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16. ABSTRACT

The Las Vegas Wash in Clark County, Nevada, is the primary drainage for 4144 km^2 of the Las Vegas Valley. The Wash supports over 1200 hectares of cattail, common reed, and salt cedar. Water supply to this unique, arid zone, brackish water wetland is by regional ground-water drainage, sewage treatment plant discharge, and urban runoff. The relationships between plant community distribution and environmental quality were examined during a study conducted from May 1986 through April 1987. Data were collected from 71 sites on vegetation, water table fluctuations, ground-water quality, and soil quality. Community species composition and stand vigor were correlated with seasonal depth to ground water and soil salinity. Cattails were closely associated with sites of high moisture and low salinity. Reed sites were slightly drier and more saline than cattail sites, while salt cedar sites exhibited the driest and most saline conditions. Soil quality appeared to be a function of both ground-water quality and water table fluctuations. The differences in soil salinity among vegetation types were very pronounced in the fall, which probably represented the driest and most saline period.

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Nothing in this report is intended to interpret the provisions of the Colorado River Compact (45 Stat. 1057), the Upper Colorado River Basin Compact (63 Stat. 31), the Water Treaty of 1944 with the United Mexican States (Treaty Series 994, 59 Stat. 1219), the decree entered by the Supreme Court of the United States in *Arizona* v. *California*, et al. (376 U.S. 340), the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), the Colorado River Storage Project Act (70 Stat. 105; 43 U.S.C. 620), or the Colorado River Basin Project Act (82 Stat. 885; 43 U.S.C. 1501).

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INTRODUCTION

The quality and quantity of riparian and wetland habitat is rapidly declining in the arid southwestern States [1,2].[1] In recent years, these unique areas have deteriorated because of overgrazing, dam construction, ground-water pumping, and conversion of lands to agricultural cropland [3].

Riparian wetlands are now considered the most modified land type in the West [4]. Many of these wetlands are associated with major streams, rivers, springs, and catchment basins [5]. Other wetlands are a result of wastewater discharges, agricultural drainage, and silt-laden reservoirs; and are often brackish or saline [6].

Wetlands management is often oriented towards maintenance of wildlife habitat because riparian wetlands provide food, cover, and water to resident and migrating wildlife [4]. Many studies of wetland systems have shown these types of habitats support greater species richness and higher densities of wildlife than any other desert habitat [7]. Also, wetland management plans often include provisions for wastewater treatment, erosion control, flood protection, food and fiber production, and recreational use [8].

The status of arid zone wetlands is well documented [4], but ecological studies examining relationships between environmental and vegetational components are relatively few. In particular, the hydrology of wetlands as it influences wetland ecology is poorly understood [9]. An understanding of the ecological processes and functions that control wetland ecosystems is necessary to provide protection for these critical areas.

The Las Vegas Wash, hereafter simply called "Wash," is located in Clark County, Nevada, and is an arid zone, brackish water wetland artificially created by man-induced processes. In recent years, the Wash has become the subject of controversial management plans and policies. Because of the unique ecological qualities and sensitive nature of the Wash as a wetland, it is necessary to provide an understanding of the ecological processes driving the system if management of the system for multiple usage is to be effective. This report provides data that could be used to predict impacts to the wetlands environment during implementation of management programs.

Purpose

Under the authority of the Colorado River Basin Salinity Control Act of 1974 (Public Law 93-320, as amended), the Bureau of Reclamation is investigating various alternatives to control the salts entering the Colorado River by way of Las Vegas Wash. Title II of the Act provides for a program to control the salinity of the Colorado River upstream of Imperial Dam as the seven Colorado River Basin States continue development of the Colorado River water supply.

A ground-water flow reduction strategy has been proposed for the Wash to reduce the leaching of native salt deposits in the soils by ground-water flow in the Wash. This would be accomplished through construction of a series of ground-water detention basins, each enclosed by an impermeable underground barrier formed by a slurry wall. These relatively impermeable barriers would hypothetically impede ground-water flow and force flows to remain at or near the ground surface within each detention basin, thereby reducing leaching of native salt deposits from the soils. This ground-water flow reduction strategy is described completely in the "Environmental Assessment for the Whitney Verification Program" [10].

The potential impacts on existing vegetation in the Wash by salinity control through ground-water flow reduction were addressed during a year-long study, which is the subject of this report. The study evaluated and monitored plant-soil-water relationships to determine the effects on existing vegetation if the ground-water flow regime were manipulated through the salinity control program. The resultant data would be used to design salinity control features that would minimize the impacts to the existing Wash environment.

Background

Historical Aspects.—The Las Vegas Valley, also located in Clark County, Nevada, is the major population center in the State, and supports more than 0.5 million people. Before urban development in the valley, extensive riparian, wetland, and meadow communities, supplied by freshwater seeps and springs, covered much of the area. Stands of Fremont cottonwood (*Populus fremontii*)[2], probably planted by early settlers, once lined the banks of many small water courses. Three extensive honey mesquite (*Prosopis glandulosa*) bosques, each comprised of thousands of trees, covered much of the lower portion of the valley [12].

In recent years, most of this vegetation has been replaced by urban development. Since 1930, surges in population in response to construction of Hoover Dam, development of local industry, establishment of the Nevada Test Site, and escalation of the tourist

[1] Numbers in brackets refer to entries in the Bibliography.

[2] Nomenclature follows Munz [11].

industry have led to the clearing of much of the existing vegetation in the valley.

The Wash is the primary drainage outlet for 4144 square kilometers of Las Vegas Valley, see figure 1. Before urban encroachment in southern Nevada, the Wash was typically dry and flowed only intermittently in response to storm events and associated runoff. Aerial photographs taken in 1950 show that extensive mesquite bosques intermixed with saltbush (*Atriplex* spp.) and desert scrub communities dominated the upper Wash area.

With the increase in population in the valley during the 1950's, flows through the Wash became permanent as a result of wastewater treatment plant discharges, industrial discharges near the city of Henderson, and increased urban and residential runoff. Discharges from wastewater treatment facilities alone are now between 265 and 285 million liters per day of treated wastewater [13]. Response to the change in water regime was evidenced within the plant community by a shift to wetland and riparian vegetation. By 1970, much of the Wash environment consisted of cattail (*Typha domingensis*) and com-

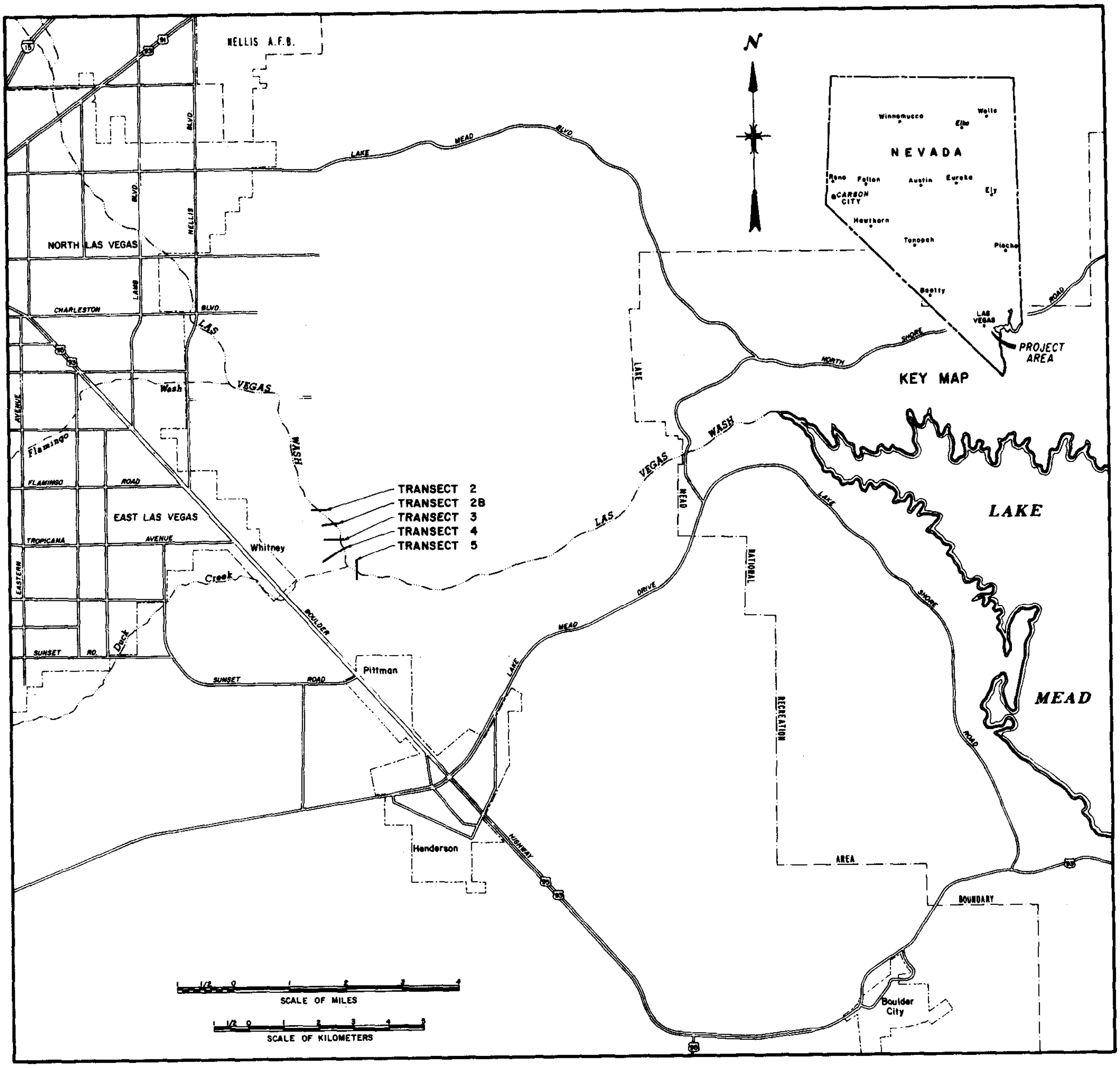


Figure 1. – Location map of Las Vegas Wash with transect locations indicated.

mon reed (*Phragmites communis*) marshes. Higher ground became invaded by salt cedar (*Tamarix chinensis*), a non-native shrub, which now composes the majority of the riparian community.

Permanent discharge into the Wash has resulted in an increase of the water table elevation and a permanent surface flow through the flood plain. Ground-water flows into the Wash are typically laden with dissolved gypsum originating from amorphous crystalline calcium sulfate deposits interspersed throughout the drainage area surrounding the Wash. Plant community distribution in the wetlands may be affected by the brackish conditions caused by the leaching of these deposits [10].

Since 1970, the wetland community in the Wash has gradually been impacted by upstream advancement of the channel headcut. Wash soils generally consist of unconsolidated alluvial materials underlain by the low permeability, tertiary "Muddy Creek" formation [10]. Increased flow velocity from the introduction of continual wastewater flows and occasional flash flood events have caused increased erosion rates in the headcut region. The channel has reached depths of 6 meters in some areas [14], resulting in a lowering of the water table and the drainage of large stands of cattails and reeds. As the erosional process continues, drainage of more of the remaining cattail marsh in the flood plain is imminent; however, marsh habitat in tributaries or seep areas peripheral to the Wash flood plain may persist as long as the high ground-water table in these areas remains unaffected.

Current Concerns.—Currently, the Wash is the subject of many opposing views on management policy. Local, State, and Federal agencies each have an interest in the Wash, often for conflicting reasons. Major concerns include management to meet water quality standards at the point of discharge into Lake Mead, provisions for valley flood control that would impact the Wash, identification of water rights for reuse or for return flow credits, and maintenance as a greenbelt for an educational and recreational facility, as well as for wildlife habitat.

The latter concern has been addressed by the formation of the WDC (Wash Development Committee), which is a public advisory group to the Clark County Board of Commissioners. The WDC's goal, as stated in the Master Plan [15], is ". . . to protect, conserve, enhance, and maintain the natural, scenic, historical, economic, and recreational qualities of lands alongside the Las Vegas Wash as the Clark County Wetlands Park." To date, WDC has spent $2.0 million on land acquisition and master plan development, and is determining the expenditure of an additional $1.5 million. It is likely that the costly problem of the headcut erosion, which is threatening the last remnants of the existing marsh, will need to be resolved before WDC can achieve its goal.

In recent years, the Bureau has worked closely with the WDC to coordinate salinity control programs with plans for park development. The ground-water flow reduction strategy, if effective, is viewed as being compatible with park development and could be implemented to benefit both objectives. For example, ponds created during the construction of salinity control features would be located within the boundaries of the proposed park facility and could provide habitat diversity in the wetlands. Changes in the ground-water regime caused by the proposed salinity control program could impact the plant communities within the park boundaries. The present study was initiated to develop data with which to better identify these impacts.

Description of Study Area.—The area of concern in this study, as delineated in the Wash vegetation type maps [16], is the area of flood plain referred to as Reach 5, and is the site of the majority of the existing wetlands vegetation (fig. 1). Of the 134 ha (hectares) of riparian and wetlands vegetation present within the boundaries of this reach, there are about 24 ha of cattail marsh, 53 ha of reed marsh, 8 ha of wetland annual and associated marsh vegetation, and 49 ha of salt cedar [16].

Under the classification system of Cowardin et al. [17], the plant communities of the Wash flood plain are characterized as a combination of palustrine emergent wetland and scrub-shrub wetland. In areas of high moisture, patches of cattail and common reed are interspersed with mixed wetland annual plants and salt cedar trees. In outlying drier areas, saltbush is the dominant vegetation type.

Water supply to the study area originates from various sources. The main source is from lateral seepage of the wastewater channel that originates upstream at the sewage treatment plants and flows adjacent to the wetlands. Another water source is the surface flow in floodway channels carrying urban and residential runoff from neighboring areas. Also, regional ground-water inflows from the valley watershed ultimately contribute to the underflow of the Wash.

