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Correlation between vegetation distribution and salinity in Artesian Slough

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CORRELATION BETWEEN VEGETATION DISTRIBUTION AND SALINITY IN ARTESIAN SLOUGH

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ABSTRACT

CORRELATION BETWEEN VEGETATION DISTRIBUTION AND SALINITY IN ARTESIAN SLOUGH

by Lynne Reardon

This study addresses the relationships between vegetation distribution and water and sediment salinities in Artesian Slough, Alviso, California. The wastewater treatment plant which discharges into the Slough is planning a wastewater diversion project which could result in increased salinities, thus impacting the Slough ecosystem. This ecosystem includes an important heron rookery that depends upon stands of California bulrush *(Scirpus californicus)*. Percent cover of six vegetation species and salinities of water and sediment pore water were measured from December 1995 through May 1996. The results indicate that California bulrush is outcompeting other species in mean water salinities below 4 ppt and sediment pore water salinities below 6 ppt. Above those salinities, alkali bulrush *(S. robustus)* and peppergrass *(Lepidium latifolium)* begin to compete successfully. It is recommended that the treatment plant manage its outflow in a manner that provides for salinity conditions that support California bulrush within the rookery area.

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INTRODUCTION AND BACKGROUND

Introduction to the Research Problem

Coastal wetlands and estuaries are biologically productive ecosystems that have been disappearing at an alarming rate, either through in-fill for development or through contamination, diking, or other alteration by human activities. Populations of wildlife that depend on these ecosystems have dwindled as their habitat has been altered or lost. According to the Office of Technology Assessment, the loss rate of wetland acreage along the Pacific coast has been approximately 1.6% per year. Approximately 94% of the tidal salt marshes that existed in the San Francisco Bay 150 years ago have been diked and/or filled (Josselyn and Buchholz 1984).

The San Francisco Bay-Delta Estuary is the largest estuarine system on the west coast of the United States and, as such, is an immensely productive ecosystem (San Francisco Estuary Project 1993). Habitat fragments remaining within the Estuary, especially the tidal salt and brackish marshes, continue to steadily deteriorate under an increasing array of negative human effects (San Francisco Estuary Project 1992). It is therefore important that efforts be made to protect the existing marsh habitats and restore marshes where possible. In order to do so, it is necessary to obtain baseline data on existing marsh conditions and monitor changes in those conditions.

This research measured the vegetation distribution and salinity in the marsh habitat along Artesian Slough in Alviso, California. This marsh was selected because it is the site of an important heron rookery, or nesting habitat, that may have developed because of wastewater discharge from the San Jose/Santa Clara Water Pollution Control Plant (WPCP) which encouraged the growth of a community of California bulrush, *Scirpus californicus* (C. Meyer) Steudel.[1] The *Scirpus* genus is commonly referred to as "bulrushes" or "tules" (Boursier 1996). The WPCP's freshwater flow is scheduled to be substantially reduced in the near future. Existing salinity conditions in the Slough are influenced significantly by this freshwater discharge; therefore, a change in discharge volume would affect salinity and, possibly, the distribution of vegetation that is important heron habitat (Arnold 1995). This research was designed to investigate the relationship between vegetation distribution and salinity under current conditions and predict how vegetation might change with different salinities. These data will also provide a basis for future monitoring when flow conditions change.

Regulatory Background

The California Environmental Quality Act (CEQA) protects rare and endangered species, including those that are not listed as endangered but that are threatened by loss of habitat. Under California law, a species that is not listed as rare, threatened, or

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1. Plant taxonomic names according to James C. Hickman, ed., The Jepson Manual: Higher Plants of California (Berkeley: University of California Press, 1993).

endangered by the state or federal government may still be considered rare if the species is subject to loss or conversion of habitat. Due to extensive loss of suitable wetlands nesting habitat, certain heron species could possibly be considered "rare" according to CEQA guidelines (Moore 1995). The California Department of Fish and Game is concerned with protection of the great egret, snowy egret, and black-crowned night heron because of their declining habitat and gives special consideration to breeding areas.

The Porter-Cologne Water Quality Control Act (State Water Code) is the primary state law regulating water quality and authorizing the state to implement the Federal Water Pollution Control Act (Clean Water Act). The Act authorizes the State Water Resources Control Board (SWRCB) to administer the National Pollutant Discharge Elimination System (NPDES) permit program and creates the nine Regional Water Quality Control Boards (RWQCBs) to administer and enforce water quality laws within their regions (Dwyer and Bergsund 1994).

The State Water Code establishes policy regarding the coastal marine environment. "Waste water discharges shall be treated to protect present and future beneficial uses, and where feasible, to restore past beneficial uses of the receiving waters. Highest priority shall be given to improving or eliminating discharges that adversely affect any of the following: (1) Wetlands, estuaries, and other biologically sensitive sites. . . (4) Ocean areas subject to massive waste discharge" (Dwyer and Bergsund 1994). "Beneficial uses" include preservation and enhancement of fish, wildlife, and other aquatic resources or preserves. Article 7 requires the use of reclaimed water in lieu of potable water for nonpotable uses, if suitable reclaimed water is available. The SWRCB has adopted a statewide water reclamation goal of 700,000 acre-feet by the year 2000 and one million acre-feet by 2010 (San Francisco Estuary Project 1996).

The SWRCB's Water Quality Control Policy for the Enclosed Bays and Estuaries of California in 1987 called for the elimination of wastewater discharges south of the Dumbarton Bridge in the South San Francisco Bay. This limitation on discharge was driven by two primary concerns: trace metals in wastewater discharge compromising the Bay ecosystem; and salt marsh conversion to brackish and freshwater marsh, caused by the large quantities of fresh (nonsaline) wastewater effluent.

