonal wet marsh; 2) herbaceous non-clonal wet marsh; 3) bar platform; 4) dry marsh; 5) upper alluvial terrace; 6) rocky channel margin; and 7) xeric (desert) species. "n" designates the number of species compared between years in each group. Group designations are identified in Table 4.02 and Appendix B.

GROUP	MEAN RELATIVE DCA AXIS 1 SCORE		MEAN RELATIVE DCA AXIS 2 SCORE		MEAN RELATIVE DCA AXIS 3 SCORE	
	1992 (n, sd)	1993 (n, sd)	1992 (n, sd)	1993 (n, sd)	1992 (n, sd)	1993 (n, sd)
1	0.884 (5, 0.017)	0.549 (5, 0.300)	0.474 (5, 0.289)	0.268 (5, 0.303)	0.412 (5, 0.259)	0.422 (5, 0.427)
2	0.903 (5, 0.058)	0.523 (5, 0.361)	0.415 (5, 0.202)	0.187 (5, 0.399)	0.461 (5, 0.196)	0.154 (5, 0.366)
3	0.867 (22, 0.225)	0.398 (22, 0.272)	0.493 (22, 0.247)	0.391 (22, 0.258)	0.515 (22, 0.239)	0.416 (22, 0.336)
4	0.939 (12, 0.043)	0.400 (12, 0.394)	0.360 (12, 0.166)	0.449 (12, 0.299)	0.252 (12, 0.217)	0.243 (12, 0.255)
5	0.917 (4, 0.055)	0.287 (4, 0.159)	0.485 (4, 0.189)	0.120 (4, 0.183)	0.141 (4, 0.125)	0.297 (4, 0.326)
6	0.884 (14, 0.097)	0.282 (14, 0.217)	0.594 (14, 0.229)	0.331 (14, 0.235)	0.424 (14, 0.312)	0.466 (14, 0.206)
7	0.853 (25, 0.212)	0.295 (25, 0.221)	0.662 (25, 0.197)	0.423 (25, 0.173)	0.469 (25, 0.261)	0.310 (25, 0.341)

Table 4.04: Mann-Whitney U statistics and serial Bonferroni tests on significance values of relative DECORANA scores within axes for seven life history groups of wetland, riparian and xeric plant species occurring along the Colorado River in Grand Canyon. Groups include: 1) clonal wet marsh; 2) herbaceous non-clonal wet marsh; 3) bar platform; 4) dry marsh; 5) upper alluvial terrace; 6) rocky channel margin; and 7) xeric (desert) species. "n" designates the number of species compared between years in each group. Group designations are identified in Table 4.02 and Appendix B.

GROUP	AXIS 1 U STATISTIC, p (COUNT, 92RANKSUM, 93RANKSUM)	AXIS 2 U STATISTIC, p (COUNT, 92RANKSUM, 93RANKSUM)	AXIS 3 U STATISTIC, p (COUNT, 92RANKSUM, 93RANKSUM)
1	22, 0.047t (5, 37, 18)	18, 0.251ns (5, 33, 22)	13, 0.011t (5, 28, 27)
2	21, 0.076t (5, 36, 19)	17, 0.347ns (5, 32, 23)	20, 0.117ns (5, 35, 20)
3	458, 0.000* (22, 711, 279)	284, 0.324ns (22, 537, 453)	278, 0.398ns (22, 531, 459)
4	126, 0.002* (12, 204, 96)	55, 0.326ns (12, 133, 167)	77, 0.773ns (12, 155, 145)
5	16, 0.021* (4, 26, 10)	15, 0.043t (4, 25, 11)	4, 0.248ns (4, 14, 22)
6	195, 0.000* (14, 310, 106)	154, 0.010t (14, 259, 147)	96, 0.926ns (14, 201, 205)
7	584, 0.000* (25, 909, 366)	518, 0.000* (25, 843, 432)	416, 0.044t (25, 741, 534)

t $0.05 < p < 0.10$
* $p < 0.05$

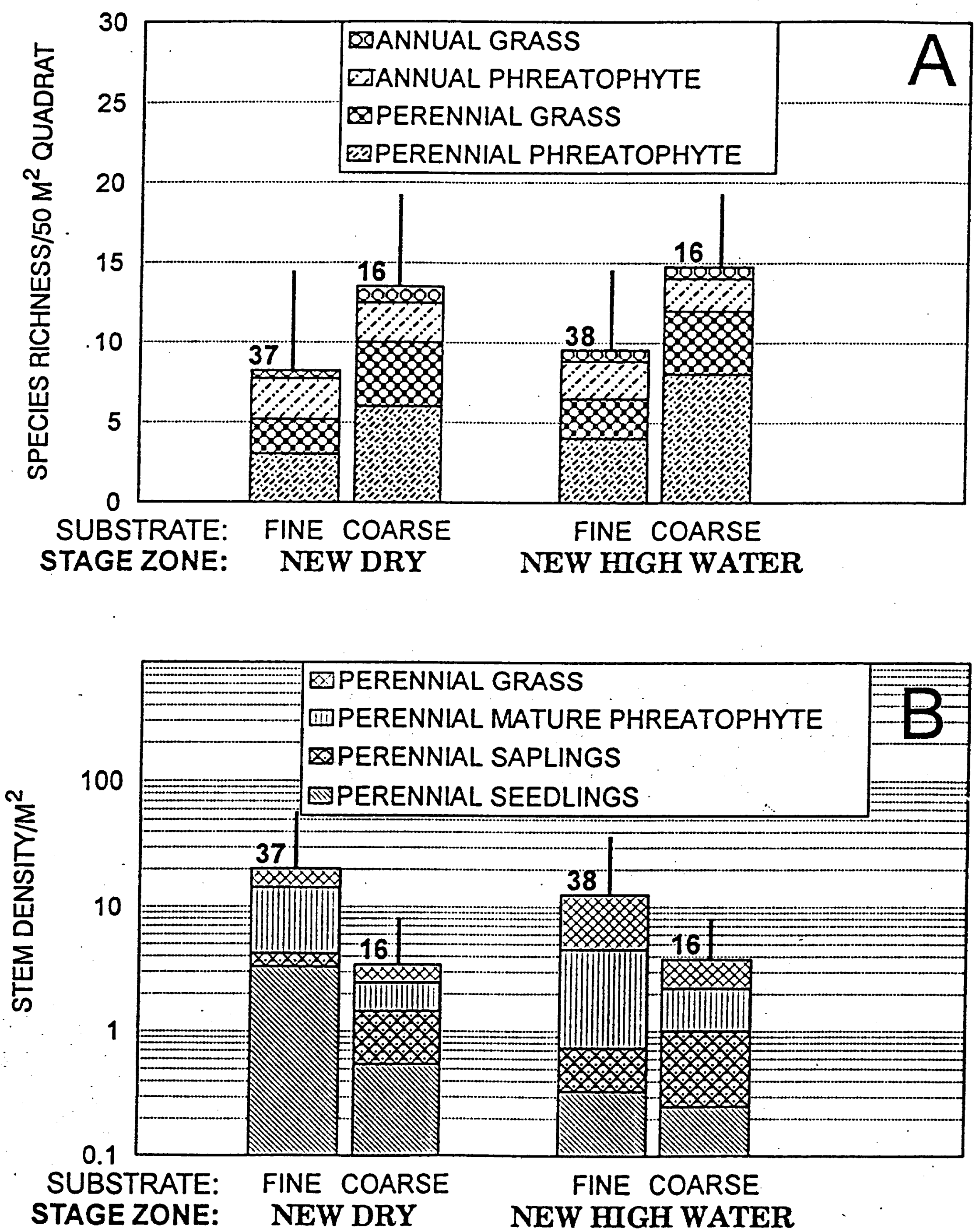


Figure 4.07: (A) Mean riparian plant species richness and (B) stem densities on randomly selected "new dry" versus "new high water" zone plots in fine versus coarse substrata through the Colorado River corridor in Grand Canyon, Arizona in 1992. Number of plots sampled and 1 sd are provided.

accord with the conclusions of Stevens and Ayers (1993). Overall, the bar platform and ND zones supported only about 50 percent of the species richness, but higher stem densities, than did the other lower riparian zone geomorphic settings under study.

1993: Analyses of stem density and species composition was also conducted on 85 randomly selected 5m x 10m quadrats which were surveyed in autumn, 1993. We used a multivariate two-factor (zone, grain-size) analysis of covariance, with three covariates: distance from Glen Canyon Dam, and arcsine-squareroot transformed percent ground cover and shrub cover. This analysis revealed a non-significant trend of lower stem density, but comparable species density, between these two zones in 1993 (zone effect in MANCOVA $F_{6,76} = 1.997$, $p = 0.076$, Table 4.05). Mature plant density ($p = 0.082$) and annual plant species density ($p = 0.086$) exhibited trends of lower, and higher, values, respectively, in the ND zone (Figs. 4.08 and 4.09). Stem density (mostly of annual herb seedlings) in 1993 was significantly greater in lower stage deposits in silt/sand deposits as compared to the NHW zone, while species density exhibited opposite but non-significant trends. Species diversity was positively correlated with distance from the dam, percent ground cover and percent shrub cover, and revealed a trend of increasing values in coarse substrata, again corroborating Stevens and Ayers (1993) findings. Both fine and coarse substrata were dominated by reproductively mature perennial taxa (clonal phreatophytes, particularly herbaceous Equisetum spp., woody Salix exigua and perennial bunch grasses. The largest proportion of species found in all zones were clonal herbaceous or woody phreatophytes, while annual grass and non-clonal phreatophyte species were more uniformly distributed across stage and substratum gradients.

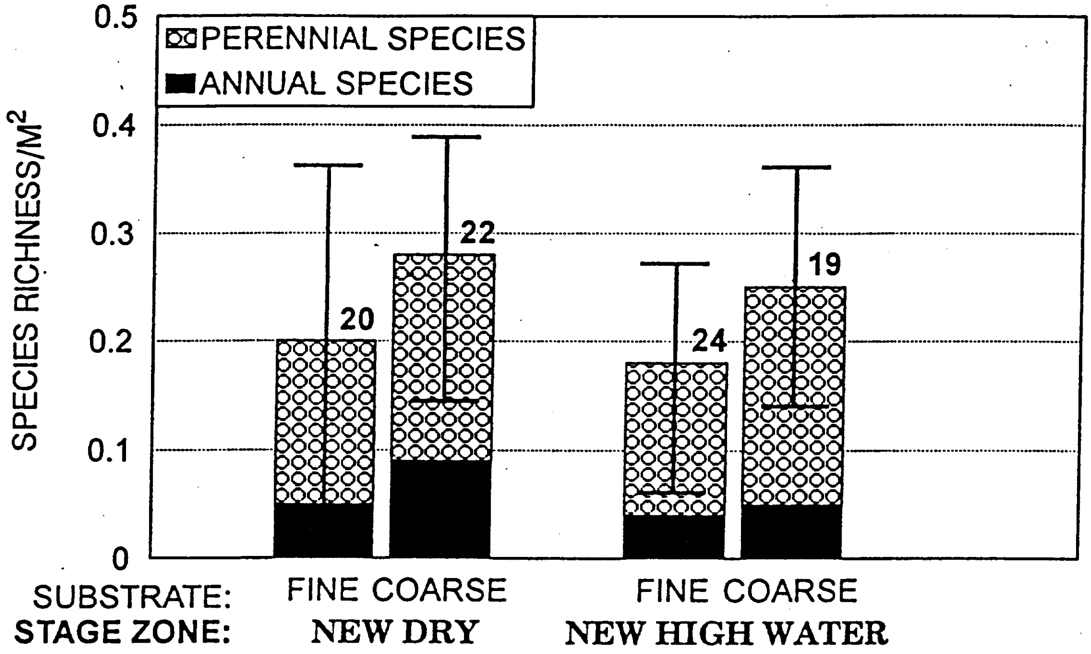
Seedlings predominated in the ND zone in 1993, indicating that colonization was still proceeding rapidly there. However, Tamarix ramosissima seedlings were rare, and virtually all those encountered occurred in fine-grained ND zone plots (Fig. 4.09). The limited amount of T. ramosissima recruitment following the January/February, 1993 LCR floods was probably attributable to the amount of time (two months) for desiccation of riparian soils prior to the spring release of T. ramosissima seeds.

Univariate analyses suggested that annual and perennial plant species diversity were positively correlated with percent ground cover and shrub cover ($p = 0.04$ and 0.005, respectively). Likewise, annual and perennial plant stem density were positively correlated with percent ground cover and shrub cover ($p = 0.001$ and 0.04, respectively). Our data suggest that annual plant diversity decreases with distance downstream in coarse-grained settings, while no distance-related trend exists for perennial species or any species in fine-grained habitats (Fig. 4.10A and B). These findings contrast with those of Nilsson et al. (1989) who described a non-linear pattern of weed diversity over distance downstream in Scandinavian rivers. We attribute the negative correlation between weed species diversity and distance in coarse habitats to be a function of increasing distance from population sources (large tributaries, such as the Paria and Little Colorado rivers) and the poor chances of colonization in rock-dominated habitats.

Table 4.05: MANCOVA table of factors influencing vegetation characteristics on 85 randomly selected 5 m x 10 m quadrats in the "new dry" and "new high water" zones through the Colorado River corridor in the Grand Canyon in 1993. Response variables included: Tamarix ramosissima seedling density/m^2 (SdD_T), other perennial seedling density/m^2 (SdD_o), perennial sapling density/m^2 (SpD), perennial mature plant density/m^2 (MD), annual species density/m^2 (ASD), and perennial species density/m^2 (PSD). Predictor variables included: zone (ND = "new dry" versus NHW - "new high water") and substratum type (F, fine = silty sand versus C, coarse = cobble/talus breccia), with distance from Lees Ferry as a covariate.

SOURCE	WILK'S LAMBDA	APPROX. F	df	p	SIGNIFICANT RESPONSE VARIABLES
Zone	0.864	1.997	6,76	0.076	MD t, ASD t
Substratum Type	0.778	3.624	6,76	0.003	MD*, PSD**, ASD t
Covariate: Distance	0.884	1.666	6,76	0.141	(ASD **)

t - 0.05 < p > 0.10
* - p < 0.05
** - p < 0.01



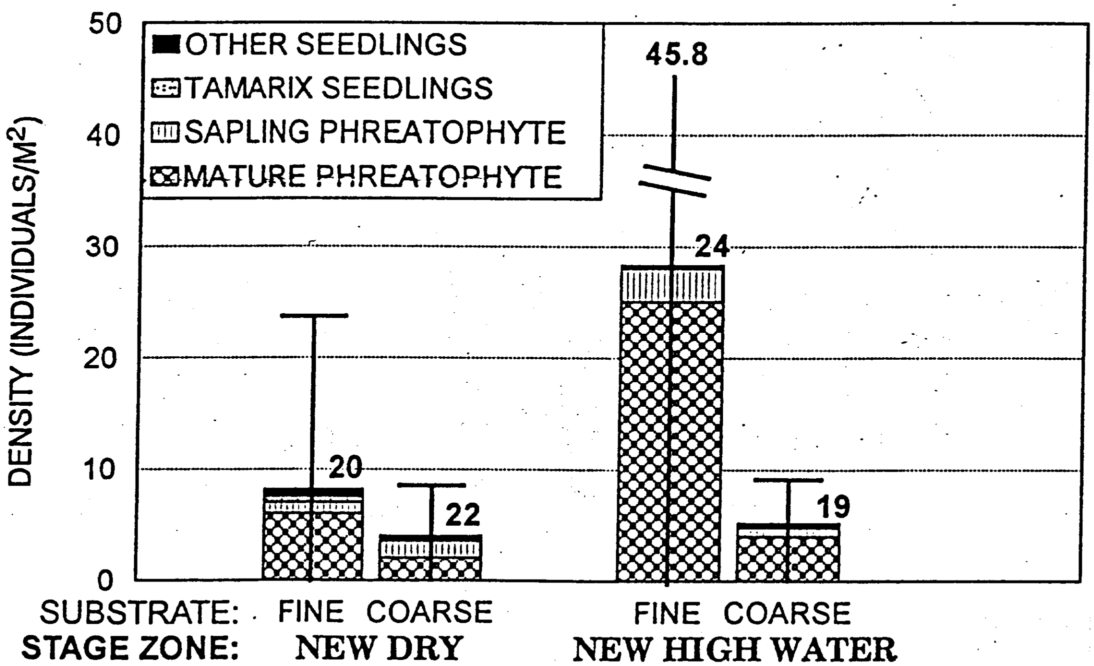


Figure 4.08 (Upper Graph): Mean perennial and annual riparian plant species richnes/m^2 on "new dry" versus "new high water" zone plots in fine versus coarse substrata along the Colorado River in Grand Canyon, Arizona in 1993. Number of plots sampled and 1 sd are provided.

Figure 4.09 (Lower Graph): Mean perennial seedling, sapling and mature plant stem densities, and Tamarix ramosissima seedling densities/m^2 on "new dry" versus "new high water" zone plots in fine versus coarse substrata along the Colorado River in 1993. Number of plots sampled and 1 sd are provided.

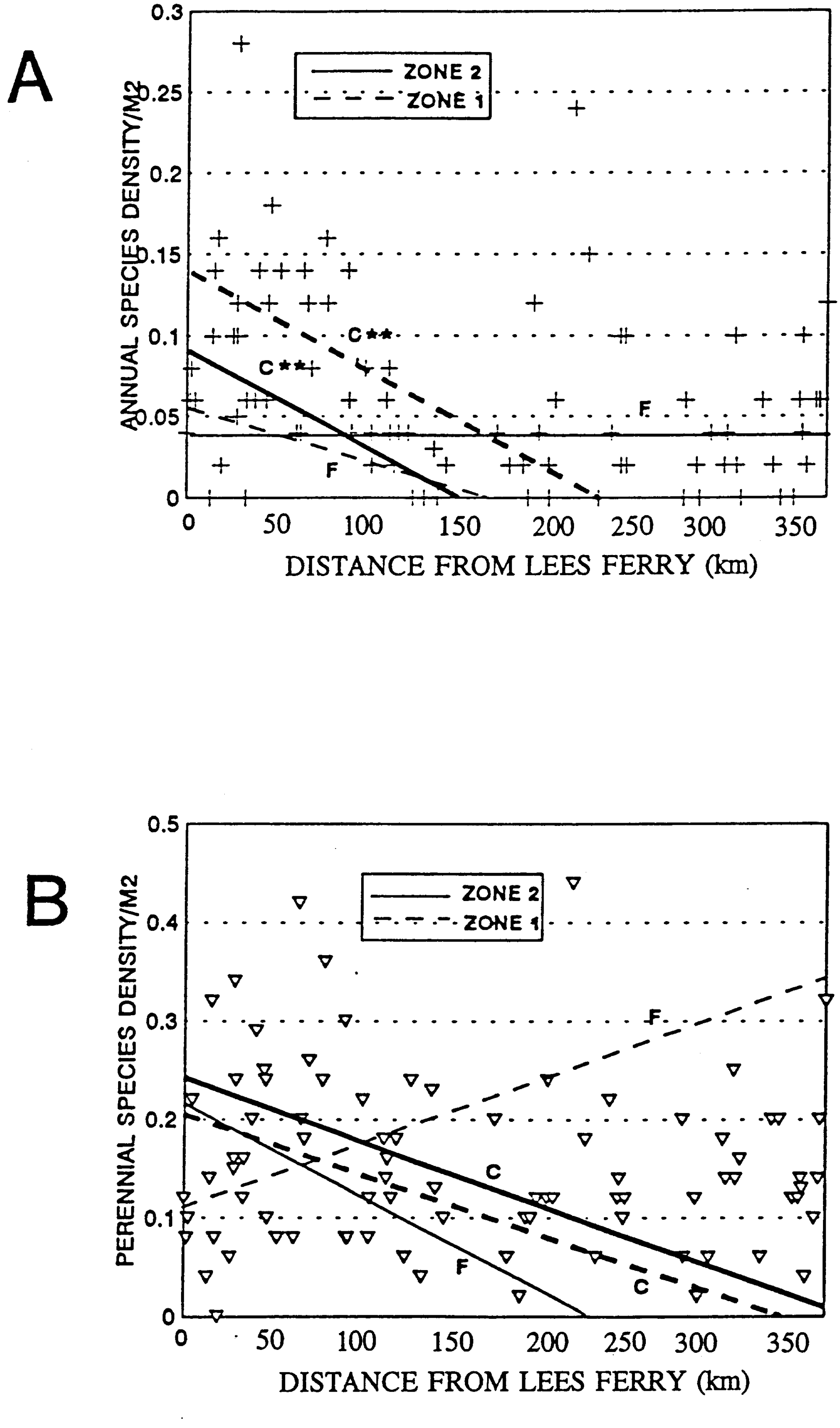


Figure 4.10: (A) Annual and (B) perennial riparian plant diversity as a function of distance downstream from Lees Ferry, Arizona in fine (F) versus coarse (C) substrata in the "new dry" (Zone 1) and "new high water" (Zone 2) stage zones in 1993.

SUMMARY

Several conclusions may be drawn from these analyses regarding initial and on-going changes in non-marsh vegetation related to interim flows.

1) The potential for control of on-going invasions by non-native plants varies between species, with some (e.g. Ravenna grass) rather easily controlled, and others (e.g. Lepidium latifolium) that may not be controlled.

2) MIPS analyses of 1991 and 1994 aerial photographs at six study areas revealed that although the overall cover of riparian vegetation at most study sites is static or increasing, the distribution of vegetation is shifting within sites. Sandbar riparian and wetland vegetation is concentrating between the 566 and 900 m^3/s stages and previously established S. exigua in high bar locations is dying back.

3) Relative axis 1 DECORANA species scores on long-term quadrats in the lower riparian zone were lower in 1993 relative to 1992 scores, reflecting a gradual shift during interim flows towards sand bar species that are more drought tolerant. This was also supported by changes in individual species mean and sum basal areas on long-term quadrats in several lower riparian zone geomorphic settings.

4) The "new dry" zone, lying between the interim flows maximum flow stage (566 m^3/s stage) and the "normal operations" stage (ca. 900 m^3/s stage), was quickly colonized by riparian plant species, particularly herbs, clonal phreatophytes and perennial grasses. , Higher stem density but lower species diversity occurred on fine-grained (silty fine sand) substrata, as compared to cobble and boulder substrata.

CHAPTER V

AN APPLICATION OF GCES GIS ANALYSIS TO RIPARIAN PLANT DIVERSITY ACROSS DISTURBANCE, PRODUCTIVITY, AND GEOMORPHOLOGY GRADIENTS

CHAPTER V:

AN APPLICATION OF GCES GIS ANALYSIS TO RIPARIAN PLANT DIVERSITY ACROSS DISTURBANCE, PRODUCTIVITY AND GEOMORPHOLOGY GRADIENTS

INTRODUCTION

Detailed mapping of topography, geomorphology, soil texture and vegetation cover was conducted at selected study areas using Bureau of Reclamation 1992 aerial photographs to address the third objective of this project: "prepare monitoring data for inclusion into the GCES/NPS GIS database." Use of remote vegetation mapping data through the GCES GIS may provide a useful component for long-term monitoring and may improve understanding processes structuring riparian vegetation.

We used GIS mapping data compiled during this project to explore the distribution of mainstream riparian plant diversity, testing Huston's (1979, 1994) dynamic equilibrium model (DEH). This model predicts that diversity should be jointly influenced by nonlinear-unimodal relationships with productivity and ecological disturbance (Fig. 5.01). Low productivity associated with environmental harshness and high productivity which permits competitive exclusion to occur should both result in relatively low diversity. Similarly, low disturbance intensity, which permits competitive exclusion, and high disturbance intensity (i.e. environmental unpredictability) should likewise both result in relatively low diversity (Connell 1978). The DEH predicts that autotroph diversity should be highest at high levels of productivity and lower levels of disturbance (Fig. 5.01, lower graph, Region A). However, few studies have sought to test these predictions using field or experimental data.

We consider three other possible scenarios for maximum diversity: 1) axial maxima (Fig. 5.01B), 2) an intermediate field maximum (Fig. 5.01C), or 3) a central point maximum (Fig. 5.01C). Additionally, recent studies of riparian vegetation in flood-prone rivers suggests that geomorphology may also exert strong influences on plant diversity (Gregory et al. 1991, Stevens et al. 1995); however, the role of geomorphology on diversity in the presence of strong disturbance and productivity gradients is unknown.

We tested the influences of productivity, flood-disturbance (as inundation frequency), geomorphology (depositional environment and soil texture), and all two-way interactions on riparian plant species density/m^2 in five Colorado River study areas. The eddy-dominated Colorado River in the Grand Canyon is well suited for this study because: 1) the history of flooding is well known; 2) related studies provide useful information on the distribution of substantially different geomorphic surfaces; 3) estimates of annual litterfall are available for those geomorphic surfaces; and 4) the system is protected from other anthropogenic disturbances besides regulated flows (e.g. grazing, mining, etc.), which might obscure the effects of these predictor variables.

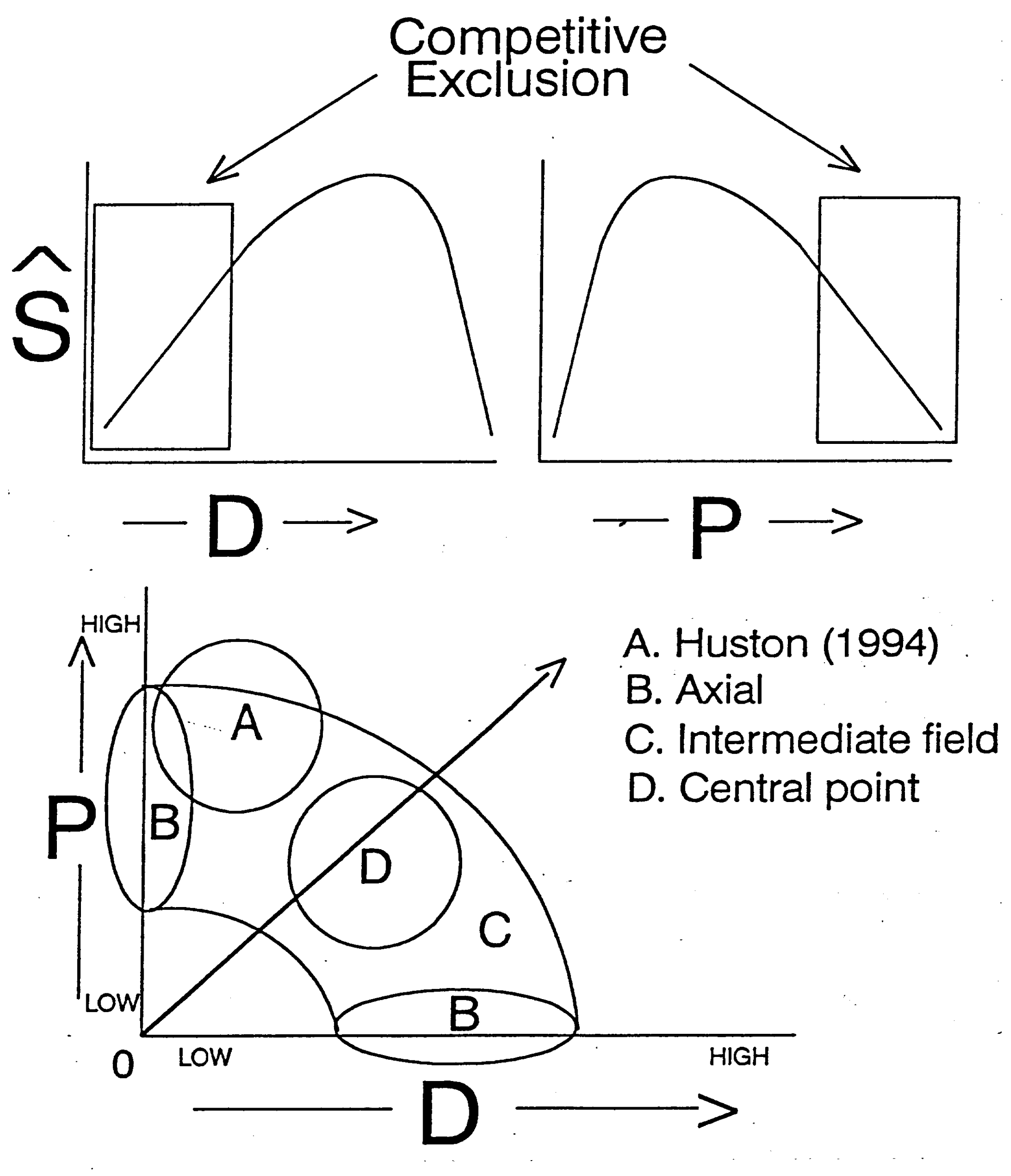


Figure 5.01: The dynamic equilibrium model of Huston (1979, 1994). Huston predicted that diversity would be suppressed in settings with low disturbance (D) or high productivity (P; top graphs) by competitive exclusion. In 1994 he predicted that autotroph diversity across gradients of D and P would be highest in region A (lower graph). We consider three other possibilities for highest diversity: B - axial maxima, C - intermediate (arcuate) across both D and P fields, and D - a central maximum point arising from interactions of the two gradients.

METHODS

Mapping Images

We selected several of our long-term debris-fan complex study locations that occurred in the GCES-GIS as primary study sites, including: miles 43, 56, 68, 123 and 209 (Fig. 5.02). In addition, we selected secondary study sites (those with historic data but which did not occur in GCES-GIS reaches), including: miles 0, 3, 8, 88, 93, and 194. In October, 1992, preliminary evaluation of vegetation was completed at these sites. Color infra-red (CIR) aerial photos were enlarged and used as base maps for the sites. During preliminary site visits it became apparent that significant growth occurred between 1990 and 1992: newly emergent vegetation was found along the riparian zone which did not appear on the 1990 CIR photos, and shadows made interpretation difficult in the CIR images, since they appear black in color infra-red images. Due to this difficulty, normal color aerial photography (1992) was preferred for mapping, improving interpretation of vegetation in shadowed areas and shifts in cover type to be detected.