METHODS

Previous Bureau studies of the Wash provided the baseline data on which to design a study to characterize plant communities and determine associated environmental conditions. To representatively sample these conditions, sample sites were established in pure vegetation types and along transition zones. At each site, measurements of vegetation, ground water, and soils were obtained.

FIELD RECONNAISSANCE AND SITE ESTABLISHMENT

The major vegetation types were defined through field reconnaissance and examination of false color infrared aerial photography of the area.

Five transects were cleared across the flood plain to obtain access to the study area (fig. 1). The transects were established perpendicular to the main direction of flow and through the riparian and wetland plant communities in the flood plain. Location of four of the five transects (Nos. 2, 3, 4, and 5) was based on the original location of these transects during earlier Bureau studies. Transect 2B was established to increase the number and diversity of sample sites.

Along the 5 transects, 75 sample sites were established at 60-meter intervals in distinct vegetation types and where transition zones were encountered. A sample site consisted of a 20-meter line extending along the transect. A ground-water measurement device, the piezometer, was installed at the midpoint of each line. There were 10 vegetation sampling stations, 5 on each side of the line, established at 2.5-meter intervals (fig. 2).

Data Collection

Data collection began in May 1986 and continued through April 1987. Table 1 summarizes the schedule of sampling events during the period of study.

Vegetation Sampling.—Vegetation data were collected in August and September 1986 when annual plant communities in the study area were mature. Three types of quantitative data were collected at each site—cover, density, and height.

Cover data were collected for both overstory and understory canopy layers. The overstory canopy was visually estimated at each sample point as the percentage of the area covered by each plant species. The understory canopy was measured using the point-frame method [18]. The point-frame device consisted of a wooden frame with two crossbars, each 1 meter long (fig. 3). There were 10 guide holes drilled into the crossbars at 10-centimeter intervals to facilitate the movement of small-diameter pins, 1 meter in length, through the frame. Support posts (legs) were inserted through the crossbars to support the frame either vertically or horizontally, depending on which layer of the canopy was to be measured.

To measure the understory canopy, the pins were lowered through the frame vertically, see figure 3(a). The first plant hit by each pin was recorded by species. These data were then averaged across the 10 pins and used as estimates of understory cover.

The point-frame method was modified to measure plant density of the overstory canopy by turning the crossbars of the frame 90°, see figure 3(b). The frame was used at each of the 10 vegetation sampling stations at each sample site. The 1-meter-long pins were pushed through the frame parallel to the ground at a height of 1 meter. The number of times each pin hit any part of a plant was recorded by species and averaged across 10 pins. The data were then averaged across the 10 sample stations to estimate the average number of plant hits, which was regarded as a measure of density.

Height of the overstory canopy was measured and averaged for the 10 sample stations.

Ground-Water Sampling.—The ground-water depth and EC (electrical conductivity) data were collected monthly from the piezometers. Each piezometer consisted of a 200-centimeter PVC (polyvinyl chloride) pipe, 5 cm in diameter and installed vertically into the soil to a depth of 150 cm. The portion of the pipe below the ground surface was perforated with 0.25-millimeter slots to facilitate seepage of ground water into the pipe. The portion of the pipe above the ground surface was capped and labeled with the transect and sample site numbers.

The distance from ground surface to the ground-water table was determined by lowering a tape measure into the pipe. After the depth to the water table was measured, the piezometer was emptied using a plastic bailing tube and allowed to recharge. The EC of the recharged ground water was then measured with a field conductivity meter.

Ground-water samples were collected quarterly from each piezometer for laboratory analysis of chemical constituents. This analysis was conducted at the Bureau's Lower Colorado Regional Water Laboratory. The methods of analysis are defined in "Land Classification Techniques and Standards" [19] and in "Methods for Determination of Inorganic Substances in Water and Fluvial Sediments" [20].

Soil Sampling.—The soil samples were collected at each sample site to characterize environmental conditions in the root zone. Samples were collected using a 5-cm-diameter hand soil auger from three depths: 0-10, 40-50, and 90-100 cm. Soil samples were air dried, then sifted to remove particles larger than 2 mm.

Data were collected twice during the study to provide information on soil conditions when the water table was depressed (October) and when the water table was elevated (March). When the water table was elevated and soils were saturated, it was not always possible to collect a sample.

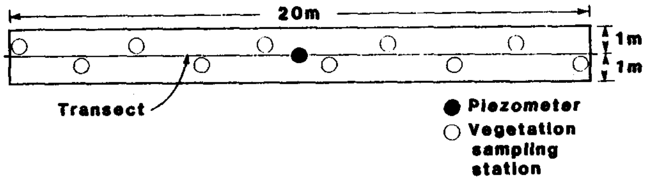


Figure 2. – Sample site showing location of ground-water piezometer and vegetation sampling stations along a transect.

Soil extracts derived from a saturated paste were made according to the methods described by the United States Regional Salinity Laboratory [21]. Conductivity of the saturation extract was measured to assess soil salinity. Chemical constituents of the soil extracts were analyzed using the same techniques used for the ground-water analysis. Determination of soil texture was not possible. The high concentration of gypsum in the soil caused excessive flocculation that prevented laboratory measurement of different sized particles.

Data Analysis

Classification.—The sample sites were classified into six vegetation types based on the relative cover of the major species comprising the overstory canopy. Delineation of vegetation types was based on preliminary observations during field reconnaissance. Since classification of sample stands into vegetation types was based on species composition rather than stand density, sparser stands were grouped with denser stands if they were compositionally similar. The six types were cattail, reed, salt cedar, cattail-reed mix, reed-salt cedar mix, and wetland annual.

Community Ordination Analysis.—An eigenvector ordination technique was used to determine community relationships. Vegetation cover data were ordinated by DCA (detrended correspondence analysis) using the Cornell Ecology Program, DECORANA [22]. The objective of this technique is to arrange multiple variable site data in a low-dimensional space; i.e., a two-dimensional plot to show similarities among sample sites. Stands that are similar vegetationally would occupy positions close together on the plot, while dissimilar stands would occupy positions farther away. The DCA technique was preferred over other ordination techniques because it corrects two major faults: (1) an "arch" distortion of the higher axes, and (2) compression of the ends of the first axis [23].

The DCA technique was used to ordinate the sample set using three different vegetation variables: cover, biomass, and importance values. Cover values were extracted from the data collected for the understory by the point-frame method and by visual estimation for the overstory. Biomass was calculated by multiplying average total hits density by the average height of each species. The biomass calculation did not enumerate biomass in the strictest sense, but provided a basis for comparison of stands based on variables that represented stand vigor. The importance value was calculated as relative estimated visual cover, plus relative total hits density, plus relative frequency (percent occurrence of a species in 10 sample stations).

A subsequent step in the analysis of plant community relationships using DCA was to assign ecological significance to each axis, and to produce an environmental interpretation of the ordination.

Correlation Analysis.—Spearman rank correlation coefficients [24] were calculated to show relationships between plant communities and environmental parameters. Five vegetation variables were used in the analysis: sample scores from DCA axes 1 and 2, and biomass values for the three most common plant species found in the study area (cattail, reed, and salt cedar).

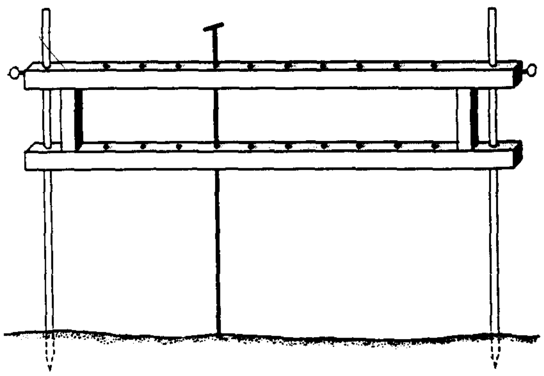
Environmental parameters used in the correlation analysis were seasonal moisture and salinity conditions in the root zone. Moisture was evaluated as a determinant of plant community position along the vegetational gradient by seasonal ground-water elevations and by duration of annual fluctuations. For evaluation of salinity effects on the vegetation, a representative root depth was defined. It was not possible to delineate a root depth typifying the requirements of every species, so dominant plant species were used as the criteria for defining a typical root depth. Rhizomes of emergent hydrophytes, such as cattail and reed, are usually located in the first 20 cm of the soil [25,26], and reed rhizomes are found as deep as 100 cm [27]. Salt cedar, a phreatophyte, sends tap roots down to the saturated zone [28], and does not use soil moisture when ground water is available [29]. Based on this information, the root zone was defined as "the area of the soil column between ground surface and a depth of 100 cm" for this study.

Salinity in the root zone was estimated as the average EC of the three sampled depths: 0-10, 40-50, and 90-100 cm. Where soil samples could not be obtained because of a high water table, and EC of the ground water was used as a measure of root zone salinity. Data were not available for the summer, so summer root zone EC was estimated as the average of spring and fall EC, based on the assumption that the root zone uniformly becomes more saline as it dries in response to evapotranspiration during the growing season.

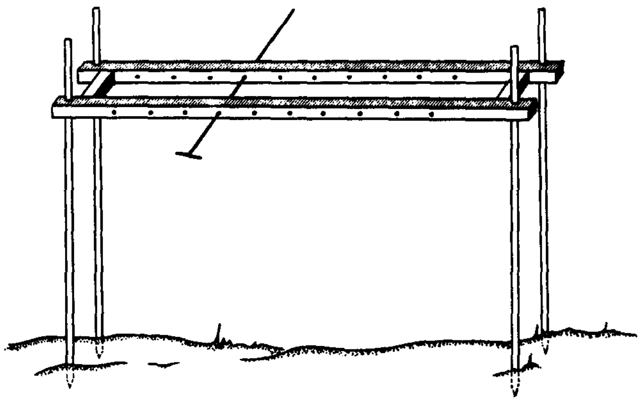
Group Comparisons.—The sample sites were grouped by vegetation type to make comparisons of

Table 1. – Schedule of field data collection and laboratory analysis of chemical parameters.

	1986									1987		
	Summer			Fall			Winter			Spring		
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Data Collection:												
Vegetation measurement				x	x							
Ground water												
Depth	x	x	x	x	x	x	x	x	x	x	x	x
Electrical conductivity	x	x	x	x	x	x	x	x	x	x	x	x
Laboratory Analyses:												
Ground water	x			x			x			x		
Soil						x					x	



(a) Frame position to measure understory canopy.



(b) Frame position to measure overstory canopy.

Figure 3. – Point-frame vegetation measurement device.

environmental parameters. These data were used to verify relationships observed in the correlation analysis. The data were also used for a general description of each vegetation type and associated environmental features.

Means and standard deviations were calculated by vegetation type for environmental parameters. Depth to ground water was examined by season. The TDS (total dissolved solids), SAR (sodium adsorption ratio); and concentrations of Na^+ (sodium), Mg^+ (magnesium), Ca^{+2} (calcium), K^+ (potassium), HCO_3^- (bicarbonate), SO_4^{-2} (sulfate), Cl^- (chloride), and B (boron) were examined by season for ground water and by sampling period for soil.

The three dominant vegetation types (cattail, reed, and salt cedar) were emphasized in the group analysis. Closer examination of the more ecologically relevant factors and abundant ions was accomplished by comparing the means and confidence intervals for the following parameters: TDS, SAR, SO_4^{-2}, Cl^-, B, and depth to ground water.

The data were statistically tested for environmental variability among vegetation types using nonparametric procedures. A Kruskal-Wallis analysis of variance by ranks test [24] was used to determine differences between values for environmental variables among the three major vegetation types. The Kruskal-Wallis test detected differences among groups; if one group was different from another, the results of the test were significant.

A subsequent test was required to determine specifically which groups were different. A Mann-Whitney paired sample test [24] for detecting differences in the median of two groups was used to determine differences between the environmental requirements of vegetation types.

RESULTS

Vegetation Analysis

Classification.—The six vegetation types and the criteria used for classification are shown in table 2.

Table 2. – Vegetation types and criteria for classification.

Numeric Symbol[1]	Vegetation Type	Sample Size	Criteria
1	Wetland Annual	7	Dominant species *Rumex crispus, Helianthus annuus,* and *Typha domingensis*; each constituting 34 to 76% combined relative cover, and not fitting other vegetation type categories.
2	Cattail	14	Dominant species *Typha domingensis* constituting ≥67% relative cover.
3	Cattail-Reed Mix	5	Dominant species *Typha domingensis* and *Phragmites communis,* each constituting 34 to 67% relative cover.
4	Reed	32	Dominant species *Phragmites communis* constituting ≥67% relative cover.
5	Reed-Salt Cedar Mix	7	Dominant species *Phragmites communis* and *Tamarix chinensis,* each constituting 34 to 67% relative cover.
6	Salt Cedar	6	Dominant species *Tamarix chinensis* constituting ≥67% relative cover.

[1] Refer to figure 4.

The three major vegetation types were cattail, reed, and salt cedar; the other three types were mixtures of the major types. The cattail-reed community was found in transitional zones between pure stands of cattail and reed. The reed-salt cedar community was composed of sparser reed stands that had been invaded by salt cedar. The wetland annual community contained two dominant annual species, dock (*Rumex crispus*) and sunflower (*Helianthus annuus*); however, this plant community was also comprised of cattails, reeds, and salt cedar, as well as other annual species.

Some sample sites were not included in the analysis, primarily sites dominated by saltbush species. This community type was not well represented, the sites tended to be located only on the outer fringes of the flood plain, and were therefore more representative of upland vegegation.