Compliance with the 1987 policy would mean 100% recycling of the WPCP's effluent; however, exceptions to the policy are allowed when "the discharger can show (1) a net environmental benefit as a result of the discharge, (2) that the project is part of a reclamation project, or (3) that the discharge will provide equivalent protection" (California Regional Water Quality Control Board 1993). The RWQCB determined that the third exception criteria had been met and reissued the WPCP's NPDES permit with a recycling requirement lower than 100%.

The South Bay Water Recycling Project (Project) was designed to divert increasing quantities of treated wastewater out of Artesian Slough and into San Jose and the surrounding communities. Phase 1 of the Project, involving recycling up to 21 million gallons per day (mgd), is scheduled to begin in November 1997. Phase II of the Project, if implemented, would call for recycling of up to 45 to 50 mgd by December

2000 (Beerman 1996). Implementation of additional recycling will depend upon several factors, including evaluation of alternatives to wastewater diversion that might provide greater net environmental benefits. The effects of diversion on the ecosystem will be a key factor in management decision-making.

Historical Background

It is believed that prior to 1956, Artesian Slough was "a tidal channel meandering through salt marsh" (H. T. Harvey & Associates 1995). The marshes surrounding the Slough were being converted to salt ponds until the early 1960s. In 1956, the cities of San Jose and Santa Clara built a POTW (publicly owned treatment works) with a flow capacity of 36 mgd of treated wastewater with a salinity of less than 1 part per thousand (ppt). Artesian Slough was only sparsely vegetated into the 1970s, a narrow channel between diked salt ponds. The heron rookery was first reported in 1977. California bulrush was reported in the Slough about the same time. During the late 1970s, the mean annual wastewater flow ranged from 77 to 102 mgd. By 1980, alkali bulrush (*Scirpus robustus* Pursh) was identified downstream of the California bulrush and discharge from the WPCP had climbed to a mean annual flow of 106 mgd. California bulrush expanded its range and quantity into the 1980s. Peppergrass (*Lepidium latifolium* L.) was identified by 1987 in brackish areas formerly occupied by alkali bulrush. Quantities of California bulrush have remained fairly stable since 1987 (H. T. Harvey & Associates 1995).

Artesian Slough supports a regionally significant heron rookery in addition to providing habitat for ducks, hawks, harbor seals, and many species of shorebirds and fish. The most abundant birds nesting in the Slough are black-crowned night herons (*Nycticorax nycticorax*), snowy egrets (*Egretta thula*), and great egrets (*Casmerodius albus*). It is believed that the herons find this area ideal for nesting because of the dense, tall (6- to 12-foot) stands of California bulrush (Shanholter 1974; Moore 1995). In fact, "nests are being built in California bulrush exclusively" (H. T. Harvey & Associates 1995). Other birds observed in the Slough include American avocet (*Recurvirostra americana*), American coot (*Fulica americana*), Canada goose (*Branta canadensis*), cattle egret (*Bubulcus ibis*), common snipe (*Gallinago gallinago*), great blue heron (*Ardea herodias*), least sandpiper (*Calidris minutilla*), little blue heron (*Florida caerulea*), long-billed curlew (*Numenius americanus*), marsh wren (*Cistothorus palustris*), red-winged blackbird (*Agelaius phoeniceus*), and Virginia rail (*Rallus limicola*).

The wastewater discharge which began in the 1950s resulted in the conversion of salt marsh in some locations to the present brackish marsh ecosystem. Vegetation distribution is dependent upon environmental conditions such as moisture, nutrient availability, and salinity. The conditions in the Slough that support the California bulrush community may be dependent upon the discharge of treated wastewater (1 ppt salinity) from the WPCP (Moore 1995).

Coyote Creek, into which Artesian Slough flows, originally supported salt marsh at the point where the two meet. Mud Slough, which joins Coyote Creek to the west of Artesian Slough, similarly contained salt marsh vegetation. Coyote Creek and Mud Slough are presently brackish marsh ecosystems. The WPCP discharge has been considered by the SWRCB to be responsible for the conversion. Loss of salt marsh habitat is especially undesirable since it supports rare wildlife species such as the endangered California clapper rail (*Rallus longirostris obsoletus*) and the salt marsh harvest mouse (*Reithrodontomys raviventris*).

The SWRCB determined that the WPCP's freshwater effluent between 1970 and 1989 had led to the conversion of more than 250 acres of salt marsh to brackish marsh along tidal Coyote Creek and Mud Slough. In an effort to halt the salt marsh conversion that had occurred downstream of Artesian Slough, the SWRCB ordered the WPCP to limit its average dry weather effluent flow to 120 mgd. To comply with State Board Order No. WQ 90-5, the WPCP proposed an Action Plan consisting of: 1) a 380-acre salt marsh mitigation project, 2) a 12-mgd water conservation program, and 3) a 45- to 50-mgd nonpotable wastewater reclamation project (Moore 1995). The average WPCP discharge to the Slough over the past three years (1993-1995) was approximately 114 mgd average dry weather flow (ADWF) of tertiary treated wastewater (Arnold 1996).

The heron rookery is not located in an area that was identified as historic salt marsh (Moore 1995) and therefore is not subject to the need for restoration to salt marsh to comply with the SWRCB order and the spirit of the Endangered Species Act. The

WPCP and the RWQCB are interested in maintaining the brackish marsh habitat that supports the heron rookery.