The scale of the 10-11 October, 1992 color aerial photography (Bureau of Reclamation, 1:4800) was too large for 3.0 m mapping accuracy. To conform with GCES GIS database accuracy standards, we enlarged images of each primary site to 1:1600. Base maps of geomorphology, soil texture and vegetation were prepared from the enlarged photographs. Secondary site maps are only relatable to the GCES-GIS reaches through the GCES system-wide survey traverses. These maps are housed with the GCES GIS and are not discussed further here.

Field Methods

Base maps were taken into the field for ground truthing. Mapped data were rectified using a series of surveyed ground control points (GCP's) on each image. Field mapping of vegetation, soils and geomorphology polygons was verified in June, 1994 at five study areas in GIS reaches (Fig. 5.02). The Mile 43 polygon map is presented as an example basemap of polygons (Fig. 5.03). We identified all plant species occurring in each polygon, and estimated the relative cover of each species in each polygon. After field ground truthing, maps were manually digitized by H. Mayes (Applied Technology Associates, Inc., courtesy of the Bureau of Reclamation) and polygon attribution was transferred from the field notes to the GCES GIS.

Disturbance Intensity: Disturbance intensity was determined in relation to the stage-to-discharge relations at each site. The centroid of each polygon was surveyed during the June, 1994 field truthing expedition. We used stage-to-discharge relationships developed by Stevens et al. (in press) at miles 43, 51, 56, 68 and 123, and we used strandlines and distinctive terraces at 94 and 209 to interpret polygon stage elevation. These data were related to published flow duration curves for the post-dam era (Fig. 5.04, Bureau of Reclamation 1990) to estimate inundation frequency (a correlate of flood disturbance intensity) for each polygon in each study area (e.g. Fig. 5.05).

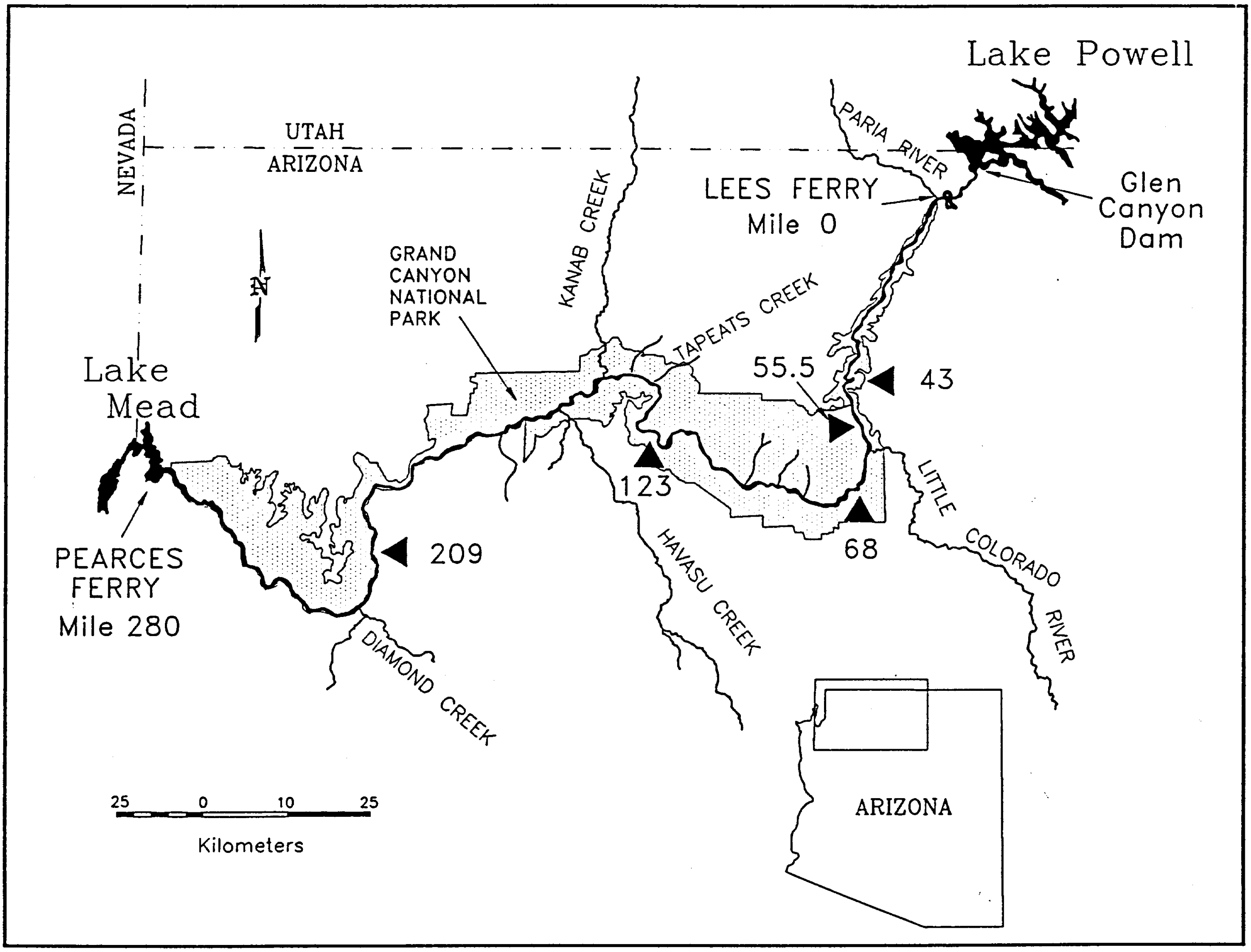


Figure 5.02: Map of the five study locations for GIS analyses.

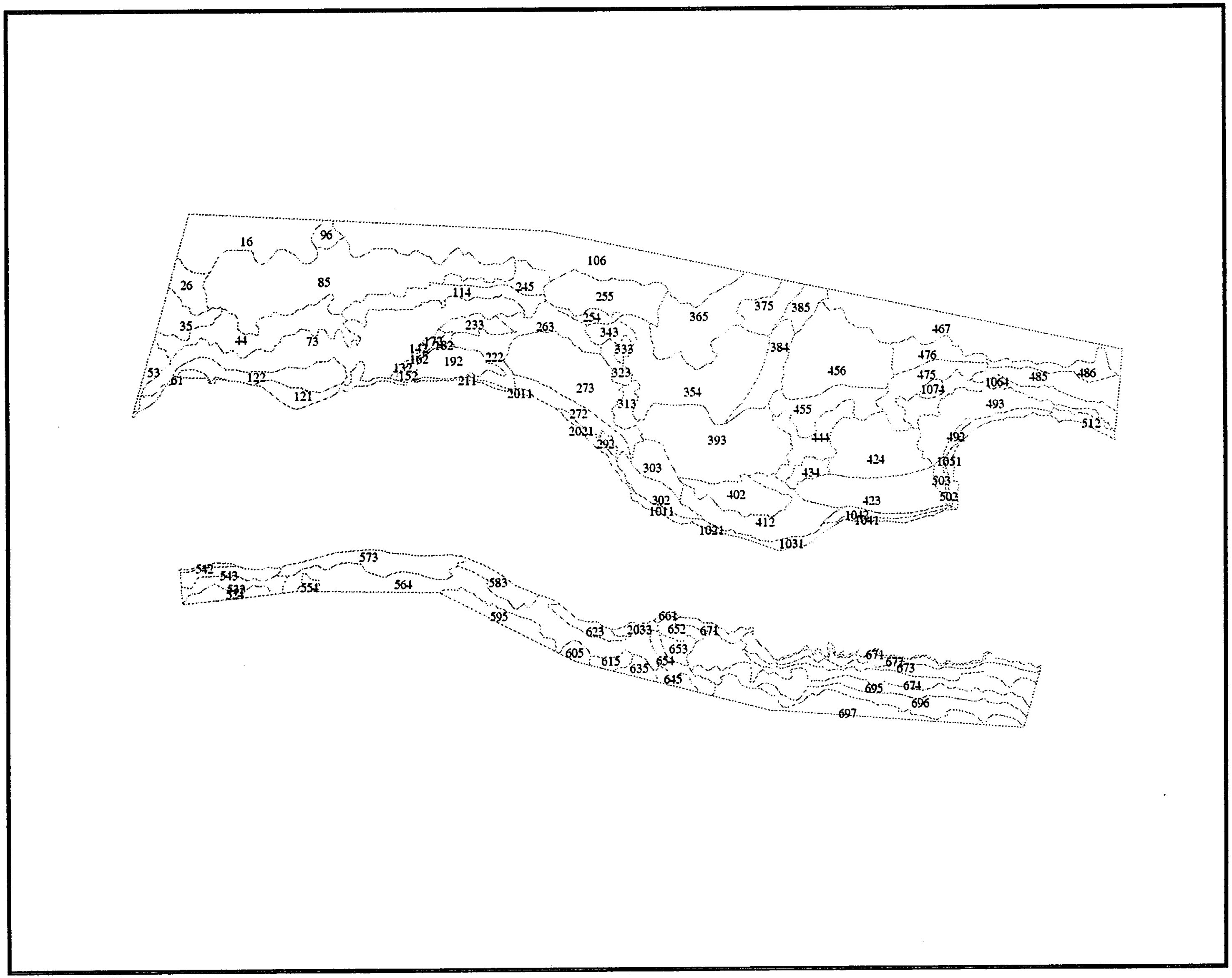


Figure 5.03: Vegetation polygon map of the Mile 43 study area from 1993 aerial photographs. Numbers refer to polygon designations.

5.05

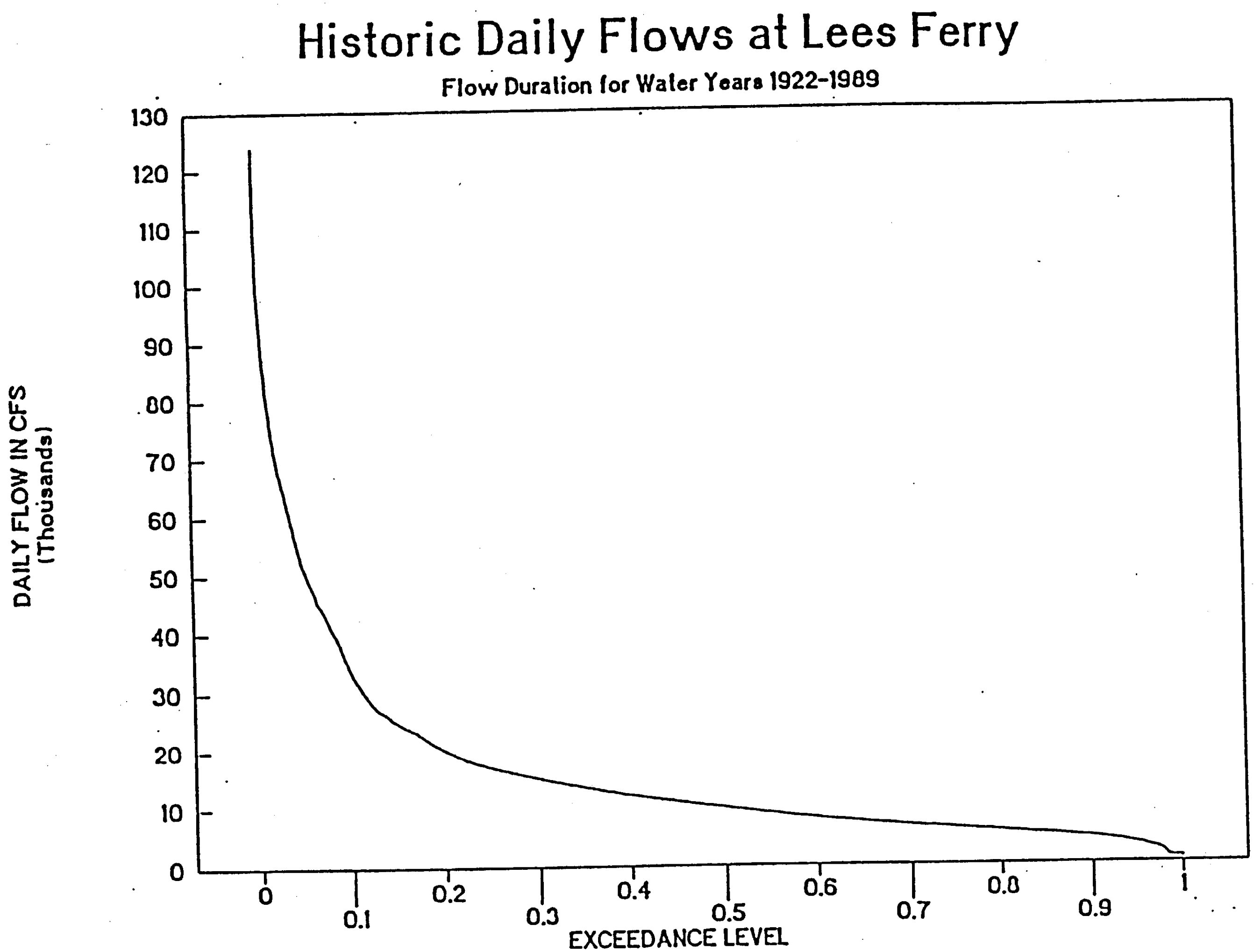


Figure 5.04: Historic daily flow duration at Lees Ferry, Arizona, 1922-1989.

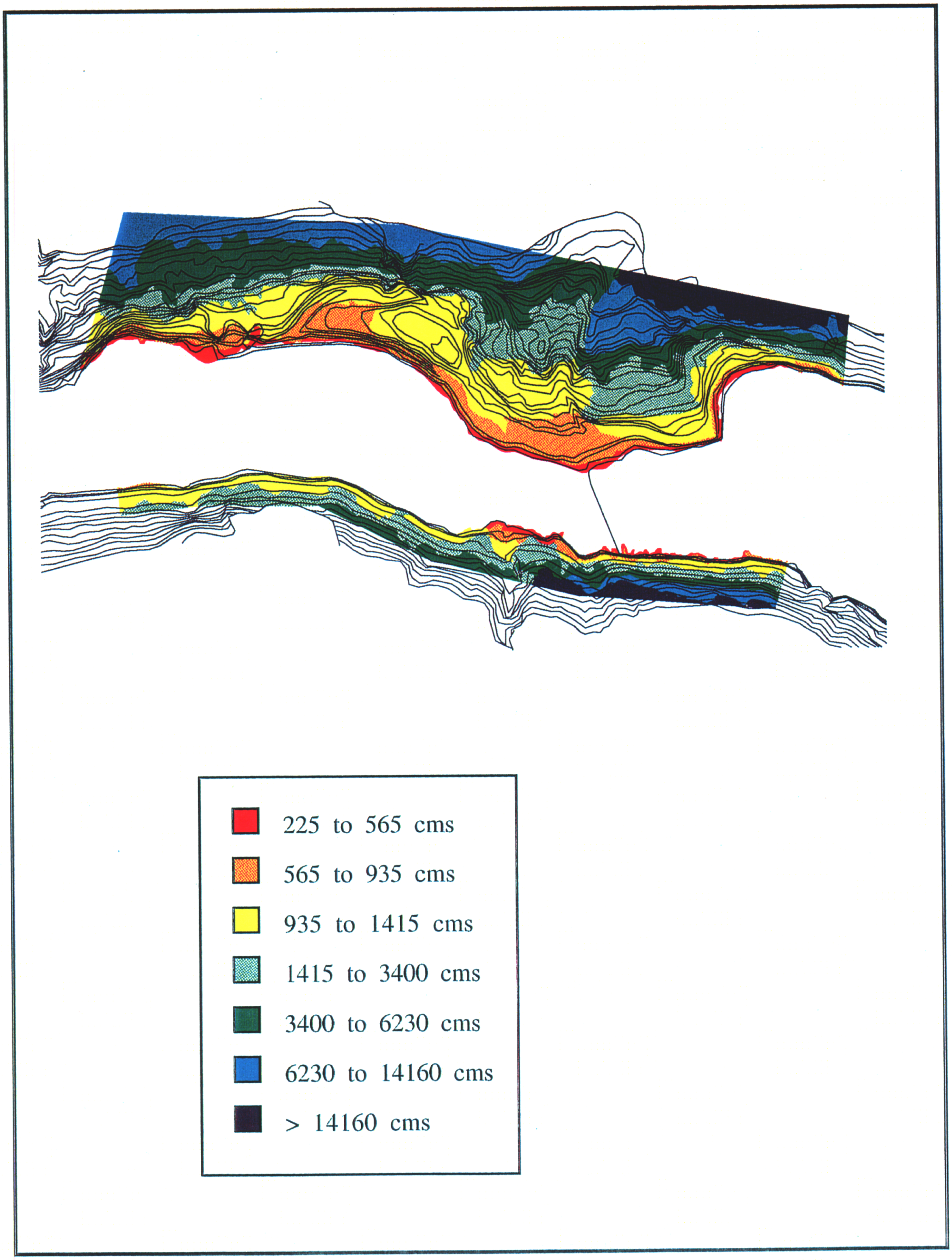


Figure 5.05: GIS overlays of topography and inundation frequency zones at the Mile 43 study area in 1994.

Productivity: Estimation of litter accumulation rate (a correlate of productivity) was accomplished by measuring gravimetric soil moisture, duff and litter depth, the number of ground, shrub and canopy cover contacts on a vertical survey rod at 148 0.5 m^2 plots. These plots were situated in relation to the long-term study quadrats throughout the river corridor and in a wide variety of geomorphic settings. Annual litterfall had been previously measured by collecting litter at one year intervals on these plots (Stevens unpublished data). Many factors (decomposition, wind or water transport, animal disturbance) influence annual litterfall; however, annual net litter accumulation provides a reasonable, readily quanitified measure of resident organic production. Also, June was selected for field sampling because that month is the driest month of the year in Grand Canyon, and the soil moisture gradient was expected to vary most strongly across stage elevation.

We developed an index of productivity using stepwise multiple linear regression (SYSTAT v. 5.03, Wilkinson 1991) to correlate these variables with measured litter accumulation rates:

$$Log_e(L) = 0.208 Log_e(D) + 1.295 \arcsin(S)^{-.5} + 0.027F - 0.157 \quad \text{(Eq. 5.1)}$$
$$\text{(SMLR adj'd } r^2 = 0.667,\ F_{3,143} = 98.691,\ p < 0.001)$$

where L = the estimated annual litter accumulation rate ($g/m^2/yr$), D = duff thickness (cm), S = percent soil moisture and F = foliage contact density.

During ground truthing we measured these same variables in each polygon at each study area. We applied Equation 5.1 to the polygon data to estimate of litter accumulation rate (e.g. Fig. 5.06).

Geomorphology: Grain size and geomorphology have been demonstrated to be strongly correlated with plant species density (Stevens et al. in press). Therefore we mapped the various geomorphic settings (e.g. Fig. 5.07), and the range of surficial particle sizes occurring in each polygon. We used the geomorphology terminology applied by J.C. Schmidt (personal communication).

Analyses

We analyzed the spatial distribution of annual and perennial plant species density/m^2 in relation to soil moisture, stage elevation (inundation frequency), slope, grain size, geomorphology, and estimated productivity gradients using GIS, Pearson correlation analysis with Bonferroni adjustment and analyses of variance (e.g. Fig. 5.08).

RESULTS AND DISCUSSION

The data collected on all sites are presented in Table 5.01 and summarized in Table 5.02. Pearson correlation analysis revealed positive correlations between litter accumulation rate (L) and all predictor variables, except annual species density (Table 5.03). L was positively correlated with slope, an effect related to higher canopy cover and litterfall on slopes overhung

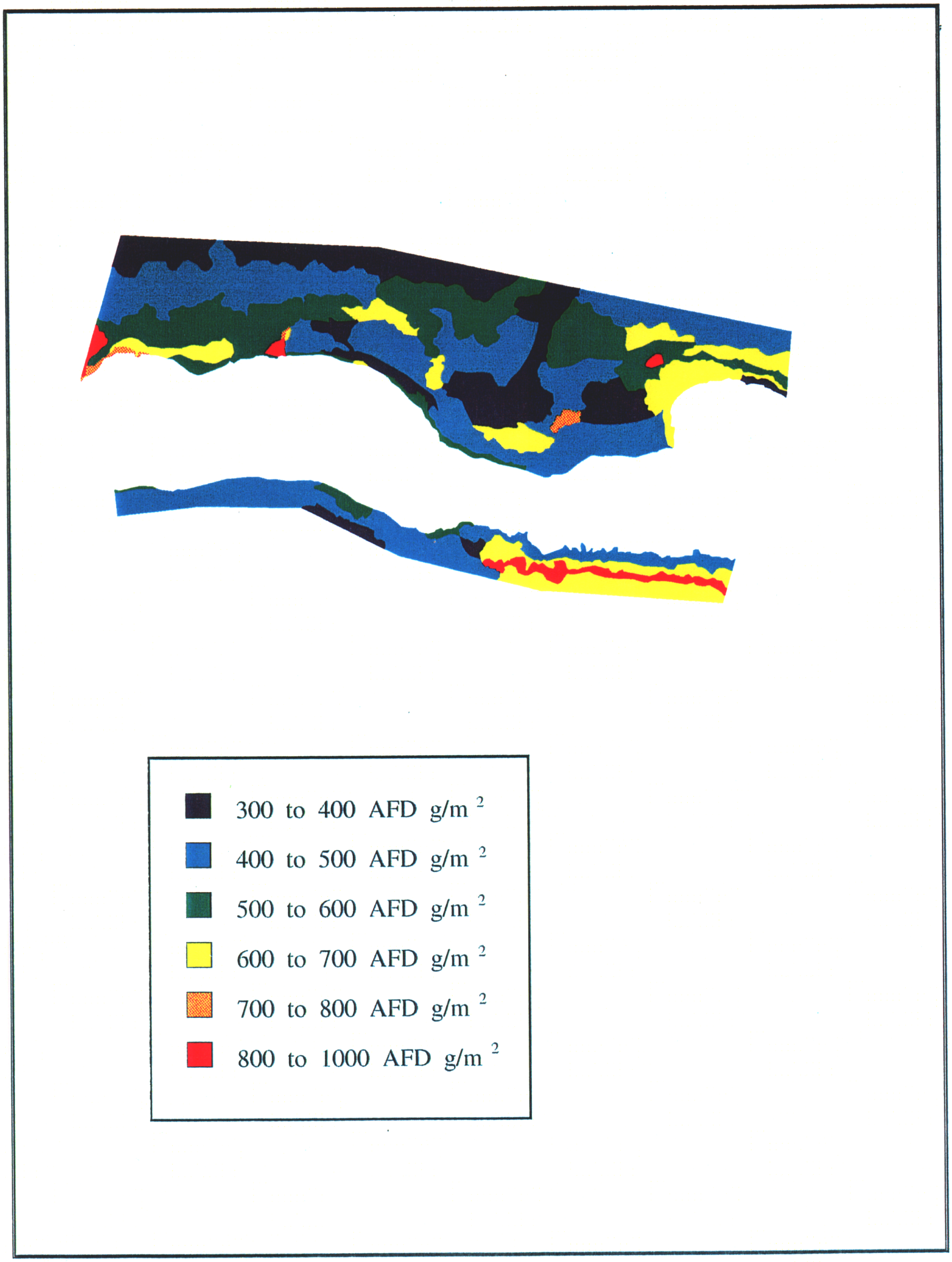


Figure 5.06: GIS overlay of estimated productivity at the Mile 43 study area in 1994.

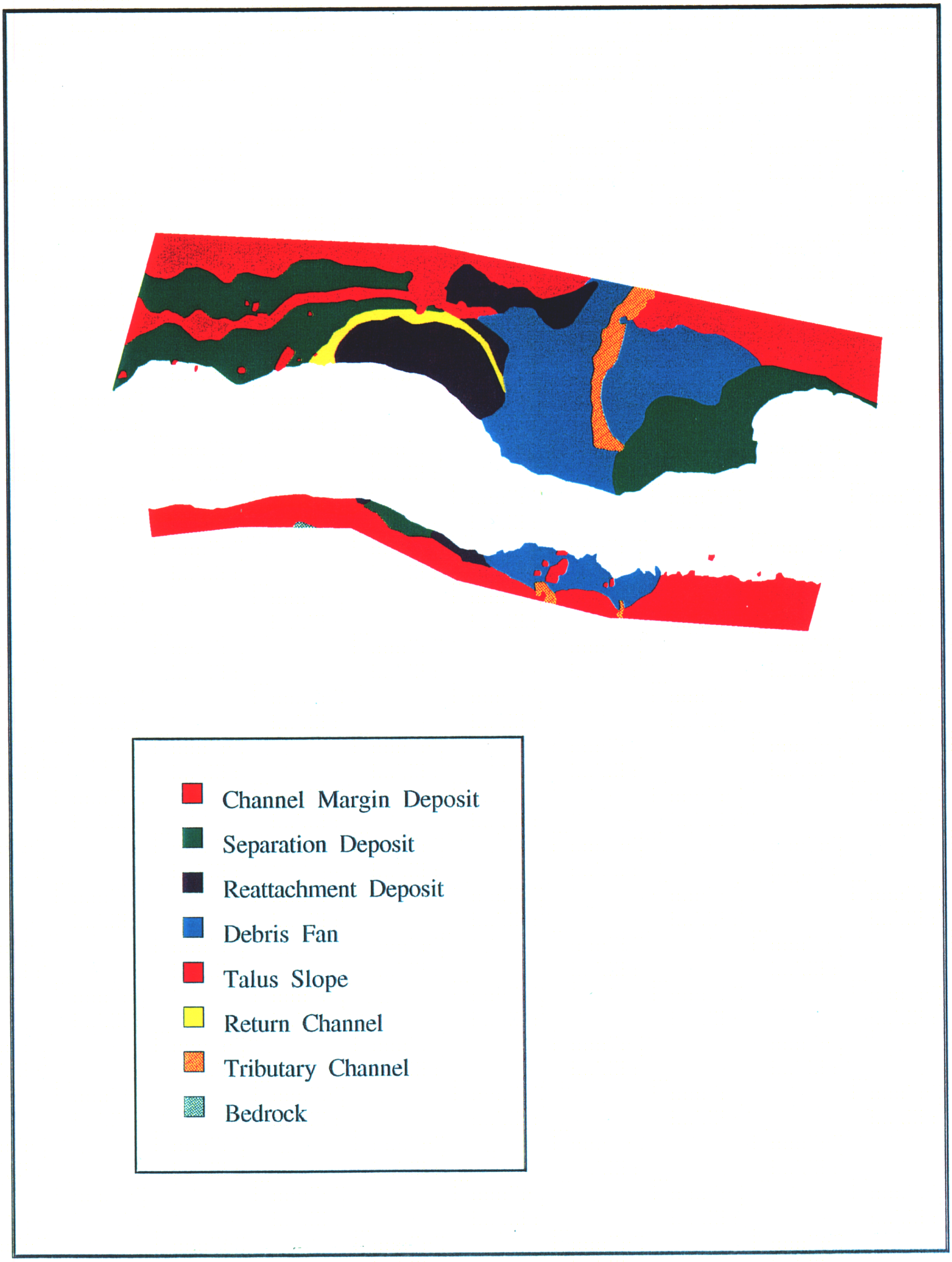


Figure 5.07: GIS overlay of geomorphic environments at the Mile 43 study area in 1994.

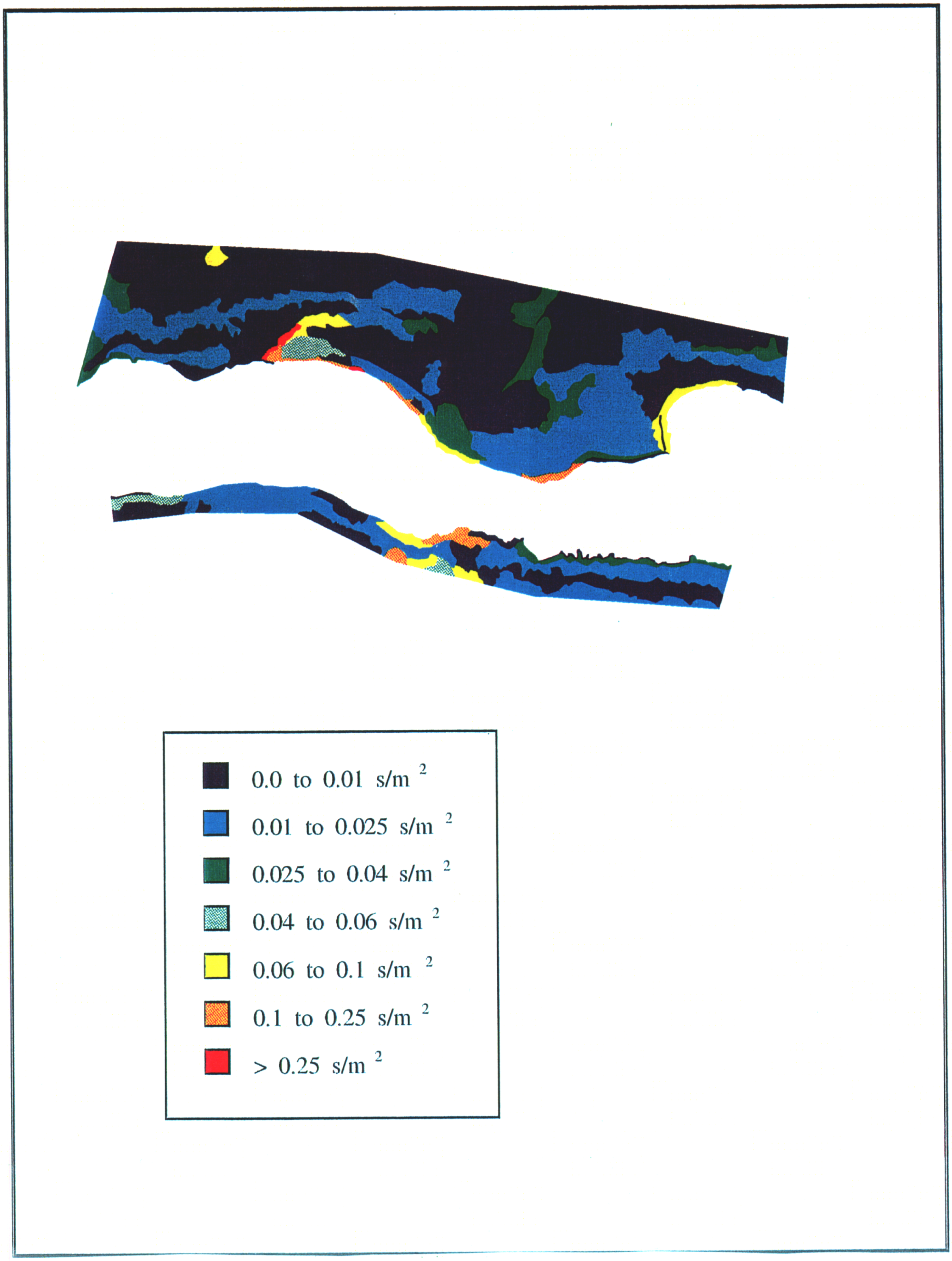


Figure 5.08: GIS overlay of plant species density (number of species (s)/m^2) at the Mile 43 study area in 1994.