Ordination.—The DCA ordination plot of cover sample scores is illustrated on figure 4. Axis 1 accounted for 70 percent of the variance between sample sites, and axis 2 accounted for 35 percent of the remaining variance. Separate clusters of cattail, reed, and salt cedar indicated that, based on species composition, these vegetation types were dissimilar. Because of similarities within vegetation types for both cattail and reed, many samples scored equally, which resulted in some samples overlaying each other on the plot. Of the cattail sites, 40 percent were similar enough to score identically in the ordination. In reed vegetation type, 45 percent of the samples were overlain by other samples on the plot. Cattail-reed and reed-salt cedar vegetation types were located at intermediate ranges between pure stands. Some of the wetland annual stands were scattered across the plot; their distribution appeared to be a function of the dominant species of these stands.

Grouping of samples classified as different vegetation types on the upper end of axis 1 was attributed to the contribution by the understory component. The eight samples delineated by the dotted line on figure 4 appear to be grouped together because of the presence of a saltgrass (*Distichlis spicata*) understory.

Ordination using cover values seemed to provide a better representation of sample similarity and dissimilarity than ordinations using biomass or importance values (not shown). Data from the understory canopy were used in the DCA for cover; whereas, in the biomass and importance value analyses, data on the understory were not available. Also, use of the relative values for the three variables comprising the importance value obscured differences among stands of the same vegetation type.

The distribution of samples across the DCA cover plot provided the basis for subsequent environmental interpretation of the axes. Preliminary observations suggested that axis 1 represented a salinity gradient and axis 2 a moisture gradient. Correlation provided the means for testing these hypotheses.

Correlation Analysis

Tables 3 and 4 show the results of the correlation analysis. Correlations were significant at probabilities of less than 0.05.

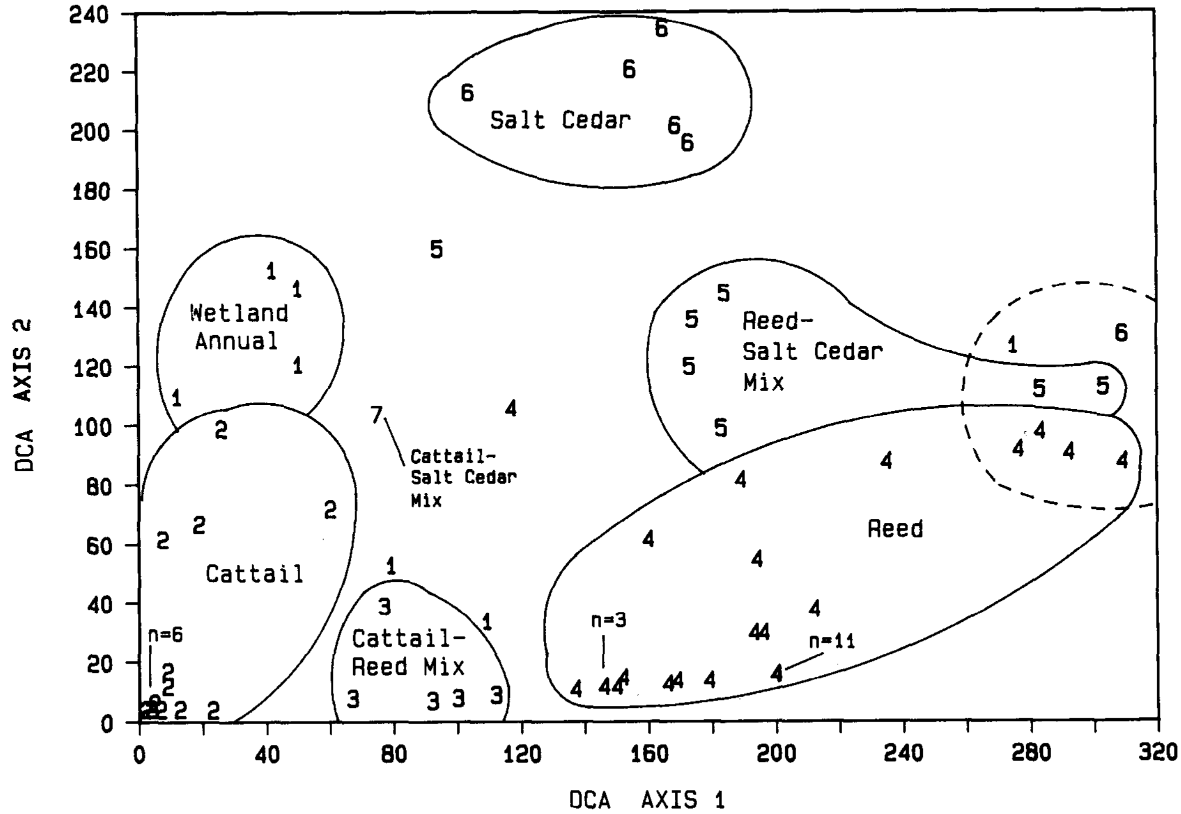


Figure 4. – Detrended correspondence analysis of 71 sample sites in Las Vegas Wash. Numbers denote vegetation types shown in table 2. Dotted line indicates cluster of sample sites grouped by understory component.

Table 3. – Correlation coefficients between vegetation variables.

Biomass	DCA axes No. 1	DCA axes No. 2	Biomass Cattail	Biomass Reed
Cattail	−0.85‡	−0.45‡		
Reed	0.62‡	−0.24*	−0.55‡	
Salt Cedar	0.33†	0.79‡	−0.42‡	−0.22

* $P \leq 0.05$
† $P \leq 0.01$
‡ $P \leq 0.001$
Note: P denotes levels of probability for test statistics.

The DCA axes were always significantly correlated with the biomass of the three major species (table 3). Highly significant relationships were found for axis 1 with both cattail and reed. Axis 2 was better correlated with salt cedar biomass than axis 1, although both correlations were significant. These correlations supported the classification scheme of vegetation type by cover, as shown on the ordination plot on figure 4. Cattail biomass was negatively correlated with the biomass of reed and salt cedar. There was no relationship between reed and salt cedar biomass.

Both DCA axes were significantly correlated with depth to ground water in the summer and fall, although axis 1 shows a somewhat stronger relationship to ground-water depth (table 4). This appears to indicate that the water table was shallower at cattail sample sites than at reed or salt cedar sites. Significant correlations found between cattail biomass and ground-water depth during each season indicated that the water table was shallowest in the densest stands of cattail. Reed biomass did not correlate with depth to ground water during any season, although there was a negative relationship between reed biomass and the number of months the water table was less than 50 cm from the ground surface. Salt cedar biomass positively correlated with depth to water in both summer and fall.

Table 4. – Correlation coefficients between vegetation variables and environmental parameters.

Environmental Parameters	DCA axes		Biomass		
Depth to ground water	No. 1	No. 2	Cattail	Reed	Salt cedar
NM <50 cm	−0.25*	−0.15	0.29†	−0.21*	−0.13
NM >100 cm	0.31†	0.21	−0.26*	0.19	0.18
Summer	0.38†	0.35†	−0.41‡	0.12	0.32†
Fall	0.39‡	0.35†	−0.34†	0.13	0.35†
Winter	0.18	0.17	−0.24*	0.04	0.10
Spring	0.23	0.21	−0.28*	0.09	0.16
Root zone EC					
Summer	0.58‡	0.28*	−0.46‡	0.20	0.30†
Fall	0.54‡	0.30†	−0.44‡	0.14	0.34†
Winter	0.59‡	0.24*	−0.46‡	0.25*	0.29*
Spring	0.63‡	0.24*	−0.51‡	0.27*	0.28*

*$P \leq 0.05$
†$P \leq 0.01$
‡$P \leq 0.001$

Note: NM<50 cm=number of months water table is less than 50 cm from ground surface; NM>100 cm=number of months water table is greater than 100 cm from ground surface.

Strong correlations existed for root zone EC with axis 1 and with cattail biomass (table 4). Axis 2 also correlated with EC, but at lower levels of probability. Reed biomass correlated with EC in the high water table seasons, winter and spring; salt cedar biomass correlated with EC throughout the year. Correlations between vegetation variables and EC at each of the specific depths are not reported because they showed similar trends to the correlations involving average root zone EC.

Correlations between depth to ground water and EC of the root zone were not significant, and are not reported.

The results of the correlation analysis generally supported the subjective environmental interpretation of the DCA axes. The data suggest that axis 1 is a salinity gradiant, although correlations between axis 1 and depth to ground water show that moisture is also related to this axis. Axis 2, which was initially thought to represent a moisture gradient, was correlated with both ground-water depth and EC. Correlations with axis 2 were not as highly significant as correlations with axis 1.

Group Comparisons

The results of the group comparisons for vegetation types indicated there were differences in the environmental conditions associated with plant communities in the Wash. The analysis comparing selected key envirionmental factors for the three major vegetation types is summarized in this section. For a seasonal summarization of all six vegetation types with all environmental parameters, see appendix A.

Ground-Water Depth.—The mean depth to ground water for each vegetation type during the four seasons is illustrated on figure 5. Annual ground-water fluctuations were present in all vegetation types. A relationship between depth to ground water and vegetation type was apparent during all seasons. There was also considerable variation in depth to ground water within vegetation types. Regardless of vegetation type, the water table was deeper during the summer and fall (the growing season) than during the winter and spring (the dormant period).

During the summer and fall growing season, the water table ranged from about 40 to 160 cm in cattail, 0 to 190 cm in reed, and 20 to 215 cm in salt cedar. There were statistically significant differences in depth to ground water over all vegetation types in the fall (table 5). The differences between cattail and the two other vegetation types were also statistically significant in the fall (Mann-Whitney test).

During the winter and spring dormant period, the range in depth to the water table was from 10 cm above to 50 cm below ground surface in cattail stands, from 4 cm above to 160 cm below ground surface in reed stands, and from 15 to 100 cm below ground surface in salt cedar stands.

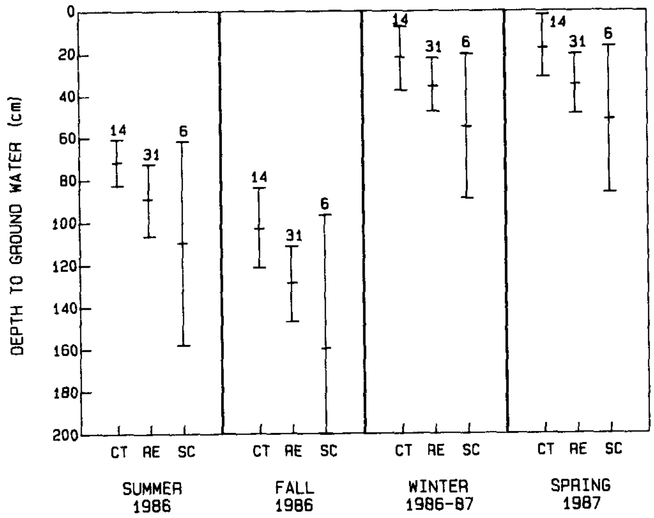


Figure 5. – Differences in depth to ground water, by season, for each major vegetation type. Midpoint horizontal lines indicate means, and vertical lines indicate 95 percent confidence intervals (with standard error). Sample sizes are shown at top of each vertical line. (CT=cattail, RE=reed, and SC=salt cedar).

All cattail sites exhibited saturated soil conditions during the dormant seasons, and surface water was present at 35 percent of these sites during portions of this period. At reed sites, the soil was usually saturated during the dormant period, and surface water was present in 10 percent of the reed sites during this time. Surface water was never present in salt cedar stands. During the growing season, the water table gradually fell as the vegetation matured.

Trends in the data were apparent during both winter and spring. Statistically significant differences were found between cattail and salt cedar vegetation types for depth to ground water during the spring (table 5).

Salinity.—Figures 6 through 15 illustrate the differences in concentrations of chemical constituents found in the ground water and in the soil extracts. Several trends in the data were apparent. Concentrations of dissolved solids were always greater in the soil extracts than in the ground water. In particular, soil extracts from the October sampling period yielded the highest concentrations of dissolved solids. There was greater fluctuation of seasonal ground water ion concentrations in salt cedar stands, and to a lesser extent in reed stands than in cattail stands. Concentrations of dissolved solids were always highly variable in salt cedar stands. In August when the water table was lowest, differences in the chemical constituents of the ground water were not generally discernable.

Analysis of the TDS in the ground water revealed that concentrations of chemical constituents varied by vegetation type (fig. 6). Ground-water TDS fluctuated from about 1500 to 5000 mg/L (milligrams per liter) in cattail stands, from about 1600 to 18 000 mg/L in reed stands, and from about 2000 to 25 000 mg/L in salt cedar stands. In all vegetation types, ground-water TDS was generally highest in November. This coincided with the rising groundwater table after the end of the growing season. Statistical analysis of the differences in TDS (table 6) showed that in November and February there were significant differences in TDS across the three vegetation types and, in particular, between cattail and reed.

The range of concentrations of TDS in soil extracts (fig. 7) was always higher than those for water quality (fig. 6). In October, the soil at the 0 to 10-cm depth exhibited the highest TDS concentrations. These concentrations ranged from 3500 to 7000 mg/L in cattail stands, 6000 to 67 000 mg/L in reed stands, and from 4500 to 95 000 mg/L in salt cedar. Significant differences in TDS of the soil extracts were found between cattail and both reed and salt cedar vegetation types in October and March.

Sodium, magnesium, and calcium were the principal cations comprising TDS. The proportion of magnesium relative to calcium has been found to be unusually high in the study area relative to that found in other areas near the Wash [30]. Mean values for each are shown in appendix A.

The proportion of sodium relative to calcium and magnesium is reflected in the sodium adsorption ratio (fig. 8). Ground-water SAR ranged from 2 to 6 in cattail stands, 3 to 12 in reed stands, and 2 to 20 in salt cedar stands. This SAR was statistically different among vegetation types except during August. In particular, the comparisons of cattail with the other vegetation types revealed significant differences (table 6).