The RWQCB reissued the WPCP's permit to discharge tertiary water to the Slough conditional upon implemention of the proposed Action Plan. This condition made the wastewater reuse project a legal requirement. Possible demand for reclaimed water could exceed the 45 to 50 mgd in the Action Plan. The maximum diversion being considered at present (45 to 50 mgd) would leave a summertime discharge of approximately 70 mgd into Artesian Slough, roughly 60% of the present discharge and comparable to flows in 1970 before establishment of the California bulrush community. Most of the wastewater diversion is expected to occur at night for landscape irrigation during the summer months, with the remainder providing year-round industrial use.

Problem Statement

The WPCP must balance the requirement to reduce its discharge with protection of an "existing beneficial use" of the waters of Artesian Slough, specifically the heron rookery. The RWQCB believes the WPCP can achieve a balance between the seemingly conflicting requirements of reusing wastewater and maintaining the California bulrush rookery habitat. Maintaining freshwater effluent flows adequate to sustaining the bulrush community will be a challenge in light of the large demand predicted for the WPCP's reclaimed water. To meet this challenge, the WPCP must obtain more data on the exact distribution of the various vegetation communities and the corresponding water and soil salinity conditions within the Slough.

RWQCB information indicates that California bulrush communities coincide with mean annual soil salinities of <20 ppt. At higher salinities, alkali bulrush communities predominate, and pickleweed (*Salicornia virginica* L.) communities take over at salinities >31 ppt (Moore 1995). Very little local information exists regarding the relationship between vegetation and salinity. The Slough itself has not been studied extensively to determine more precisely how these species correlate with salinities, both spatially and temporally. Once baseline data are established, the WPCP can monitor any changes that occur after wastewater discharge is reduced. With accurate local data, the WPCP can make more informed management decisions to protect the California bulrush community that supports the heron rookery.

Other vegetation species are found in Artesian Slough, among them pickleweed, California cordgrass (*Spartina foliosa* Trin.), and spearscale (*Atriplex triangularis* Willd.). These three species are typically found in salt marsh habitats. Peppergrass is an invasive non-native species, a member of the mustard family commonly found in saline flats (Munz 1964). It is a "recent invader of San Francisco Bay marshes" and little is known about its habitat requirements (H. T. Harvey & Associates 1995). The data from this study will contribute to the knowledge of the salinity tolerances of these species, in addition to bulrush species.

Salinity varies with tidal cycle and the seasons. It also varies with depth in the stratified water column. It will be necessary for the WPCP to understand salinity variations within Artesian Slough over time. For example, as reclaimed water is in high demand during the summer months, effluent will be greatly reduced through the Slough. How much will summer salinities increase in the Slough without this discharge? How much will salinities drop again when the rains begin? How will the California bulrush community respond to these changes? Further study will help clarify these issues, using salinity as the independent variable and vegetation distribution as the dependent variable. Much research has already established the dependence of vegetative communities on soil and/or water salinity (Bradley et al. 1990; Cain 1979; Clark 1974; Latham et al. 1991; Mall 1969; Poljakoff-Mayber and Gale 1975; Twilley and Barko 1990). The WPCP needs enough information to predict vegetation distribution based on salinity at this particular location.

When wastewater discharge into the South Bay first began in 1956, less information was available about Bay circulation patterns, impacts on salt and brackish marsh habitats and the species they support, and the importance of wetlands in general. As technical knowledge has increased, so has public awareness and appreciation of the value of wetlands. Similarly, as public awareness has grown, so has research.

One of the recommended actions in the San Francisco Estuary Comprehensive Conservation and Management Plan (1993) is to "better evaluate ecosystem responses to immediate, phased, and long-term water quality and flow standards" and "design and conduct new studies that increase the understanding of how physical, chemical, and biological processes are being affected by human activities and improve the scientific basis for managing the Estuary" (San Francisco Estuary Project 1993). The Plan recommends action for the benefit of wildlife to "preserve, create, restore, and manage large, contiguous expanses of tidal salt marsh and necessary adjacent uplands for the California clapper rail and the salt marsh harvest mouse." Other recommended actions encourage water reclamation projects.

The South Bay dilemma illustrates the complexities of human impacts on natural systems. Humans have altered natural ecosystems, reducing habitats for some species while creating habitats for others. Our challenge in managing habitats is to balance the needs of many species given the limited remaining habitat.

Objectives

This study focused on determining current conditions in Artesian Slough with regard to bulrush communities and soil and water salinities. The objectives of this study were: 1) to characterize the distribution patterns of the predominant vegetative species occupying the Slough within two meters of the channel edge, 2) to characterize the water and sediment pore water salinity patterns along the Slough, and 3) to investigate the relationships between spatial and temporal patterns of salinity and vegetation distribution in order to understand at what salinity levels alkali bulrush and salt marsh species begin replacing California bulrush. Refer to Research Questions for the specific hypotheses tested in this study.

Implications

This research is intended to provide the WPCP and RWQCB with data needed to make decisions regarding wastewater flow volumes that may be necessary to maintain the stability of the California bulrush community that supports the heron rookery. The results will provide the WPCP with a basis for monitoring salinity changes resulting from the impending wastewater diversion project and identifying potential problems with the bulrush community (Arnold 1995). In addition, this research will provide other agencies and municipalities with new information regarding bulrush species salinity requirements. It also provides evidence of the salinities at which salt marsh vegetation begins replacing freshwater species.

This information may also be useful for other wetland projects. By providing information on the salinity preferences of both saltwater and freshwater vegetation species, this work may aid planners of either salt marsh or freshwater marsh restoration or mitigation projects.