Table 5.01: Physical and diversity data for five GIS study areas in the Colorado River corridor in Grand Canyon National Park, Arizona. Mi= river mile from Lees Ferry, AZ. Stage (elevation): 1 = 227-566 m^3/s, 2 = 566-935 m^3/s, 3 = 935-1415 m^3/s, 4 = 1415-3400 m^3/s, 5 = 3400-7080 m^3/s, 6 = 7080-14160 m^3/s, 7 > 14160 m^3/s. GEOMRED: 1 = reattachment or separation bar surface, 2 = return current channel, 3 = debris fan/cobble bar, 4 = talus slope. Soil texture classes: 1 = clay, 2 = silt, 3 = sand, 4 = fine gravel, 5 = coarse gravel, 6 = cobble/small boulder (< 1.0 m), 7 = large (>1.0 m) boulder, 8 = bedrock.

MI	STAGE	GEOMRED	NO. OF POLYGONS	MEAN AREA (m	ISD AREA (m	TOTAL AREA(m2)	MEAN %SOIL MOISTURE	ISD %SOIL MOISTURE	MEAN SOIL TEXTURE*	ISD SOIL TEXTURE	MEAN SLOPE (o)	ISD SLOPE (o)	MEAN LITTER DEPTH (cm)	ISD DUFF/LITTE DEPTH(cm)	MEAN GROUND COVER	ISD % GROUND COVER	MEAN CANOPY COVER	ISD CANOPY COVER	MEAN LITTER ACC. RATE(gC/yr	ISD LAC (gC/yr	MEAN PERENNIAL SPP/m2	ISD PERR. SPP/m2	MEAN ANNUA SPP/m2	ISD ANN. SPP/m2	MEAN TOTAL SPP/m2	ISD TOT. SPP/m2
43	1	1	8	197.8	151.0	1582.7	0.198	0.094	3.000	1.102	11.375	4.922	0.018	0.029	0.125	0.354	1.888	3.026	594.064	108.301	0.105	0.122	0.024	0.034	0.129	0.154
43	1	3	3	114.0	88.2	341.9	0.163	0.042	4.000	0.866	5.000		0.033	0.029	0.333	0.577	0.000	0.000	536.862	43.195	0.083	0.079	0.028	0.024	0.111	0.103
43	1	4	1				0.197		5.600				0.000		0.000		0.000		585.954							
43	2		1	441.9		441.9	0.165		2.750		6.000		0.230		1.000		3.000		808.432		0.032		0.016		0.048	
43	2	1	10	334.7	269.5	3346.7	0.080	0.086	3.095	0.809	9.000	6.261	0.819	1.213	0.625	0.518	2.219	2.024	497.872	130.291	0.034	0.031	0.008	0.008	0.044	0.038
43	2	2	5	50.1	31.3	250.5	0.154	0.100	2.000	0.000	1.200	1.643	0.598	0.352	1.000	0.000	6.434	3.598	727.167	180.417	0.383	0.149	0.076	0.041	0.438	0.179
43	2	3	4	710.1	476.8	2840.5	0.077	0.026	3.500	0.612	18.000		0.438	0.684	0.875	1.181	2.583	3.098	512.877	59.157	0.041	0.042	0.009	0.008	0.049	0.049
43	2	4	1	617.5		617.5															0.023		0.005		0.028	
43	3	1	12	877.3	997.4	10527.0	0.017	0.015	2.900	0.357	12.375	7.539	1.804	1.293	0.417	0.515	6.195	4.812	523.719	134.087	0.028	0.026	0.011	0.014	0.039	0.038
43	3	2	2	478.8	234.1	957.5	0.038	0.008	2.750	0.354	14.500	6.364	2.840	2.348	1.000	0.000	6.125	2.652	612.007	22.047	0.032	0.017	0.010	0.008	0.043	0.025
43	3	3	4	884.5	1229.4	3537.9	0.023	0.015	4.313	0.775	12.500	2.121	0.083	0.069	0.250	0.500	1.043	1.787	383.529	24.584	0.050	0.059	0.009	0.012	0.059	0.072
43	3	4	1	763.5		763.5															0.012		0.001		0.013	
43	4	1	2	893.1	935.0	1786.2	0.018	0.023	3.000	0.000			1.840	2.249	0.000	0.000	10.750	15.203	578.558	255.679	0.008	0.006	0.005	0.005	0.014	0.001
43	4	3	5	896.3	1032.8	4481.6	0.021	0.011	3.132	0.456	22.000	18.971	0.828	0.690	0.400	0.548	6.400	9.456	527.380	205.330	0.015	0.008	0.006	0.004	0.021	0.010
43	4	4	6	1337.6	526.5	8025.8	0.036	0.015	3.877	1.051	10.333	5.033	1.509	1.375	1.417	2.060	5.250	1.866	569.570	93.323	0.011	0.004	0.001	0.001	0.011	0.005
43	5	1	2	2750.3	2090.1	5500.7	0.055	0.068	2.065	0.092	22.500	3.536	1.055	1.098	0.500	0.707	3.625	1.945	513.267	28.870	0.008	0.007	0.002	0.001	0.009	0.008
43	5	3	5	1008.7	530.2	4034.9	0.011	0.010	3.158	0.189			1.170	1.491	0.250	0.500	2.250	2.723	456.450	108.145	1.138	2.509	0.002	0.002	1.138	2.508
43	5	4	7	448.4	418.7	3138.9	0.029	0.023	2.679	0.773	30.200	8.979	1.421	2.008	0.857	0.378	6.357	3.567	543.724	185.530	0.044	0.038	0.010	0.009	0.055	0.045
43	6		1				0.025		2.500				2.600		1.000		7.000		808.585							
43	6	1	1	411.5		411.5	0.030		2.670		15.000		0.250		1.000		0.000		407.637		0.019		0.007		0.027	
43	6	3	1	2238.6		2238.6	0.008		3.000				2.400		1.000		8.250		558.030		0.002		0.001		0.003	
43	6	4	8	1532.3	1439.7	7993.8	0.017	0.019	3.428	1.103	21.887	4.041	1.372	2.495	0.400	0.548	3.450	4.458	482.954	135.811	0.022	0.023	0.004	0.008	0.026	0.029
43	7	4	2	2010.9	1084.8	4021.8	0.082		4.830				0.080		0.000		1.000		475.207		0.008	0.004	0.001	0.001	0.008	0.003
55.5	1	1	3	789.8	424.1	2369.4	0.174	0.105	2.877	0.125	2.000		0.100	0.173	0.333	0.577	1.833	3.175	1729.4	2024.7	0.031	0.016	0.007	0.005	0.038	0.020
55.5	1	2	5	448.1	181.5	2240.3	0.307	0.105	2.188	0.239	8.000	5.292	1.215	1.345	1.000	0.000	14.813	19.472	1367.2	1047.4	0.036	0.028	0.008	0.008	0.044	0.034
55.5	2	1	20	458.0	285.0	9160.5	0.130	0.070	2.673	0.926	4.571	6.630	1.393	1.021	0.850	0.386	11.275	6.016	826.824	255.873	0.033	0.019	0.010	0.006	0.043	0.022
55.5	2	2	1	460.2		460.2	0.231		2.380				1.050		1.000		7.500		851.805		0.020		0.009		0.028	
55.5	3		2	514.1	488.2	1028.2	0.000		3.000		14.000		0.380		0.000		1.750		350.060		0.077		0.036		0.112	
55.5	3	1	6	568.9	546.0	3413.1	0.015	0.015	2.862	0.428	2.333	1.155	1.213	0.869	0.333	0.516	9.418	7.280	570.352	192.613	0.017	0.011	0.008	0.008	0.025	0.018
55.5	3	2	1	1021.8		1021.8	0.033		3.000		5.000		0.850		1.000		10.000		591.064		0.006		0.001		0.007	
55.5	4	1	1	209.1		209.1	0.005		3.000				6.900		0.000		11.000		711.755							
55.5	4		1	579.3		579.3	0.008		3.000		1.000		0.130		0.000		1.250		371.568		0.016		0.007		0.022	
55.5	4	1	4	1711.0	2908.8	6844.2	0.008	0.007	3.000	0.000	3.000		1.565	1.789	0.500	0.707	8.500	4.243	532.663	138.507	0.008	0.008	0.005	0.005	0.012	0.010
55.5	5	1	2	1171.5	427.6	2342.9	0.034	0.048	3.000	0.000	15.000		0.325	0.389	0.500	0.707	6.250	6.718	489.341	2.837	0.005	0.004	0.002	0.001	0.007	0.005
55.5	5	4	1	3284.5		3284.5	0.013		2.750				7.930		1.000		6.500		680.144		0.002		0.001		0.003	
55.5	6	1	3	976.2	804.9	2928.5	0.000		3.000		17.000	11.314	0.330		1.000		7.000		401.124		0.011	0.004	0.005	0.003	0.017	0.007
55.5	6	4	2	2083.3	2246.1	4166.6	0.004	0.001	2.815	0.445			0.105	0.035	1.000	0.000	2.875	0.884	375.987	15.256	0.012	0.014	0.002	0.002	0.015	0.018
88	1	1	5	828.2	1220.4	4131.0	0.212	0.124	2.200	0.740			0.288	0.240	0.400	0.548	2.800	2.986	683.255	197.858	0.030	0.035	0.006	0.006	0.038	0.040
88	1	3	1	290.4		290.4	0.192		3.000		10.000		0.000		1.000		3.000		610.058		0.010		0.000		0.010	
88	2	1	9	407.1	313.1	3664.0	0.078	0.056	2.761	0.418	3.000		0.278	0.206	0.429	0.535	4.049	2.512	523.818	103.013	0.033	0.043	0.011	0.025	0.043	0.087
88	2	3	1	179.3		179.3	0.241		2.670		4.000		1.030		1.000		7.670		867.118		0.050		0.011		0.061	
88	3	1	9	588.1	735.2	5292.7	0.028	0.034	2.875	0.354	3.000	1.414	1.830	2.566	0.125	0.354	6.490	4.796	544.466	248.337	0.015	0.012	0.006	0.007	0.021	0.019
88	3	3	3	761.5	744.9	2284.5	0.008	0.007	3.333	0.577			0.227	0.197	0.000	0.000	1.610	1.397	373.881	36.001	0.022	0.021	0.007	0.004	0.030	0.025
88	3	4	1	550.2		550.2	0.005		2.830		15.000		0.270		1.000		5.330		395.002		0.015		0.002		0.018	
88	4	1	9	1740.8	1499.7	15667.1	0.136	0.358	2.944	0.187	5.000		0.963	1.578	0.222	0.441	7.832	5.274	492.075	141.427	0.004	0.003	0.002	0.001	0.006	0.004
88	4	3	2	2656.4	3083.6	5312.8	0.006	0.008	3.500	0.707			0.030	0.000	0.000	0.000	2.830	2.121	384.269	15.225	0.010	0.012	0.007	0.008	0.017	0.021
88	4	4	2	89.2	94.8	178.5	0.012		3.000		8.000		0.800		0.000		8.000		508.952		0.055	0.050	0.029	0.023	0.084	0.073
88	5	1	4	1164.9	632.9	4659.5	0.014	0.018	3.000	0.000	4.000	2.828	2.125	1.813	0.000	0.000	10.418	3.745	578.026	93.744	0.003	0.002	0.002	0.001	0.004	0.004
88	5	3	1	265.4		265.4	0.012		4.000		2.000		0.000		1.000		0.000		359.170		0.015		0.011		0.026	
88	5	4	2	519.9	402.7	1039.7	0.020		3.000		5.000		0.238		1.000		0.000		********		0.006	0.003	0.007	0.008	0.013	0.012
88	6	3	1	611.4		611.4	0.011		2.500				4.500		1.000		2.000		539.325		0.003		0.002		0.005	
88	6	4	3	804.6	735.3	2413.9	0.012	0.007	2.750	0.354	19.500	14.849	0.100	0.141	0.000	0.000	0.000	0.000	384.793	5.551	0.006	0.006	0.002	0.002	0.008	0.008

MI	STAGE	GEOMRED	NO. OF POLYGONS	MEAN AREA (m	1SD AREA (m	TOTAL AREA(m2)	MEAN %SOIL MOISTURE	1SD %SOIL MOISTURE	MEAN SOIL TEXTURE*	1SD SOIL TEXTURE	MEAN SLOPE (o)	1SD SLOPE (o)	MEAN LITTER DEPTH (cm)	1SD DUFF/LITTE DEPTH(cm)	MEAN GROUND COVER	1SD % GROUND COVER	MEAN CANOPY COVER	1SD CANOP COVER	MEAN LITTER ACC. RATE(gC/yr	1SD LAC (gC/yr	MEAN PERRENIAL SPP/m2	1SD PERR. SPP/ m2	MEAN ANNUA SPP/m2	1SD ANN. SPP/ m2	MEAN TOTAL SPP/m2	1SD TOT. SPP/ m2
123	1	1	4	505.069	533.832	********	0.163	0.079	3.438	1.760	4.000		0.750	1.500	0.000	0.000	0.000	0.000	582.244	8.632	0.020	0.027	0.010	0.013	0.031	0.041
123	1	3	6	346.094	241.730	********	0.150	0.056	4.000	1.061	6.333	7.506	0.094	0.093	0.600	0.548	1.100	0.894	548.386	71.907	0.047	0.048	0.022	0.019	0.069	0.066
123	2	1	10	481.629	449.387	********	0.033	0.036	3.188	1.710	6.500	3.507	0.800	1.767	0.375	0.518	4.350	5.271	913.008	897.705	0.030	0.024	0.018	0.020	0.047	0.038
123	2	3	7	436.190	423.542	********	0.031	0.058	3.714	0.951	7.600	5.683	0.029	0.076	0.286	0.488	0.286	0.756	380.337	93.571	0.113	0.199	0.041	0.054	0.154	0.243
123	3		1	76.950		76.950	0.007																			
123	3	1	7	413.022	290.212	********	0.009	0.006	3.214	0.567	2.333	2.517	0.621	1.068	0.714	0.488	6.429	6.003	456.933	109.838	0.024	0.013	0.013	0.017	0.038	0.019
123	3	3	14	491.914	852.251	********	0.011	0.010	3.615	0.712	11.143	12.720	0.738	1.288	0.385	0.506	5.154	4.811	451.346	132.462	0.086	0.167	0.016	0.014	0.101	0.179
123	3	4	1	152.571		152.571																				
123	4	1	2	211.730	246.714	423.460	0.000		3.500	0.707			0.200	0.141	1.000	0.000	4.500	0.707	377.935		0.162	0.189	0.084	0.108	0.246	0.297
123	4	3	13	********	810.865	********	0.099	0.298	3.231	0.388	4.600	4.336	0.550	0.824	0.308	0.480	4.538	6.132	425.040	98.305	0.014	0.009	0.004	0.005	0.018	0.013
123	4	4	7	534.827	337.317	********	0.007	0.006	3.000	0.000	20.000		0.175	0.098	0.500	0.577	3.000	2.708	383.811	46.275	0.033	0.029	0.005	0.003	0.039	0.031
123	5	3	10	********	********	********	0.015	0.007	3.250	0.463	5.200	1.924	0.129	0.168	0.750	0.463	5.416	4.414	429.946	54.939	0.025	0.038	0.005	0.006	0.030	0.045
123	5	4	6	********	********	********	0.015	0.010	3.000	0.000	22.000		0.640	0.764	1.000	0.000	6.200	3.114	467.973	50.428	0.012	0.014	0.003	0.004	0.018	0.019
123	6	3	1	********		********	0.000		3.000		0.000		0.200		0.000		13.000		462.782		0.002		0.001		0.003	
209	1	1	5	256.071	431.481	********	0.146	0.098	3.026	0.488	17.500	10.607	0.106	0.150	0.400	0.548	4.600	6.338	599.681	166.194	0.220	0.166	0.051	0.042	0.271	0.187
209	2	1	12	254.443	269.448	********	0.074	0.074	2.971	0.577	5.500	6.740	1.190	1.493	0.583	0.515	13.000	16.591	865.737	813.697	0.099	0.117	0.027	0.024	0.126	0.138
209	2	3	8	280.208	242.125	********	0.025	0.022	3.969	1.366	2.400	1.517	0.556	0.747	0.375	0.518	6.938	7.033	513.786	165.934	0.063	0.054	0.019	0.016	0.081	0.069
209	3	1	10	350.174	176.977	********	0.025	0.039	2.889	0.220	12.200	9.859	1.214	1.169	0.444	0.527	9.034	8.284	566.940	181.867	0.033	0.034	0.016	0.038	0.049	0.070
209	3	3	5	393.027	303.282	********	0.017	0.006	4.300	0.570	3.000		0.570	0.543	0.600	0.548	6.100	3.912	453.654	50.464	0.038	0.014	0.009	0.005	0.047	0.019
209	4		1	867.375		867.375	0.030		4.000		15.000		0.500		1.000		4.500		481.510		0.021		0.005		0.025	
209	4	1	10	948.206	917.135	********	0.014	0.002	3.167	0.707	2.333	1.528	0.892	1.422	0.667	0.500	5.266	3.647	456.793	78.101	0.019	0.019	0.005	0.005	0.023	0.023
209	4	3	4	277.366	126.010	********	0.017	0.005	3.500	0.577			0.300	0.469	0.500	0.577	0.500	0.577	391.541	26.281	0.036	0.010	0.012	0.005	0.048	0.013
209	5	1	11	********	********	********	0.013	0.007	2.889	0.333	16.000	11.158	0.748	0.466	1.000	0.000	5.455	5.087	852.351	826.349	0.011	0.009	0.011	0.016	0.022	0.022
209	5	3	2	313.415	128.728	626.829	0.009	0.001	3.500	0.707			0.150	0.212	0.500	0.707	5.000	7.071	422.013	95.684	0.047	0.017	0.015	0.011	0.061	0.028
209	6	1	6	418.392	383.353	********	0.012	0.005	2.458	0.459	2.000		1.833	2.353	1.000	0.000	8.167	5.529	491.484	156.087	0.017	0.013	0.024	0.020	0.040	0.033

Table 5.02: Summary of mean physical characteristics and diversity data for five GIS study areas in the Colorado River corridor in Grand Canyon National Park, Arizona. Mi = river mile from Lees Ferry, AZ. Stage (elevations): 1 = 227-566 m^3/s, 2 = 566-935 m^3/s, 3 = 935-1415 m^3/s, 4 = 1415-3400 m^3/s, 5 = 3400-7080 m^3/s, 6 = 7080-14160 m^3/s, 7 > 14160 m^3/s. GEOMRED: 1 = reattachment or separation bar surface environment, 2 = return current channel environment, 3 = debris fan/cobble bar environment, 4 = talus slope environment. Soil texture classes: 1 = clay, 2 = silt, 3 = sand, 4 = fine gravel, 5 = coarse gravel, 6 = cobble/small boulder, 7 = boulder, 8 = bedrock.

GEOMOR ENVIR	MEAN %SOIL MOIST	MEAN REL. SOIL TEXT	MEAN LITTER+ DUFF DPTH(cm)	MEAN %GROUND COVER	MEAN TOTAL CANOPY CONTACTS	MEAN POLYGN AREA(m2)	MEAN EST'D LITTER ACCUM. RATE (g C/m2/yr)	MEAN SLOPE(o)	MEAN PER.SPP. DEN/m2	MEAN TOT.SPP. DEN/m2	MEAN INUND FREQ.
BREAKDOWN BY GEOMORPHIC ENVIRONMENT:											
1	0.068	2.904	1.036	0.509	6.793	697.721	657.180	8.284	0.037	0.050	0.127
2	0.180	2.279	1.186	1.000	10.090	352.166	905.501	5.083	0.158	0.192	0.233
3	0.045	3.561	0.487	0.444	3.882	820.211	457.993	6.965	0.046	0.058	0.098
4	0.026	3.145	1.080	0.629	4.331	1010.130	549.394	13.532	0.024	0.029	0.026
BREAKDOWN BY MILE:											
MILE											
43	0.067	3.118	0.967	0.512	4.240	766.507	537.605	11.881	0.057	0.070	---
56	0.105	2.735	1.345	0.696	9.370	770.165	812.370	7.164	0.026	0.034	---
68	0.072	2.877	0.894	0.283	5.128	893.684	565.746	6.541	0.018	0.024	---
123	0.045	3.373	0.480	0.474	4.197	809.810	513.964	7.563	0.047	0.062	---
209	0.035	3.204	0.887	0.632	7.331	590.500	624.247	7.722	0.050	0.067	---
BREAKDOWN BY STAGE:											
STAGE											
1	0.190	3.118	0.284	0.395	3.230	417.329	780.051	10.079	0.067	0.087	0.325
2	0.084	3.028	0.846	0.623	7.171	387.008	699.870	6.297	0.071	0.091	0.125
3	0.017	3.234	1.048	0.417	6.191	567.732	499.910	8.312	0.038	0.050	0.075
4	0.052	3.199	0.871	0.400	5.339	1085.330	468.089	7.409	0.023	0.030	0.003
5	0.018	2.984	1.003	0.711	5.676	1303.040	627.560	11.074	0.019	0.026	<0.001
6	0.012	2.859	1.297	0.700	5.113	1171.560	451.620	11.848	0.014	0.023	<<0.001
7	0.082	4.630	0.080	0.000	1.000	2010.910	475.207	6.674	0.008	0.008	<<<0.001

Table 5.03: Pearson correlation analysis with a Bonferroni adjustment between several GIS variables at study areas on which litter accumulation rates were measured. S/m^2 is species density.

	Estimated Litter Accum. Rate	Inundation Frequency	Slope	Duff Depth (cm)	% Soil Moisture	Perennial S/m^2	Annual S/m^2
Estimated Litter Accum. Rate	1.000 (0.000)						
Inundation Freq.	0.259 (0.006)	1.000 (0.000)					
Slope	0.212 (0.006)	0.005 (1.000)	1.000 (0.000)				
Duff Depth (cm)	0.280 (<0.001)	-0.158 (0.151)	-0.054 (1.000)	1.000 (0.000)			
% Soil Moisture	0.485 (<0.001)	0.702 (<0.001)	0.006 (1.000)	-0.016 (1.000)	1.000 (0.000)		
Perennial S/m^2	0.179 (0.047)	0.256 (<0.001)	0.016 (1.000)	-0.107 (1.000)	0.320 (<0.001)	1.000 (0.000)	
Annual S/m^2	0.077 (1.000)	0.227 (0.002)	0.003 (1.000)	-0.120 (1.000)	0.179 (0.049)	0.795 (<0.001)	1.000 (0.000)

by dense vegetation. Percent soil moisture was positively correlated with perennial and annual species density. Also, perennial and annual species density was positively correlated.

Disturbance intensity varied across the riparian landscape in a fashion consistent with stage relations (Figs. 5.09 and 5.10). Mean species density remained uniformly low (ca. $0.035/m^2$) on the pre-dam terraces. Mean species density reached a highly variable maximum of $0.085/m^2$ at stage elevations that were inundated 15 to 43 percent of the days from 1922 to 1989, and then abruptly decreased to near zero when daily inundation frequency approached 50 percent.

Total species density varied in the predicted fashion with respect to disturbance (Connell 1978), but diversity was monotonically, positively correlated with productivity only at intermediate disturbance levels. This lends support to Huston's (1979, 1994) model, but results in a pattern not predicted by that model. Diversity was strongly skewed towards the water's edge (Fig. 5.09), providing evidence of suppor for Miller's (1982) contention that diversity need not be maximal at the middle of disturbance gradients.

The positive correlation between species density and productivity was strongly, conditionally dependent on disturbance intensity (Fig. 5.10). At low and high levels of disturbance, diversity was not correlated with productivity; however, at intermediate levels of disturbance, diversity was strongly positively correlated with productivity. This finding supports a variant of the intermediate field hypothesis. However, productivity and disturbance gradients are, themselves, closely correlated in river ecosystems. Low stage elevations are subject to greater disturbance intensity but also have the highest soil moisture availability. Therefore, conditions of high productivity (low stage elevation) and low disturbance intensity (high stage elevation) do not overlap, limiting our ability to fully test the DEH. Overall, this study supports Huston's (1979) contention that diversity is influenced by the interaction between disturbance intensity and productivity.

Stepwise multiple linear regression (SMLR) revealed that soil texture ($p_{2\text{-tailed}} = 0.033$) and interaction between inundation frequency and productivity ($p_{2\text{-tailed}} < 0.001$) exerted weak but significant influences on total plant species density/m²:

$$\log_e S = 0.06 - 0.04\log_e(T) + 0.018\log_e[(\text{arcsine}(I)^{0.5})*L]$$
$$(r = 0.333,\ F_{2,284} = 17.739,\ p < 0.001)$$

where S is species density/m², T is soil texture, I is inundation frequency and L is estimated litter accumulation rate. This pattern was similar when perennial S was analyzed separately ($p < 0.001$) , but annual S was only strongly influenced by I ($p < 0.001$). Because soil texture is strongly correlated with geomorphic environment, these results indicate that riparian plant diversity is influenced jointly by interactions between productivity, disturbance intensity and geomorphology.

A more complete test of the DEH will require experimentation and more detailed analyses of the distribution of riparian vegetation. Stevens (1989) reported that under conditions of low disturbance and high moisture availability at Grand Canyon springs, plant diversity is reduced to just two common species: Phragmites australis and Cladium californicum. These two species vary in dominance apparently in relation to moisture availability, with the former dominant in drier conditions. Under the array of gradients available at desert springs, the central point hypothesis is more likely to be supported.

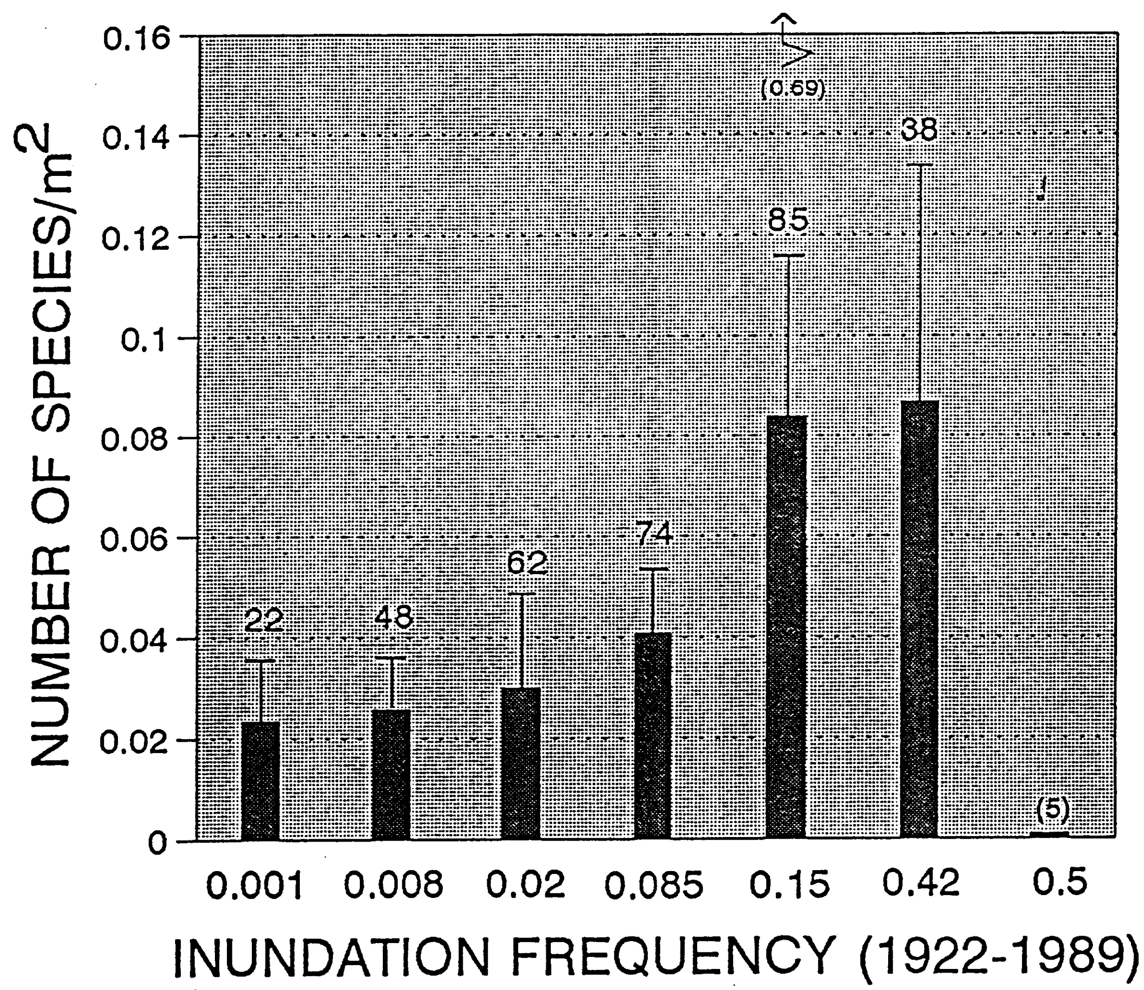


Figure 5.09: Plant species density as a function of inundation frequency (1922-1989) from five study areas along the Colorado River in the Grand Canyon, Arizona. Numbers above bars indicate the number of polygons measured in each inundation frequency zone, and error bars are 1 sd.