Sodium adsorption ratios were often higher in the soil extracts (fig. 9), ranging from 2 to 6 in cattail, 3 to 25 in reed, and 4 to 49 in salt cedar. The SAR's of the soil extracts were always statistically different across vegetation types (table 7). The concentrations of the major anions, sulfate and chloride, exhibited trends similar to those of TDS in both ground water and soil (figs. 10, 11, 12, and 13). The sulfate ion concentration was a major contributor to TDS, usually constituting 50 percent of the total. Chloride ion concentration usually constituted 10 to 20 percent of TDS. As with other constituents, sulfate and chloride concentrations in the soil extracts were generally much higher than in the ground water, particularly in October.

Boron was the only minor constituent examined during this study. Trends similar to those of the major

Table 5. – Test statistics and levels of significance for group comparisons of vegetation types for depth to ground water. Sample sizes are as shown on figure 5. Critical values of the test statistics are for a one-tailed Kruskal-Wallis test and a two-tailed Mann-Whitney test.

Season	Kruskal-Wallis	Mann-Whitney		
		CT vs RE	RE vs SC	CT vs SC
Summer	5.22	NT	NT	NT
Fall	7.61*	1.95*	1.72	2.23*
Winter	4.66	NT	NT	NT
Spring	6.39*	1.47	1.69	2.35*

* $P \leq 0.05$

NT (No Test) Test was not performed unless Kruskal-Wallis result was significant.

CT = Cattail, RE = Reed, and SC = Salt Cedar

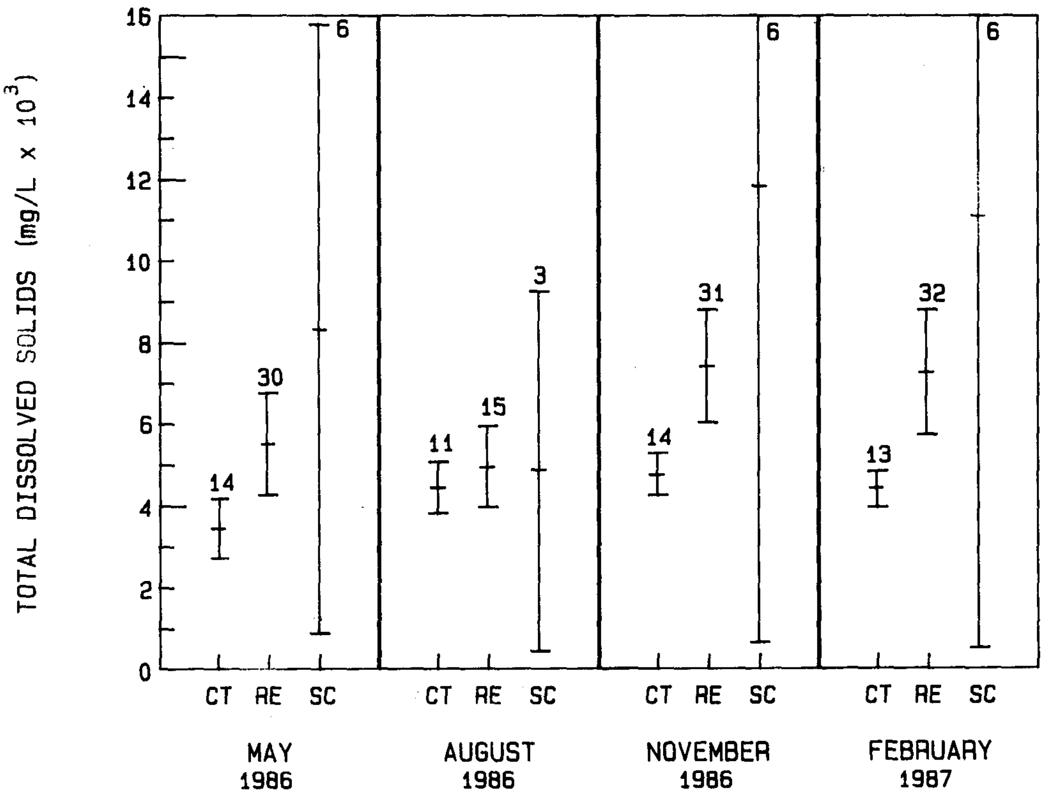


Figure 6. – Differences in TDS of ground water, by quarterly sampling period, for each major vegetation type.

constitutents were present (figs. 14 and 15). In the soil, boron generally remained at levels similar to those measured in the ground water, in contrast to other ions which were consistently found in higher concentrations in the soil extracts.

DISCUSSION

The investigation of plant-soil-water relationships in the Wash indicated that depth to ground water, ground-water quality, and soil quality were major environmental determinants of plant community distribution. In particular, soil characteristics were important because most wetland plants extract water and nutrients from the soil. Concentration of dissolved solids in the soil water appeared to be a function of ground-water quality. Soil moisture, which is in part determined by ground-water fluctuations, also determines plant distribution by excluding species that are intolerant of either anaerobic or dry soil conditions [31]. The importance of these factors in controlling plant distribution was substantiated by the correlation of the biomass of characteristic plant species with the seasonal depth to ground water and the EC of the root zone. The comparison of the environmental characteristics of vegetation type groups provided conclusive evidence to support this theory.

Table 6. – Test statistics and levels of significance for group comparisons of vegetation types for ground-water quality parameters. Sample sizes are as shown on figures 6, 8, 10, 12, and 14. Critical values are as shown in table 5.

Environmental Parameters	Kruskal-Wallis	Mann-Whitney		
		CT vs RE	RE vs SC	CT vs SC
May 1986				
TDS	4.61	NT	NT	NT
SAR	12.75†	3.02†	1.37	2.76†
SO_4^{-2}	4.12	NT	NT	NT
Cl^-	9.92†	2.86†	0.594	2.35*
B	ND	ND	ND	ND
August 1986				
TDS	0.567	NT	NT	NT
SAR	0.932	NT	NT	NT
SO_4^{-2}	0.291	NT	NT	NT
Cl^-	1.24	NT	NT	NT
B	ND	ND	ND	ND
November 1986				
TDS	6.80*	2.60†	0.103	1.36
SAR	6.26*	2.50†	0.103	1.28
SO_4^{-2}	6.97*	2.56†	0.103	1.61
Cl^-	6.64*	2.61†	−0.515	0.908
B	8.81†	3.06†	−0.618	0.557
February 1987				
TDS	7.42*	2.77†	1.27	0.220
SAR	7.94*	2.78†	−0.733	1.11
SO_4^{-2}	7.42*	2.78†	0.140	1.27
Cl^-	8.78†	2.92†	0.000	1.71
B	5.07	NT	NT	NT

*$P \leq 0.05$
†$P \leq 0.01$
NT (No Test) Test was not performed unless Kruskal-Wallis result was significant.
ND indicates No Data

Vegetation

The Las Vegas Wash wetlands encompass a diversity of vegetation, characterized by "spatially heterogeneous" patches separated by sharply defined transition zones. Zonation is typically sharply demarcated in wetlands because environmental gradients are "ecologically steep." Even though plant species may overlap along the gradient, the principal distribution of plant communities remains distinct [32].

Three major plant community types (cattail, reed, and salt cedar) were identified in the Wash during the study and are described in this section. The cattail-reed and salt cedar-reed communities were generally transitional, and exhibited environmental conditions that were intermediate between the pure vegetation types. The wetland annual community was not well represented in this study, and conclusions were not drawn about the nature of its distribution. The data for this community type (app. A) show that environmental conditions were generally intermediate between conditions of cattail and reed stands, indicating that these areas could be transition zones between cattail and reed vegetation types. The dominance of annual species in this vegetation type also suggested that these stands may be early successional stages towards a climax community.

Cattail.—Tropical cattail is a low elevation species found in coastal marshes and valleys in the Western States. It is the major cattail species found in the arid Southwest [6]. Cattail is primarily a plant of damp ground and relatively low salinity; it is not found on soils that dry out during any time of the year [33]. Seeds are the means of colonization in new areas, but germination of seeds in established areas is inhibited by allelopathic reactions [34], and spreading and maintenance of these stands is by vegetative reproduction. Cattail rhizomes branch freely and grow rapidly at an estimated rate of 100 cm per year, primarily during late fall and spring [35].

The Wash now supports 56 ha (hectares) of pure cattail marsh, a decrease of 117 ha since 1975, which was prior to the erosion induced drainage of the marsh. Cattails in the Wash were almost always

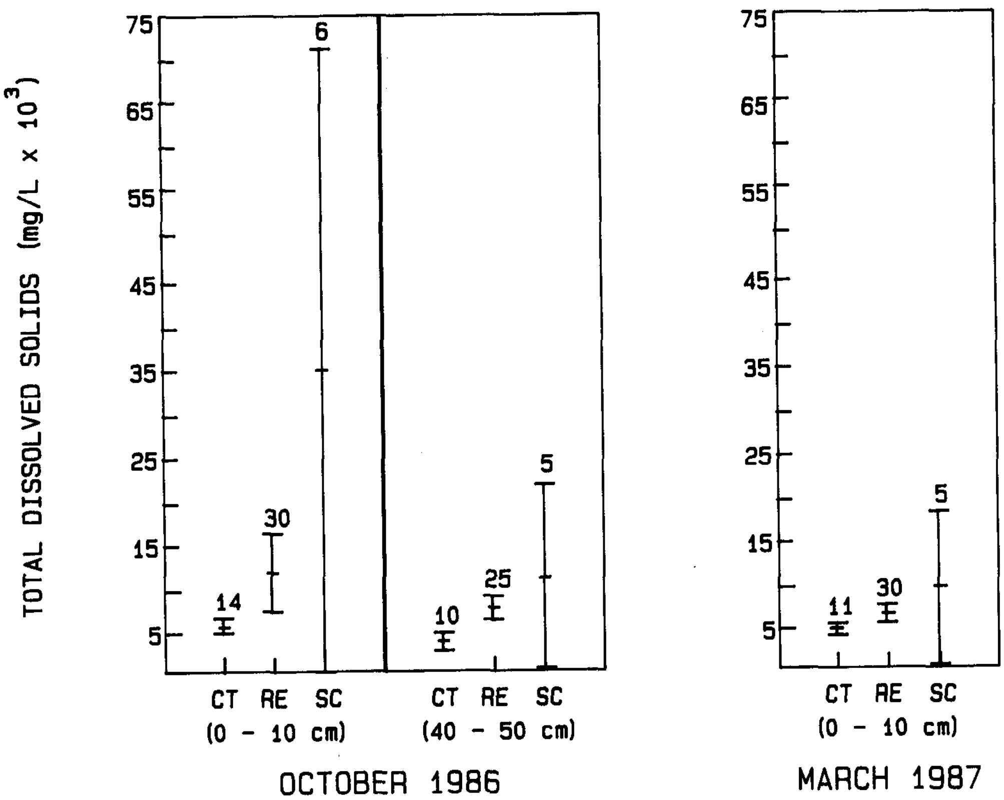


Figure 7. – Differences in TDS of soil extracts, by semiannual sampling period, for each major vegetation type.

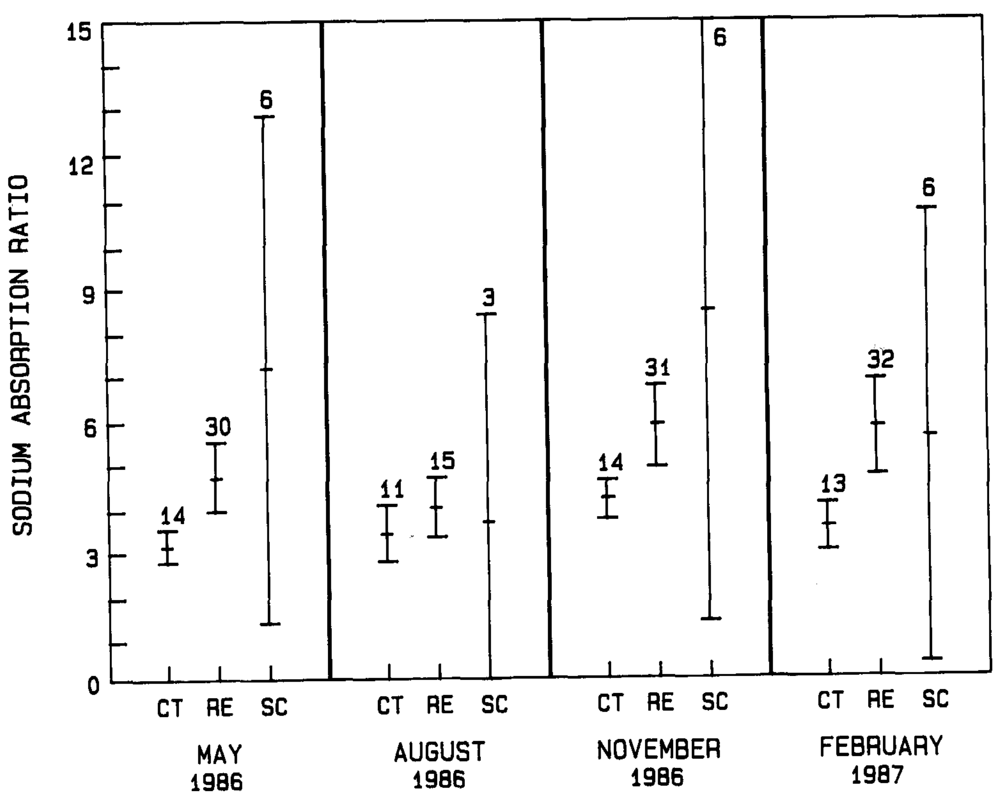


Figure 8. – Differences in SAR of ground water, by quarterly sampling period, for each major vegetation type.