RELATED RESEARCH AND LITERATURE REVIEW

Relevant Literature

Most salinity research conducted on coastal marshes appears to have focused on salt marsh rather than brackish marsh ecosystems. Previous studies have established the dependence of vegetative communities on soil and/or water salinity; however, there are few studies published on the salinity preferences or tolerances of California bulrush, particularly with regard to soils in the root zone.

The niches inhabited by California bulrush, alkali bulrush, cordgrass, and pickleweed are summarized below per Atwater and Hedel (1976). California bulrush ranges in elevation from a variable upper limit to a lower limit of 0.3 meters below mean lower low water (MLLW) in freshwater and 0.3 m below mean tide level (MTL) in brackish water, suggesting a higher tolerance for submergence by freshwater. Alkali bulrush ranges between MTL and mean higher high water (MHHW) where salinities are low enough for it to reproduce but high enough to preclude competition from California bulrush. Cordgrass ranges from 0.0-0.3 m below MTL to 0.2-0.5 m below MHHW. It prefers freshwater, but due to its competitive inferiority is found in mean winter water salinities greater than 15 ppt and mean summer water salinities greater than 20 ppt. In lower salinities it is replaced by *Scirpus* spp. and other species. Pickleweed is found in the high marsh near MHHW and tolerates soil salinities greater than 35 ppt. Less information is available on peppergrass and spearscale habitat preferences; however, these species appear to occupy a wide range of elevations within the marsh (H. T. Harvey & Associates 1995).

Cattail (*Typha* spp.), a plant that inhabits fresh to brackish Bay Area marshes, may have similar requirements to California bulrush. One study (Beare and Zedler 1987) of cattail (*Typha domingensis* Pers.) revealed that salinity tolerance varies with life history stage and that 2 to 3 months of low salinity are required. High seed germination rates (80-100%) were only seen in 0 ppt salinity. Adult, rhizome-bearing plants had greatly decreased growth at 10 ppt and no growth at 25 ppt. Older, rhizomatous plants were less sensitive to salinity than seeds and seedlings. Zedler et al. (1990) found that low-salinity periods of 2 to 3 months between August and February were required for cattail invasion and establishment to sustain a population in soils with salinities greater than 40 ppt. They also found similar results in a study conducted in Western Australian salt marshes (Zedler et al. 1990).

Cain (1979), in his study of a South San Francisco Bay salt marsh, reiterated a long-held conclusion that "soil salinity--along with tidal inundation--has long been considered a major factor influencing growth and distribution of plants, and maintaining the distinct patterns of vegetational zonation within the marsh." Cain reported that the growing season of *Spartina foliosa* is from March to October, with flowering beginning in late June and continuing through October. Large quantities of viable seed are produced but "relatively few seedlings can be found in a mature marsh: for reasons not understood. Even this salt marsh inhabitant germinates most effectively in fresh water, typically in the winter and early spring when water and sediment salinities are reduced. Cain also reported that plant growth is inhibited as soil salinity increases.

Salinity alone, however, may not be responsible for any spatial vegetation distribution differences found along different salinity gradients within the Slough (Latham et al. 1991). Available nitrogen and dissolved oxygen are key factors in ecosystem productivity (Clark 1974). Other factors include elevation, hydroperiod, soil characteristics, and competitive interactions.

Burdick et al. (1989) suggested that a combination of factors including soil oxidation and sulfide and nitrogen levels were of greater importance to plant growth than any single factor. Their study was conducted at a brackish marsh that was dominated by *Spartina patens*, *S. alterniflora*, and *Distichlis spicata*, with some (less than 1% of dry weight) *Aster* and *Scirpus* species. Soil parameters measured were redox potential, percent moisture, salinity, pH, free sulfides, and ammonium on soil cores taken to 15 cm depths. It was found that from streamside up the bank, salinity increased with bank elevation.

The literature documents the importance of evaluating both water and sediment salinities when studying vegetation distribution. Moore (1995) stated that soil salinity in Artesian Slough had not been studied and that water salinity monitoring that had been conducted would not indicate the salinity of the soils that are in direct contact with the bulrush rhizomes. Pacific Estuarine Research Laboratory (1990) recommended that monitoring of both soil and water salinities be conducted at marsh restoration projects. Soil salinity is expected to be higher than water salinity (Ustin et al. 1982). It is also expected that salinities are higher during the dry summer months. Rollins (1973) established a correlation between soil salinity and water salinity at Suisun Marsh in North San Francisco Bay. He found that soil pore water salinity was 1.3 to 2.0 times that of water. In another Suisun Marsh study, average summer salinities were found to range from 18 to 29 ppt and average winter salinities 13 to 18 ppt (H. T. Harvey & Associates 1995). These conditions supported an alkali bulrush community.

Clark (1974) confirmed that salinity requirements change over the vegetation life cycle. Ungar (1991) discussed the effect of salinity on seed germination and growth of vascular halophytes. As with halophytes, it can be assumed that with freshwater and brackish marsh vascular macrophytes germination and growth rates are also highly variable and species specific.

In his seminal work A Guide to Waterfowl Habitat Management in Suisun Marsh, Rollins (1981) explored issues similar to those affecting Artesian Slough. He discussed the requirements of bulrush communities and the idea that salinity changes in managed wetlands cause vegetative changes that affect waterfowl habitat. He focused on the requirements of alkali bulrush and fat hen (*Atriplex patula* L., similar to spearscale), stating that the maximum tolerable water salinity for these species ranged from 5 to 7 ppt from February to May and 8 to 18 from June to January. He also reported that for maximum seed production and germination of alkali bulrush, the ratio of soil water salinity to water salinity should be 2:1. More extreme salinities over several years, such as during drought, would be expected to reduce bulrush productivity.