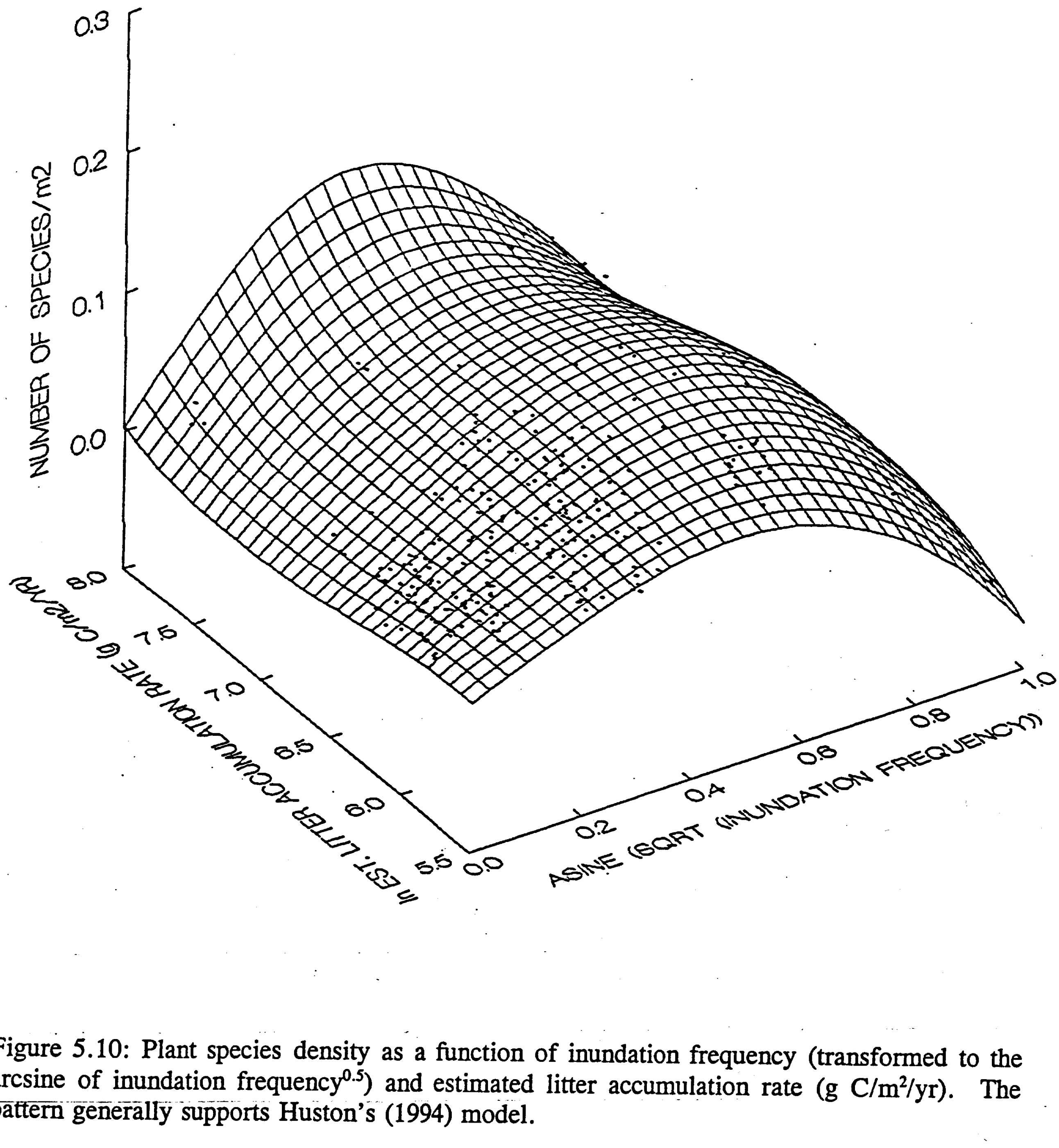


Figure 5.10: Plant species density as a function of inundation frequency (transformed to the arcsine of inundation frequency$^{0.5}$) and estimated litter accumulation rate (g C/m^2/yr). The pattern generally supports Huston's (1994) model.

CHAPTER VI:

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

GENERAL OBSERVATIONS

Interim Flows Effects

Interim flows criteria were designed to limit negative effects of dam operations during the GCD/EIS process, and interim flows are exerting several different short- and longer-term impacts on riparian vegetation in the Colorado River corridor downstream from Glen Canyon Dam. From the 2.5 yr of data analyzed in this report, the consistently lower water levels that characterize interim flows (as compared to the 1987-1991 period of "normal dam operations") have resulted in a rapid, short-term increase in riparian vegetation in the newly stabilized, low elevation portions of the Colorado River corridor. At every site we examined, this "new dry" zone lying between the 566 m^3/s and 890 m^3/s stages, has sustained a surprising amount of primary colonization by emergent herb, macrophyte and clonal perennial vegetation. Thus interim flows are contributing to increased shoreline colonization in the Grand Canyon. Interim flows are, in essence, concentrating riparian plant life to a narrower zone near the water's edge, but where it is certain to be more susceptible to scour during high flow events.

The system-wide extent of the "new dry" zone has not been mapped; however, it varies from approximately 0.5 m on vertical banks in wide reaches, to tens of meters on low-lying sandbars, such as those at the Mile 51.2L and 55.5R study sites. If the mean width of the "new dry" zone is only 1.0 m, this constitutes an additional 41 ha of new riparian habitat in the river corridor. Thus, more marsh and riparian vegetation presently occurs at lower stage elevations than previously in this system.

Longer-term changes associated with interim flows include a gradual dieback of previously established marsh and Salix exigua at high bar positions. We have observed and documented the gradual replacement of marsh vegetation with grasses and willow in previously established fluvial marshes, and the dieback of willow at several study sites. Because non-native Tamarix ramosissima is more drought tolerant than S. exigua (Stevens and Ayers 1993), interim flows may favor T. ramosissima over S. exigua, and retard the rate of successional change taking place on sandbars in this system (Stevens 1989).

Planned Flooding as a Management Strategy

Management strategies that permit non-native plant populations to increase threaten the integrity of established and developing native vegetation communities in the Colorado River corridor and its many pristine tributaries and desert springs. However, direct management of well-established non-native species may be difficult to achieve. Planned high releases outlined in the draft Glen Canyon Dam EIS (U.S. Bureau of Reclamation 1995) present a dilemma for habitat managers who must be simultaneously be concerned with restoration of characteristic geomorphic settings (i.e., large open sandbars and associated backwaters), while also limiting colonization of non-native species. We suggest that at least part of this dilemma may be solved by timing planned flooding so that it coincides with the lowest possible seed density of non-native plant species. For example, peak Tamarix ramosissima seed dispersal occurs in May and June, and decreases throughout the remainder of the growing season. Tamarix ramosissima seed viability is less than 2 months (Stevens 1989) and the lowest viable seed density occurs in late winter in the Grand Canyon. Planned high flows will provide excellent germination conditions for T. ramosissima, and at least one full month, and possibly more time, is required following a flood to allow riparian soils to desiccate, thereby preventing widespread T. ramosissima germination. Therefore, planned high flow events can be timed as late as late March to accomplish geomorphological management objectives while simultaneously allowing sufficient time for riparian soils to desiccate.

Reduced flow variability under interim flows appears to limit T. ramosissima recruitment, and the lack of that species' establishment following the January-February, 1993 floods demonstrates that flooding can be used as a management strategy for reshaping sand bars without causing widespread expansion of the Tamarix population. However, additional research is warranted to understand the rate of soil desiccation following flooding under the range of climatic conditions present in the river corridor. Such research will increase management flexibility in planning high release events, and the potential for expansion of T. ramosissima in this system.

The concentration of vegetation at low stage elevations and dieback at higher stage elevations leaves the riparian vegetation in this system highly susceptible to scour under planned or unplanned high flow events. We consider it probable that interim flows coupled with planned flooding, as outlined in the draft EIS (U.S. Bureau of Reclamation 1995) will result in reduced marsh and other riparian vegetation in this system through time.

The January/February 1993 Little Colorado River floods provided an excellent opportunity to evaluate the potential for planned floods to reactivate and scour return current channels (RCCs). The approximate 5 days of 950 m^3/s were inadequate for RCC reactivation and these short duration flooding events resulted in aggradation of existing RCCs. Prolonged flows of 1150 m^3/s in 1980 failed to alter the morphology of six sandbars under study at that time (Stevens 1985), whereas flows of 2825 m^3/s in 1983 were sufficient to thoroughly scour the 43.1L bar surface and return channel, and those at other sites (Stevens and Waring 1985, Stevens et al. in press). The threshold for activation of RCCs under evaluation as marsh habitats lies between these values. Short duration, low magnitude releases may not be sufficient to maintain characteristic habitats in this system. Management of sandbar geomorphology and associated vegetation in this system may therefore require substantial commitments of water and losses of power revenues.

SPECIFIC CONCLUSIONS

Fluvial Marshes

1) The 1993 inventory revealed that wet marsh (cattail/reed) patch density/km between Lees Ferry and Diamond Creek increased 3.5-fold over the 1991 total (253); however, total estimated fluvial wet marsh area decreased by 22 percent from 9.0 ha to 7.03 ha. Areal losses were related to scour downstream from the Little Colorado River by the January-February 1993 floods, with marsh area losses of up to 90 percent in some narrow reaches. In contrast, the

unflooded section of the river upstream from the Little Colorado River exhibited a slight gain in marsh area during this period. Additional but smaller marshes have developed as a result of flooding impacts and interim flows effects. If these developing marshes are permitted to grow, marsh area can be expected to increase again dramatically; however, planned flooding will undoubtedly scour most of these new marshes, as well as much of the other "new dry" zone vegetation, from the river corridor.

2) Comparison of MIPS analysis of marsh area at 24 sites between 1988 and 1994 reveals a great increase in fluvial marsh area through time up to 1992; however, overall marsh area declined significantly between 1992 and 1993 as a result of Little Colorado River flooding and probably also because of decreased inundation frequency of marsh vegetation at higher stage elevations. These analyses suggest that interim flows are having the hypothesized effect of reducing marsh area and concentrating marsh growth along channel margins and return current channel mouths.

3) Wet marsh cover above the maximum interim flows stage (566 m^3/s) has decreased through the interim flows period, and composition has shifted towards dominance by woody phreatophytes (especially Salix exigua).

4) Silt-rich, low-slope shoreline habitats between the 425 and 566 m^3/s stages (protected from daily inundation) have undergone primary colonization by wet marsh taxa during the interim flows period. Colonization occurred through clonal expansion of existing marsh stands in return current channel mouths and by primary colonization of reattachment point and channel margin settings.

5) Flooding of the Little Colorado River during the January and February 1993 demonstrated that short-duration (5-day) flows of maximum powerplant discharge (950 m^3/s) aggrade RCCs, increasing the baselevel and further reducing inundation frequency. Short-term floods are therefore unlikely to reactivate scour of RCC's, limiting the utility of such events in restoration of RCC habitats. Higher magnitude and/or longer duration flows are required to reform RCC habitats. However, such floods will eliminate increased marsh cover that has developed at low (425-566 m^3/s) stages. The result of coupling an interim flows regime with planned mainstream and erratic tributary floods is likely to reduce fluvial marsh cover in this system.

Xylem Water Potential Studies

1) S. exigua growth was negatively correlated with stage elevation, and stem age, stem length and basal area influenced growth, and is a suitable indicator of marsh moisture stress.

2) Temperature and relative humidity varied in relation to stage elevation, between day and night, between months in 1993 and between sites (over distance downstream from Glen Canyon Dam).

3) Temperature and humidity-adjusted xylem water potential (XWP) varied by time of day, between study sites and between months.

4) Log_n-transformed S. exigua annual stem growth was positively correlated with log_n-transformed distance downstream (D) and with both mean monthly pre-dawn and mean mid-day adjusted XWP values, and was negatively correlated with log_n-transformed ramet age.

5) The distinctive patterns of XWP in S. exigua document a change in water availability and suggests that compositional and structural shifts of previously established fluvial marsh assemblages documented above are related to soil moisture availability.

Other Non-Wetland Vegetation

1) The potential for control of on-going invasions by non-native plants varies between species, with some (e.g., Erianthus ravennae) being rather easily controlled, and others (e.g., Lepidium latifolium) that may not be controlled.

2) MIPS analyses of 1991 and 1994 aerial photographs at six study areas revealed that although the overall cover of riparian vegetation at most study sites is static or increasing, the distribution of vegetation is shifting within sites. Sandbar riparian and wetland vegetation is concentrating between the 566 and 900 m^3/s stages and previously established S. exigua in high bar locations is dying back.

3) Axis 1 DECORANA species scores on long-term quadrats in the lower riparian zone were lower in 1993 relative to 1992 scores, reflecting a gradual shift during interim flows towards sand bar species that are more drought tolerant.

4) The "new dry" zone, lying between the interim flows maximum flow stage (566 m^3/s stage) and the "normal operations" stage (ca. 900 m^3/s stage), was quickly colonized by riparian plant species, particularly herbs, clonal phreatophytes and perennial grasses. , Higher stem density but lower species diversity occurred on fine-grained (silty fine sand) substrata, as compared to cobble and boulder substrata.

Mapping and GIS

1) Data have been compiled in ASCII and Lotus 123 elecronic formats and hard copy formats, and archived at the U.S. Bureau of Reclamation Glen Canyon Environmental Studies Office in Flagstaff, AZ, which is the designated Scientific Information Management site for river corridor data. These data are available for NPS or NBS data storage and maintenance uon request.

2) GIS related mapping of five long-term study areas was completed and has been contributed to the GCES GIS. We used GIS overlay analyses and found support for the dynamic equilibrium and intermediate disturbance models in explaining plant diversity on these sites.

Monitoring, Research and Management Recommendations

Continued monitoring of interim flows effects on fluvial marshes and other riparian vegetation is important because streamside vegetation is a diverse, biologically productive habitat that is subject to inundation by dam discharges and erratic tributary floods. The effects of interim flows on riparian vegetation will be cumulative, with both rapid and more gradual changes in composition and distribution. For example, short-term responses of fluvial marsh vegetation to interim flows may be obscured by exceptionally high precipitation. Therefore, monitoring of fluvial marshes and other new high water zone habitats should be consistent during interim flows, and should be included in long-term monitoring.

Vegetation monitoring in this system can be refined to some extent. We recommend that fluvial marsh transects be monitored only once per year (rather than twice per year), preferably in September or October. The springtime censuses of these study sites is presently compromised by incomplete vegetation development, particularly of Phragmites australis and Typha spp. which leaf out rather slowly. Likewise, we recommend that censusing of long-term quadrats should be conducted once per year in the autumn months, at the end of the growing season. Mapping from aerial photographs may be a useful monitoring approach, but polygon identification and description are likely to vary greatly between technicians, thereby compromising the accuracy and the utility of interpretation.

We recommend that the National Park Service consistently monitor non-native plant invasions, and adopt a rigorous program to limit non-native plant species establishment in this system. Non-native plant species are likely to have long-lasting deleterious impacts on river and tributary ecosystems. Where possible, site specific control measures may be appropriate for clonal non-native species, such as Alhagi camelorum. Lastly, we recommend that unanticipated flow events (unusual high or prolonged low dam releases or exceptional tributary floods) should be investigated as soon afterwards as possible.

CHAPTER VI

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

LITERATURE CITED

LITERATURE CITED

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

Ayers, T.J. R.W. Scott, L.E. Stevens, K. Warren, A.M. Phillips III and M.D. Yard. 1994. Additions to the flora of Grand Canyon National Park. Journal of the Arizona-Nevada Academy of Sciences 28:70-75.

Beus, S.S. and C.C. Avery. 1992. The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam: final report. U.S. Bureau of Reclamation Glen Canyon Environmental Studies Report, Flagstaff, AZ.

Blinn, D.W., L.E. Stevens and J.P. Shannon. 1992. The effects of Glen Canyon Dam on the aquatic food base in the Colorado River corridor in Grand Canyon, Arizona. Bureau of Reclamation Glen Canyon Environmental Studies Report No. II-02, Flagstaff, AZ.

Budhu, M. 1992. Mechanisms of erosion and a model to predict seepage-driven erosion due to transient flow. Chapter II in Beus, S.S. and C. Avery, editors. The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam, Final Report. Bureau of Reclamation Glen Canyon Environmental Studies Report, Flagstaff.

Busch, D.E., N.L. Ingraham, and S.S. Smith. 1992. Water uptake in woody riparian phreatophytes of the southwestern U.S.: a stable isotope study. Ecological Applications 2:450-459.

Carpenter, M.C., R.L. Carruth, J.B. Fink, J.K. Boling and B.L. Cluer. 1992. Hydrogeology of beaches 43.1L and 172.3L and the implications on flow alternatives along the Colorado River in the Grand Canyon. Chapter III in Beus, S.S. and C. Avery, editors. The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam, Final Report. Bureau of Reclamation Glen Canyon Environmental Studies Report, Flagstaff.

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. Pp. 253-260 in Linn, R.M., editor. Proceedings of the First Conference on Scientific Research in the National Parks, Vol. I.

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

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science 199:1302-1309.

Day, R.T., P.A. Keddy, J. McNeill and T. Carleton. 1988. Fertility and disturbance gradients: a summary model for riverine marsh vegetation. Ecology 69:1044-1054.

Donovan, L.A. and J.R. Ehlringer. 1991. Ecophysiological differences among juvenile and reproductive plants of several woody species. Oecologia 86:594-597.

Fenner, P, W.W. Brady, and D.R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. Desert Plants 6: 55-58.

Gregory, S.V., F.J. Swanson, W.A. McKee and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Hale, M.G. and D.M. Orcutt. 1987. The physiology of plants under stress. John Wiley & Sons, New York.

Hill, M.O. 1979. DECORANA, a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Microcomputer Power, Ithaca, New York.

Hupp, C.R. 1988. Plant ecological aspects of flood geomorphology and paleoflood history. Pp. 335-357 in Baker, V.R., editor. Flood geomorphology. John Wiley & Sons, New York.

Huston, M.A. 1979. A general hypothesis of species diversity. American Naturalist 113:81-99.

Huston, M.A. 1994. Biological diversity: the coexistence of species on changing landscapes. Cambridge University Press, Cambridge, UK.

Johnson, R.R. 1991. Historic changes in vegetation along the Colorado River in the Grand Canyon. Pp. 178-206 in Marzolf, G.R. Colorado River ecology and dam management. National Academy Press, Washington, D.C.

Kearney, T.H. and R.H. Peebles (eds). 1960. Arizona flora. University of California Press, Berkeley, CA.

Kozlowski, T.T. 1984. Flooding and plant growth. Academic Press, Inc. Orlando, FL.

Miller, T.E. 1982. Community diversity and interactions between the size and frequency of disturbance. American Naturalist 120:533-536.

Nilsson, C. 1984. Effect of stream regulation on riparian vegetation. Pp 93-106 in Lilliehammer, A. and S.J. Saltveit, editors. Regulated rivers. Oxford Univ. Press, NY.

Nilsson, C., G. Grelsson, M. Johansson and J. Sperens. 1989. Patterns of plant species richness along riverbanks. Ecology 70: 77-84.

Odum, E.P. 1981. The effects of stress on the trajectory of ecological succession. Pp 43-47 in G.W. Barret and R.Rosenberg, eds. Stress effects on natural ecosystems. John Wiley & Sons, N.Y.

Patten, D.T. 1990. Glen Canyon Environmental Studies Phase II integrated research plan. Bureau of Reclamation Glen Canyon Environmental Studies, Salt Lake City, UT.

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

Price, P.W. 1989. Clonal development of coyote willow, Salix exigua (Salicaceae), and attack by the shoot-galling sawfly, Euura exiguae (Hymenoptera: Tenthridinidae). Environmental Entomology 18:61-68.

Rice, W.R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Schmidt, J.C. and J. B. Graf. 1990. Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona. U.S. Geological Survey Professional Paper 1493.

Schollander, P.F., H.T. Hammel, E. D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Simcox, D.E. and E.H. Zube. 1985. Arizona riparian areas: a bibliography. Suppl. to Johnson, R.R. lead editor. Riparian ecosystems and their management: reconciling conflicting uses. U.S. Department of Agriculture Forest Service General Technical Report RM-120. Washington.

Stevens, L.E. 1989. Mechanisms of riparian plant community organization and succession in the Grand Canyon, Arizona. Northern Arizona Univ. PhD Dissertation, Flagstaff.

Stevens, L.E. and T.J. Ayers. 1993. The effects of Glen Canyon Dam on the Riparian Vegetation of the Colorado River corridor downstream from Glen Canyon Dam, Arizona, final report. Cooperative Parks Studies Unit, Northern Arizona University, Flagstaff, AZ.

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

Stevens, L.E. and G.L. Waring. 1985. The effects of prolonged flooding on riparian vegetation. In Johnson, R.R. lead editor. Riparian ecosystems and their management: reconciling conflicting uses. U.S. Department of Agriculture Forest Service General Technical Report RM-120. Washington, D.C.

Stevens, L.E. and G.L. Waring. 1988. Effects of post-dam flooding on riparian substrates, vegetation, and invertebrate populations in the Colorado River corridor in Grand Canyon, Arizona. U.S.D.I. Bureau of Reclamation Glen Canyon Environmental Studies Rept. No. 19. NTIS No. PB88183488/AS.

Stromberg, J.C. and D.T. Patten. 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers 2:221-235.

Stromberg, J.C. S.D. Wilkins and J.A. Tress. 1993. Vegetation-hydrology models: implications for management of Prosopis velutina (velvet mesquite) riparian ecosystems. Ecological Applications 3: 307-314.

Ter Braak, C.J.F. 1992. CANOCO, v. 2.1. Microcomputer Power, Ithaca, NY.

Turner, R.M. and M.M. Karpiscak. 1980. Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. U.S. Geological Survey Professional Paper 1132.

Wilkinson, L. 1991. SYSTAT: the system for statistics. SYSTAT, Inc., Evanston, IL.

U.S. Bureau of Reclamation. 1995. Operation of Glen Canyon Dam, final Environmental Impact Statement. Bureau of Reclamation, Salt Lake City, UT.

COOPERATIVE AGREEMENT: CA 8021-8-0002

NAME: THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA: FINAL ADMINISTRATIVE REPORT

PRINCIPAL INVESTIGATOR: LAWRENCE E. STEVENS AND TINA J. AYERS

GOVERNMENT TECHNICAL REPRESENTATIVE: DR. PETER G. ROWLANDS

SHORT TITLE OF WORK: FINAL ADMINISTRATIVE REPORT

STARTING DATE: 15 JUNE, 1992

DURATION: 27 Months

DATE OF THIS REPORT: 31 DECEMBER, 1995

FUNDING AMOUNT: $262,410.00

SUPPORTED BY: The Bureau of Reclamation
Glen Canyon Environmental Studies Program
P.O. Box 22459
Flagstaff, AZ 86002-2459

SUBMITTED TO: The National Biological Service
Northern Arizona University, Box 5614
Flagstaff, AZ 86011

COOPERATIVE AGREEMENT: CA 8021-8-0002

NAME: THE EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON RIPARIAN VEGETATION ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK, ARIZONA: FINAL ADMINISTRATIVE REPORT

PRINCIPAL INVESTIGATOR: LAWRENCE E. STEVENS AND TINA J. AYERS

GOVERNMENT TECHNICAL REPRESENTATIVE: DR. PETER G. ROWLANDS

SHORT TITLE OF WORK: FINAL ADMINISTRATIVE REPORT

STARTING DATE: 15 JUNE, 1992

DURATION: 27 Months

DATE OF THIS REPORT: 31 DECEMBER, 1995

FUNDING AMOUNT: $262,410.00

SUPPORTED BY: The Bureau of Reclamation
Glen Canyon Environmental Studies Program
P.O. Box 22459
Flagstaff, AZ 86002-2459

SUBMITTED TO: The National Biological Service
Northern Arizona University, Box 5614
Flagstaff, AZ 86011

ADMINISTRATIVE REPORT
BIO 35J3

ITEM	FY92		FY93		FY94		TOTAL	
	ESTIMATE	ACTUAL	ESTIMATE	ACTUAL	ESTIMATE	ACTUAL	ESTIMATE	ACTUAL
SALARY								
Co-PI Ayers	$6700	-0-	$11,300	$6420	$6700	-0-	$24,700	$6420
Crew leader	$8000	$877	$30,000	$23,735	$20,000	$24,278	$58,000	$48,890
Photo Analyst	$4000	-0-	$16,000	$18,461	-0-	-0-	$20,000	$18,461
Field Crew	$17,200	$15,165	$39,200	$56,440	$19,100	$20,659	$75,500	$92,264
total ERE's		$1482		$16,455		$8424		$26,361
subtotal	$38,270	$17,524	$102,150	$121,511	$47,990	$53,361	$188,340	$192,396
TRAVEL	$1000	$335	$1700	$1764	$1500	$987	$4,200	$3,086
EQUIPMENT	$4000	-0-	$1040	$5296	$500	-0-	$5,540	$5,296
SUPPLIES	$5000	$922	$6500	$4176	$4530	$6318	$16,530	$11,416
SOIL ANALYSES	$1500	-0-	$3000	-0-	-0-	$2903	$4,500	$2,903
TOTAL DIRECT COSTS	$49,770	$18,925	$114,390	$132,602	$54,520	$63,570	$218,680	$215,097
TOTAL INDIRECT (20% NAU)	$9950	$3969	$22,880	$27,356	$10,090	$11,662	$43,730	$42,987
TOTAL	$59,720	$22,894	$137,270	$159,958	$65,420	$75,232	$262,410	*$258,084

*The remaining balance of $4,326 will be spent on salary and supplies ($3,615) and indirect costs ($711). We anticipate completion of the grant by 31 January 1995.

ADMINISTRATIVE REPORT -- BIO 35J5

ITEM	FY93		FY94		TOTAL	
	ESTIMATE	ACTUAL	ESTIMATE	ACTUAL	ESTIMATE	ACTUAL
SALARY						
Field Crew	$2,625	$1,560	$2,625	$4,675	$5,250	$6,235
Benefits	$208	$149	$208	$443	$416	$592
Total	$2,833	$1,709	$2,833	$5,118	$5,666	$6,827
FIELD SUPPLIES	$500	$203	$500	-0-	$1,000	$203
TOTAL DIRECT COSTS	$3,333	$1,912	$3,333	$5,118	$6,666	$7,030
TOTAL INDIRECT (20% NAU)	$667	$382	$667	$285	$1,334	$667
TOTAL	$4,000	$2,294	$4,000	$5,403	$8000	$7,697*

* A remainder of $302.31 was left unspent as of 1 Oct 1994.