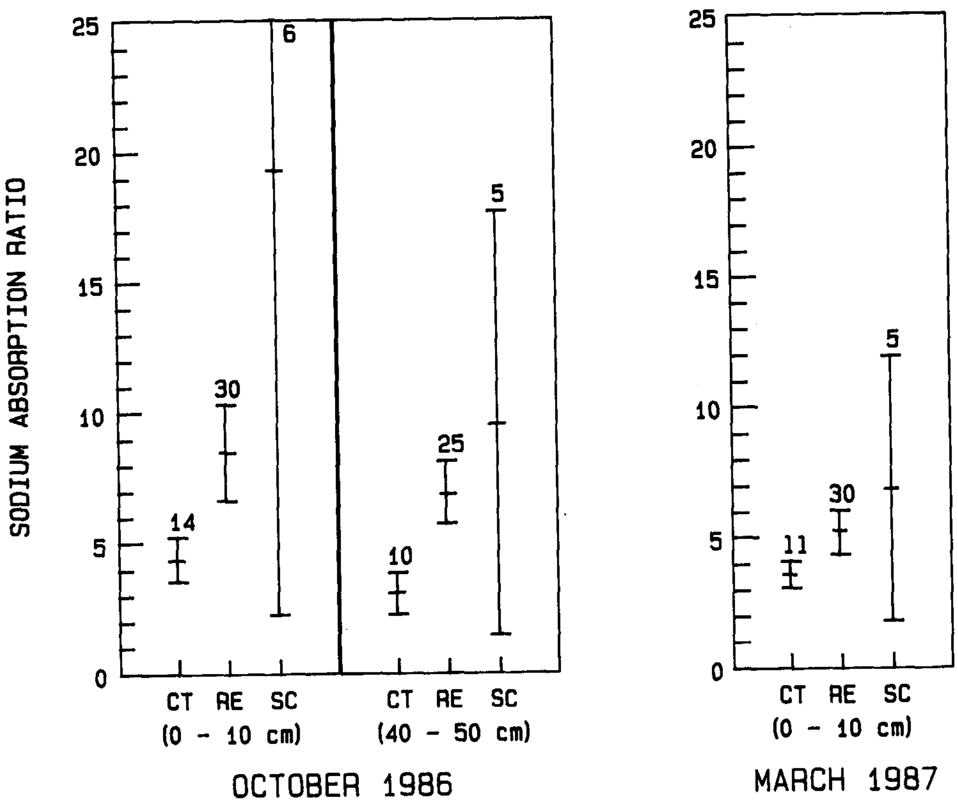


Figure 9. – Differences in SAR of soil extracts, by semiannual sampling period, for each major vegetation type.

Table 7. – Test statistics and levels of significance for group comparisons of vegetation types for soil quality parameters. Sample sizes are as shown on figures 7, 9, 11, 13, and 15. Critical values are as shown in table 5.

Environmental Parameters	Kruskal-Wallis	Mann-Whitney		
		CT vs RE	RE vs SC	CT vs SC
October				
Depth = 0 to 10 cm				
TDS	9.45†	2.73†	1.30	2.02*
SAR	14.20‡	3.16†	1.85	2.68†
SO_4^{-2}	14.76‡	3.48‡	1.46	2.52†
Cl^-	8.21*	2.32*	1.30	2.27*
B	8.51†	2.64†	1.90	1.01
Depth = 40 to 50 cm				
TDS	12.72†	3.49‡	0.278	2.14*
SAR	15.81‡	3.89‡	0.839	2.39*
SO_4^{-2}	10.89†	3.21†	0.222	2.02*
Cl^-	16.11‡	3.83‡	0.000	2.76†
B	10.94†	3.15†	0.418	2.22*
March				
Depth = 0 to 10 cm				
TDS	7.39*	2.28*	0.825	2.38*
SAR	7.93*	2.40*	0.849	2.34*
SO_4^{-2}	6.11*	2.13*	0.542	2.15*
Cl^-	5.36	NT	NT	NT
B	4.10	NT	NT	NT

*$P \leq 0.05$
†$P \leq 0.01$
‡$P \leq 0.001$
NT (No Test) Test was not performed unless Kruskal-Wallis result was significant.

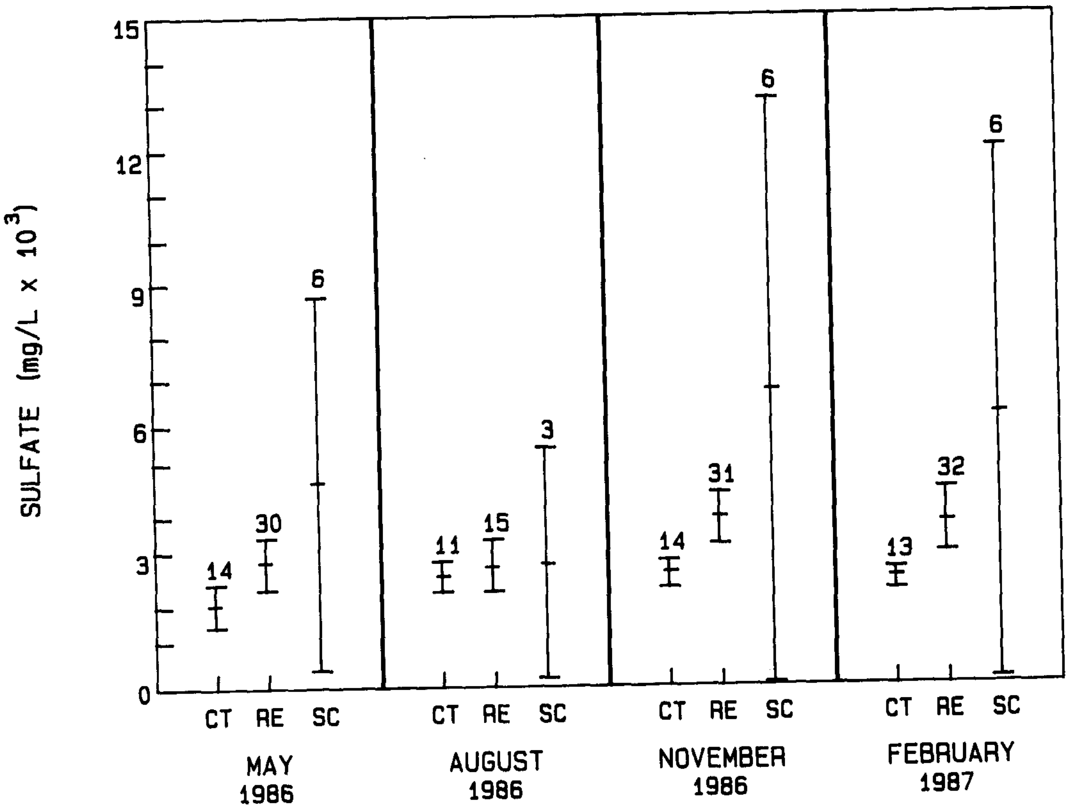


Figure 10. – Differences in sulfate concentrations of ground water, by quarterly sampling period, for each major vegetation type.

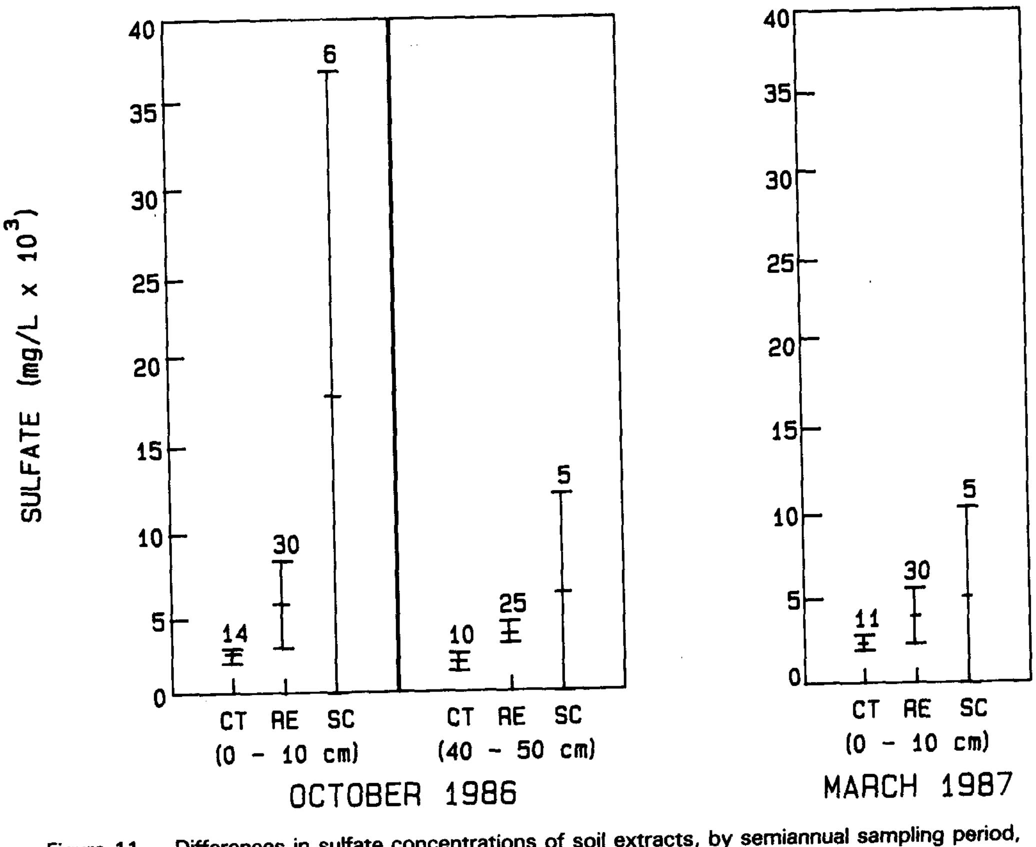


Figure 11. – Differences in sulfate concentrations of soil extracts, by semiannual sampling period, for each major vegetation type.

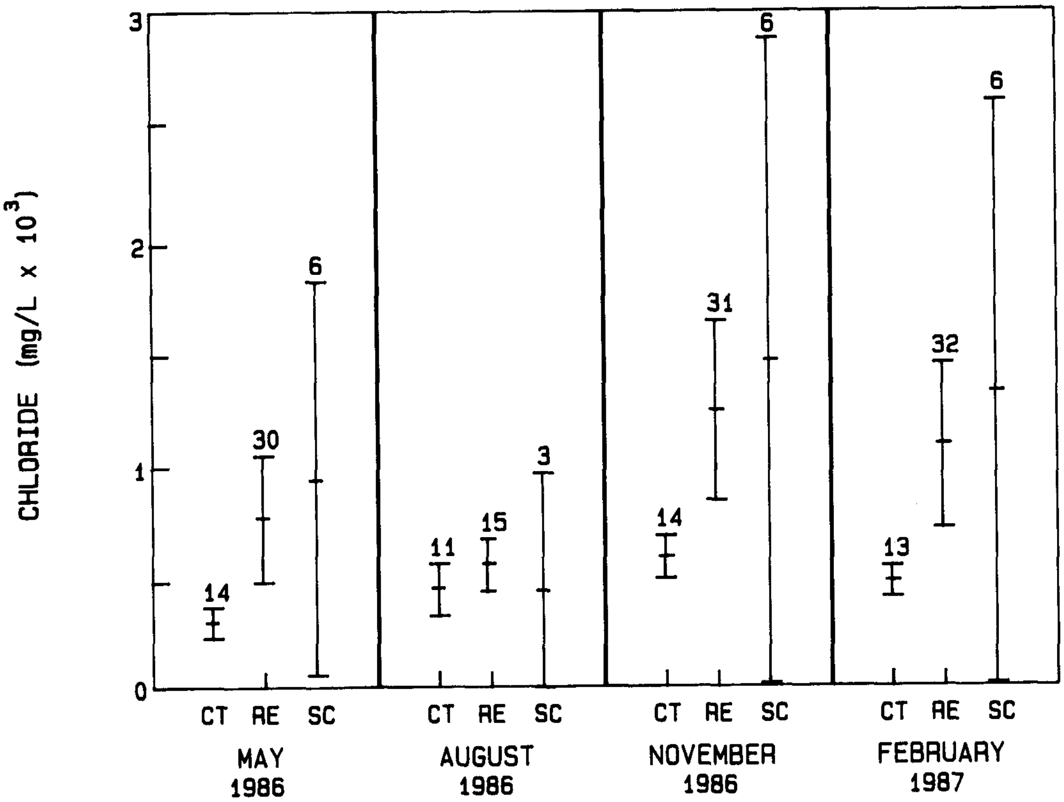


Figure 12. – Differences in chloride concentrations of ground water, by quarterly sampling period, for each major vegetation type.

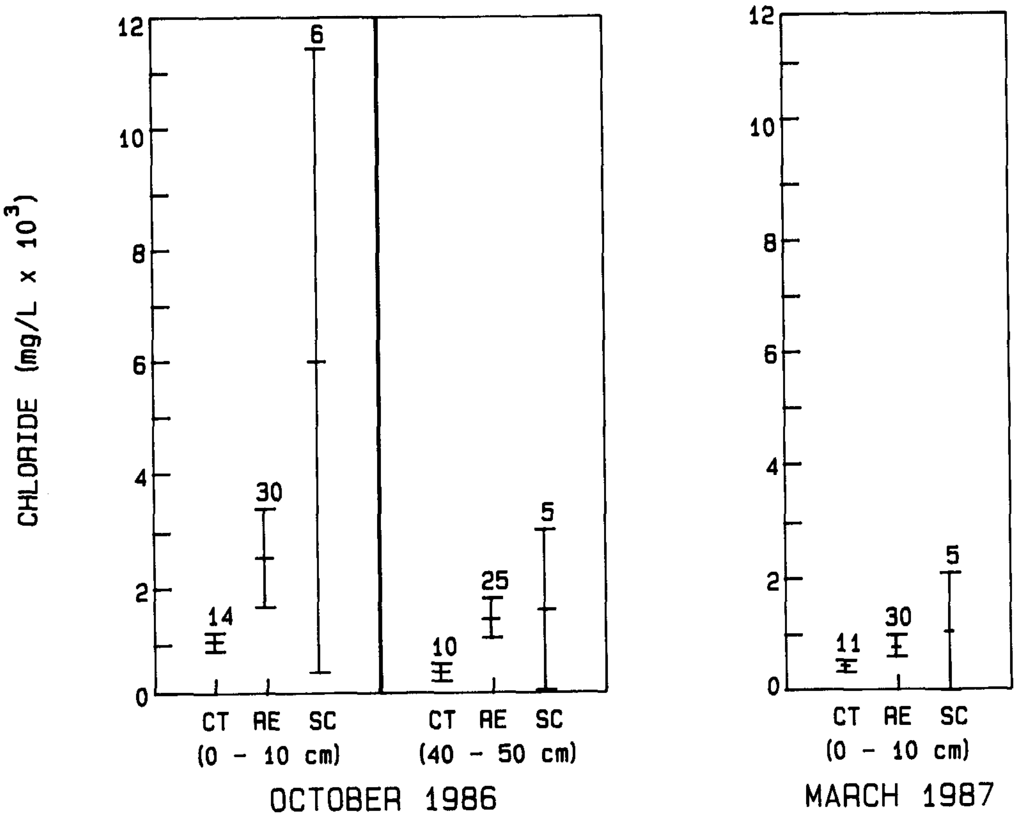


Figure 13. – Differences in chloride concentrations of soil extracts, by semiannual sampling period, for each major vegetation type.