According to Mall (1969), length of soil submergence is an important variable influencing plant distribution, and "within the tolerances for submergence, the concentration of salts in the root zone determined the relative presence or absolute absence of a given plant species." In his study of Suisun Marsh, Mall (1969) found that spring soil salinity was the principle factor controlling alkali bulrush seed production. The bulrush occupied areas where mean annual salinity concentrations in the root zone ranged from 6.9 to 32.5 ppt. The most favorable level was 22 ppt; salinities below about 8 ppt resulted in competition favoring other species. He found that soil salinity was related to season, with higher salinities during the dry summer months.

At Shell Marsh, Peyton Slough, in Contra Costa County, California, an alkali bulrush community containing small amounts of California bulrush was found growing in soils with total soluble salts (as determined by saturated soil paste extraction) of approximately 7 to 15 ppt (Woodward-Clyde Consultants 1995).

Mall (1969) found that the mean annual soil salinity optimum for pickleweed ranged from 18.5 to 81 ppt. Its competitive ability increased in soils where mean annual soil salinity exceeded 31 ppt; below 31 ppt it became increasingly vulnerable to competition. Zedler (1983) found that pickleweed declined severely when flooding caused a decrease in soil salinity to less than 20 ppt. Mall (1969) found *Atriplex* in mean annual salinities ranging from 12.8 to 49.2 ppt, with below 19 ppt reducing its competitive ability. Cattails and tules (such as California bulrush) had the competitive advantage over alkali bulrush in mean annual salinities below 10 ppt.

Schemel (1971) found that water salinities near the point where Coyote Creek meets South San Francisco Bay ranged from 14.6 ppt in April to 27.4 ppt in October 1969. Fluctuation of salinity in relation to tides and seasons highlights the importance of a study methodology that includes monitoring over as long a period of time as possible.

Ustin et al. (1982) found that both water and soil salinities changed substantially over the seasons, being lowest in winter and spring and highest in summer. In their study at Sonoma Creek, near the north end of the San Francisco Bay Estuary, they found alkali bulrush to be dormant during the winter, with new shoots developing from tubers during March and April, and rapid growth occurring during May and June before the dramatic summer increases in salinity.

Bradley et al. (1990) conducted a study on a 1985 water diversion project at the Cooper River in South Carolina. In this study, a tidal prism mixing model was used to simulate salinity distribution changes caused by a 70% reduction in freshwater discharge through the river, from 442 to 130 m^3/sec. The researchers concluded that, over time, salinity intolerant species would be excluded, unless provided with periods of high freshwater discharge to provide "windows" for growth.

Stratification often occurs where fresh waters and saline ocean waters meet. In stratified water bodies, deeper waters are saltier than surface waters (Clark 1974; Daiber 1974). The relationship between salinity and vertical mixing in an estuary becomes important when water quality managers are considering altering water discharges (Kuo and Neilson 1987). Freshwater discharge will affect stratification during different seasons and tides (Simpson et al. 1990). Salinity stratification can play a role in vegetation distribution (Schroeder et al. 1990).

Theoretical Setting

Competition for resources, such as space, water, and nutrients, is generally thought to be most intense between similar species. According to Greuter (1972), the strongest competitors are other plants of the same species. "Since competition involves two organisms utilizing the same resource, it is obvious that competing organisms must have, to some extent, overlapping niches. Current evolutionary theory holds that selection pressure drives species within a community to partition the environment (utilize different parts of the environment) with the result that competition is minimized" (Barbour et al. 1980). Theory also suggests that another means by which species reduce the intensity of competition is by establishing "competitive superiority." Superiority can be manifested by: height, size, and rate of growth of photosynthetic organs to capture available light; size of the root system to uptake nutrients and fill available space; ability to lower soil water potential or ionic concentrations at the root surface; and rate of transpiration (Fittner and Hay 1987).

Alkali and California bulrush provide an excellent example of competitive superiority. Alkali bulrush tolerates more extreme conditions than California bulrush, although it grows better in freshwater in the absence of competition from California bulrush (H. T. Harvey & Associates 1995). Zedler (1983) states this concept as species living "in stressful environments not out of preference but because of their tolerance to severe conditions." This theory is well supported by field studies. For example, Barbour (1980) reports a study of wheatgrass and cheatgrass species with similar life cycles. Results indicated that cheatgrass had the competitive advantage because its faster root growth during the winter enabled it to obtain deeper water during dry months. A study by Marshall and Jain on interspecific competition between two related species of oats found that one produced more seeds per plant when grown in competition and concluded that it would eventually exclude the other (Ricklefs 1979).

California bulrush demonstrates competitive superiority in freshwater habitats by the greater height of its photosynthetic organs to capture available light and the depth of its root system to uptake nutrients and compete for available space in the sediment strata.

In annuals, seed production is often a more important factor in competition than their individual growth capacity. Some natives, such as cordgrass, have low seed germination rates and poor seedling survival; therefore, "most expansion is vegetative, and initial establishment plays a significant role in determining the distribution of later dominants" (Zedler 1983).

Salinity levels are the most important during seed germination periods. Ungar (1991) reported a study in which *S. robustus* was at its optimum germination (90%) in freshwater, with greatly reduced germination (40%) in 0.5% NaCl, and 5% germination in 1.0% total salts. Even in halophytes, germination often takes place when salinity levels are reduced (Ungar 1991). "Few angiosperms are obligate halophytes; most are only salt-tolerant and become abundant in salinity too high for competitors, but grow better without salt if freed from competition" (Gillham 1957). Species in the genus *Salicornia* are some of the few obligate halophytes that reach optimum growth at salinities greater than 0.5% NaCl (Chapman 1975).