ACCOUNT BIO 35J3 FROM 7/1/92-10/10/94

ACCOUNT RECAP

CATEGORY	Budget	Amount Encum	Amount Expended	Encum + Expenditures	Available Balances	% USED
Salaries - Full Time			73,770.82	73,770.82		
Salaries - Occasional			84,247.42	84,247.42		
Salaries - Student Wage			8,016.53	8,016.53		
TOTAL SALARIES	178,200.00	0.0	166,034.77	166,034.77	12,165.23	93%
TOTAL ERE	10,210.00	0.00	26,361.30	26,361.30	(16,151.30)	258%
OPERATIONS	21,570.00	0.00	16,712.26	16,712.26	4,857.74	77%
TRAVEL	4,200.00	0.00	3,085.76	3,085.76	1,114.24	73%
ANALYSES	4,500.00	0.00	2,902.50	2,902.50	1,597.50	65%
TOTALS	218,680.00	0.00	215,096.59	215,096.59	3,583.41	98%
INDIRECT	43,730.00	710.73	42,987.24	43,697.97	32.03	100%

8.04

GLEN CANYON INTERIM FLOWS - BIO 35J3 10/13/94

Obj Code	Date	Vendor	RX/PD 3BIO35J3#	PC 93#	Documented	Pre-Encumbered	Amount Encumbered	Amount Expended	Explanation
92 7322/20	08/21	Jacks Plastic Welding	RX 002					185.07	waterproof bags
7322/20	11/06	Fisher	RX 003					* 387.45	top loading balance
7322/20	09/01	Lisa Kearsley	PD 001					108.63	food for river trip
7322/20	09/03	Amy Holm	PD 002					80.85	first aid supplies,
	09/23	Michael Kearsley	PD 003					159.62	film, food, bags, ha
93 7322/20	10/13	Liquid Air	PD 004					10.75	nitrogen
7322/20	10/19	Amy Holm	PD 005					141.27	garbage bags, pruner
7322/20	10/23	Liquid Air	PD 006					10.75	nitrogen
7322/20	11/04	Lisa Kearsley	PD 007					79.92	food, camera battery
7322/20	11/16	Michael Kearsley	PD 008					51.35	survey flags, marker
7351/20	11/04	Office Copy Machine						0.95	
7322/20	12/21	Forestry Suppliers	RX 004	BS0000928				6.50	sling psychrometers
7322/20	01/23	IDB/Bilby						420.00	ignition testing
7322/20	12/08	Larry Stevens	PD 009					106.60	
	01/25	Office Copy Machine						2.70	
7322/20	02/22	Tina Ayers	PD 010					47.50	Utah Flora book
7322/20	02/22	Larry Stevens	PD 011					283.54	
	02/28	Office Copy Machine						1.25	
7320/20	03/08	Microcomputer Power	PD 012					293.64	Canoco software
7350/20	04/08	Photo Outfitter	PD 013					8.88	fixer
	04/26	Michael Kearsley	PD 014					206.18	computer cases, film
7320/20	04/13	Bookstore						252.24	Lotus, Systat
7320/20	04/13	Grid Systems Corp	RX 005	LW0002483				962.33	penpal software, lic
7351/20	03/02	Office Copy Machine						0.60	
7322/20	04/28	Fisher	PD 015					124.74	thermometers
	05/24	Michael Kearsley	PD 016					68.38	survey flags, rulers
7331/30	06/15	Michael Kearsley	PD 017					80.00	cleaning laptop comp
7331/30	06/17	Mark Easter	PD 018					20.00	fabricate instrument
7351/20	05/04	Office Copy Machine						1.35	
	06/30	MBRS FAX charges						3.50	
7322/20	07/26	VWR	PD 001					412.63	soil sieves
7350/20	07/28	Michael Kearsley	PD 002					81.13	film, processing
	07/31	Dean's Copy Machine						0.21	
7320/10	08/16	AST Research (GRID)	PD 004					79.00	communication utilit
7330/20	08/16	Tina Ayers	PD 003					104.32	water line parts
7351/20	08/14	Office Copy Machine						2.05	
	09/15	Michael Kearsley	PD 005					311.30	photocopying, mylar,
94	10/13	VWR	PD 006					90.59	soil sieve
	10/27	IX 4BIO35J3001						-47.34	BIO 32F5/1117 waterl
	10/07	Department FAX charges						2.00	
	10/04	Office Copy Machine						1.85	
	11/19	Michael Kearsley	PD 007					179.19	ruler, batteries, el
	12/09	IX 4BIO1117023						52.88	stockroom supplies
	11/03	Office Copy Machine						9.00	
	12/03	University Stores - MS 8090						42.00	toner cartridge
	01/31	Larry Stevens	RX 002	CS0002389				1352.45	postage, film, stora
	01/25	JV 4DJC0000160						84.80	to close BIO 35K3
7351/20	02/16	Michael Kearsley	PD 008					33.28	photocopies

7310/10	03/07	Bookstore						43.59	bond paper, knife
7322/20	03/07	Herbarium Supply Co.	RX 003	CS0002552				654.93	USC genus
7331/30	03/09	Forestry Suppliers	PD 011					55.27	compass repair
7322/20	03/09	Forestry Suppliers	RX 004	CS0002559				584.38	compass, clinometer,
7350/20	03/22	Photo Outfitter	PD 012					491.44	camera, zoom lens
7351/20	12/09	Office Copy Machine						0.40	
7351/20	01/06	Office Copy Machine						0.15	
7310/80	04/04	Allen Precision Equipment	RX 005	BK0002311				1422.74	radios, batteries, c
7350/20	04/04	Photo Outfitter	PD 013					487.23	camera, zoom lens
7350/20	04/05	Michael Kearsley	PD 014					33.02	UV filters
7322/10	04/15	Missouri Botanical Garden	PD 015					27.00	herbarium handbook
7322/20	05/06	Michael Kearsley	PD 016					191.29	survey flags, radio
7350/20	05/24	Michael Kearsley	PD 017					61.77	full color contact s
7351/20	04/14	Office Copy Machine						3.40	Jan - March
7355/20	04/11	RRF 1576						5.25	postage
7351/20	05/13	Office Copy Machine						11.50	
7340/20	06/08	IV 4BIO4840053						1.00	May FAX
7351/20	06/01	Office Copy Machine						3.20	May
7351/20	07/05	Office Copy Machine						2.45	June
7351/20	09/07	Office Copy Machine						0.85	May
7350/20	07/25	Michael Kearsley	PD 001					21.30	film processing
	08/16	Michael Kearsley	PD 002					182.61	color copies, film p
7322/20	09/16	Michael Kearsley	PD 003					73.90	field supplies
7322/20	09/19	Michael Kearsley	PD 004					86.23	veg. trip supplies
		Operations Totals			0.00	0.00	0.00	11,415.78	

Obj Code	Date	Vendor	RX/PD 3BIO35J3#	PC 93#	Documented	Pre-Encumbered	Amount Encumbered	Amount Expended	Explanation
	09/14	Tina Ayers	TAO 01					335.00	
	03/01	Robert Weber	TAO 02					259.10	
	03/19	Robert Weber	TAI 01					63.75	
	04/23	Michael Kearsley	TAI 02					391.89	
	07/31	Diana Kimberling						292.60	
	07/31	Douglas Bechtel	TAO 04					502.60	
	08/03	Michael Kearsley	TAO 03					252.25	
	12/07	Michael Kearsley	TAI 01					75.00	
	08/06	Michael Kearsley	TAO 01		0.00			913.57	
		Travel Totals			0.00	0.00	0.00	3,085.76	

Obj Code	Date	Vendor	RX/PD 3BIO35J3#	PC 93#	Documented	Pre-Encumbered	Amount Encumbered	Amount Expended	Explanation
7830/20	04/13	Bookstore						2010.56	Zenith 325L portable
7830/20	04/13	Grid Systems Corp	RX	005 LW0002483				3285.92	pen computer
		Equipment Totals			0.00	0.00	0.00	5,296.48	

Obj Code	Date	Vendor	RX/PD 4BIO35J3#	PC 94#	Documented	Pre-Encumbered	Amount Encumbered	Amount Expended	Explanation
7510/90	12/08	IAS Laboratories	RX	001 CS0002219				1237.50	soil sample analysis
7510/90	05/09	IAS Laboratories	RX	006 CS0002856				1665.00	soil sample analysis
		Analyses Totals			0.00	0.00	0.00	2,902.50	

05-05-95
23:50
REPORT ID: OFCFS09R-01

NORTHERN ARIZONA UNIVERSITY
SUMMARY MONTHLY AREA/ORGN REPORT
FOR PERIOD ENDING 04/30/95

NOTES: MONTHLY RUN

FUND: 35J5 INTERIM FLOW/MARSH MONITORING
AREA: BIO BIOLOGICAL SCIENCE
ORGN: 35J5 INTERIM FLOW/MARSH MONITORING
SORG:

AREA MANAGER: PRIOR, DAVID
ORGN MANAGER: AYERS, TINA

* * * * * * * * * * EXPENSE BUDGET SUMMARY * * * * * * * * * *

OBJT/SUB	SUB-OBJT NAME	INCEPTION TO DATE BUDGET	ACTUAL CURRENT MONTH	ACTUAL YEAR-TO-DATE	ACTUAL INCEPTION TO DATE	ENCUMBRANCE PRE-ENCUMBRANCE	UNCOMMITTED BUDGET BALANCE
7111		6,305.00	.00	.00	.00	.00	6,305.00
	TOTAL OBJT 7111	6,305.00 *	.00 *	.00 *	.00 *	.00 *	6,305.00 *
7124 99	H-OCC (CONV)	.00	.00	.00	6,235.11	.00	6,235.11CR
	TOTAL OBJT 7124	.00 *	.00 *	.00 *	6,235.11 *	.00 *	6,235.11CR*
7200		528.00	.00	.00	.00	.00	528.00
	TOTAL OBJT 7200	528.00 *	.00 *	.00 *	.00 *	.00 *	528.00 *
7210 99	FICA -(CONV)	.00	.00	.00	476.97	.00	476.97CR
	TOTAL OBJT 7210	.00 *	.00 *	.00 *	476.97 *	.00 *	476.97CR*
7230 99	WORK/CMP-CNV	.00	.00	.00	17.49	.00	17.49CR
	TOTAL OBJT 7230	.00 *	.00 *	.00 *	17.49 *	.00 *	17.49CR*
7280 99	UNEMPL - CNV	.00	.00	.00	98.03	.00	98.03CR
	TOTAL OBJT 7280	.00 *	.00 *	.00 *	98.03 *	.00 *	98.03CR*
	TOTAL PERSONAL SVCS	6,833.00 **	.00 **	.00 **	6,827.60 **	.00 **	5.40 **
7300		500.00	.00	.00	.00	.00	500.00
	TOTAL OBJT 7300	500.00 *	.00 *	.00 *	.00 *	.00 *	500.00 *
7322 20	LAB SUPPLIES	.00	.00	.00	203.09	.00	203.09CR
	TOTAL OBJT 7322	.00 *	.00 *	.00 *	203.09 *	.00 *	203.09CR*
7999		667.00	.00	.00	.00	.00	667.00
7999 10	INDR CST AUT	.00	.00	.00	667.00	.00	667.00CR
	TOTAL OBJT 7999	667.00 *	.00 *	.00 *	667.00 *	.00 *	.00 *
	TOTAL NON-PRSNL SVCS	1,167.00 **	.00 **	.00 **	870.09 **	.00 **	296.91 **
	TOTAL EXPENSES	8,000.00	.00	.00	7,697.69	.00	302.31

* * * * * * * * * * REVENUE BUDGET SUMMARY * * * * * * * * * *

RSRC/SUB	SUB-RSRC NAME	INCEPTION TO DATE BUDGET	REVENUE CURRENT MONTH	REVENUE YTD	REVENUE INCEPTION TO DATE	REVENUE BUDGET BALANCE
5330		8,000.00	.00	.00	.00	8,000.00
5330 40	DOA	.00	.00	25,400.00	25,400.00	25,400.00
5330 50	OTHER FED	.00	.00	25,400.00CR	17,702.31CR	17,702.31CR
	TOTAL REVENUE	8,000.00	.00	.00	7,697.69	302.31

AYERS, TINA (ADM22PX)

PACKET PAGE NUMBER 23 ***

APPENDICES

APPENDIX A

PLANT SPECIES COLLECTED

IN THE GRAND CANYON, ARIZONA

PRELIMINARY CHECKLIST OF PLANTS FROM THE COLORADO RIVER CORRIDOR GRAND CANYON NATIONAL PARK

*Nomenclature follows that of *A Catalogue of the Flora of Arizona* by J. Harry Lehr

**Numbers following species refer to localities in river miles from Lee's Ferry

Aceraceae		
	Acer	*negundo* L. 41
Adiantaceae		
	Astrolepis	*cochisensis* (Goodd.) Benham & Windham 156.5
	Notholaena	*parryi* D.C. Eaton 104, 157, 155, 136.1
Agavaceae		
	Nolina	*sp.* 136.5
Amaranthaceae		
	Amaranthus	*albus* L. 143.5
		fimbriatus (Torr.) Benth. in Wats. 71
		graecizans L. 208.5, 124, 16.4, 124
		retroflexus L. 71.2
	Tidestromia	*oblongifolia* (Wats.) Standl. 155, 164.9, 123, 122.8, 123, 137
Anacardiaceae		
	Rhus	*glabra* L. 125
		radicans L. 143.5
		trilobata Nutt. 42, 52
Apiaceae		
	Apium	*graveolens* L. 43.1, 44.7, 55.5, 51.5
Apocynaceae		
	Amsonia	*sp.* 11.5
		tomentosa Torr. & Frem. 52.5,
Asclepiadaceae		
	Asclepias	*latifolia* (Torr.) Raf. 21.8
	Sarcostemma	*cynanchoides* Decne. in DC. 188,
Asteraceae		
	Acourtia	*wrightii* (Gray) Reveal & King 84, 95, 197.8, 148
	Agoseris	*heterophylla* (Nutt.) Greene 104, 136
	Ambrosia	*acanthicarpa* Hook. 21.8, 51.5, 172, 7.8, 122, 78.2, 144, 194
		confertiflora DC. 194, 20, 172, 88
		dumosa (Gray) Payne 134, 194
		sp. 43, 143.5
	Artemesia	*campestris* L. 31
	Artemisia	*bigelovii* Gray 3.4, 7.8
		carruthii Wood 120,
		dracunculus L. 194, 67.6, 43, 76.5, 52, 119, 20, 43, 172, 85
		filifolia Torr. 172, 171.8, 213.5, 160.2
		frigida Willd. 194, 42, 35, 172
		ludoviciana Nutt. 194, 20, 8, 84, 172, 104, 124.7, 143.5, 172, 44.6, 20, 43, 41
		sp. 26, 122.2, 43, 18
		tridentata Nutt. 42, 213.5
	Aster	*coerulescens* DC. 133.5, 51.2, 132, 103

	foliaceus Lindl. 55.5, 16
	glaucodes Blake 11, 43, 143, 20, 144.9
	sp. 21.8
	spinosus Benth. 26, 142, 93, 255, 122.8, 61.2
	subulatus Michx. 172, 194, 20.5, 43, 51.5, 136, 172, 55.5, 194, 43.2, 53, 55.5
Baccharis	*brachyphylla* Gray 47
	cf. brachyphylla Gray 41
	cf. emoryi Gray 43
	emoryi Gray 137, 0, 143.4, 124.7, 51.5
	salicifolia (R. & P.) Pers. 20, 37, 61.5, 159.9, 179.5, 20, 160
	sarothroides Gray 31.5, 43, 71.5, 93.6, 136, 133.5, 160.5, 165.1, 172, 194, 190.4, 220, 31.5
	sergiloides Gray 126, 35, 93.6, 71.2, 143.4, 119, 94
	sp. 64.7, 109
Baileya	*multiradiata* Harv. & Gray 171
Bebbia	*juncea* (Benth.) Greene 55.5, 180, 172, 166.5, 164.9, 221, 194, 104, 194
Bidens	*frondosa* L. 51.5, 172, 6.5
Brickellia	*atractyloides* Gray 157, 104
	californica (Torr. & Gray) Gray 79, 104, 140.7, 143.5, 166.8, 41, 35, 194
	coulteri Gray 148
	longifolia Wats. 8, 43, 20
	microphylla (Nutt.) A. Gray 68.3
	multiflora Kellogg 165.1
	scabra (Gray) Nels. 166
Calycoseris	*cf. parryi* Gray 68.1
Centaurea	*repens* L. .8
Chaenactis	*cf. douglasii* (Hook.) H. & A. 52.5
	stevioides Hook. & Arn. 71.8
Chrysothamnus	*nauseosus* (Pall.) Britt. 60, 55.5, 0
	paniculatus (Gray) H.M. Hall 255
	viscidiflorus (Hook.) Nutt. 68.3
Cichorium	*intybus* L. 16
Cirsium	*neomexicanum* Gray 132, 133.5
	rydbergii Petrak 47, 41, 48.5
	sp. 48, 131.8
Conyza	*canadensis* (L.) Cronq. 55.5, 38, 43, 51.5, 93.6, 172, 194, 2.6, 209, 20
Dicoria	*brandegei* Gray 43, 68.1, 91, 93.6, 96, 122.7, 45.5, 136, 53.8, 51.5, 122.2, 122, 22, 144
	canescens Gray 8, 122.1, 94.9
	sp. 55.5
Dyssodia	*acerosa* DC. 140.7, 145, 172, 41
	papposa (Vent.) Hitchc. 30, 106
	pentachaeta (DC.) Robins 56, 41, 172, 30, 122, 194, 18
	porophylloides Gray 171.4, 95, 104, 95, 172, 104, 166
Eclipta	*alba* (L.) Hassk. 194
Encelia	*frutescens* Gray 71.1
	virginensis Nels. 55.5, 71.2, 129
Enceliopsis	*nudicaulis* (Gray) Nels. 3.5
Erigeron	*caespitosus* Nutt. 194
	cf. divergens Torr. & Gray 55.5
	cf. utahensis Gray 31.7
	concinnus (Hook. & Arn.) Torr. & Gray 46.5, 31.5, 194, 122.8, 43, 41, 51.5, 52.5
	divergens Torr. & Gray 43, 55.5, 51.5, 47, 122.7, 41, 44.6, 148, 51.5, 119, 136
	lobatus Nels. 43, 45.9, 104, 160, 172, 55.5, 194, 41.5, 122.8, 55.5, , 103, 148, 172, 125.5
	sp. 110, 51.5, 41
	utahensis Gray 122.7
Filago	*arizonica* Gray 198.5
	californica Nutt. 122.7
	depressa Gray 39.5
Flaveria	*macdougalii* Theroux, Pinkava & Keil 148
Gaillardia	*pinnatifida* Torr. 144, 143.5
	spathulata Gray 143

Gnaphalium	*chilense* Spreng. 20, 43, 84, 43.1, 51.5, 133, 20, 55.5, 160.2, 41, 2.6, 52.5, 20, 133.7, 122.1
	sp. 51.5
Grindelia	*squarrosa* (Pursh) Dunal 38, 55.5, 21.8
Gutierrezia	*microcephala* (DC.) Gray 8, 31.5, 43, 172, 140.7
	sarothrae (Pursh) Britt. & Rusby 194, 55.5, 21.8, 43, 172, 140.6, 5.8, 0
	sp. 26, 21.8
Haplopappus	*scopulorum* (Jones) Blake 31
Helianthella	*microcephala* Gray 68.3
Heterotheca	*villosa* (Pursh) Shinners 84, 51.5, 56, 35, 213.5, 20, 16
Hymenopappus	*filifolius* Hook. 68.3
Hymenoxys	*acaulis* (Pursh) Parker 95, 68.3
	cf. cooperi (Gray) Cockerell 198
	richardsoni (Hook.) Cockerell 20.8
Isocoma	*acradenia* (Greene) Greene 137
	drummondii (Torr. & Gray) Greene 1, 27, 20, 61, 55.5, 172, 109, 71.2, 0, 55.5, 137, 144
	sp. 174.5
Iva	*acerosa* (Nutt.) Jackson 52
	cf. acerosa (Nutt.) Jackson 133.5
Lactuca	*sp.* 179
Leucelene	*ericoides* (Torr.) Greene 31.7
Machaeranthera	*canescens* (Pursh) Gray 35
	gracilis (Nutt.) Shinners 38, 157, 209, 71.2
	linearis Greene 172, 194, 172
	pinnatifida (Hook.) Shinners 84, 91, 130, 140.7, 88, 172, 55.5, 61.5, 103.9, 41, 95, 144, 94
	sp. 132
	spinulosus (Pursh) DC. 104
	tanacetifolia (H.B.K.) Nees 213.5
Malacothrix	*californica* DC. 44.6, 71, 62.5
	cf. californica DC. 68.1
	glabrata D.C. Eaton 67
	sonchoides (Nutt.) Torr. & Gray 71
Melampodium	*leucanthum* Torr. & Gray 198
Micropus	*californicus* F. & M. 61.5, 209, 106, 61.5
Microseris	*linearifolia* (DC.) Schultz Bip. 47
Parthenium	*incanum* H.B.K. 52.9
Perityle	*congesta* (Jones) Shinners 128, 37, 127, 37
	emoryii Torr. 74, 160, 71, 156.8
Peucephyllum	*schottii* Gray 133.7, 220
Pleurocoronis	*cf. pluriseta* (Gray) King & Robinson 160.2
	pluriseta (Gray) King & Robinson 157, 37, 209, 122, 166.5, 148
Porophyllum	*gracile* Benth. 131, 91, 220, 198.5, 131, 134, 108.5, 94
Prenanthella	*exigua* (Gray) Rydb. 61.5, 30
Psilostrophe	*sparsiflora* (Gray) A. Nels. 18.5, 94, 52.5
	tagetina (Nutt.) Greene 52.5
Rafinesquia	*neomexicana* Gray 148, 122
Senecio	*cf. douglasii* DC. 55.5
	cf. multilobatus Torr. & Gray 20.8
	douglasii DC. 21.8, 16.5, 31.5, 43, 55.5, 16.5, 16, 62.9, 21.8
	multilobatus Torr. & Gray ex Gray 44.6, 116.5, 148, 20.8,
Solidago	*altissima* L. 31.5
	canadensis L. 116, 172, 184.2, , 35, 46.9, 137, 123
	cf. occidentalis (Nutt.) T. & G. 51.5
	missouriensis Nutt. 55.5, 93.6, 52, 148
	multiradiata Ait. 122, 132
	occidentalis (Nutt.) Torr. & Gray 43, 122.7, 65.5, 144, 31
	sparsiflora Gray 133.5, 137, 50
Sonchus	*asper* (L.) Hill 194, 56, 43, 56, 55.5, 51.5, 139, 172, 43, 20, 16, 133.7, 171.5, 213.5, 20
	oleraceus L. 104
	sp. 55.5, 20, 51.5, 55.5
Stephanomeria	*cf. exigua* Nutt. 122.7, 20.5

	exigua Nutt. 122.7
	pauciflora (Torr.) A. Nels. 8, 52
	tenuifolia (Torr.) H.M. Hall 43, 123, 140.7, 172, 122
Taraxacum	*officinale* Weber 51.5, 2.6
Tessaria	*sericea* (Nutt.) Shinners 43, 51.5
Thelesperma	*subnudum* Gray 8
Tragopogon	*dubius* Scop. 55.5, 122
	porrifolius L. 48
Trixis	*californica* Kell. 104, 221, 84, 91, 95
Verbesina	*encelioides* (Cav.) Benth. & Hook. 113, 156.5
Viguiera	*annua* (Jones) Blake 78
Xanthium	*strumarium* L. 55.5, 43, 51.5, 194
Xylorhiza	*tortifolia* (Torr. & Gray) Greene 41, 61.3
Zinnia	*grandiflora* Nutt. 68.6
Berberidaceae	
Berberis	*haematocarpa* Wooton 47
Bignoniaceae	
Chilopsis	*linearis* (Cav.) Sweet 157, 210.9
Boraginaceae	
Amsinckia	*intermedia* Fisch. & Mey. 106, 198.6, 104
Cryptantha	*ambigua* (Gray) Greene 61.5
	barbigera (Gray) Greene 43, 22.5, 84.1, 138, 22.5, 20.5, 64.5, 136, 104, 171.5, 126
	capitata (Eastw.) Johnst. 47, 52.1, 50, 94
	cf. barbigera (Gray) Greene 42
	cf. decipiens (Jones) Heller 20.5
	cf. flava (A.Nels.) Payson 84
	cf. racemosa (Wats.) Greene 91
	confertiflora (Greene) Payson 52.1, 48, 104
	decipiens (Jones) Heller 43, 42, 98.2, 106, 198.5, 198, 71, 198
	fendleri (Gray) Greene 61.5
	pterocarya (Torr.) Greene 127.5, 98.2, 132, 43, 42, 198.5, 70.7
	racemosa (Wats.) Greene 64.5, 20.5, 198, 106, 113, 16.4, 20.5, 44.6, 123, 46.9, 126, 22
	sp. 172, 108.5, 8
	utahensis (Gray) Greene 132
Heliotropium	*convolvulaceum* (Nutt.) Gray 122.8, 144, 47
	curassavicum L. 194, 114, 143.5
Lappula	*echinata* Gilib. 136, 48, 30, 47
	redowskii (Hornem.) Greene 45, 31.5, 47.3, 157, 166.5, 160.2, 148.3, 43
	texana (Scheele) Britton 64.8
Lithospermum	*incisum* Lehm. 52.5
	sp. 123
Pectocarya	*heterocarpa* Johnst. 43, 106, 198.5
	platycarpa Munz & Johnst. 122, 126.2
	recurvata Johnst. 220
Plagiobothrys	*jonesii* Gray 45
Tiquilia	*canescens* (DC.) A. Richardson 42, 47, 43, 93.6, 74, 151.5, 220, 43, 68
	latior (I. M. Johnst.) A. Richardson 52, 166.5, 52, 71, 155.5, 12, 123
Brassicaceae	
Arabis	*fendleri* (Wats.) Greene 30
	perennans Wats. 43.1, 45, 43, 43.2, 81.5, 84.1, 47.5, 44.9, 30, 44.9, 7.5
Chorispora	*tenella* (Pall) DC. 20.5, 171.4, 47, 171.5, 20.5
Descurainia	*pinnata* (Walt.) Britton 43.1, 43, 45, 31.5, 40.1, 198.5, 136.1, .8, 194, 8, 171.5
Dithyrea	*wislizeni* Engelm. 61.7
Draba	*cuneifolia* Nutt. 133.5, 143.5, 126, 156.8, 106
	verna L. 121.5
Lepidium	*cf. fremontii* Wats. .8

	fremontii Wats. .8, 48, 47, 156.8, 108, 145, 2.6, 155.7, 42, 171.4, 43
	lasiocarpum Nutt. 43.1, 43, 143.5, 30, 171.5, 194, 108, 8, 20.5, 34.5, 198.5, 204, 20.5
	latifolium L. 55.5, 194, 43.1, 43, 71.2, 23.9, 35, 58.8, 56, 74, 56, 137, 24.5
	montanum Nutt. 45, 55.5, 47, .1, 51.5, 44.9, 52.9, 52.5, 47
	sp. 51.5
Lesquerella	*arizonica* Wats. 171.5
	cinerea Wats. 166.5, 157
	purpurea (Gray) Wats. 116.5, 87.5
Malcolmia	*africana* (L.) R. Br. 42, 48, 126.2, 30
Rorippa	*islandica* (Oeder) Borbas 55.5, 43, 51.5, 51.7
	nasturtium-aquaticum (L.) Schinz & Thell 31.5, 20, 48, 51.5, 20, 133.7, 179.4, 43
	sp. 51.5
Sisymbrium	*altissimum* L. 42, 166.5, 225.5, 31.5
	cf. irio L. 43.1, 42
	irio L. 30, 47
	sp. 213.5
Stanleya	*albescens* Jones 137
	pinnata (Pursh) Britton 61.2, 43, 122.7, 133.7
Streptanthella	*longirostris* (Wats.) Rydb. 42, 125, 198.5, 8, 2.6, 8, 71.2
Thelypodium	*integrifolium* (Nutt.) Endl. 47
	wrightii Gray 48, 131.6, 136.1, 131.6, 52.3
Thysanocarpus	*curvipes* Hook. 91
	laciniatus Nutt. 47
Cactaceae	
Echinocereus	*engelmannii* (Parry) Lem. 30
Campanulaceae	
Lobelia	*cardinalis* L. 143, 52.1, 147.7, 147.8
Nemacladus	*glanduliferus* Jepson 98, 121.5, 209, 106
Capparidaceae	
Wislizenia	*refracta* Engelm. 55.5, 194, 50.5, 22, 122.7
Caryophyllaceae	
Silene	*antirrhina* L. 91
	antirrhinum L. 208.5
Spergularia	*marina* (L.) Griseb. 225, 213
Stellaria	*nitens* Nutt. 127.5
Celastraceae	
Mortonia	*scabrella* Gray 171.5, 198, 166, 171.5
Chenopodiaceae	
Atriplex	*confertifolia* (Torr. & Frem.) Wats. .8, 2.6, 61.5, 2.6, 7.5
	rosea L. 156.5
Bassia	*cf. hyssopifolia* (Pallas) Kuntze 194
	hyssopifolia (Pallas) Kuntze 213.5, 122.2
Chenopodium	*album* L. 55.5
	cf. berlandieri Moq. 55.5
	cf. botrys L. 209
	cf. desiccatum Nels. 122.7
	cf. glaucum L. 55.5
	fremontii Wats. 198, 20.4
	glaucum L. 55.5
	sp. 152
Corispermum	*nitidum* Kit. 55.5, 43.1, 51.2, 144, 55.5, 51.2, 43, 146
Eurotia	*lanata* (Pursh) Moq. 122.2, 137
Kochia	*scoparia* (L.) Shrad. 194, 215, 156.5
Salsola	*iberica* Sennen & Pau 55.5, 43.1, 55.5, 51.2, 61.5