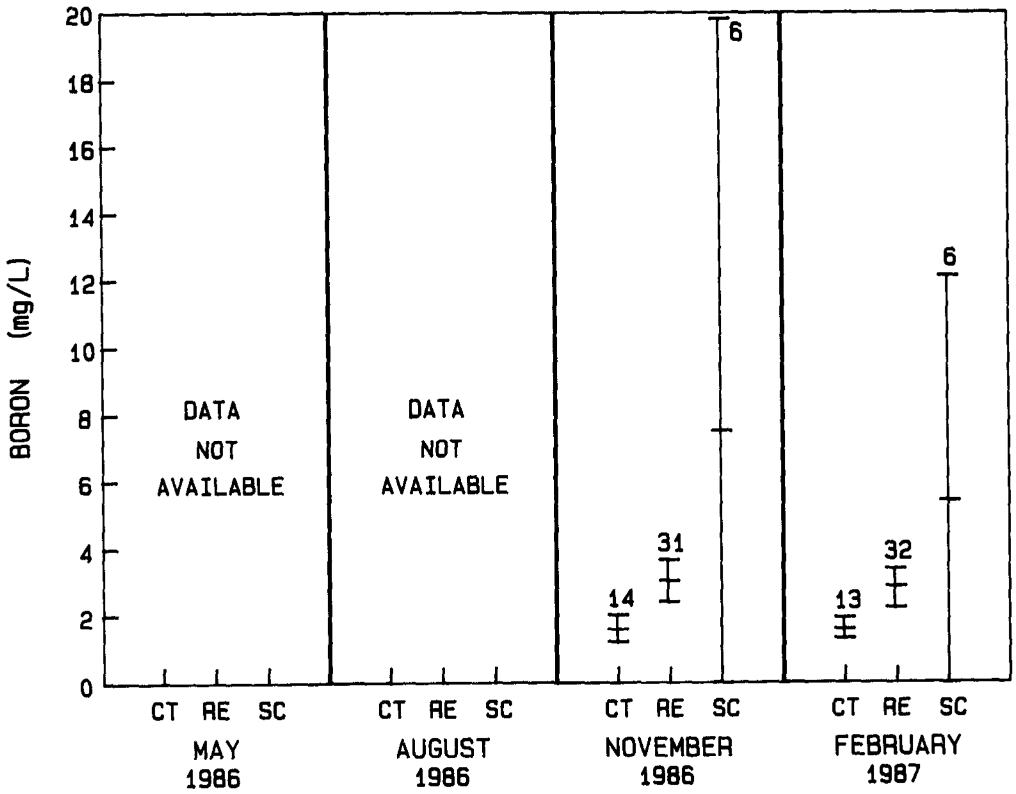


Figure 14. – Differences in boron concentrations of ground water, by quarterly sampling period, for each major vegetation type.

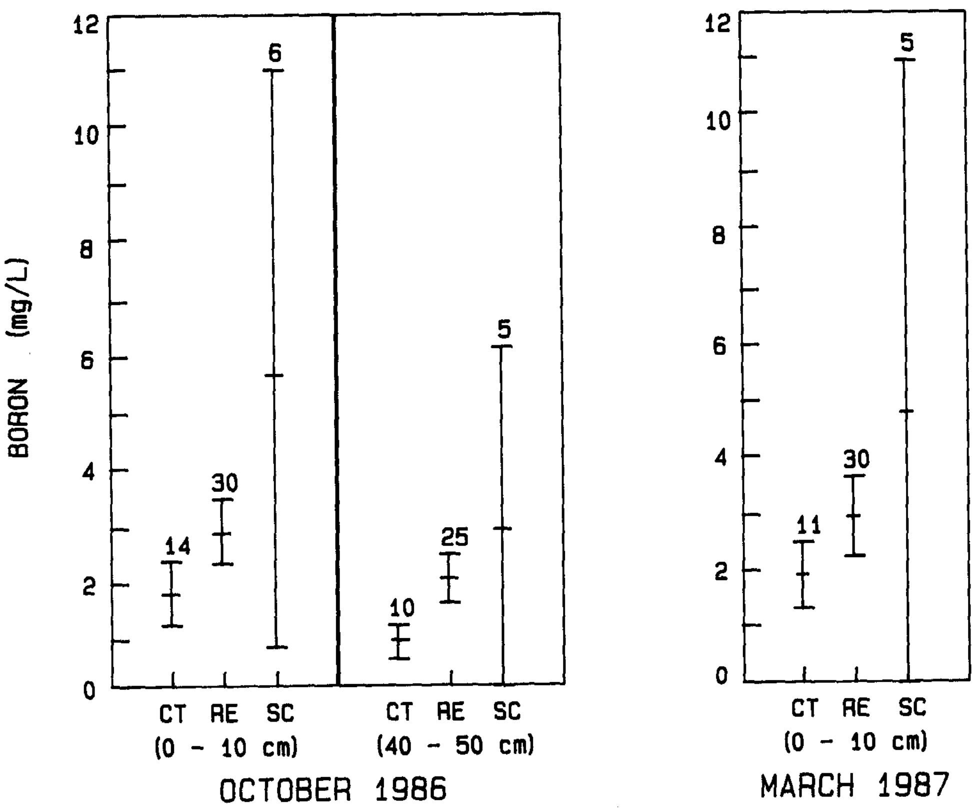


Figure 15. – Differences in boron concentrations of soil extracts, by semiannual sampling period, for each major vegetation type.

found in pure stands where moisture was most abundant. Reeds and wetland annuals were often interspersed with cattail in slightly drier areas, but salt cedar was rarely associated with cattail.

Prior to 1984, portions of the marsh downstream of the study area were dominated by pure, extremely dense, and highly vigorous stands of cattail approaching 5 meters in height. The vigor of these cattails was attributed to nutrient rich, relatively low salinity (1200 mg/L) surface flows and to the presence of surface water during the entire year. Most of these stands have disappeared because of the headcut erosion and accompanying drainage of the marsh.

The existing cattail marsh does not exhibit the extraordinary vigor of cattail stands fed by surface flowing sewage effluent. Much of the existing cattail vegetation is dependent on surface flow from valley drainage, in which salinity averages 4000 to 5000 mg/L, and on subsurface seepage from adjacent surface channels that generally has a higher TDS.

Conditions at cattail sites were generally wetter and less saline than in other vegetation types. Annual fluctuations of salinity were almost nonexistent, probably because of the high moisture content of the soils. In general, frequently flooded marsh soils maintain salinity levels in equilibrium with the flooding source [32]. Thus, maintenance of high soil moisture appears to contribute significantly to low, stable salinity in cattail stands [36].

Cattails in nonarid lands grow in shallow to moderately deep surface water for at least part of the year. Permanence of surface water was cited as a major factor controlling the distribution of emergent marsh vegetation in prairie potholes [37]. The lack of permanent surface water and the shallowness of the occasional surface water that was present at cattail sites in the Wash seemed to distinguish this wetland from others in less arid climates.

Salinity at cattail sites in the Wash was lower than in other vegetation types; however, cattail sites exhibited much lower salinity levels than what this species is reported to tolerate in other regions. In California, tropical cattail tolerated salinities of 12 000 mg/L, but growth was stunted and plants did not grow more than 1 meter high [33]. Studies in Utah showed that growth of young cattail was restricted at 9600 µmhos/cm² (micromhos per square centimeter), and growth of mature cattail plants was restricted at 21 000 µmhos/cm² [38][3]. In contrast, cattails in the Wash were found in low salinity areas where salinity did not exceed 7000 mg/L.

[3] 1 µmho/cm² is approximately equivalent to 0.640 mg/L.

Reed.—The common reed is a species of cosmopolitan distribution commonly found in fresh and brackish waters in the United States. It is a perennial grass with an extensive rhizome system that is the primary means of reproduction in established stands. Reeds develop horizontal and vertical rhizome systems; the horizontal rhizomes are responsible for spreading the plant while vertical rhizomes produce the above ground shoots [27].

In the Wash, reed stands are variable in density, height, and vigor. When viewed from above, large reed clones are visible as dense circular patches that expand and contract from year to year. Under suitable conditions, these clones can advance at a rate of 2 meters per year [39]. Dense stands of reed retain a standing dead biomass equivalent to the current year's live biomass. In sparser stands, reed stems are shorter and appear less vigorous. Salt cedar is the only overstory species that readily invades reed stands. The understory of sparser stands generally consists of grasses, usually salt grass and scratchgrass (*Muhlenbergia asperifolia*). The soil, where exposed, exhibits a crusty white layer of precipitated salts.

The data from this study indicated that reed stands were intermediate between cattail and salt cedar in moisture and salinity, and that reed was found growing under a wide variety of conditions. In general, reed is known to grow in a wide range of water levels if competition is low and nutrient status is satisfactory [27]. Reed sites were generally drier than cattail sites, but some reed sites had surface water that produced an elevated water table. Minor stream channels that cut across reed beds created this surface water.

In the Wash, reed sites exhibited a wide range of salinities. Haslam [39] also found that reeds grew optimally at 10 000 mg/L, but were tolerant of concentrations approaching 40 000 mg/L.

Salt Cedar.—This shrub was introduced to the United States from the Mediterranean area early in the 20th century as an ornamental shrub. The planting of salt cedar for windbreaks and erosion control hastened its spread [40]. This phreatophytic shrub spread rapidly through the Southwest, colonizing riparian zones and other areas with adequate moisture [41].

Reproduction is through wind and water seed dissemination. Salt cedar produces seed over a much longer period than its competitors; thus, if conditions are suitable, it can become established when seeds of other species are not present [41]. Salt cedar does not establish quickly and will not compete well in established communities [28]. Its tolerance to flooding and fire provides a means for establishment in disturbed areas [42]. The high rate of seed production and efficient seed dissemination have contributed to the rapid spread of salt cedar in the Southwest [43].

The spread of salt cedar along the lower Colorado River drainage area coincided with the damming of the river by Hoover Dam in the 1930's [44]. The flood plain terraces that once existed under a regime of natural annual flooding became suitable seedbeds for the establishment of salt cedar with the stabilization of river flows and levels. The presence of salt cedar in the Wash flood plain is undoubtedly because of the invasion of this species from the Colorado River riparian zone.

Salt cedar in the Wash covers about 300 ha [16], and is the dominant riparian species in the Wash. Riparian species native to the adjacent Colorado River, such as Fremont cottonwood and seepwillow (*Baccharis glutinosa*), rarely grow in the Wash, possibly because of high salinity levels. Although there are a number of stands of mature salt cedar close to the study area, particularly in outlying areas, sample sites within the flood plain usually consisted of a low shrubby growth form. Growth of this shrubby salt cedar in the flood plain was quite vigorous, possibly because of an adequate moisture supply.

Salt cedar sites were often characterized by deeper ground-water tables and higher concentrations of dissolved solids in the root zone than in other vegetation types, but conditions at these sites were highly variable, demonstrating the adaptability of this species to a variable environment. Salt cedar was not found on saturated ground; cattail stands rarely contained this species. Salt cedar is not known to develop densely where the water table is at 150 cm or less [41]; it is a facultative phreatophyte that usually draws moisture from the water table. Also, it can survive indefinitely in the absence of saturated soil, and uses soil moisture when ground water is not available [28,29]. The TDS were often found in higher concentrations in the soils underlying salt cedar stands than in other vegetation types. Salt cedar is more tolerant of salinity than many native species [28], tolerating salinities as high as 15 000 mg/L [45].

The mechanism of salt tolerance found in salt cedar probably contributed to the exceptionally high soil salinity found in the soil at the ground surface in October. Transport of salts to the foliage of salt cedar from the roots and stems of the plant acts as a salt tolerance mechanism by removing salts from plant tissues. Salt glands in the foliage concentrate excess salts from the internal cellular tissues of the plant and excrete them to the exterior leaf surface. Salt glands have been found to be nonselective in salt excretion; however, much smaller quantities of sodium have been found in the roots and stems than in the leaves [46]. The continual process of salt exudation and subsequent leaf fall could result in the accumulation of salts on the soil surface, which could deter germination and growth of less tolerant species in salt cedar stands.

Factors Influencing Plant Distribution

Gleason [62] concluded that the vegetation of an area is the result of "the fluctuating and fortuitous immigration of plants, and an equally fluctuating and variable environment" [47]. Adapted to wetlands, this theory suggests that zonation of plant communities in wetlands is caused, in part, by: (1) physical or chemical conditions of a habitat, (2) competitive interactions between plants, (3) destruction of existing vegetation, and (4) invasion and establishment of new species [48]. The consequences of these influences on plant communities in the Wash are discussed below.