Rollins (1981) found that *S. californicus* outcompeted *S. robustus* in Suisun Marsh when mean annual salinity levels were below 10 ppt and that 18 ppt provided an advantage for *S. robustus* (although 18 ppt was its estimated maximum tolerable limit). He established that the maximum tolerable long-term water salinity for *S. robustus* ranged from 5 ppt in February and March (months of germination) to 18 ppt in August and September.

The findings of Bradley et al. (1990) support the expectation that salinity increases caused by a large-scale freshwater diversion would result in more salt-tolerant species being more competitive. This study found that it is not mean annual salinities that are the primary governing factor, but salinities during peak germination or growth periods, that play the most important role in vegetation distribution. Emery and Stephenson (1957) state that "the ecologically significant aspect of salinity is not the mean condition but its range on a daily and seasonal basis, and its rate of change through the tidal cycle."

The literature shows that salinity is a very important variable in vegetation distribution, that individual species are unique in their tolerances, and that tolerance varies with life stage. Salinity varies with tidal cycles and seasons as well as with depth of the water column. The effect of salinity on plant growth also varies with the seasons. Weather conditions such as heat, wind, and humidity affect plant responses to saline conditions. Greater salt damage has been noted during warm summer months than cooler winter months (Gale 1975). This factor could have implications for the planned wastewater diversion in San Jose, which is intended to be at its peak during the summer.

Current vegetation distribution patterns cannot be explained by current salinity patterns; vegetation at a particular location also reflects historical environmental factors (Zedler 1995). While tidal cycles and seasons in the future can be reasonably expected to remain similar to conditions during the past few years, salinity and water depth in the Slough channel may change once diversion begins. Since little literature appears to exist on present South Bay slough salinities and the requirements of California bulrush, this study fills a gap in knowledge that is critical to sound environmental management.

Research Questions

This study focused on determining the relationship between salinity and vegetation in Artesian Slough. The following null hypotheses were tested:

1. Mean water and sediment pore water salinities in the Slough are not significantly different from each other. Further, they are not correlated with each other.

2. The percent cover of California bulrush, alkali bulrush, peppergrass, and other species found in the Slough is not correlated with mean water or sediment pore water salinities.

3. Mean water salinities are not significantly different between low tide and high tide.

4. Mean water salinities are not significantly different from the surface of the Slough channel to the bottom.

5. Mean water and sediment pore water salinities in the Slough do not change significantly over a six-month period.

METHODOLOGY

Site Description

Artesian Slough, also known as Mallard Slough, is located on the southeastern edge of South San Francisco Bay next to the town of Alviso, California, at latitude 37° 27' N and longitude 121° 57' W (Figure 1). From its beginning at Los Esteros Road to its end at Coyote Creek, it measures 2.15 miles (3.46 kilometers). The Slough has a triangular side channel, or "oxbow," that runs westward into the heart of the heron rookery (circled on Figure 1). On the east and west borders of the Slough are salt evaporation ponds.

The area has a mediterranean climate with warm, dry summers and cool, rainy winters. The average annual rainfall is 14 inches, primarily occurring between October and April. Rainfall during 1995 and 1996 was higher than average according to Santa Clara Valley Water District records.

Upper Artesian Slough, nearest the WPCP discharge point, is freshwater marsh habitat consisting at water's edge primarily of California bulrush and cattail (*Typha latifolia* L.). The Slough becomes increasingly brackish as it approaches Coyote Creek as tidal influx from South San Francisco Bay waters increases salinities. The WPCP finds that South Bay waters range from 12 to 25 ppt as measured approximately one mile north of the Dumbarton Bridge.