Suaeda	*torreyana* Wats. 209, 68.5
Convolvulaceae	
Convolvulus	*equitans* Benth. 51.5
Cucurbitaceae	
Citrullus	*lanatus* (Thunb.) Mansfeld 21.8, 22.2
Cyperaceae	
Carex	*aquatilis* Wahl. 43, 22, 43.1, 32, 35, 7, 41, 32
	curatorium Stacy 46, 47, 171, 155.5
	hystricina Muhl. 194, 84, 133.5, 194
	kelloggii W. Boott. 43.5, 43
	sp. 51.5, 42
Cladium	*californicum* Wats. 180, 133.5, 132
Cyperus	*cf. difformis* L. 39.5
	cf. laevigatus L. 39.5
Eleocharis	*cf. rostellata* (Torr.) Torr. 136
	macrostachya Britt. 0, 136
	parishii Britt. 43
	sp. 51.5
Scirpus	*acutus* Muhl. 43.1, 51.5
	americanus Pers. 56, 55.5, 52.5, 55.5, 194, 51.7, 51.2, 190.4, 155, 93.6, 25, 55.5
	pallidus (Britt.) Fern. 51
	paludosus A. Nels. 194, 43.5
	sp. 131.8
	validus Vahl. 194, 55.5, 194, 51.5, 43, 55.5, 52.5
Elaeagnaceae	
Shepherdia	*rotundifolia* Parry 43.1, 43, 42
Equisetaceae	
Equisetum	*arvense* L. 55.5, 43.1, 43, 51.5
	hiemale L. 194, 55.5, 122.8, 7
	laevigatum A. Braun. 43.1, 51.5, 122.8, 143.5, 172
Euphorbiaceae	
Argythamnia	*neomexicana* Muell. & Arg. 119
Bernardia	*incana* Morton 81.5, 156.5
Croton	*corymbulosus* Engelm. 164.9
	texensis (Klotzsch) Muell. Arg. 122, 123
Euphorbia	*aaron-rossii* A. & N. Holmgren 20.5, 18.5, 20.5, 16.9, 44, 44.6, 46, 47
	arizonica Engelm. 104
	cf. ocellata Dur. & Hilg. 143.5
	cf. polycarpa Benth. 220
	cf. prostrata Aiton 220, 93.6
	eriantha Benth. 213, 216
	glyptosperma Engelm. 143.5
	micromera Boiss. 72
	parryi Engelm. 68
	revoluta Engelm. 95, 198.5
	sp. 194, 43.1, 56
Reverchonia	*arenaria* Gray 142
Fabaceae	
Alhagi	*camelorum* Fisch. 68.4, 93.5
Astragalus	*amphioxys* Gray 123, 122.7, 52.5
	cf. amphioxys Gray 7.5
	cf. bryantii Barneby 104
	cf. crassicarpus Nutt. 22

	cf. desparatus Jones 68.1
	cf. eremiticus Sheldon 52.5
	cf. recurvus Greene 65, 0
	kentrophyta Gray 68.1, 68
	lentiginosus Dougl. 136, 68.4, 3.4, 14
	mollissimus Torr. 68.4, 68
	nuttallianus DC. 171.4, 136, 52.1, 106, 98.2, 198, 136, 30, 104, 148, 220, 71.5
	praelongus Sheldon 125
	sp. 43.1, 143.5, 51.5
	xiphoides (Barneby) Barneby 22, 21.8, 7.5, 364
Cassia	*covesii* (Gray) Irwin & Barneby 71.2, 198.5, 87.5, 198.5, 220, 126, 108, 87.8, 142, 220
Cercidium	*microphyllum* (Torr.) Rose & Johnston 10
Cercis	*occidentalis* Torr. 149, 148, 32, 38
Dalea	*cf. amoena* Wats. 221
	cf. lanata Sprengel 43,
	cf. terminalis Jones 122.7
	fremontii Torr. 133, 220, 209, 68.5, 93.4, 94
	terminalis Jones 43, 123
Lotus	*neomexicanus* Greene 51
	wrightii (Gray) Greene 204
Lupinus	*arizonicus* Wats. 220.5
	pusillus Pursh. 122.7, 126, 8
Medicago	*sativa* L. 8, 20, 194, 2.6, 21.8
Melilotus	*albus* Desr. 194, 55.5, 194, 51.5, 172, 8
	officinalis (L.) Lam. 55.5, 43.1, 20, 43, 43.1, 51.5, 43.5
	sp. 31.5
Parryella	*filifolia* Torr. & Gray 68, 171, 93.4, 104.2
Petalostemum	*occidentale* (Helier) Fern 123
	purpureum (Vent.) Rydb. 122.7, 139
Prosopis	*cf. pubescens* Benth. 122
Psoralea	*cf. lanceolata* Pursh. 143.5
	junceum (Eastw.) Rydb. 94
	lanceolata Pursh. 55.5, 52.1, 188.5
Robinia	*neomexicana* Gray 52.5
Trifolium	*repens* L. 51.7
Vicia	*exigua* Nutt. 45, 132, 133.7, 52.1
Gentianaceae	
Centaurium	*calycosum* (Buckl.) Fern. 55.5, 98, 51.5, 144, 51.7, 215.5, 55.5, 209, 51.3, 54.9
	cf. exaltatum (Griseb.) Wight ex Piper 55
	exaltatum (Griseb.) Wight ex Piper 51.5, 55.5, 54.9, 51.5
Geraniaceae	
Erodium	*cicutarium* (L.) L'Her. 44, 136, 20.5
	texanum Gray 72, 52.5
Hydrophyllaceae	
Eucrypta	*micrantha* (Torr.) Heller 98, 106, 156.5
Phacelia	*affinis* Gray 61.5, 43.1
	ambigua Jones 42
	cf. integrifolia Torr. 43.1
	corrugata Nels. 20.5
	crenulata Torr. 61.5, 71, 30
	cryptantha Greene 52
	curvipes Torr. ex. Wats. 127
	demissa Gray 123, 48, 127.5, 198.5
	glechomifolia Gray 143, 156.5
	laxiflora J.T. Howell 52.5
	lutea (H. & A.) J. T. Howell 20.5
	rotundifolia Torr. 106

	sp. 84
	vallis-mortae J. Voss 95
Philostoma	*auritum* (Lindl.) Lilja 106, 91
Iridaceae	
Sisyrinchium	*demissum* Greene 155.5
	sp. 155
Juncaceae	
Juncus	*acutus* L. 221.5
	articulatus L. 194, 55.5, 51.5, 43, 172, 0, 194, 31.7, 194, 31.5, 37, 93.6, 1.7, 194
	balticus Willd. 32, 2.6, 55.5, 0, 93.6, 50, 136, 172, 56, 18.5, 194
	bufonius L. 43, 37, 51.7, 213
	cf. articulatus L. 51.5, 194, 71.2, 93.6
	cf. balticus Willd. 179.9
	cf. ensifolius Wikstr. 194
	cf. saximontanus A. Nels. 51, 194
	cf. tenuis Willd. 43.5
	cf. torreyi Coville 43, 52.5, 37, 52.5
	cf. xiphioides E. Mey. 30
	ensifolius Wikstr. 194, 55.5, 20, 43.5
	nevadensis L. 51.5, 43
	nodosus L. 118, 31
	saximontanus Nels. 43, 37, 51.3, 136
	sp. 43, 71.2, 144
	tenuis Willd. 20, 55.5
	torreyi Coville 194, 56, 55.5, 43, 20, 194, 51.5, 43, 84, 136, 143.5, 172, 37, 43.5, 55.5, 37
	xiphioides E. Mey. 136, 43, 51.5, 31
Krameriaceae	
Krameria	*cf. parvifolia* Benth. 179.8, 194, 209, 220
	parvifolia Benth. 71.5, 220, 255.5, 209, 185, 215.5
	sp. 209
Lamiaceae	
Hedeoma	*nanum* (Torr.) Briq. 43.1, 43, 116.5, 122.7, 44.6, 138, 32
	oblongifolium (Gray) Heller 133.5, 138, 157, 148, 219, 136, 20.5, 116.5, 171.5, 116.5
Lycopus	*americanus* Muhl. 6.5
Marrubium	*vulgare* L. 16.5
Mentha	*arvensis* L. 55.5, 51.5, 0, 51.7, 52.9, 43
Salazaria	*mexicana* Torr. 198.5, 171.5
Salvia	*davidsonii* Greenm. 149, 148
	dorrii Torr. 68.5, 75, 132
Stachys	*cf. palustris* L. 136
Liliaceae	
Allium	*sp.* 52.5
Asparagus	*officinalis* L. 0
Calochortus	*flexuosus* Wats. 71
Loasaceae	
Mentzelia	*albicaulis* Dougl. 39.2, 48, 143.5, 185.2, 107.5
	cf. albicaulis Dougl. 194, 122.1
	puberula J. Darl. 151.5, 72
	pumila (Nutt.) Torr.& Gray 3, 126, 61.5, 94, , 137, 123
	sp. 47.3
Loranthaceae	
Phoradendron	*californicum* Nutt. 198.5

Malphighiaceae		
	Janusia	*gracilis* Gray 109, 98, 171.5, 108
		sp. 98
Malvaceae		
	Abutilon	*cf. californicum* Benth. 225
		incanum (Link) Sweet 71.5, 185
		parvulum Gray 149
	Sphaeralcea	
		ambigua Gray 43.1
		cf. ambigua Gray 171.5
		cf. parvifolia Nels. 71.2
		grossulariifolia (H. & A.) Rybd. 122.7, 136
		sp. 55.5, 164.9, 123
Nyctaginaceae		
	Abronia	*elliptica* A. Nels. 72, 166, 122.7, 188.5
		fragrans Nutt. ex Hook. 68
		sp. 136
		villosa Wats. 95
	Allionia	*incarnata* L. 208.5, 122.1, 209, 11.7, 43.2, 72
	Anulocaulis	*leiosolenus* (Torr.) Standl 171
	Boerhaavia	*wrightii* Gray 93.6
	Mirabilis	*bigelovii* Gray 87.5, 108.5, 64.5, 61.5, 7.8, 94, 202, 209, 103, 136
	Tripterocalyx	*carnea* (Greene) Galloway 123
Oleaceae		
	Fraxinus	*anomala* Torr. 47, 116.5
		pennsylvanica Marsh 198
Onagraceae		
	Camissonia	*brevipes* (Gray) Raven 209
		cf. parryi (Wats.) Raven 123
		cf. refracta (Wats.) Raven 98
		chamaenerioides (Gray) Raven 42
		multijuga (Wats.) Raven 125, 143.5, 172, 204, 156.8, 143, 205, 148, 16.8, 148, 106, 179.5
		refracta (Wats.) Raven 221
	Epilobium	*adenocaulon* Hausskn. 55.5, 43, 51.5, 55.5, 133.5
		cf. adenocaulon Hausskn. 35
		paniculatum Nutt. 125
		sp. 51.5, 157, 121.5
	Gaura	*coccinea* Pursh 143.4
		parviflora Dougl. 157, 143.4, 156.5
	Oenothera	*albicaulis* Pursh. 43.1
		caespitosa Nutt. 30
		cavernae Munz 52.5
		cf. caespitosa Nutt. 133.5
		cf. deltoides Torr. & Frem. 194
		cf. hookeri Torr. & Gray 31.5, 43
		cf. pallida Lindl. 43
		cf. primiveris Gray 52.5
		deltoides Torr. & Frem. 194, 71
		hookeri Torr. & Gray 43, 16, 133.7
		laciniata Hill 71
		longissima Rydb. 55.5
		pallida Lindl. 43.1, 93.6, 172, 122.7, 107.5, 122.1, 8, 108
		sp. 39.2, 51.5, 65
Orchidaceae		
	Epipactis	*gigantea* Douglas ex Hook. 133.5, 157, 171.5, 52.1, 215.5, 148

Orobanchaceae	
Orobanche	*multiflora* Nutt. 51.5, 194, 117, 198.5, 122.2, 120
Papaveraceae	
Argemone	*corymbosa* Greene 20.5
	munita Dur. & Hilg. 21.8
Plantaginaceae	
Plantago	*argyraea* Morris 40.1, 71.5, 96, 22.5, 166.5, 122.8
	cf. argyraea Morris 127
	lanceolata L. 55.5, 20, 18.7, 18.5, 51.5
	major L. 194, 56, 55.5, 194, 43.1, 22.5, 20, 43, 51.5, 56, 157, 20
	ovata Forsskal 220, 210, 52, 198.5, 61.5, 156.5, 61.5
	purshii R. & S. 122.6, 122.5, 106, 136, 51.5
	sp. 148.3
Poaceae	
Agropyron	*cf. smallii* 171.5
	desertorum (Fisch.) Schult. 20
	sp. 55.5, 43, 51.5, 6, 20, 43
	trachycaulum (Link) Malte 20, 51.3, 41
Agrostis	*exarata* Trin. 46.4
	semiverticillata (Forsk.) C. Chr. 194, 55.5, 43.5, 20.5, 20, 56, 61.5, 172, 179.5, 171.5
	sp. 56
	stolonifera L. 194, 56, 55.5, 41, 43, 20, 194, 43.1, 51.5, 31.5, 122.8, 137, 172, 55.5, 194
Andropogon	*gerardi* Vitm. 108.5, 194, 213.5
	glomeratus (Walter) B.S.P. 194, 133.5, 184, 125, 95, 181, 95, 179.5
Aristida	*adscensionis* L. 91, 144, 32, 104, 136, 220, 106
	glauca (Nees) Walp. 108.5, 43.1
	purpurea Nutt. 131.8, 95, 106, 144, 133.5, 104, 48, 41, 216, 106
Avena	*fatua* L. 94, 76.5
Bothriochloa	*barbinodis* (Lag.) Herter 43, 133.5, 172, 43.1, 108.5, 136, 194
	saccharoides (Steudel) Gould 104, 46.9, 193, 43.5, 51.5, 41, 31
Bouteloua	*aristidoides* (H.B.K.) Grisb. 71.5
	barbata Lag. 61.2, 144, 71.5, 95, 136
	curtipendula (Michx.) Torr. 131.8, 71.1, 31, 136
	eriopoda (Torr.) Torr. 52.5, 95
	gracilis (H.B.K.) Lag. ex. Steud. 31
	trifida Thurb. in Wats. 106, 132, 220
Bromus	*arizonicus* (Shear) Stebbins 31.6
	cf. madritensis L. 116.5
	inermis Leyss. 55.5, 51, 179.5
	madritensis L. 194
	rigidus Roth. 61.2, 157, 41, 8, 171.5, 179.5
	rubens L. 41, 43, 43.2, 45, 43.1, 40.1, 184, 8
	tectorum L. 51.5, 133.7, 8, 120, 194
	trinii Desv. 136
	wildenowii Kunth. 55.5, 41, 134, 43, 8, 20.5, 43.1, 51.5, 43, 55.5, 160, 44.6
Calamagrostis	*scopulorum* Jones 46.4, 46
Cenchrus	*incertus* M. Curtis 143.4
	longispinus L. 144, 143
Chloris	*virgata* Swartz. 51.5, 150, 194, 143
Cortaderia	*selloana* (Schult.) Aschers. & Graebner. 14.6
Cynodon	*dactylon* (L.) Pers. 51.5, 31, 172, 144, 143.5
Dactylis	*glomerata* L. 0
Dichanthelium	*lanuginosum* (Elliott) Gould 31.5, 131.8, 133.5, 147.7, 53
Digitaria	*sanguinalis* (L.) Scop. 172
Distichlis	*spicata* (L.) Greene 51.5, 2.6
Echinochloa	*crus-galli* (L.) Beauv. 194, 43.5, 194, 43.1, 51.5, 172, 143.4, 144, 194

Elymus	*canadensis* L. 55.5, 43.5, 43.1, 51.5, 6, 51.5
	cf. salina M. E. Jones 43.1
	cinereus Scribn. & Merr. 131.8
Enneapogon	*desvauxii* Beauv. 133.5, 68.1, 71
Eragrostis	*cf. barrelieri* Daveau 172
	curvula (Schrad.) Nees 51.5, 43.1, 50, 122
	pectinacea (Michx.) Nees 55.5, 43.5, 51.5, 43, 52.9, 1.7, 51.5, 220.2
Erianthus	*ravennae* (L.) Beauv. 71.5, 2.5, 208
Erioneuron	*avenaceum* (H.B.K.) Tateoka 157
	pilosum (Buckl.) Nash. 106
	pulchellum (H.B.K.) Tateoka 2.6, 61.2, 71.5, 122.2, 131.8, 119
Festuca	*arundinacea* Schreber 51.2
	pacifica Piper 91, 104, 91
Heteropogon	*contortus* (L.) Beauv. 84, 122, 122.5, 93.6, 84
Hilaria	*cf.rigida* (Thurb.) Benth. 123
	jamesii (Torr.) Benth. 68.1, 71.2
	rigida (Thurb.) Benth. 131.8, 122.2, 122
Hordeum	*jubatum* L. 55.5, 43.5, 43.1, 43.5, 43, 20, 194, 43.1, 51.5, 172, 44.6, 133.7, 51.7
	leporinum Link 122
Imperata	*brevifolia* Vasey 84, 118, 132, 171.5, 136, 171.5, 133.7
Koeleria	*pyramidata* (Lam.) Beauv. 55.5, 93.6
Leptochloa	*uninervia* (Presl) Hitchc. & Chase 70.1, 198.5
Muhlenbergia	*asperifolia* (Nees & Mey.) Parodi 194, 55.5, 43, 43.1, 84, 137, 143.5, 172, 172.2, 51.7
	cf. porteri Scribn. 143.5, 30
	cf. richardsonis (Trin.) Rydb. 155.5
	microsperma (DC.) Kunth. 91, 113,
	porteri Scribn. 42, 45, 8, 137, 43.5, 118, 21.8, 156.8, 44.9, 122.5
	richardsonis (Trin.) Rybd. 65.5
	rigens (Benth.) Hitchc. 133.7
	sp. 41, 136.4, 172, 143.5
	thurberi Rydb. 41, 168, 32
Oryzopsis	*hymenoides* (R.& S.) Ricker 43, 43.1
	milacea (L.) Benth. & Hook. 194, 157, 172, 190.4, 156.8
Panicum	*bulbosum* H.B.K. 46.9
	capillare L. 194, 56, 43.5, 43, 194, 43, 43.1, 51.5, 172, 55.5, 51.5
	cf. hirticaule Presl. 193
	obtusum H.B.K. 187.5, 143
Paspalum	*dilatatum* Poir. 194
Phragmites	*australis* (Cav.) Trin. 55.5, 43.1, 51.5
Poa	*annua* L. 20
	bigelovii Vasey & Scribn. 43, 132, 169, 91, 171.5, 148
	canbyi (Scribn.) Piper 41
	compressa L. 43, 47
	fendleriana (Steud.) Vasey 43, 30, 95
	interior Rydb. 32
	sp. 56, 172, 157
Polypogon	*interruptus* H.B.K. 194
	monspeliensis (L.) Desf. 194, 55.5, 43, 20, 21.8, 43.1, 51.5, 133.5, 172, 179.5, 51.7, 31
	sp. 136,
Puccinellia	*distans* (L.) Parl. 194
	nuttalliana (Schult.) Hitchc. 194
Schismus	*arabicus* Nees 67, 20.5
	barbatus (L.) Thell. 64.5, 106, 125, 208.5
Schizachrium	*scoparium* (Michx.) Nash 143.5
Setaria	*glauca* (L.) Beauv. 87.6, 95
Sporobolus	*airoides* Torr. 194, 172, 171, 145, 71.2, 111.5
	contractus Hitchc. 194, 43, 208.5, 156.8, 30
	cryptandrus (Torr.) Gray 194, 55.5, 41, 43, 45, 56, 104, 123, 143.5, 172, 51.5, 97.9, 171.8
	flexuosus (Thurb.) Rydb. 194, 43.5, 8, 104, 172
	giganteus Nash. 102, 172, 183, 51.5

	sp. 43
Stipa	*cf. webberi* (Thurber) B.L. Johnson 137
	comata Trin. & Rupr. 30
	sp. 137
	speciosa Trin. & Rupr. 46.9, 52.1, 132, 20.5, 30, 43.1, 32
Trichachne	*californica* (Benth.) Chase 91
Tridens	*muticus* (Torr.) Nash 51.5, 2.6, 131.8, 160.2, 132, 136, 108.5, 136, 106
Vulpia	*octoflora* (Walter) Rydb. 53, 122.6, 43, 125, 185
Polemoniaceae	
Gilia	*cf. gilioides* (Benth.) Greene 71.5
	cf. sinuata Dougl. ex. Benth. 132
	filiformis Parry ex. Gray 121.5
	scopulorum Jones 132
	sinuata Dougl. ex. Benth. 194, 98, 68, 122.7, 106, 134.5
Ipomopsis	*aggregata* (Pursh) V. Grant 43.5
	gunnisonii (T. & G.) V. Grant 122.8, 123
Langloisia	*setosissima* (Torr. & Gray) Greene 125, 122.7
Linanthus	*bigelovii* (Gray) Greene 106, 71, 198
Loeseliastrum	*cf. schottii* (Torr.) Timbrook 122.7
Polygalaceae	
Polygala	*scoparioides* Chodat. 108.5, 156.8, 116.4, 168, 166
Polygonaceae	
Chorizanthe	*brevicornu* Torr. 132
Eriogonum	*cf. deflexum* Torr. in Ives 122.8
	cf. leptophyllum (Torr.) Woot. & Standl. 87.5
	cf. microthecum Nutt. 43.5
	corymbosum Benth. 3, 52
	deflexum Torr. 71.5, 68, 198.6, 71.2, 65.5, 204, 185.2, 9.3, 74
	divaricatum Hook. 22, 22.2
	fasciculatum Benth. 220, 209, 189, 209
	heermannii Dur. & Hilg. 84.1, 31, 85
	inflatum Torr. & Frem. 43
	insigne Wats. 143.5, 166.5
	palmerianum Reveal 68
	polycladon Benth. in DC. 189.9, 222.5
	sp. 42, 71.5, 74, 180
	trichopes Torr. 22
	wrightii Torr. 225
	zionis J. T. Howell 95
Polygonum	*amphibium* L. 32
	aviculare L. 194, 16.5, 18.5, 51.5, 55.5, 16.5, 55.5, 16
	cf. aviculare L. 55.5
	cf. persicaria L. 51.5
	densiflorum Meisn. .8, 51.5, 0
	lapathifolium L. 194, 157, 194, 143.5, 6.5
	persicaria L. 194
	punctatum Ell. 156.5, 171
	sp. 20, 31.5, 51.5
Pterostegia	*drymarioides* Fisch. & Mey. 198.6, 148, 132, 91, 88, 91, 136
Rumex	*californicus* Rech.f. .8
	crispus L. 194, 51.5, 46.5
Portulacaceae	
Claytonia	*perfoliata* Donn. 132
Portulaca	*oleracea* L. 16.5, 143, 16.5
Primulaceae	

Androsace	*occidentalis* Pursh 106
Primula	*specuicola* Rydb. 41.5, 46
Samolus	*parviflorus* Raf. 106

Ranunculaceae

Anemone	*tuberosa* Rydb. 52, 104, 30
Aquilegia	*chrysantha* Gray 48, 148
	sp. 41.5, 48
Clematis	*ligusticifolia* Nutt. 47, 104, 133.5
	sp. 52.5
Delphinium	*parishii* Gray 194, 209, 198.5, 171
	scaposum Greene 220
Ranunculus	*cymbalaria* Pursh 55.5, 56, 71.2, 7, 41, 43
	inamoenus Greene 194
	repens L. 0
	sp. 55.5, 51.5

Rhamnaceae

Rhamnus	*betulifolia* Greene 171, 168, 171.5
Ziziphus	*obtusifolia* (Torr. & Gray) A. Gray 194

Rosaceae

Amelanchier	*utahensis* Koehne 52.2
Cowania	*mexicana* D. Don , 138
Fallugia	*paradoxa* (D. Don) Endl. 20, 23.6
Fragaria	*ovalis* (Lehm.) Rydb. 98
Petrophytum	*caespitosum* (Nutt.) Rydb. 48, 171.5

Rubiaceae

Galium	*aparine* L. 47
	multiflorum Kellogg 106, 116.5
	proliferum Gray 136
	sp. 52, 143.5
	stellatum Kell. 104, 93.6, 144, 220, 91, 106, 104, 194, 87.5, 41, 47, 41, 30, 44.6

Rutaceae

Ptelea	*trifoliata* L. 47, 20.5
Thamnosma	*montana* Torr. & Frem. 41, 134, 22, 122, 52.3, 122.2

Salicaceae

Salix	*bonplandiana* H.B.K 156.5
	cf. lasiolepis Benth. 133.5
	exigua Nutt. 43.1, 43, 51.5, 43
	gooddingii Ball 205

Scrophulariaceae

Castilleja	*chromosa* Nels. 122.7, 41, 68
	integra Gray 172
	linariifolia Benth. 60.5
Cordylanthus	*parviflorus* (Ferris) Wiggens 68
Maurandya	*antirrhiniflora* Humb. & Bonpl. 51.5, 132, 168, 116.5, 104, 20.5, 168
Mimulus	*cardinalis* Dougl. 31.5, 179.5, 148
	glabratus H.B.K. 26
	guttatus DC. 43.1, 43, 136.5, 136.2, 104, 219
	rubellus Gray 106
Orthocarpus	*cf. purpurascens* Benth. 68.5
Penstemon	*bicolor* (Brandegee) Clokey & Keck 220
	eatoni Gray 148.3, 25, 106, 24
	palmeri Gray 156
Verbascum	*thapsus* L. 143

Veronica	*americana* (Raf.) Schwein. 55.5, 157, 172
	anagallis-aquatica L. 55.5, 43.1, 20, 51.5, 136.2, 133.5, 20, 172, 51.7, 194
	cf. anagellis-aquat. L. 43.1
	sp. 51.5
Solanaceae	
Datura	*meteloides* D.C. 55.5
Lycium	*andersonii* Gray 42, 41, 20.5, 44.6, 209
	cooperi Gray 45
	exsertum Gray 171
	pallidum Miers. 44.6
	sp. 19.6
Nicotiana	*glauca* Graham 157, 166.5
	sp. 149
	trigonophylla Dunal 136, 125, 68, 65.5, 132, 126
Petunia	*parviflora* Juss. 209
Physalis	*crassifolia* Benth. 84.1, 20.5, 166.5, 255.5, 64.6, 86.6, 21.8, 126, 87.8, 86.6, 64.6, 155.5
	hederifolia Gray 185.2
	sp. 136.5, 91
Solanum	*americanum* Miller 194, 133.5, 148
	elaeagnifolium Cav. 172, 87.8, 172
	nodiflorum Jacq. 171.5, 166.5
Sterculiaceae	
Ayenia	*pusilla* L. 156.8
Tamaricaceae	
Tamarix	*pentandra* Pall. 55.5, 43.1, 20, 43, 51.5, 20, 55.5, 8
Typhaceae	
Typha	*angustifolia* L. 43.1, 51.7, 50
	domingensis Pers. 194, 55.5, 43, 43.1, 55.5, 50
Ulmaceae	
Celtis	*reticulata* Torr. 44.6
Urticaceae	
Boerhaavia	*cylindrica* (L.) Sw. 34.7
Parietaria	*hespera* Hinton 43.1, 45, 43, 91, 148, 156.5, 106
	pensylvanica Muhl. 148, 136, 20.5, 171.5, 148, 116.4, 156.5
Verbenaceae	
Aloysia	*wrightii* (Gray) Heller 47.5, 96, 67.6, 143.4
Verbena	*bracteata* Lag. & Rodr. 194, 20, 213.5, 194, 34, 171.5
	macdougalii Heller 136.5
Verbeneaceae	
	bracteata Lag. & Rodr. 5.7
Viscaceae	
Phoradendron	*sp.* 180.3
Vitaceae	
Parthenocissus	*inserta* (Kerner) A. S. Hitchc. 144.8
Vitis	*arizonica* Engelm. 143.5, 157, 156.8
Zannichelliaceae	
Zanichellia	*palustris* L. 52
Aster	*coerulescens* DC. 133.5, 51.2, 132, 103

Zygophyllaceae

Kallstroemia	*californica* (Wats.) Vail 71.2, 68.5	
Larrea	*tridentata* (DC.) Cov. 220, 171.5	

APPENDIX B

PLANT SPECIES, IDENTIFYING NUMBERS, AND LIFE HISTORY GROUP DESIGNATIONS FOR SPECIES USED IN OUR VEGETATION ANALYSES

Appendix B: Plant species, identifying numbers and life history groups used in wetland and riparian vegetation descriptions. Groups include: 1) clonal wet marsh; 2) herbaceous non-clonal wet marsh; 3) bar platform; 4) dry marsh; 5) upper alluvial terrace; 6) rocky channel margin; and 7) xeric (desert) species.

SPECIES	IDNO	GROUP	SPECIES	IDNO	GROUP
Abronia elliptica	201	4	Eragrostis spp.	30	3
Acacia greggii	1	7	Eriogonum corymbosum	604	7
Acer negundo	203	5	Eriogonum inflatum	32	7
Acourtia wrightii	203	6	Eriogonum deflexum	33	7
Agropyron sp. undet.	209	4	Eriogonum spp. undet.	605	7
Agrostis spp.	2	1	Erigeron divergens	31	3
Agave utahensis	212	7	Erigeron lobatus	317	6
Alhagi camelorum	3	3	Erigeron spp. undet.	313	-
Amaranthaceae undet.	142	2	Erioneuron pulchellum	319	7
Ambrosia spp.	4	2	Euphorbia spp.	124	7
Andropogon glomeratus	76	6	Fallugia paradoxa	324	5
Apocynum cannabinum	222	3	Annual grass spp. undet.	72	3
Artemisia dracunculus	5	3	Gaillardia pinnatifida	329	6
Artemisia ludoviciana	6	6	Gallium stellatum	328	7
Aristida purpurea	227	7	Gnaphalium chilense	33	3
Aristida sp. undet.	96	7	Perennial grass undet.	71	3
Aster spinosus	7	3	Gutierrezia spp.	34	7
Aster subulatus	8	1	Isocoma acredenius	129	3
Astragalus spp.	237	3	Heliotropium convolvulaceum	339	7
Atriplex canescens	238	5	Heliotropium curassavicum	341	7
Baccharis emoryi	9	4	Hillaria rigida	484	7
Baccharis sarothroides	10	6	Hordeum jubatum	35	3
Baccharis sergiloides	244	6	Juncus balticus	37	3
Baccharis salicifolia	11	3	Juncus mexicanus	349	1
Baccharis spp. undet.	131	3	Juncus spp. undet.	39	4
Bebbia juncea	248	6	Juncus tenuis	351	1
Bidens frondosa	119	2	Juncus nevadensis	606	1
Bothriochloa spp.	93	6	Juncus torreyana	40	1
Bouteloua spp.	252	7	Lepidium montanum	113	6
Brickellia atractyloides	253	6	Lepidium fremontii	41	5
Brickellia californica	114	6	Lepidium spp. undet.	361	-
Brickellia longifolia	256	6	Machaeranthera spp.	367	7
Bromus rigidus	259	3	Mammillaraia tetrancistra	368	7
Bromums rubens	12	3	Mentha arvense	42	2
Bromus tectorum	13	7	Melilotus albus	97	2
Bromus wildenowii	14	2	Melilotus officinale	87	2
Bromus spp. undet.	258	3	Melilotus spp. undet.	43	2
Camissonia spp.	263	6	Medicago sativa	44	2
Carex aquatilis	17	1	Mentzelia albicaulis	374	6
Castilleja spp.	16	6	Muhlenbergia asperifolia	45	4
Celtis reticulata	601	5	Muhlenbergia spp. undet.	383	-
Centaurium exaltum	18	2	Nasturtium spp.	108	2
Cercium spp.	19	6	Nicotianan trigonophyllum	389	6
Corispermum nitidum	21	4	Nolina microcarpa	607	6
Chrysothamnus nauseosus	20	4	Oenothera hookeri	46	3
Conyza canadensis	22	2	Oenothera pallida	47	3
Cryptantha barbigera	602	7	Onagraceae undet.	396	-
Cryptantha spp.	603	7	Opuntia basilaris	397	7
Cynodon dactylon	23	2	Opuntia spp. undet.	401	7
Datura wrightii	287	6	Opuntia erinacea	399	7
Dicoria brandegei	24	4	Oryzopsis hymenoides	118	5
Dyssodia pentachaeta	294	7	Orthocarpus lutea	403	3
Dichanthelium lanuginossum	291	6	Panicum capillare	48	3
Echinochloa crus-galli	25	1	Paspalum dilatatum	127	1
Echinocereus triglochidiatus	298	7	Phragmites australis	49	1
Elymus canadensis	26	4	Plantago lanceolata	50	4
Encelia farinosa	301	7	Plantago major	51	4
Encelia frutescens	300	7	Poa spp.	120	-
Ephedra torreyana	305	7	Porophyllum gracile	417	6
Epilobium adenocaulon	27	3	Polygonum spp.	52	2
Equisetum arvense	28	1	Polypogon monspeliensis	53	4
Equisetum laevigatus x hyemale	29	4	Prosopis glandulosa	95	5

Appendix B (Continued)

SPECIES	IDNO	GROUP
Ranunculus spp.	126	2
Sarcostemma cynanchoides	427	6
Salix exigua	54	4
Salix gooddingii	55	3
Salsola iberica	56	3
Schizachyrium scoparium	99	6
Streptanthella spp. undet.	435	5
Scirpus spp. undet.	57	1
Scirpus americanus	111	1
Scirpus marinus	142	1
Scirpus pungens	58	1
Scirpus validus	107	1
Sonchus asper/Lactuca serriola	59	2
Solanum spp. undet.	505	6
Solidago canadensis	60	6
Solidago occidentalis	389	4
Solidago spp. undet.	441	-
Sphaeralcea spp. undet.	448	7
Sorghum halepense	608	3
Sporobolus contractus	61	3
Sporobolus cryptandrus	62	3
Sporobolus flexuosus	63	3
Sporobolus giganteus	447	3
Sporobolus spp. undet.	91	3
Stipa sp.	101	7
Stanleya pinnata	454	5
Stephanomeria spp. undet.	456	6
Taraxacum officinale	64	4
Tamarix pentandra=ramosissima	65	3
Tessaria sericea	66	3
Thamnausma montanum	461	7
Tragopogon dubius	67	3
Typha spp.	68	1
Tridens muticus	463	7
Chenopodiaceae undet.	69	2
Dicotyledon undet.	70	-
Annual grass undet.	72	-
Grass undet.	73	-
Veronica spp.	74	1
Vulpia spp.	609	5
Xanthium strumarium	75	3
Elymus cinereus	610	4
Hedeoma oblongifolium	611	7
Krameria parvifolia	612	7
Machaeranthera pinnatifida	613	7
Aster sp.	614	5
Solidago missouriensis	615	3
Senecio multilobatus	616	7
Boerhavvia wrightii	617	6

APPENDIX C

MARSH PLOTS DATA SUMMARY

1991 TO 1993

APPENDIX C

Species mean basal area/m2 (1 sd, number of plots), and total basal area on monitoring transects at eight marshes in the Colorado River corridor in the Grand Canyon in the autumn of 1991, 1992 and 1993. Identifying numbers (below) are used for species listed in this appendix and in Appendix B.