Physical and Chemical Characteristics.—The relatively recent alterations of the surface and ground-water regimes in the flood plain, from steadily increasing wastewater discharge and valley runoff, have affected the Wash environment by altering the flow regime and water quality of the aquifer. The formation of the wetlands was a result of these changes.

The combination of moisture and salinity in the soil is a major influencing factor of plant growth in wetlands [26]. Soil-moisture stress is brought on by decreases in soil-water potential, which in turn is related to both concentration of dissolved solids and relative water content. For plants to take up soil water under conditions of high soil-moisture stress, plant roots must have even lower water potential than the soil. One way to accomplish this is through the accumulation of specific ions within plant tissues, which may decrease absorption of essential nutrients or inhibit growth by toxicity [26]. Even so, the total concentration of dissolved solids in the soil solution, rather than specific chemical constituents, is probably the dominant factor responsible for inhibitory effects on plant growth [21,31,38].

Concentration of salts during the spring has a major influence in determining plant response [36]; young cattail plants in particular are intolerant of salinity [38]. In the Wash, spring was the time of greatest moisture and lowest salinities in all vegetation types, which probably helped initiate the reemergence of plant communities. Overall soil salinity was generally highest in late summer and fall, corresponding to the period of lowest soil moisture and senescence of the vegetation.

The SAR of ground and soil water is indicative of another potential limiting factor to water uptake. Excess sodium on the soil exchange complex causes dispersion and puddling of the soil, which in turn is responsible for poor aeration and low water availability [21]. Also, sodium-sensitive plants may be affected by sodium accumulation in plant tissues. An SAR higher than 10 indicates that a moderate sodium problem may be present, and higher than 18 indicates a severe impact by high sodium levels [21]. At most sites, the SAR usually fell within acceptable limits. In salt cedar sites, the SAR was occasionally very high in the soil. Salt cedar was probably not affected by soil SAR levels because it uses ground water as its moisture supply.

In the Wash, boron concentrations in the soil were particularly high compared to most other regions. Boron is not typically found in excess, and it is often a limiting factor [49]. Concentrations of this micronutrient in excess of 1.5 mg/L are usually considered unsafe for sensitive crop plants; most plants do not tolerate boron concentrations greater than 4 mg/L [21]. Boron levels in cattail and reed stands were generally not this high. At salt cedar sites, boron levels occasionally exceeded 4 mg/L, indicating a possible tolerance of high concentrations of boron by this species.

Competition.—The spatial distribution of plant communities in the Wash is partially a function of interspecific competition among the dominant plant species. In general, the capture of resources such as moisture, mineral nutrients, space, and light is the mechanism whereby a plant suppresses the fitness of a neighbor by modifying its environment [50].

Successful competition for a low salinity moisture supply was apparently responsible for domination of cattails at sites exhibiting these conditions. Cattails are generally successful competitors with most other emergents [35,51]. Among the three dominant plant species in the Wash, cattail had the strictest habitat requirements, which was illustrated by the comparatively narrow range of environmental conditions under which it was found. Cattail probably had a competitive advantage over reeds and salt cedars, which resulted in their exclusion, even when conditions were appropriate for their survival.

In areas where the water table was deeper and salinity was greater, cattail was replaced by other vegetation. Species such as reed and salt cedar were probably restricted to these severe habitats because they were poor competitors on the more optimum sites. In general, salt tolerant plants (halophytes) are not necessarily limited to highly saline areas due to a physiological requirement for excess salt but because they can tolerate low water potentials [52]. Conversely, species that grow in nonsaline environments cannot withstand high salinities, leaving halophytes an open habitat for colonization. Competitive exclusion by species such as cattail in more optimum areas may explain why reeds and salt cedar were restricted to marginal areas.

Reed is generally a poor competitor, yet extremely adaptable, surviving under a wide variety of conditions ranging from standing fresh water to water with salinity concentrations approaching that of sea water [39]. Reed sites in the Wash exhibited a wide range of environmental conditions. In shallow water, reeds are outcompeted by other species if nutrient availability is high [27]. In the Wash, competition by cattail rather than low tolerance of excessive moisture is probably the most limiting factor.

Competition by salt cedar is probably limited in dense reed stands because of dense mats of debris that limit light at ground level. Reed occurred sparsely under dry conditions. The invasion of sparse reed stands by salt cedar in dry areas was probably due to the poor competitive ability of reeds. Salt cedar is opportunistic and will invade readily if competition is not present [28]. The limits of distribution of reed under dry conditions is probably due to lack of moisture rather than competition.

Salt cedar was found in reed stands; however, this invasion appeared to be restricted to zones of drier and more saline conditions where reeds were shorter and sparser. Salt cedar is probably incapable of invading reed stands where the litter is thick. This suggests that salt cedar is not outcompeting reed; rather, it colonizes areas where reed cannot grow.

Destruction of Existing Habitat.—The Wash undergoes constant perturbations, that impact existing vegetation, from such activities as construction, damming, clearing, woodcutting, and fires. Disturbance allows the invasion of pioneer species such as bulrush (*Scirpus* spp.) in wetlands and exotic species such as Russian thistle (*Salsola pestifera*), smotherweed (*Bassia hyssopifolia*), and salt cedar in the uplands. Mesquite is subject to woodcutting and fires, and its reestablishment in the Wash is relatively unsuccessful due to its slow regeneration and lack of fire tolerance. Fires in riparian zones usually result in a shift to salt cedar dominance because of its fire hardiness [42].

Invasion by Exotics.—Another man-induced impact radically changed the composition of the flood plain plant community, which was the introduction of salt cedar to the regional flora. Salt cedar invaded native plant communities because of its highly adaptive characteristics. The success of this species is probably due to its tolerance of a wide range of conditions, rather than its effectiveness as a competitor. The early introduction of salt cedar to the Wash resulted in a major impact to the riparian component of the wetlands.

Factors Influencing Environmental Quality

Distribution of plant communities was directly correlated with ground-water table depth and soil quality that influenced soil moisture. Other interrelated factors contributed to the composition and distribution of plant communities in the Wash wetlands. These include microtopography, water quality, and evapotranspiration.

Microtopography.—The effect of microtopography on community distribution is demonstrated in the plan and profile of Transect 2B (fig. 16). Hummocks, depressions, and small channels occur irregularly across the landscape because of fluctuations in ground elevation. Depth to ground water is clearly affected by ground surface contours. The ground-water table is shallower near channels and beneath low lying areas. The lack of correlation between ground-water depth and root zone EC indicated that high soil moisture, which keeps soil salinity concentrations low, is probably a function of surface water percolation as well as a shallow water table. These features provide a suitable microhabitat for the growth and maintenance of cattail marshes, which require greater moisture than other vegetation types. Since the TDS of local overland flows rarely exceeds 5000 mg/L, leaching and the accompanying high soil-moisture content in these areas keep soil salinity low.

In general, frequently flooded marsh soils, as in tidal salt marshes, contain salinity levels in equilibrium with the flooding source [32]. This situation also appears to exist in inland marshes. In the Wash, cattails were dominant in low-lying areas, and salt cedar occupied the high and dry islands interspersed with marsh vegetation.

Water Quality.—Bolen [26] determined that distribution of plant communities in the salt marshes of Utah was determined indirectly by water quality, and that salinity of the soil in wetlands was relative to soil depth and position of the water table.

Water quality in the Wash appeared to be a major factor contributing to salinity in the root zone; however, its effect was dependent on whether the source was from below (the ground-water table) or above (overland flow). Capillary action of the water table results in the deposition of salts in the capillary fringe as ground-water elevation drops. In general, surface water provides leaching benefits if the quality of the water source is better than that of the soil water.

As previously mentioned, soil salinity remained consistently low in cattail marshes because of the high moisture content of the soils. In reed marshes, where conditions were typically drier and surface flows were present only as occasional flows along the minor water courses, soil salinity was typically higher. The fluctuating water table deposited salts in the soil capillary fringe above the saturated zone.

In salt cedar stands, the water table was typically deeper and soil moisture lower than in reed stands, causing conditions even more favorable for salt accumulation. Buildup of salinity was aggravated on the soil surface from the excretion of salts by salt-exuding glands present in the foliage of salt cedar [46]. Occasional overland flow or precipitation has the potential to leach surface salts into the soil layer underlying the ground surface.

Evapotranspiration.—The evaportranspiration in wetlands results in a seasonal drawdown of the water table and buildup of soil salinity through moisture depletion. The rate of transpiration is dependent on plant species and stand density. Cattails have an inherent low transpiration rate but high unit mass of leaves, while reeds have an inherently high transpiration rate but low unit mass of leaves [51].

Evapotranspiration rates in cattail stands range from 150 to 300 cm per unit area per year [38,53,54,55], whereas reed evapotranspiration rates range from 100 to 150 cm per year [27,56] and salt cedar stands range from 150 to 210 cm per year [41,57].

In the Wash wetlands, evapotranspiration presumably accelerated with the onset of the growing season in March and April, and continued through October when the majority of the vegetation went dormant. This resulted in a steady drop in the water table elevation and accumulation of salts in stands as soils became dry. With little precipitation and no overland flow to leach these salts, accumulation probably continued until the cation exchange capacity of the soil particles was met. Occasional storm events provided limited leaching benefits. By the end of the growing season in October, soil salinities were presumably higher than during the rest of the year. The October soils data probably represented the most extreme salinity conditions for the plant communities because of the duration of water loss from the soils through evapotranspiration.

Habitat Values

Arid zone wetlands are critical habitats for wildlife because they provide food, cover, and water within a comparatively depauparate environment. The Wash supports at least 248 species of resident and migrating birds, which constitutes 69 percent of the total number of species recorded for the state of

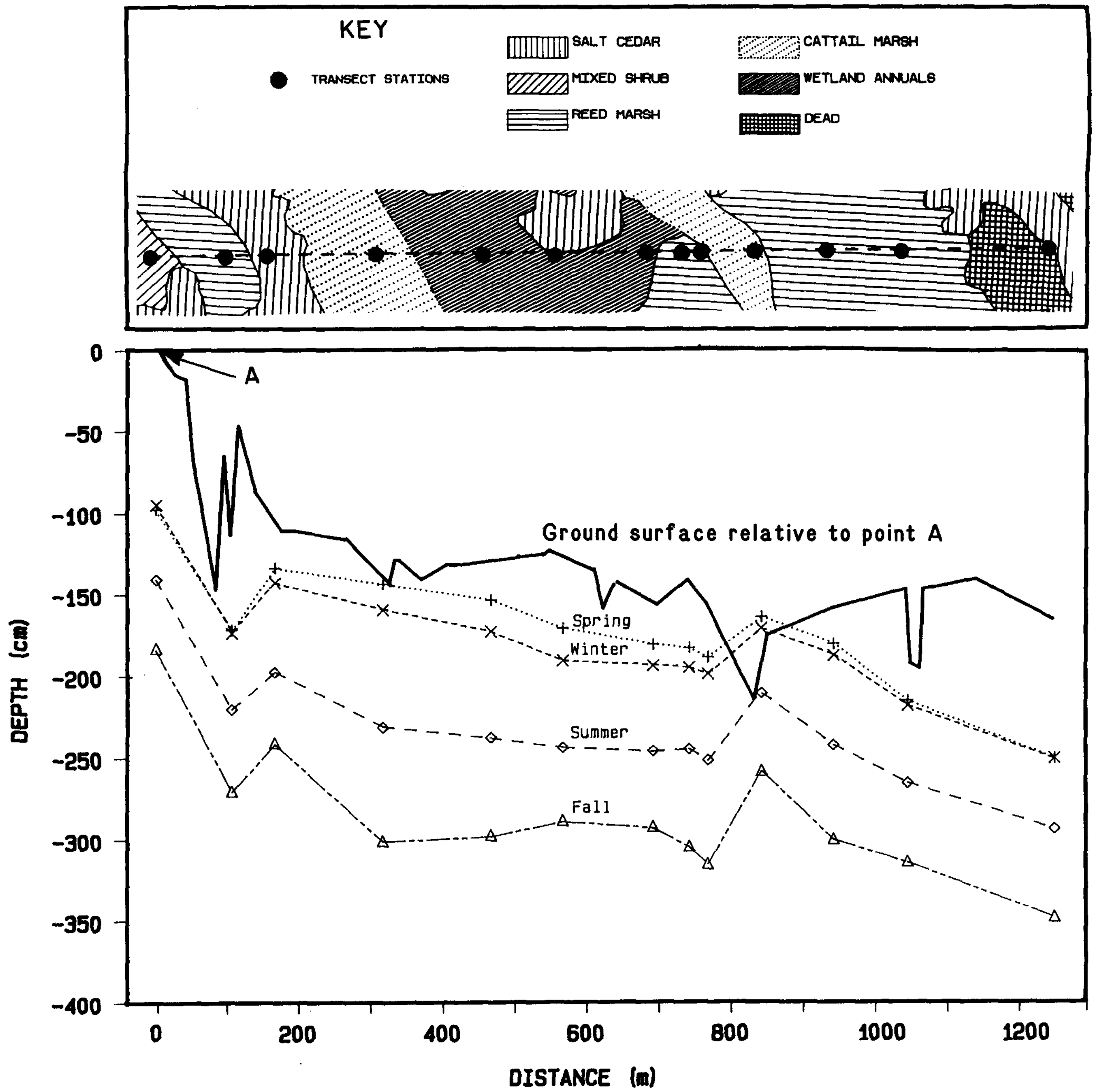


Figure 16. – Plan and profile of Transect 2B showing relationship between relative ground surface and depth to ground water by season. Symbols on each view denote sample stations.

Nevada [58]. A variety of mammals, amphibians, and reptiles are also associated with the Wash [59].

Wildlife values in wetlands are generally correlated with the diversity and structure of the vegetation. Heterogeneity of plant communities in a mosaic, such as that found in the Wash, provides habitat diversity which in turn induces high species richness. Structure of emergent communities rather than taxonomic composition is of greater importance to nesting birds [60]. Presence of surface water also plays a role in attracting wildlife to these plant communities. Presence of standing water for even part of the year provides resources to a wider variety of wildlife than in drier emergent vegetation.