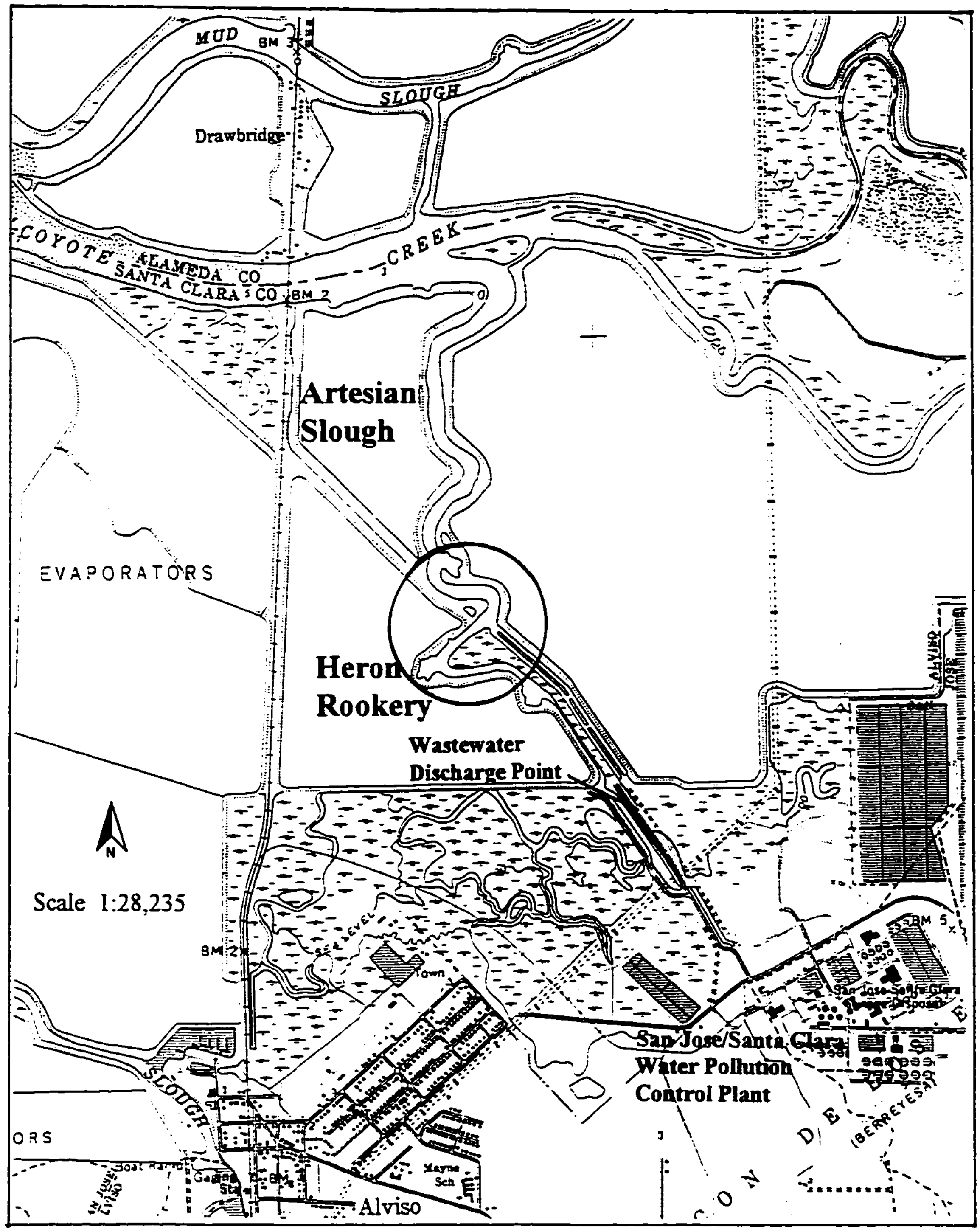

Figure 1. Artesian Slough Study Area

From United States Department of the Interior Geological Survey.
Milpitas Quadrangle California Topographic Map, 1980.

Introduction and Sample Point Selection

This study involved collecting data during the winter and spring, when salinities play an important role in determining the germination and reproductive success of California bulrush. The study began with a review of existing information related to Artesian Slough, including research, maps, and aerial photographs. From a map provided by the WPCP, a field map was generated. On this map, the Slough was divided into four areas along its 3.46-km length: zones A, B, C, and D. Thirty-two sample points were selected randomly, eight in each zone, along the center of the slough channel (Figure 2). Zone B included the triangular side channel in which much of the rookery was located. Points that included the heron rookery area were included to determine the environmental conditions associated with the California bulrush habitat upon which the rookery depends. The sample points were located and marked on a field map using an Alvin plan measure at a scale of 1,000 ft = 4.5 cm.

From each of the mapped 32 points, an imaginary perpendicular line was drawn to the channel edge and a 1 x 1 x 8-ft redwood stake was planted in the sediment at the border of the vegetative growth to mark the sample point. The stakes were numbered with paint and whenever possible placed such that they barely protruded above the vegetative canopy (tall stakes attract raptors that prey on water-associated birds) (Pacific Estuarine Research Laboratory 1990). Odd-numbered points were staked on the right-hand side of the channel and even-numbered points on the left to avoid bias that might be created by sampling only one side of the channel. At each of these points, a 2 x 1-m