KEY: MARSH PLANT SPECIES NAMES AND IDENTIFYING NUMBERS

NO.	SPECIES	NO.	SPECIES
1	Acacia greggii	31	Erigeron spp.
2	Agrostis spp.	32	Eriogonum deflexum
3	Alhagi camelorum	33	Gnaphalium chilense
4	Ambrosia spp.	34	Gutierrezia spp.
5	Artemesia dracunculus	35	Hordeum jubatum
6	Artemesia ludoviciana	36	Juncus articulata
7	Aster spinosus	37	Juncus balticus
8	Aster subulatus	38	Juncus encifolius
9	Baccharis emoryi	39	Juncus spp.
10	Baccharis sarothroides	40	Juncus torreyana
11	Baccharis salicifolia	41	Lepidium latifolium
12	Bromus rubens	42	Mentha arvense
13	Bromus tectorum	43	Undet. Melilotus spp.
14	Bromus wildenowii	44	Medicago sativa
15	Centaurium calycosum	45	Muhlenbergia asperifolia
16	Castilleja spp.	46	Oenothera hookeri
17	Carex aquatilus	47	Oenothera pallida
18	Centaurium exaltum	48	Panicum capillare
19	Cersium spp.	49	Phragmites australis
20	Chrysothamnus nauseosus	50	Plantago lanceolata
21	Corispermum nitidum	51	Plantago major
22	Conyza canadensis	52	Undet. Polygonum spp.
23	Cynodon dactylon	53	Polypogon monspeliensis
24	Dicoria brandegii	54	Salix exigua
25	Echinochloa crus-galli	55	Salix gooddingii
26	Elymus canadensis	56	Salsola iberica
27	Epilobium adenocaulon	57	Scirpus spp.
28	Equisetum arvense	58	Scirpus pungens
29	Equisetum laevigatum x hymale	59	Sonchus asper+Lactuca serriola
30	Eragrostis spp.	60	Solidago canadensis

APPENDIX 2 KEY (Continued)

NO.	SPECIES
61	Sporobolus contractus
62	Sporobolus cryptandrus
63	Sporobolus flexuosus
64	Taraxacum officinale
65	Tamarix ramosissima
66	Tessaria sericea
67	Tragopogon dubius
68	Typha spp.
69	Undet. Chenopodiaceae
70	Undet. dicotyledon
71	Undet. perennial grass
72	Undet. annual grass
73	Undet. grass
74	Veronica anagallis-aquatica
75	Xanthium strumarium
76	Andropogon glomeratus
87	Melilotus albus
89	Solidago occidentalis
93	Bothriochloa spp.
96	Undet. Aristida spp.
95	Prosopis glandulosa
97	Melilotus albus
99	Schizachyrium scoparium
101	Stipa speciosa
107	Scirpus validus
108	Undet. Nasturtium spp.
111	Scirpus americana
113	Lepidium montanum
114	Bromus inermis
118	Oryzopsis hymenoides
119	Bidens frondosa
121	Undet. Poa spp.
126	Undet. Ranunculus spp.
127	Paspalum dilatatum
129	Isocoma acredenius
131	Undet. Baccharis sp.
141	Undet. Amaranthaceae
142	Scirpus marinus

MILE SIDE	SPP	1991 MEANBA	sd	n	SUMBA	1992 MEANBA	sd	n	SUMBA	1993 MEANBA	sd	n	SUMBA
43L	1	0.010	---	1	0.01	0.018	0.010	4	0.070	0	---	0	0
43L	2	5.500	1.655	2	11.00	0.272	0.358	11	2.990	0.188	0.171	6	1.131
43L	5	0.090	0.113	2	0.18	0	---	0	0	0	---	0	0
43L	6	0	---	0	0	0.145	0.134	2	0.290	0.176	0.268	5	0.880
43L	8	0	---	0	0	0	---	0	0	0.738	0.735	5	3.691
43L	9	20.485	26.467	2	40.97	340.300	532.398	3	1020.900	12.404	14.752	4	49.617
43L	12	0	---	0	0	0	---	0	0	0.264	0.350	2	0.527
43L	13	0	---	0	0	0.060	---	1	0.060	0	---	0	0
43L	14	0	---	0	0	9.300	---	1	9.300	0	---	0	0
43L	17	2.467	3.987	3	7.4	4.027	4.151	3	12.080	2.553	1.074	7	17.868
43L	21	0.107	0.072	3	0.32	0	---	0	0	0	---	0	0
43L	22	1.131	2.124	11	12.44	0.352	0.401	19	6.680	0.863	1.507	8	6.904
43L	26	1.45	1.626	2	2.9	1.780	1.089	2	3.560	6.122	6.818	4	24.489
43L	27	0	---	0	0	0.745	0.460	2	1.490	0.105	0.043	3	0.314
43L	28	1.401	1.652	9	12.61	0.418	0.536	8	3.340	0.168	0.074	7	1.178
43L	29	1.492	1.070	14	20.87	1.500	1.509	21	31.500	2.039	2.416	32	65.259
43L	30	0	---	0	0	0	---	0	0	0	---	0	0
43L	31	0.692	1.484	23	15.91	0.200	---	1	0.200	0.094	---	1	0.094
43L	33	0.361	0.564	7	2.53	0.111	0.128	8	0.890	0.249	0.212	9	2.238
43L	34	0.95	---	1	0.95	7.070	---	1	7.070	0.283	---	1	0.283
43L	35	0	---	0	0	0	---	0	0	1.767	---	1	1.767
43L	36	0	---	0	0	0.160	---	1	0.160	0.942	---	1	0.942
43L	37	0	---	0	0	1.114	1.761	8	8.910	1.063	1.360	9	9.566
43L	38	0	---	0	0	0	---	0	0	0	---	0	0
43L	39	2.502	3.884	11	27.52	1.137	0.962	6	6.820	0.640	0.894	2	1.280
43L	40	4.053	6.726	4	16.21	0.300	0.071	2	0.600	0.236	0.111	2	0.471
43L	41	0	---	0	0	0	---	0	0	0.086	0.022	2	0.173
43L	42	0	---	0	0	0.030	--	1	0.030	0	---	0	0
43L	43	0.071	0.068	8	0.57	0.273	0.306	4	1.090	0.730	1.231	3	2.191
43L	45	3.552	3.668	18	63.94	2.155	4.687	28	60.350	0.978	1.177	30	29.350
43L	46	0.043	0.029	6	0.26	0.739	1.453	8	5.910	0.111	0.072	8	0.887
43L	47	0.13	---	1	0.13	0	---	0	0	0	---	0	0
43L	49	2.29	---	1	2.29	3.460	--	1	3.460	17.043	---	1	17.043
43L	50	0	---	0	0	0.010	--	1	0.010	0	---	0	0
43L	51	0.826	0.814	18	14.86	1.316	1.237	13	17.110	0.932	0.840	11	10.257
43L	52	0	---	0	0	0.020	--	1	0.020	0	---	0	0
43L	54	6.991	9.343	47	328.56	9.118	8.886	44	401.180	8.560	12.150	41	350.952
43L	56	0.06	---	1	0.06	0	---	0	0	0	---	0	0
43L	57	11.31	---	1	11.31	0	---	0	0	0	---	0	0
43L	59	0.313	0.401	15	4.7	1.179	2.176	14	16.50	0.595	1.362	12	7.137
43L	61	0	---	0	0	0	---	0	0	7.147	6.549	3	21.441
43L	62	0.3	---	1	0.3	25.586	44.280	10	255.860	19.032	31.632	16	304.515
43L	64	0.05	0.028	2	0.1	0	---	0	0	0.785	---	1	0.785
43L	65	5.713	7.704	7	39.99	10.215	10.834	6	61.290	4.295	4.788	7	30.065
43L	66	0.935	0.318	2	1.87	0.136	0.065	3	0.410	0.968	0.773	4	3.872
43L	68	56.591	59.654	9	509.32	59.136	48.703	9	532.230	20.119	3.452	7	140.835
43L	70	0.175	0.326	12	2.1	0.079	0.111	12	0.950	---	---	-	---
43L	71	2.042	1.816	5	10.21	0.660	0.770	4	2.640	---	---	-	---

MILE SIDE	SPP	1991				1992				1993			
		MEANBA	sd	n	SUMBA	MEANBA	sd	n	SUMBA	MEANBA	sd	n	SUMBA
43L	73	5.521	(5.100,	34)	187.71	0.160	(-- ,	1)	0.160	---	(---	-)	---
43L	74	0.18	(0.195,	6)	1.08	0.270	(-- ,	1)	0.270	0.063	(--- ,	1)	0.063
43L	89	0	(--- ,	0)	0	4.030	(2.791,	4)	16.120	0.886	(1.689,	6)	5.317
43L	93	0	(--- ,	0)	0	10.954	(15.487,	16)	175.270	18.883	(25.748,	11)	207.713
43L	95	0	(--- ,	0)	0	0.010	(-- ,	1)	0.010	---	(---	-)	---
43L	96	0	(--- ,	0)	0	15.000	(-- ,	1)	15.000	---	(---	-)	---
43L	99	0	(--- ,	0)	0	0.723	(0.967,	3)	2.170	3.181	(2.746,	3)	9.543
43L	101	0	(--- ,	0)	0	0.040	(-- ,	1)	0.040	---	(---	-)	---
43L	102	0	(--- ,	0)	0	0.200	(0.099,	2)	0.400	---	(---	-)	---
43L	107	0	(--- ,	0)	0	3.325	(2.524,	2)	6.650	---	(---	-)	---
43L	123	0	(--- ,	0)	0	0	(--- ,	0)	0	0.821	(1.553,	4)	3.283
43L	124	0	(--- ,	0)	0	0	(--- ,	0)	0	0.008	(--- ,	1)	0.008

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
51L	1	0	---	0	0	0	---	0	0	113.100	---	1	113.100
51L	2	0	---	0	0	1.835	1.640	7	12.847	14.285	31.797	12	171.420
51L	4	0	---	0	0	0.071	---	1	0.071	0.125	0.106	2	0.250
51L	8	0	---	0	0	0.330	0.286	8	2.643	2.520	3.283	3	7.560
51L	9	9.62	---	1	9.62	0.126	---	1	0.126	1.915	2.524	2	3.830
51L	11	9.82	9.093	2	19.64	0	---	0	0	0	---	0	0
51L	12	0	---	0	0	0.196	---	1	0.196	0	---	0	0
51L	13	0	---	0	0	0	---	0	0	0.130	0.099	2	0.260
51L	14	2.978	5.664	9	26.8	2.129	5.494	8	17.035	20.204	28.310	9	181.840
51L	15	0.015	0.007	2	0.03	0	---	0	0	0	---	0	0
51L	17	11.5	12.49	3	34.5	0.459	0.274	4	1.838	0	---	0	0
51L	21	0	---	0	0	0.024	---	1	0.024	0.020	--	1	0.020
51L	22	0.802	0.713	6	4.81	0.216	0.202	4	0.864	0.400	0.333	9	3.60
51L	25	0	---	0	0	0.458	0.326	3	1	2.070	--	1	2.070
51L	26	1	---	1	1	2.774	3.346	5	13.870	0	---	0	0
51L	27	0.01	---	1	0.01	0.283	---	1	0.283	0.093	0.088	9	0.840
51L	28	0	---	0	0	0.060	0.032	3	0.181	0.191	0.161	9	1.720
51L	29	1.358	1.525	17	23.08	1.495	1.378	23	34.393	3.491	2.611	19	66.340
51L	30	0	---	0	0	4.697	3.601	11	51.671	0	---	0	0
51L	31	0	---	0	0	0.353	---	1	0.353	44.996	113.926	8	359.970
51L	32	0	---	0	0	0	---	0	0	0	---	0	0
51L	33	1.222	2.119	5	6.11	0.834	1.601	11	9.179	1.106	1.301	18	19.920
51L	34	0.05	---	1	0.05	0.503	---	1	0.503	0.600	--	1	0.60
51L	35	0.6	0.566	2	1.2	8.427	---	1	8.427	0	---	0	0
51L	36	0	---	0	0	0.421	0.326	5	2.105	0.930	0.014	2	1.860
51L	37	7.005	9.892	2	14.01	1.335	0.111	2	2.670	0.850	--	1	0.850
51L	38	4.55	3.465	2	9.1	0	---	0	0	0	---	0	0
51L	39	2.1	---	1	2.1	0.263	0.069	2	0.526	2.735	3.147	4	10.940
51L	40	1.96	2.065	5	9.8	4.948	---	1	4.948	3.530	--	1	3.530
51L	41	0	---	0	0	0.326	0.201	3	0.978	0.060	--	1	0.060
51L	43	0.253	0.245	3	0.76	0.075	0.017	2	0.149	0.266	0.065	3	0.80
51L	45	1.497	1.094	3	4.49	2.277	5.054	9	20.491	0.343	0.412	10	3.430
51L	48	0	---	0	0	0	---	0	0	1.542	1.353	4	6.170
51L	49	0.39	---	1	0.39	4.241	---	1	4.241	0	---	0	0
51L	50	2.75	3.182	2	5.5	0.035	0.039	2	0.071	2.110	--	1	2.110
51L	51	2.634	2.978	15	39.51	0.364	0.334	12	4.367	3.228	5.345	13	41.970
51L	52	1.114	1.842	10	11.14	0.016	---	1	0.016	0	---	0	0
51L	53	1.01	2.062	11	11.11	0	---	0	0	0	---	0	0
51L	54	7.283	10.483	35	254.91	8.489	10.807	25	212.230	12.543	17.851	30	376.30
51L	56	0.155	0.205	2	0.31	0	---	0	0	0.020	--	1	0.020
51L	59	0.724	0.615	9	6.52	0.195	0.229	5	0.976	2.573	5.573	13	33.450
51L	62	0	---	0	0	60.429	---	1	60.429	18.651	32.056	6	111.910
51L	64	1.34	2.304	3	4.02	0	---	0	0	0	---	0	0
51L	65	17.965	22.320	6	107.79	24.715	10.828	2	49.431	14.066	14.335	5	70.330
51L	66	4.045	2.708	2	8.09	2.816	2.227	2	5.631	3.235	1.252	2	6.470
51L	68	5.3	---	1	5.3	4.987	---	1	4.987	8.070	--	1	8.070
51L	70	0.01	0	2	0.02	0	---	0	0	5.675	9.848	14	79.450
51L	71	0.4	---	1	0.4	0	---	0	0	5.500	6.661	2	110

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
51L	72	0	---	0	0	3.658	5.116	6	21.950	11.597	19.974	3	34.790
51L	73	3.568	4.340	29	103.48	0	---	0	0	0	---	0	0
51L	74	1.273	1.200	8	10.18	0	---	0	0	0.030	--	1	0.030
51L	89	0	---	0	0	0.196	---	1	0.196	0	---	0	0
51L	95	0	---	0	0	0.750	0.972	2	1.500	0	---	0	0
51L	107	0	---	0	0	5.655	---	1	5.655	6.775	5.975	2	13.550
51L	108	0	---	0	0	0.675	0.822	2	1.351	1.025	1.258	4	4.10
51L	113	0	---	0	0	0	---	0	0	0.165	0.114	4	0.660
51L	114	0	---	0	0	0	---	0	0	0.778	0.924	5	3.890
51L	118	0	---	0	0	0	---	0	0	9.620	--	1	9.620
51L	119	0	---	0	0	0.024	---	1	0.024	0.250	--	1	0.250
51L	121	0	---	0	0	0	---	0	0	44.770	--	1	44.770
51L	123	0	---	0	0	0.039	0.025	4	0.157	0.193	0.150	3	0.580
51L	124	0	---	0	0	0	---	0	0	0.010	--	1	0.010
51L	126	0	---	0	0	0	---	0	0	0.640	--	1	0.640

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
56R	2	3.094	4.228	9	27.85	1.016	1.548	17	17.270	0.341	0.548	9	3.073
56R	6	0.13	---	1	0.13	0	---	0	0	0.016	---	1	0.016
56R	8	0.556	0.560	7	3.89	0.321	0.519	28	90.000	0.280	0.382	5	1.402
56R	9	7.256	9.832	5	36.28	6.556	12.009	7	45.890	6.002	13.611	6	36.011
56R	11	1.3	---	1	1.3	0	---	0	0	0	---	0	0
56R	12	0.79	---	1	0.79	0.160	--	1	0.160	0.147	---	1	0.147
56R	13	0	---	1	0	0.040	--	1	0.040	0	---	0	0
56R	14	3.257	1.287	3	9.77	8.523	12.422	3	25.570	0.338	0.344	2	0.675
56R	15	0.3	0.141	2	0.6	0	---	0	0	0	---	0	0
56R	17	1.39	1.526	3	4.17	1.767	3.108	4	7.070	0.308	0.119	3	2.303
56R	18	0.267	0.307	11	2.94	0.058	0.090	6	0.350	0.102	---	1	0.102
56R	19	0.2	---	1	0.2	0	---	0	0	0	---	0	0
56R	20	0.03	---	1	0.03	1.770	--	1	1.770	0	---	0	0
56R	21	0.02	0.014	2	0.04	0.025	0.007	2	0.050	0	---	0	0
56R	22	1.167	1.492	9	10.5	0.332	0.541	6	1.990	0	---	0	0
56R	24	0.23	---	1	0.23	0.080	--	1	0.080	0.437	0.616	15	6.550
56R	26	1.6	---	1	1.6	63.620	--	1	63.620	0.196	---	1	0.196
56R	27	0.207	0.113	7	1.45	0.091	0.072	8	0.730	0.314	---	1	0.314
56R	28	1.757	3.188	10	17.57	0.520	0.978	6	3.120	0.039	---	1	0.039
56R	29	4.55	5.387	9	40.95	4.897	8.349	20	97.930	2.867	3.943	2	5.733
56R	31	4.62	4.870	7	32.34	0.310	0.282	3	0.930	4.899	1.219	18	88.178
56R	33	2.573	5.596	27	69.48	4.470	10.156	30	134.110	2.450	5.271	14	34.306
56R	35	0.4	0.2	3	1.2	2.690	0.406	3	8.070	0.291	---	1	0.291
56R	36	14.233	13.652	3	42.7	0	---	0	0	1.767	---	1	1.767
56R	37	0	---	0	0	7.030	7.835	2	14.060	0.581	0.200	2	1.162
56R	38	12.18	12.687	4	48.72	0	---	0	0	0	---	0	0
56R	39	9.45	12.536	4	37.8	4.158	4.660	4	16.630	0.491	0.028	2	0.982
56R	40	1.987	1.414	3	5.96	1.610	1.332	3	4.830	0	---	0	0
56R	41	2.705	1.223	2	5.41	0.110	0.113	2	0.220	0.456	---	1	0.456
56R	42	0.14	---	1	0.14	0.330	0.283	2	0.660	0.378	---	1	0.378
56R	43	0.15	0.231	11	1.65	0.937	1.519	15	14.050	3.345	1.689	19	63.554
56R	44	0	---	0	0	0.020	--	1	0.020	0	---	0	0
56R	45	1.014	1.359	9	9.13	2.085	2.745	20	41.690	3.198	5.316	18	57.562
56R	46	0.39	---	1	0.39	0	---	0	0	0	---	0	0
56R	48	0	---	0	0	0.630	0.042	2	1.260	3.953	6.626	10	39.531
56R	49	5.327	8.453	3	15.98	12.053	13.120	4	48.210	11.918	15.147	6	71.511
56R	50	1.17	---	1	1.17	0.010	--	1	0.010	3.664	3.271	2	7.328
56R	51	0.602	0.678	12	7.22	1.093	1.868	21	22.950	0.594	1.599	14	8.313
56R	52	3.585	2.489	12	43.02	0	---	0	0	0	---	0	0
56R	53	1.051	2.032	8	8.41	0.220	--	1	0.220	0	---	0	0
56R	54	11.223	30.494	23	258.13	22.241	80.306	31	689.470	11.260	32.037	19	213.937
56R	56	0.02	---	1	0.02	0.070	--	1	0.070	0	---	0	0
56R	57	2.8	1.809	3	8.4	0.740	--	1	0.740	1.500	---	1	1.500
56R	58	4.18	4.045	2	8.36	0	---	0	0	3.008	2.152	5	15.040
56R	59	0.657	1.554	10	6.57	0.181	0.248	16	2.890	0.074	0.119	6	0.442
56R	60	0	---	0	0	0	---	0	0	0.173	0.022	2	0.346
56R	61	209.31	179.379	2	418.62	0	---	0	0	2.105	1.822	2	4.210

MILE SIDE	SPP	1991				1992				1993			
		MEANBA	sd	n	SUMBA	MEANBA	sd	n	SUMBA	MEANBA	sd	n	SUMBA
56R	62	0	---	0	0	55.205	81.129	6	331.230	1 424.668	---	1	1424.668
56R	63	39.665	54.978	2	79.33	0	---	0	0	0.691	---	1	0.691
56R	64	3.02	---	1	3.02	0.780	--	1	0.780	0.262	0.202	3	0.786
56R	65	14.898	34.050	15	223.47	11.080	36.066	17	188.360	2.663	4.770	11	29.290
56R	67	0.2	---	1	0.2	0	---	0	0	0	---	0	0
56R	70	23.391	64.935	9	210.52	0.632	0.910	28	17.700	0	---	0	0
56R	71	14.162	29.849	5	70.81	0.220	0.168	7	1.540	0	---	0	0
56R	72	0.22	0.274	3	0.66	0.010	--	1	0.010	0	---	0	0
56R	73	0.413	0.749	18	7.43	0	---	0	0	0	---	0	0
56R	74	0.239	0.187	7	1.67	0.010	--	1	0.010	0	---	0	0
56R	89	0	---	0	0	1.900	0.935	3	5.700	0.516	0.987	6	3.095
56R	91	0	---	0	0	0.010	--	1	0.010	0.188	0.044	2	0.377
56R	107	0	---	0	0	0	---	0	0	2.284	2.653	3	6.852
56R	111	0	---	0	0	5.230	3.708	15	78.450	0	---	0	0
56R	141	0	---	0	0	2.360	--	1	2.360	0	---	0	0
56R	142	0	---	0	0	0	---	0	0	0.377	---	1	0.377

MILE SIDE	SPP	1991 MEANBA	sd	n	SUMBA	1992 MEANBA	sd	n	SUMBA	1993 MEANBA	sd	n	SUMBA
71L	2	0.330	---	1	0.330	---	---	-	---	0.188	---	1	0.188
71L	3	0.989	0.843	7	6.920	---	---	-	---	1.372	2.383	10	13.723
71L	9	2.840	---	1	2.840	---	---	-	---	0.079	---	1	0.079
71L	11	12.778	14.110	4	51.110	---	---	-	---	8.684	7.843	3	26.052
71L	12	6.432	8.797	5	32.160	---	---	-	---	0.387	0.264	9	3.479
71L	17	0	---	0	0	---	---	-	---	0.620	---	1	0.620
71L	18	0	---	0	0	---	---	-	---	0	---	0	0
71L	22	0.978	1.494	6	5.870	---	---	-	---	0	---	0	0
71L	23	2	1.429	4	8	---	---	-	---	0	---	0	0
71L	28	0.070	---	1	0.070	---	---	-	---	0	---	0	0
71L	29	4.162	5.935	13	54.110	---	---	-	---	2.125	2.708	6	12.747
71L	31	0	---	0	0	---	---	-	---	0.008	---	1	0.008
71L	32	0.030	---	1	0.030	---	---	-	---	0	---	0	0
71L	33	0.475	0.756	8	3.800	---	---	-	---	0	---	0	0
71L	34	0	---	0	0	---	---	-	---	0.165	---	1	0.165
71L	36	0	---	0	0	---	---	-	---	0	---	0	0
71L	37	2.970	---	1	2.970	---	---	-	---	0	---	0	0
71L	38	2.200	---	1	2.200	---	---	-	---	0	---	0	0
71L	39	5.037	7.197	6	30.220	---	---	-	---	0.772	1.290	3	2.317
71L	43	0.770	1.316	3	2.310	---	---	-	---	0.006	0.003	4	0.026
71L	45	11.390	7.744	3	34.170	---	---	-	---	8.537	11.381	4	34.149
71L	48	0	---	0	0	---	---	-	---	0	---	0	0
71L	49	4.958	5.862	12	59.490	---	---	-	---	4.797	8.942	11	52.765
71L	50	0	---	0	0	---	---	-	---	0	---	0	0
71L	51	0.07	---	1	0.070	---	---	-	---	0	---	0	0
71L	52	0	---	0	0	---	---	-	---	0	---	0	0
71L	53	0.2	---	1	0.200	---	---	-	---	0	---	0	0
71L	54	7.360	11.460	25	184.010	---	---	-	---	10.971	20.698	18	197.481
71L	55	380.130	---	1	380.130	---	---	-	---	249.242	287.293	2	498.484
71L	57	0	---	0	0	---	---	-	---	0.071	---	1	0.071
71L	58	0	---	0	0	---	---	-	---	0	---	0	0
71L	60	0	---	0	0	---	---	-	---	0.456	0.524	5	2.278
71L	62	2.203	2.549	3	6.610	---	---	-	---	0	---	0	0
71L	63	2.500	---	1	2.500	---	---	-	---	0.542	---	1	0.542
71L	65	66.153	145.5	12	793.840	---	---	-	---	25.605	52.649	12	307.254
71L	66	3.406	4.200	5	17.030	---	---	-	---	12.192	14.180	6	73.152
71L	68	0.640	---	1	0.640	---	---	-	---	0	---	0	0
71L	70	0.037	0.046	3	0.110	---	---	-	---	0	---	0	0
71L	71	0	---	0	0	---	---	-	---	0.471	0.222	2	0.942
71L	72	0	---	0	0	---	---	-	---	0.520	0.597	2	1.041
71L	73	0.140	0.225	3	0.420	---	---	-	---	0	---	0	0
71L	119	0	---	0	0	---	---	-	---	1.767	---	1	1.767
71L	123	0	---	0	0	---	---	-	---	0.057	0.075	2	0.114
71L	131	0	---	0	0	---	---	-	---	12.566	---	1	12.566

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
123L	2	0.774	0.520	5	3.870	0.830	0.826	3	2.490	1.467	1.642	5	7.336
123L	6	0.070	---	1	0.070	0.310	0.156	2	0.620	0	---	0	0
123L	8	0	---	0	0	0.165	0.049	2	0.330	0	---	0	0
123L	9	0	---	0	0	0	---	0	0	1.225	---	1	1.225
123L	11	0	---	0	0	0.030	--	1	0.030	0	---	0	0
123L	12	0	---	0	0	0	---	0	0	0.310	0.094	3	0.931
123L	13	0.255	0.346	2	0.510	0	---	0	0	0.071	---	1	0.071
123L	16	0.523	0.428	3	1.570	0.220	0.269	2	0.440	0	---	0	0
123L	22	0.892	0.916	11	9.810	0.616	0.520	14	8.630	0.059	0.039	2	0.118
123L	24	0.451	0.569	7	3.160	0.108	0.073	9	0.970	0.058	0.023	3	0.174
123L	29	11.688	13.864	15	175.320	7.315	9.980	21	153.620	8.809	12.438	16	140.944
123L	31	0	---	0	0	0.141	0.202	7	0.990	0	---	0	0
123L	33	0	---	0	0	0.070	0.000	3	0.210	0	---	0	0
123L	43	0.010	0	2	0.020	0.050	0.028	2	0.100	0	---	0	0
123L	45	0.330	---	1	0.330	2.540	3.930	3	7.620	0	---	0	0
123L	47	0.130	---	1	0.130	0.065	0.007	2	0.130	0	---	0	0
123L	49	0.505	0.177	2	1.010	1.140	0.812	4	4.560	40.375	76.192	4	161.500
123L	52	2.020	---	1	2.020	0	---	0	0	0	---	0	0
123L	54	8.139	18.385	15	122.090	8.098	14.742	20	161.950	6.780	14.601	14	94.920
123L	56	0.010	---	1	0.010	0	---	0	0	0	---	0	0
123L	59	1.003	0.995	3	3.010	0.125	0.263	11	1.370	0	---	0	0
123L	62	0	---	0	0	1.243	0.929	4	4.970	0	---	0	0
123L	65	8.702	11.153	6	52.210	14.078	18.652	6	84.470	20.681	31.608	5	103.405
123L	66	0	---	0	0	0.320	--	1	0.320	1.804	2.839	4	7.216
123L	70	0	---	0	0	0.096	0.136	9	0.860	0	---	0	0
123L	71	0.010	---	1	0.010	1.375	0.276	2	2.750	0	---	0	0
123L	72	0	---	1	0	0.015	0.007	2	0.030	0.062	0.051	2	0.124
123L	74	0.400	0	2	0.800	0	---	0	0	0	---	0	0
123L	89	0	---	0	0	3.620	2.913	2	7.240	2.909	2.980	5	14.545
123L	91	0	---	0	0	0	---	0	0	0.408	---	1	0.408
123L	102	0	---	0	0	0.130	---	1	0.130	0	---	0	0
123L	114	0	---	0	0	4.910	---	1	4.910	0	---	0	0