The mosaic of vegetation created by the interspersion of wetland emergents, such as cattail and reed with a riparian component represented by salt cedar trees, provides a diversity of structural components and associated ecological niches for wildlife. General observations indicated that the cattail component of the vegetation mosaic provided the best habitat for marsh birds in the Wash. In particular, high densities of virginia rails, common yellowthroats, song sparrows, and marsh wrens were associated with this vegetation type. Reed stands also supported these marsh species, especially where surface flows were present.

Despite the known low habitat value of salt cedar, this species was found to provide structural diversity to the wetlands, providing upper canopy for riparian species and perches for raptors. Along the lower Colorado River, salt cedar vegetation has been found to have low wildlife values compared to other native species, although habitat values can be enhanced when associated with other species [61].

CONCLUSIONS

Wetlands in the Wash are characterized by a spatially heterogeneous distribution of plant species controlled through interrelated environmental and biotic components. Soil salinity is a major determinant of plant community distribution in the Wash. Ground-water quality and water table fluctuations seem to influence the salinity of the upper soil layers that comprise the root zone. Factors such as surface water and microtopography have an influence on soil moisture that could also influence soil salinity. Vegetation also influences moisture and salinity in the environment through evapotranspiration. Competition between plant species plays a major role in the distribution and diversity of plant communities. The interactions between the physical and chemical environment with the biotic components of the ecosystem has resulted in a diverse and dynamic wetland of high diversity and habitat value.

The Wash is subject to frequent man-induced disturbances due to its close proximity to an urban population center. In particular, the natural drainage capabilities of the Wash have provided a valuable resource to the Las Vegas Valley for its wastewater disposal requirements. As a result, continuous deterioration of the wetlands has occurred as the erosive forces of perennial flow have degraded the alluvial material underlying the marsh. Considerable wetland losses have been accrued over the last decade due to advancement of the channel headcut. Deepening and advancement of the stream channel has also posed a threat to personal safety and property.

Control of erosion has been investigated by concerned entities; however, the prohibitive cost and unwillingness of any one agency to carry the financial burden demonstrates the unfortunate dilemma that the Clark County Wash Development Committee faces in their efforts to save the wetlands. The recreational and habitat value of the Wash has been compromised to a great extent in favor of management strategies that provide economic advantages.

While most concerned entities have acknowledged the need to cooperate when formulating development and management plans for the Wash, few have carried through with collaborative efforts. An example of one such effort is the cooperative agreement between the WDC (Water Development Committee) and the Bureau of Reclamation. In recognition of the need for preservation and development of the wetlands for its ecological and recreational values, the WDC seeks a management plan oriented towards protection of the wetland resource. The Bureau has acknowledged the feasability of integrating WDC's wetland park proposal with salinity control objectives. This study of vegetation-environment relationships provides information that can be applied to future management of the Wash.

The construction of salinity control features, such as ground-water detention basins, could impact the existing mosaic of plant communities that provides the spatial diversity conducive to wildlife populations. The impacts of ground-water detention basins could range from inundation of land area to drying of wetlands. Specific scenarios should be recognized that would impact the existing wetlands:

- Surface water and ground-water regulation may affect plant community distribution. In general, cattails could be eliminated by drying of the capillary zone resulting from surface flow reduction or elimination, or from ground-water table draw-down. If surface water in cattail stands is reduced or eliminated, salinity levels in the capillary fringe may increase because of ground-water table fluctuations, encouraging environmental conditions that cattail apparently cannot tolerate.

- Increases in the depth of surface water may eliminate certain vegetation types. Emergent hydrophytes will tolerate flooding, but salt cedar could be eliminated by a permanently saturated soil column [41].

- Elevational increase of the ground-water table could alter plant composition in sparsely vegetated areas by creating perennially wetted soils. Root zone saturation could provide a suitable environment for the growth of emergents. Accessibility of the water table to the tap roots of low-growing salt cedars may increase the size, density, and vigor of individual trees.

- Surface flow plays an important role in maintaining root zone salinities at relatively low levels. Maintaining surface and near surface flows could promote the growth of plants with lower salinity tolerances, such as cattail.

The recent concern about loss and conversion of wetlands in the United States indicates there is significant need to protect areas such as Las Vegas Wash. Man-induced perturbations in the Wash could result in conversion of the existing vegetation mosaic from a highly diverse system to a more homogeneous environment of lower habitat value. If disturbances to existing plant communities are to be minimized, management plans should include provisions to maintain community diversity and protect the wetlands from further degradation.

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APPENDIX A

MEAN DEPTHS TO GROUND WATER AND MEAN CONCENTRATIONS OF CONSTITUENTS

Table A-1. – Mean depths to ground water in centimeters ±1 standard deviation, by season, for the six common vegetation types found in Las Vegas Wash.

Season	CT (14)	RC (5)	WA (7)	RE (31)	RS (7)	SC (6)
Summer 1986	72±19	65±28	73±20	90±46	97±40	109±46
Fall 1986	102±32	97±42	116±39	129±48	142±52	160±60
Winter 1986-87	22±26	16±16	17±15	35±35	37±40	55±33
Spring 1987	17±27	13±12	15±15	34±39	35±43	55±33

Notes: CT = cattail, RC = reed-cattail mix, WA = wetland annual, RE = reed,RS = reed-salt cedar mix, and SC = salt cedar. Numbers in parentheses represent group sample size.

Table A-2. – Mean concentrations of constituent ions and SAR ±1 standard deviation in ground water, by vegetation type, from samples collected in May 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (12)	CR (5)	WA (7)	RE (30)	RS (7)	SC (6)
TDS	3348±1304	3913±1469	3867±1398	5513±3342	6533±3341	8307±7108
Na^+	306±117	397±171	383±141	628±468	794±481	1159±1219
K^+	28.8±9.9	30.0±10.6	32.6±8.9	57.3±52.3	83.5±76.5	181±263
Ca^{+2}	475±175	523±172	504±166	515±159	531±144	492±115
Mg^{+2}	186±108	222±111	243±122	127±350	524±364	642±667
HCO_3^-	430±141	452±152	413±128	551±262	570±210	533±396
Cl^-	279±104	345±134	376±167	747±759	864±569	924±830
SO_4^{-2}	1792±804	2105±849	2066±825	2796±1595	3375±1731	4588±3943
B	ND	ND	ND	ND	ND	ND
SAR	3.04±0.66	3.42±0.99	3.48±0.66	4.64±2.08	5.55±2.26	7.12±5.50

ND indicates no data available.

Table A-3. – Mean concentrations of constituent ions and SAR ±1 standard deviation in ground water, by vegetation type, from samples collected in August 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (11)	CR (4)	WA (3)	RE (15)	RS (3)	SC (3)
TDS	4437±940	4433±446	4350±1216	4953±1774	5423±2286	4849±1771
Na^+	398±146	462±22	389±187	491±238	636±442	454±301
K^+	37.6±8.1	38.4±7.4	42.1±13.3	42.3±17.7	79.1±63.0	44.3±26.3
Ca^{+2}	579±73	520±61	582±40	524±135	448±122	538±91
Mg^{+2}	276±101	284±53	307±157	371±181	416±258	366±239
HCO_3^-	297±126	361±154	318±241	361±189	481±429	330±167
Cl^-	438±173	453±85	432±250	545±212	695±468	423±208
SO_4^{-2}	2480±477	2406±268	2556±489	2700±1022	2812±1005	2784±1038
B	ND	ND	ND	ND	ND	ND
SAR	3.33±0.97	4.06±0.39	3.19±0.84	3.92±1.23	5.00±2.84	3.55±1.94

ND indicates no data available.

Table A-4. – Mean concentrations of constituent ions and SAR ±1 standard deviation in ground water, by vegetation type, from samples collected in November 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (14)	CR (5)	WA (7)	RE (31)	RS (7)	SC (6)
TDS	4743±907	5013±859	5160±1305	7397±3757	9907±5019	11 829±10 656
Na^{+}	490±111	561±206	592±222	895±605	1353±856	1662±1766
K^{+}	38.0±8.2	37.0±9.0	40.1±10.0	67.2±52.8	138±128	254±399
Ca^{+2}	587±119	586±85	569±100	606±89	594±70	601±60
Mg^{+2}	308±118	356±114	358±148	631±453	900±569	985±1075
HCO_3^{-}	357±267	211±252	116±158	341±352	326±523	455±288
Cl^{-}	573±59	645±170	669±296	1218±1089	1754±1209	1447±1364
SO_4^{-2}	2516±522	2650±507	2827±630	3748±1629	4942±2387	6602±6201
B	1.62±0.68	2.46±1.26	2.09±0.85	3.03±1.61	5.94±5.97	6.56±10.70
SAR	4.11±0.78	3.95±0.90	4.75±1.36	5.75±2.5	7.73±3.5	8.40±6.7

Table A-5. – Mean concentrations of constituent ions and SAR ±1 standard deviation in ground water, by vegetation type, from samples collected in February 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (13)	CR (5)	WA (7)	RE (32)	RS (7)	SC (6)
TDS	4419±718	4812±761	4962±780	7250±4274	8126±4891	11 084±10 053
Na^{+}	416±120	497±150	524±122	899±742	974±746	1562±1766
K^{+}	34.6±5.7	32.2±8.1	37.9±6.5	70.6±74.7	119±115	246±363
Ca^{+2}	590±73	622±60	572±29	575±44	561±32	590±66
Mg^{+2}	293±82	305±67	344±92	618±497	747±605	945±1039
HCO_3^{-}	420±100	460±112	441±70	536±260	573±265	640±281
Cl^{-}	464±111	536±161	577±152	1069±1010	1092±802	1302±1236
SO_4^{-2}	2355±387	2525±316	2635±425	3683±1914	4289±2547	6074±5657
B	1.53±0.51	1.42±0.65	2.23±0.80	2.85±1.83	4.02±3.22	5.42±6.37
SAR	3.42±0.84	4.05±0.99	4.25±0.76	5.74±3.07	5.87±3.04	5.49±4.15

Table A-6. – Mean concentrations of constituent ions and SAR ±1 standard deviation in soil extracts, by vegetation type, for soil at 0 to 10 cm depth in October 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (14)	CR (5)	WA (7)	RE (30)	RS (7)	SC (6)
TDS	5353±1028	5246±1309	11 843±11 912	11 370±12 215	25 582±17 029	34 457±34 858
Na^{+}	555±208	669±244	1802±1819	1636±1876	4463±3164	5920±6572
K^{+}	103±46	57.0±13.3	119±114	177±224	421±358	1178±2134
Ca^{+2}	636±118	542±164	649±98	619±113	741±128	688±175
Mg^{+2}	330±111	327±48	977±1382	966±1316	2139±1661	2717±2480
HCO_3^{-}	252±88	182±80	228±120	200±63	316±113	621±996
Cl^{-}	918±248	859±356	2640±2607	2417±2401	6559±4819	5902±5255
SO_4^{-2}	2327±721	2618±568	5441±5965	5340±6669	11 047±8086	17 680±18 308
B	1.67±0.95	2.00±0.59	3.06±2.65	2.77±1.52	4.44±3.93	5.54±4.40
SAR	4.40±1.44	5.53±1.71	9.65±4.82	8.55±4.86	17.2±10.6	19.3±16.3

Table A-7. – Mean concentrations of constituent ions and SAR ±1 standard deviation in soil extracts, by vegetation type, for soil at 40 to 50 cm depth in October 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (10)	CR (2)	WA (7)	RE (25)	RS (6)	SC (5)
TDS	3378±1227	3327±2109	6247±3873	7166±3165	7967±3907	10 668±84 80
Na^+	316±155	397±252	847±754	1002±563	1124±717	1652±1502
K^+	40.7±15.0	32.5±16.3	59.7±41.5	83.4±68.5	108±83	281±362
Ca^{+2}	461±186	363±286	578±118	576±133	598±81	544±135
Mg^{+2}	187±90	209±75	433±382	507±296	585±363	805±837
HCO_3^-	140±31	98±26	118±29	124±38	120±56	129±45
Cl^-	367±209	387±295	1073±1102	1343±849	1346±897	1472±1176
SO_4^{-2}	1862±700	1824±1120	3144±1543	3530±1486	4098±1975	5815±4765
B	0.81±0.40	0.95±0.64	1.44±0.72	1.92±1.05	2.28±1.22	2.82±2.60
SAR	3.10±1.04	3.98±1.46	5.99±3.27	6.98±2.81	7.46±3.70	9.55±6.52

Table A-8. – Mean concentrations of constituent ions and SAR ±1 standard deviation in soil extracts, by vegetation type, for soil at 0 to 10 cm depth in March 1986.

Constituents, mg/L	Vegetation Type (sample size)					
	CT (11)	CR (5)	WA (6)	RE (30)	RS (7)	SC (5)
TDS	4401±977	4913±1050	5447±859	6121±2490	12 689±9149	9113±7063
Na^+	420±122	511±213	623±110	719±412	2022±2007	1177±1146
K^+	58.0±18.1	61.8±14.2	65.8±16.1	106±71	218±141	170±172
Ca^{+2}	571±78	594±33	585±23	583±74	611±54	597±49
Mg^{+2}	271±105	307±91	374±122	436±260	977±805	742±784
HCO_3^-	191±39	168±18	179±40	185±39	203±52	200±32
Cl^-	446±163	534±180	627±101	799±524	2242±2300	1017±869
SO_4^{-2}	2484±572	2748±547	3044±543	4074±4245	6321±4513	5162±4188
B	1.94±0.88	2.02±0.53	2.97±1.18	2.96±1.88	5.50±4.18	4.82±5.08
SAR	3.59±0.72	4.19±1.51	4.94±0.66	5.25±2.17	10.52±8.45	6.89±4.08

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