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
172L	8	0	---	0	0	0.070	---	1	0.070	0	---	0	0
172L	2	0.010	0	4	0.040	1.417	1.846	3	4.250	1.070	1.177	5	5.349
172L	4	0.010	0	2	0.020	0.130	---	1	0.130	0	---	0	0
172L	6	2.267	2.336	3	6.800	0.865	0.318	2	1.730	0	---	0	0
172L	7	0.880	0.962	2	1.760	0	---	0	0	0	---	0	0
172L	8	0	---	0	0	0.106	0.068	5	0.530	0	---	0	0
172L	9	1.205	2.854	11	13.260	0.327	0.272	6	1.960	3.925	6.782	9	35.327
172L	10	0	---	0	0	14.175	25.573	6	85.050	4.179	3.989	11	45.969
172L	11	0	---	0	0	0.060	---	1	0.060	0	---	0	0
172L	12	0.217	0.358	3	0.650	0	---	0	0	1.543	1.294	7	10.799
172L	13	0	---	0	0	0	---	0	0	0.432	0.150	4	1.728
172L	17	0.010	---	1	0.010	0.220	---	1	0.220	0	---	0	0
172L	22	0.552	0.942	25	13.810	0.446	0.487	13	5.800	0.031	---	1	0.031
172L	23	4.122	6.601	30	123.660	3.820	2.900	13	49.660	1.081	0.733	17	18.370
172L	24	1.400	---	1	1.400	0	---	0	0	0	---	0	0
172L	29	4.961	4.560	28	138.900	4.209	4.125	25	105.230	8.096	14.806	25	202.400
172L	30	0	---	0	0	0.790	---	1	0.790	0	---	0	0
172L	31	0.125	0.049	2	0.250	0	---	0	0	0	---	0	0
172L	33	0.105	0.165	12	1.260	1.095	1.007	11	12.040	0.024	0.014	3	0.071
172L	34	3.645	5.112	2	7.290	0	---	0	0	0.283	---	1	0.283
172L	35	0.200	---	1	0.200	0	---	0	0	0	---	0	0
172L	36	1.400	---	1	1.400	0	---	0	0	0	---	0	0
172L	37	22.750	27.224	2	45.500	0	---	0	0	1.200	0.948	4	4.799
172L	39	0.020	---	1	0.020	0	---	0	0	0	---	0	0
172L	40	4.903	7.886	3	14.710	5.400	1.454	3	16.20	0	---	0	0
172L	43	0.073	0.038	7	0.510	2.263	4.751	16	36.210	0.872	0.200	2	1.744
172L	44	3.140	---	1	3.140	0	---	0	0	0	---	0	0
172L	45	0.954	1.847	5	4.770	2.842	2.714	15	42.630	0.188	0.140	7	1.319
172L	48	0.480	0.454	3	1.440	0	---	0	0	0	---	0	0
172L	49	0.093	0.040	3	0.280	0.475	0.134	2	0.950	0.827	0.154	7	5.789
172L	51	0.010	0	2	0.020	0.583	0.476	3	1.750	0	---	0	0
172L	52	0.986	1.009	13	12.820	0	---	0	0	0	---	0	0
172L	53	0.254	0.547	14	3.550	0	---	0	0	0	---	0	0
172L	54	2.993	3.096	40	119.700	4.810	4.525	36	173.160	3.253	2.561	35	113.848
172L	56	0.010	---	1	0.010	0	---	0	0	0	---	0	0
172L	59	0.219	0.290	7	1.530	0.130	0.194	4	0.520	0.092	0.159	5	0.461
172L	60	0.130	---	1	0.130	0	---	0	0	0	---	0	0
172L	89	0	---	0	0	0	---	0	0	0	---	0	0
172L	61	1.002	0.702	4	4.010	0	---	0	0	0	---	0	0
172L	62	7.500	---	1	7.500	46.717	60.033	3	140.150	0.424	---	1	0.424
172L	65	54.390	73.299	5	271.950	88.944	115.636	5	444.720	40.097	70.254	6	240.583
172L	66	1.157	0.898	3	3.470	1.770	--	1	1.770	0.491	0.417	2	0.982
172L	70	0.040	0.052	3	0.120	0.143	0.261	10	1.430	0	---	0	0
172L	71	1.500	---	1	1.500	0.160	--	1	0.160	0	---	0	0
172L	72	0	---	0	0	0.310	0.057	2	0.620	0	---	0	0
172L	73	0.604	0.797	10	6.040	0	---	0	0	0	---	0	0
172L	76	14.140	---	1	14.140	0	---	0	0	0	---	0	0
172L	77	0	---	0	0	0	---	0	0	0.651	0.796	8	5.207

MILE SIDE	SPP	1991 MEANBA	sd	n	SUMBA	1992 MEANBA	sd	n	SUMBA	1993 MEANBA	sd	n	SUMBA
172L	89	0	(--- ,	0)	0	1.135	(0.573,	2)	2.270	0.199	(0.197,	3)	0.597
172L	91	0	(--- ,	0)	0	24.170	(26.135,	2)	48.340	0	(--- ,	0)	0
172L	93	0	(--- ,	0)	0	6.237	(9.421,	3)	18.710	0	(--- ,	0)	0
172L	129	0	(--- ,	0)	0	0.030	(-- ,	1)	0.030	0	(--- ,	0)	0
172L	131	0	(--- ,	0)	0	0.939	(1.547,	11)	10.330	0.126	(--- ,	1)	0.126

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
194L	2	1.582	2.457	11	17.400	0.715	0.768	8	5.720	2.728	5.211	6	16.368
194L	3	0.450	---	1	0.450	0.350	--	1	0.350	0	---	0	0
194L	6	5.418	8.027	5	27.090	0.458	0.357	4	1.830	0.291	0.189	2	0.581
194L	7	0.09	---	1	0.090	0.870	--	1	0.870	0.730	---	1	0.730
194L	8	0	---	0	0	0.565	0.608	6	3.390	0.283	---	1	0.283
194L	9	0.070	---	1	0.070	1.835	0.997	2	3.670	13.045	17.207	3	39.136
194L	10	3.920	4.063	3	11.760	4.410	2.630	2	8.820	1.665	1.244	2	3.330
194L	12	2.313	3.466	3	6.940	0	---	0	0	2.020	2.138	4	8.082
199L	13	0	---	0	0	0	---	0	0	0.157	---	1	0.157
194L	17	3.450	4.402	6	20.700	1.540	--	1	1.540	0	---	0	0
194L	22	0.378	0.652	9	3.400	0.655	0.669	4	2.620	0.385	0.533	2	0.770
194L	23	8.015	8.846	18	144.270	6.121	16.413	18	110.180	1.681	2.967	23	38.669
194L	24	0	---	0	0	0.320	--	1	0.320	0	---	0	0
194L	25	17.675	2.779	2	35.350	0.030	0.000	2	0.060	6.354	8.786	2	12.708
194L	29	3.288	3.913	5	16.440	1.434	1.263	10	14.340	0.856	0.676	10	8.561
194L	33	0.206	0.284	11	2.270	8.100	15.841	4	32.40	0	---	0	0
194L	35	0.010	0	3	0.030	0.040	0.000	2	0.080	0.785	---	1	0.785
194L	37	0	---	0	0	0.380	--	1	0.380	3.711	4.249	2	7.422
194L	39	1.410	---	1	1.410	3.793	6.902	4	15.170	0.031	---	1	0.031
194L	40	2.256	2.349	7	15.790	1.627	1.288	3	4.880	0	---	0	0
194L	42	0	---	0	0	0.550	--	1	0.550	0.016	---	1	0.016
194L	43	6.168	7.724	16	98.680	1.374	1.726	15	20.610	0.641	0.834	16	10.249
194L	45	0	---	0	0	0.537	0.689	12	6.450	1.403	2.759	12	16.831
194L	47	0.125	0.092	2	0.250	0	---	0	0	0	---	0	0
194L	48	4.268	5.105	5	21.340	0	---	0	0	0	---	0	0
194L	49	0.790	---	1	0.790	4.025	4.306	2	8.050	23.464	15.411	2	46.928
194L	50	0	---	0	0	0	---	0	0	0.002	---	1	0.002
194L	51	0.985	0.865	6	5.910	0.143	0.103	4	0.570	3.786	4.643	2	7.571
194L	52	6.255	19.403	19	118.840	0.270	0.113	2	0.540	0	---	0	0
194L	53	0.140	0.225	3	0.420	0.220	--	1	0.220	0	---	0	0
194L	54	0.506	0.509	5	2.530	2.783	4.051	4	11.130	3.030	2.486	6	18.182
194L	56	0.710	---	1	0.710	0	---	0	0	0	---	0	0
194L	58	0	---	0	0	0	---	0	0	0.874	0.676	3	2.623
194L	59	0.123	0.179	3	0.370	0.108	0.083	5	0.540	0.006	---	1	0.006
194L	59	0	---	0	0	0	---	0	0	0.016	---	1	0.016
194L	62	0	---	0	0	0	---	0	0	0	---	0	0
194L	61	1.538	1.517	4	6.150	1.770	--	1	1.770	0	---	0	0
194L	62	0	---	0	0	24.666	20.630	5	123.330	17.735	28.176	3	53.205
194L	65	16.931	32.109	10	169.310	17.737	25.294	13	230.580	13.311	20.636	14	186.350
194L	66	3.520	---	1	3.520	4.670	--	1	4.670	48.416	61.484	2	96.832
194L	68	112.495	121.646	13	1462.430	47.257	58.843	15	708.860	25.952	23.554	17	441.176
194L	69	0.200	---	1	0.200	0	---	0	0	0	---	0	0
194L	70	0.030	---	1	0.030	0.010	--	1	0.010	0	---	0	0
194L	71	38.490	---	1	38.490	77.355	107.388	2	154.710	0	---	0	0
194L	72	0	---	0	0	0.060	--	1	0.060	9.444	12.468	2	18.889
194L	73	0.400	---	1	0.400	0	---	0	0	0	---	0	0
194L	74	0.980	---	1	0.980	0	---	0	0	0.027	0.017	2	0.055
194L	75	0.130	---	1	0.130	0	---	0	0	0	---	0	0

MILE SIDE	SPP	1991 MEANBA	sd	n	SUMBA	1992 MEANBA	sd	n	SUMBA	1993 MEANBA	sd	n	SUMBA
194L	76	0	(--- ,	0)	0	0	(--- ,	0)	0	3.142	(,	1)	3.142
194L	89	0	(--- ,	0)	0	0.715	(0.951,	4)	2.860	0.614	(--- ,	8)	4.909
194L	93	0	(--- ,	0)	0	0	(--- ,	0)	0	0.511	(--- ,	1)	0.511
194L	102	0	(--- ,	0)	0	0.790	(--- ,	1)	0.790	0	(--- ,	0)	0
194L	107	0	(--- ,	0)	0	1.510	(-- ,	1)	1.510	0.188	(--- ,	1)	0.188
194L	121	0	(--- ,	0)	0	0	(--- ,	0)	0	0.393	(--- ,	1)	0.393
194L	127	0	(--- ,	0)	0	0.660	(0.057,	2)	1.320	0.652	(0.648,	4)	2.608

MILE SIDE	SPP	1991 MEANBA	1991 sd	1991 n	1991 SUMBA	1992 MEANBA	1992 sd	1992 n	1992 SUMBA	1993 MEANBA	1993 sd	1993 n	1993 SUMBA
213L	2	0	---	0	0	0	---	0	0	0.157	---	1	0.157
213L	8	0	---	0	0	0	---	0	0	0.338	---	1	0.338
213L	10	0	---	0	0	0	---	0	0	5.082	6.504	3	15.245
213L	11	0	---	0	0	0	---	0	0	10.049	14.112	2	20.098
213L	12	0	---	0	0	0	---	0	0	0.143	0.200	7	1.430
213L	22	0	---	0	0	0	---	0	0	0.263	0.550	7	1.838
213L	33	0	---	0	0	0	---	0	0	0.047	---	1	0.047
213L	35	0	---	0	0	0	---	0	0	6.401	5.498	3	19.203
213L	43	0	---	0	0	0	---	0	0	0.066	0.069	5	0.330
213L	49	0	---	0	0	0	---	0	0	4.955	3.591	25	123.884
213L	58	0	---	0	0	0	---	0	0	0.141	---	1	0.141
213L	59	0	---	0	0	0	---	0	0	0.267	0.283	3	0.801
213L	62	0	---	0	0	0	---	0	0	0.723	0.933	2	1.445
213L	65	0	---	0	0	0	---	0	0	4.037	3.532	2	8.074
213L	70	0	---	0	0	0	---	0	0	0.030	0.021	5	0.151
213L	77	0	---	0	0	0	---	0	0	1.080	1.343	4	4.322
213L	83	0	---	0	0	0	---	0	0	0.031	---	1	0.031
213L	89	0	---	0	0	0	---	0	0	0.031	---	1	0.031
213L	96	0	---	0	0	0	---	0	0	12.216	14.474	3	36.647
213L	99	0	---	0	0	0	---	0	0	0.628	0.733	4	2.513
213L	131	0	---	0	0	0	---	0	0	13.868	17.502	3	41.603

APPENDIX D

MEAN BASAL AREA (n, 1 sd) OF PLANT SPECIES OCCURRING ON LONG-TERM STUDY QUADRATS IN 1992 (APPENDIX D1) AND 1993 (APPENDIX D2)

Appendix D1: Mean total 1992 plant species basal area (cm^2/m^2), with n and 1 sd, in channel margin, bar platform and debris fan geomorphic settings at 20 eddy study areas through the Colorado River in the Grand Canyon, Arizona. Refer to Appendix B for species identifying numbers.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm^2)	n	1sd BASAL AREA (cm^2)	SP	MEAN BASAL AREA (cm^2)	n	1sd BASAL AREA (cm^2)	SP	MEAN BASAL AREA (cm^2)	n	1sd BASAL AREA (cm^2)
1	0.0116667	6	0.00408248	1	0.01	3	0	201	0.01	1	
2?	8.55	1		209	1.33	1		1	0.0544444	9	0.114903
2	1.19333	3	1.65995	2	1.115	2	1.01116	2	0.27	1	
212	0.57	1		3	1.13	3	1.48395	3	0.09	2	0.0848528
3	0.545	2	0.360624	222	0.01	1		5	0.01	1	
5?	0.14	1		5	0.14	1		227	4.11	7	6.39699
5	1.15	2	1.6122	227	1.87	2	2.46073	96	6.28857	7	10.6419
227	0.225	2	0.289914	96	0.975	2	1.15258	6	0.18	3	0.193132
96	9.106	5	13.5123	6	0.915	4	1.74338	6?	12.12	1	
6	2.364	10	4.85799	7	0.72	2	1.00409	7	2.08	2	2.1496
7	1	3	1.5199	8	0.01	2	0	8	0.01	1	
8	0.0366667	3	0.046188	237	0.01	1		237	0.01	1	
237	0.06	1		10	1.625	4	1.34869	131	2.185	2	3.07591
238	0.01	2	0	11	0.01	1		9	7.79	1	
131	0.07	2	0.0707107	93	0.52	3	0.336452	10	3.08	5	3.52697
9	2.038	5	2.73604	93?	0.01	1		244	0.36	2	0.19799
10	0.285	2	0.360624	253	0.01	1		11	0.05	1	
244	0.99	2	0.452548	256	0.4025	4	0.778348	248	2.22	3	3.7932
11	3.77333	3	3.91082	259	0.01	1		93	3.4975	8	2.93065
248	2.03	2	2.81428	258	0.01	2	0	93?	0.01	1	
93	3.592	5	4.76892	14	0.25	1		256	2.19273	11	6.04629
93?	0.01	2	0	263	0.01	1		258	0.01	2	0
252	0.05	1		70	0.04	1		14	0.075	2	0.0919239
256	0.705	8	0.592477	21	0.016	5	0.00894427	263	0.01	1	
14	0.64	1		22	0.0333333	3	0.0251661	70	0.07	1	
12	0.06	3	0.0866025	23	1.3175	4	1.0471	21	0.1	1	
258	0.01	1		24	0.2275	4	0.324795	22	0.01	3	0
17	0.21	1		70	0.105	2	0.13435	23	0.285	6	0.306317
20	0.01	1		70	0.01	1		287	0.01	2	0
22	0.0342857	7	0.0415761	305	0.02	1		24	0.0133333	3	0.0057735
70	0.01	1		29	0.13	4	0.165126	70a	0.03	1	
603	0.01	1		605	0.01	1		294	0.0745455	11	0.135894
23	1.70667	3	2.76732	124	0.01	2	0	291	0.17	1	
70	0.29	1		73	0.0485714	7	0.0788307	25	0.17	1	
294	21.72	2	30.6743	71	0.0766667	3	0.0585947	300	0.2	2	0.268701

Appendix D1, continued.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm²)	n 8	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)
25	0.04	1		34?	0.05	1		70b	0.05	1	
610	0.02	1		34	0.01	3	0	305	0.166	5	0.267825
300	0.0275	4	0.035					70c	0.01	1	
301	0.01	1		129	0.27	3	0.202237	31	0.01	1	
29	0.55875	8	0.655841	611	1.12	1		313	0.02	1	
605	0.01	1		351	0.16	1		32	0.05	1	
31	38.09	1		367	0.02	1		317	0.02	1	
313	0.06	1		367?	0.01	1		319	0.0933333	3	0.135769
317	0.105	2	0.0494975	97	0.06	1		73	0.0172727	11	0.0100905
124	0.01	2	0	43	0.015	4	0.01	329	0.01	1	
324	0.123333	3	0.162891	45	0.143333	3	0.146401	328	0.015	2	0.00707107
73	0.03875	8	0.0408613	383	0.02	1		71	0.786667	6	1.35656
328	0.263333	3	0.438786	47	0.456667	3	0.765005				
33	0.0325	4	0.0262996	396	0.01	1		34	0.098	6	0.147716
71	0.071429	7	0.0985611	118	3.04	3	5.09302	34?	1.936	5	3.3453
34	0.414286	7	0.87869	50	0.02	1		70d	0.566667	3	0.381357
34?	0.29	6	0.656567	51	0.01	1		612	0.01	1	
129	0.364	5	0.476686	417	0.01	1		367	0.01	1	
339	2.25	1		95	0.01	1		367	0.01	3	0
611	0.01	1		54	2.71875	8	2.91137	613	0.115	2	0.148492
35	4.745	2	6.66802	441	0.01	1		43	0.01	1	
37	0.04	1		389	0.52	1		45	0.01	1	
349	1.23	1		448	0.01	1		389	0.01	1	
39	0.01	1		61	1.434	5	1.87889	70e	0.01	1	
40	1.15	1		62	9.96167	6	23.6741	47	0.01	1	
361	0.01	1		63	8.675	2	12.1269	397	0.39	1	
367	0.01	1		447	4.6175	4	5.90445	401	1.2	1	
368	0.03	1		91	1.07	3	0.9755	118	2.1525	4	2.23834
97	0.06	2	0.0141421	454	0.06	1		417	0.19	4	0.327109
43	0.09	3	0.08544	456	4.185	2	5.90434	53	0.02	1	
45	0.015	6	0.0083666	65	13.46	6	22.8907	95	0.03	1	
46	0.2	2	0.268701	66	2.3775	4	2.59348	427	0.07	1	
47	0.01	1		74	0.0275	8	0.0455914	54	0.715	4	0.65465
49	0.06	1						99	5.51333	3	5.19324
417	0.02	4	0.0141421					59	0.01	1	
427	0.01	2	0					448	0.07	3	0.0793725
54	2.07	6	2.26586					61	6.64	6	9.50318

Appendix D1, continued.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm²)	n 8	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)
99	3.87	3	4.04578					62	4.158	10	9.85037
59	0.01	6	0					63	1.7875	8	2.36776
389	0.54	3	0.574195					447	0.61	2	0.848528
448	0.02	3	0.0173205					91	3.71	5	5.03915
61	2.19	4	1.69631					454	0.575	2	0.742462
62	0.836667	6	1.0797					456	1.118	10	3.10727
63	0.8275	4	0.903378					65	2.70667	9	2.88891
91	0.472	5	0.614386					66	1.19	3	1.2435
101	0.01	1						461	0.54	1	
454	0.02	1						70f	0.0111111	9	0.00600925
456	0.2725	4	0.363169								
64	0.01	1									
65	9.66857	14	19.042								
66	2.014	5	2.43103								
461	0	1									
463	0.09	1									
74	0.26	1									
70	0.24	1									

Appendix D2: Mean total 1993 plant species basal area (cm²/m²), with n and 1 sd, in channel margin, bar platform and debris fan geomorphic settings at 20 eddy study areas through the Colorado River in the Grand Canyon, Arizona. Refer to Appendix B for species identifying numbers.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm²)	n 8	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)
1	0.00108	6	0.00116	1	0.00016	2		201	0.00204	6	0.18
2	0.39	5	0.64338	2	0.5079	1		1	0.07788	1	
212	1.1888	1		3	0.11026	1		3	0.0696	2	0.18
222	0.0157	1		4	0.0033	1		4	0.21152	4	0.2909
5	0.00346	4		5	0.02466	1		227	11.0897	2	11.22
227	1.24746	6	0.79106	227	1.97206	2		96	4.55348	12	5.6862
96	5.21316	7	9.34158	96	2.39814	2	3.38948	6	2.33954	4	3.26416
209	0.22324	6	0.40702	6	0.14152	1		7	0.7101	1	
7	17.4002	1		7	1.51256	1		237	0.00062	1	
131	0.02764	5		614	0.03156	1		131	0.00188	1	
9	4.0516	6	4.2773	9	0.00016	2		9	8.00832	3	0.18
10	1.53334	4	1.6829	10	7.33996	2	10.2569	10	1.28358	3	1.66496
244	0.95532	3	1.72854	256	0.07266	1		244	1.48962	1	
11	3.53358	1		14	12.1619	1		11	0.00062	3	0.18
248	0.15864	6		21	0.00204	5		248	1.42666	6	2.349
93	1.18096	1		22	0.0194	2	0.03512	93	6.75188	1	
256	0.24196	11	0.27118	23	0.31764	9	0.3612	252	0.00158	1	
258	0.00126	1		24	0.0462	2	0.0544	256	0.629228	1	
259	0.31808	1		70	0.00118	1	0.00122	14	0.00314	1	
14	0.01256	1		305	0.02466	2		22	0.00016	1	
17	0.28634	1		29	0.01712	2	0.01578	603	0.01118	5	0.18
22	0.02514	11	0.05852	124	0.01398	1	0.0193	23	0.11694	1	
602	0.00188	3		73	0.00156	2		287	0.01006	1	
603	0.00184	5	0.00192	76	0.00424	2	0.00512	24	0.00314	1	
23	0.70284	2	0.82178	34?	0.0225	2	0.02824	70a	0.0036	1	
24	0.02748	9	0.03798	34	0.13422	4	0.1878	294	0.02122	13	0.0291
70	0.01974	5	0.05102	129	0.61826	1		25	0.74036	1	
294	0.10482	1		37	0.09688	1		301	0.14956	4	0.18
298	0.02262	1		43	0.00252	3	0.18	305	0.04148	2	0.01948
300	0.00142	3		45	0.34758	3	0.35276	313	0.00166	2	0.0019
301	0.0698	1		47	0.3273	3	0.44978	319	0.78558	4	1.11046
29L	1.5621	1		118	2.31516	1	3.0289	73	0.2641	3	0.49582
29	0.8635	16	1.9021	50	0.02654	7	0.18	328	0.01282	6	0.01952
				54	1.68724	4	1.58572	71	0.18494	8	0.43854
324	0.0165	6	0.01176	56	0.00422	1		34	0.24756	2	
73	0.03924	2	0.05436	59	0.00062	1					

Appendix D2, continued.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm²)	n 8	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)	SP	MEAN BASAL AREA (cm²)	n	1sd BASAL AREA (cm²)
328	0.00996	1		389	1.06280	1		34	0.00078	1	
33	0.13384	8	0.180	448	0.01260	1		129	0.203	1	
71	0.46940	7	0.73584	61	7.48248	7	15.65950	611	1.55134	1	
34?	0.54260	2	0.85846	63	3.77142	6	5.24472	367	0.00994	1	0.01442
34	0.01202	8	0.00034	91	0.05724	2	0.10156	374	0.01006	5	
129	0.64266	1		456	3.91740	4	4.98468	45	0.25414	1	0.54528
339	0.25132	1		65	1.83802	5	1.50274	70b	0.00376	1	
37	0.10022	1		66	1.91050	1		47	0.00126	1	
40	0.46402	1		601	0.02654	1		399	0.3927	6	
41	0.70500	1		209	0.42648	1		118	1.62494	4	1.59632
368	0.20422	1		12	0.00020	1		417	0.33378	2	0.65262
97	0.00376	2		484	0.15050	1		95	0.00794	1	
43	0.01288	6	0.0111	39	0.11402	1		427	0.0201	2	
45	0.24100	1		615	0.69780	1		54	1.56944	1	
401	0.09048	1		113	0.21990	1		56	0.00674	3	0.18000
118	0.03534	1		30	3.22318	1		99	4.27692	1	4.94206
49	0.00062	5		505	0.00738	1		616	0.03552	2	
417	0.03432	2	0.0706					448	0.34692	2	0.29066
53	0.24054	3	0.30264					61	7.68698	1	
95	0.00294	2	0.00412					62	1.72862	15	1.78012
427	0.01038	6	0.0091					63	1.94244	1	
54	2.40822	2	3.1766					447	0.33	8	0.18000
99	0.81008	6	1.09564					91	0.97028	1	
59	0.00214	2	0.00234					454	0.11356	1	
441	0.06188	1						456	0.87144	15	1.43254
389	0.04462	5						65	2.56344	2	2.21068
448	0.01740	5	0.01478					66	0.13446	1	
61	0.83512	1						461	0.1365	1	
62	1.74474	12	2.46306					463	0.03426	1	
63	0.83252	7	1.04408					609	0.0071	1	
91	0.65902	1						70c	0.02136	1	
454	0.00142	5						70d	0.06284	1	
456	0.24974	1						601	0.0509	2	
67	0.00142	6						12	0.00864	4	0.00998
65	6.40384	17	10.9149					484	0.09304	1	
66	1.57056	2	1.42642					617	0.00078	2	
463	0.16722	2	0.11894					20	0.01006	1	

Appendix D2, continued.

CHANNEL MARGIN SITES				BAR PLATFORM SITES				DEBRIS FAN SITES			
SP	MEAN BASAL AREA (cm2)	n 8	1sd BASAL AREA (cm2)	SP	MEAN BASAL AREA (cm2)	n	1sd BASAL AREA (cm2)	SP	MEAN BASAL AREA (cm2)	n	1sd BASAL AREA (cm2)
12	0.00078	2	0.00092					93	5.27610	1	
484	0.03866	2	0.05400					607	0.09864	1	
93	4.20732	1						13	0.00036	1	
607	0.31416	2						70e	0.01500	1	
13	0.00810	1						26	1.00530	1	
39	0.23904	1						317	0.00392	1	
70	0.00186	1									
44	0.00016	1									
616	0.04726	1									
26	0.81682	2									
6?	0.03330	2	0.04622								
76	0.45444	2	0.63466								

APPENDIX E

PRESENTATIONS AND PUBLICATIONS

APPENDIX E:

PRESENTATIONS AND PUBLICATIONS

The following presentations and papers were produced from this project in 1993:

1. Ayers, T.J. R.W. Scott, L.E. Stevens, K. Warren, A.M. Phillips III and M.D. Yard. 1994. Additions to the flora of Grand Canyon National Park. Journal of the Arizona-Nevada Academy of Sciences 28:70-75.

2. Bechtel, D.A., L.E. Stevens, M.J. Kearsley and T.J. Ayers. 1993. Geomorphic and hydrologic controls on riparian vegetation in the Grand Canyon, Arizona. August,1993 Ecological Society of America meeting, Madison, WI.

3. Kearsley, M.J., L.E. Stevens, and T.J. Ayers. 1993. Geomorphic and hydrologic controls on riparian vegetation along the dam-regulated Colorado River in the Grand Canyon, Arizona. April 1993 Arizona Riparian Council meeting, Tucson, AZ.

4. Stevens, L.E., M.J. Kearsley, and T.J. Ayers. Riparian vegetation composition and structure along the dam-regulated Colorado River in Grand Canyon National Park, Arizona. 27 October, 1993, Second Biennial Conference of Research on the Colorado Plateau.

5. Stevens, L.E., J.C. Schmidt, T.J. Ayers and B.T. Brown. 1994. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. Ecological Applications 5:1025-1039.