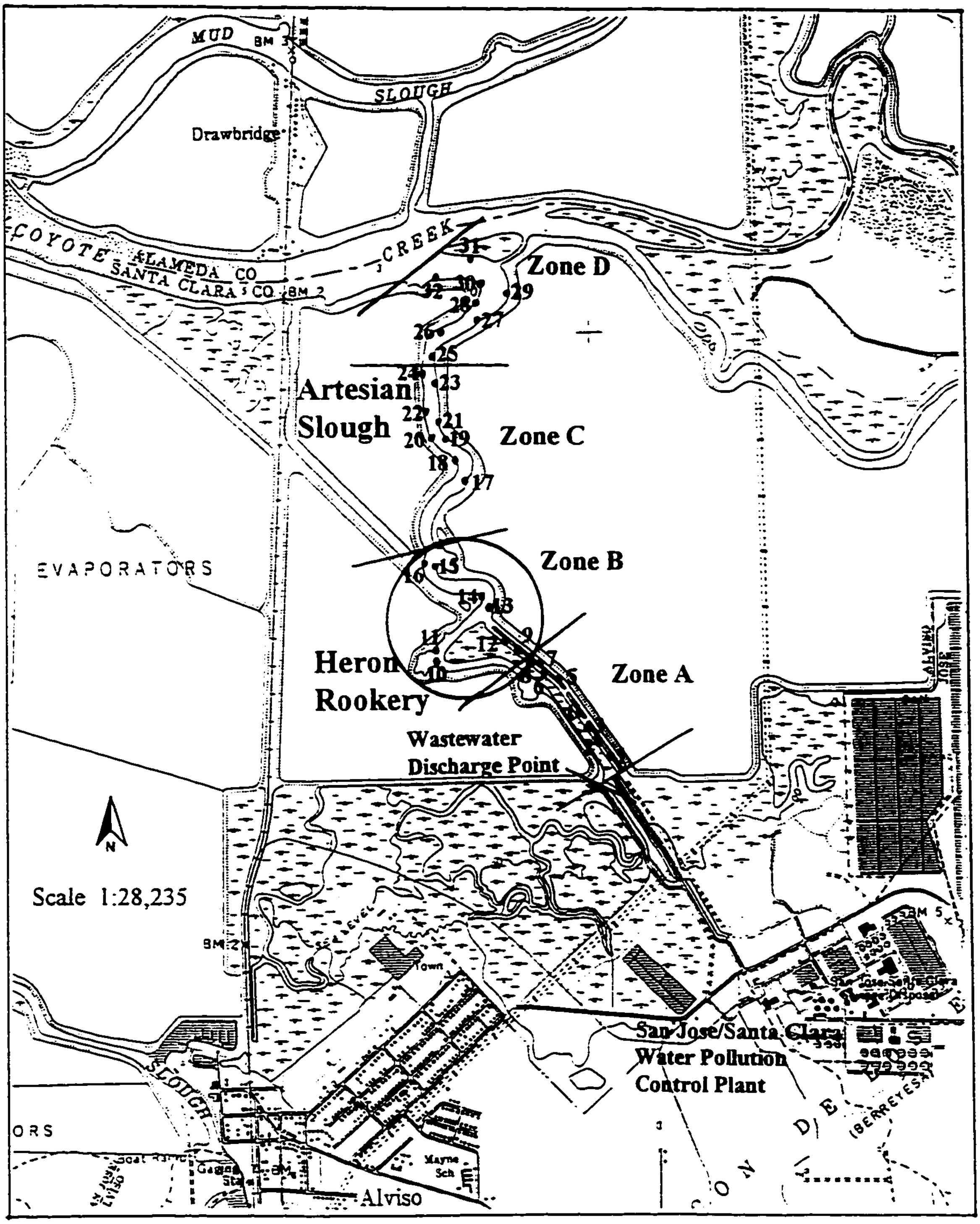

Figure 2. Artesian Slough Study Zones and Sampling Point Locations

From United States Department of the Interior Geological Survey.
Milpitas Quadrangle California Topographic Map, 1980.

quadrat was used to estimate percent cover of each species in each quadrat. One sediment sample was collected from the right front corner of each quadrat. Water parameters were measured in the channel across from each sample point.

Sample Collection

A special use permit was obtained from the U.S. Fish and Wildlife Service for access to the study area. Authorization was obtained from the City of San Jose for working on its premises.

Data were collected from December 1995 through May 1996 and logged on field data sheets. Data from March, April, and May included zones C and D only, since access to zones A and B was restricted during the breeding season at the rookery. Sampling dates were December 4, 7, 19, and 21, 1995; and January 17, February 16 and 20, March 15, April 15 and 26, and May 17 and 24, 1996.

Water salinity, temperature, pH, and depth readings were taken at random channel center points across from random sediment sampling points at least twice monthly, once at high (MHHW) tide and once at low (MLLW) tide. Tide levels were determined using the 1995 and 1996 issues of Tidelog (Born 1994, 1995) for Northern California. Water salinity and temperature were measured at the surface and at 1-m depths until the channel bottom was reached. Depending upon the tide level and the sample point location, the depths ranged from 1 to 5 m. Water salinity and temperature were measured in situ with a YSI 30 salinity conductivity temperature meter that automatically converted conductivity to parts per thousand salinity.

Water salinity readings, collected during eight sampling events on seven sampling days from December 1995 through February 1996, were measured during four low tides and four high tides. During the four high tide collection times, all 32 points were sampled. During the four low tide times, points 10 and 11 could not be reached either by boat or on foot because these points required entering a tributary of the main slough that required crossing a shallow ridge that was exposed at low tide. This tributary runs west into the heart of the rookery. On two of those four occasions, substitute (surface only) salinity readings were taken at the entrance to this tributary where trickles of water were running from the rookery over the ridge and into the main slough channel.

At each of the 32 sampling points, surface salinity was recorded. Salinity readings were recorded at regular depth intervals until the channel bottom was reached by the probe. The lowest possible depth readings obtained varied from 1 to 5 m, depending upon the tide level at the time of the readings. For the reasons described previously, on two of the low-tide sampling days, surface readings were recorded for points 10 and 11 and on two of the sampling days, no readings were recorded for these points.

Once per month, vegetation type was determined, and percent vegetative cover was estimated in a 2-m quadrat at each of the 32 random points. Six primary vegetation species were found along the slough banks to within 2 m of the water: California bulrush, alkali bulrush, peppergrass, spearscale, pickleweed, and cordgrass. Percent cover was chosen as the method for determining vegetation distribution because invasive methods such as collecting samples and determining density by mass would have been too disruptive to the bird colony. Six cover classes (Table 1) were used as per Pacific Estuarine Research Laboratory (1990).

Table 1.--Vegetation Cover Classes

Cover Class (%)	Midpoint of Cover Class (%)
>0-1	0.5
1-5	3.0
6-25	18.5
26-50	38.5
51-75	63.5
76-100	88.5

Sediment was collected once per month within each quadrat using a 1-in-diameter butyrate soil recovery probe sample liner. California bulrush rhizomes were found to reach depths of 15 to 30 cm. The samples were collected in the root zone to a depth of 10 to 30 cm, sealed in 1-gallon plastic ziplock bags, and placed in an ice chest. The liner was cleaned between each sample, rinsed with deionized water, and shaken dry. The sediment was transported to the WPCP laboratory for salinity analysis. All of the sediment samples were moist and consisted of very fine clay particles.

Tide level affected accessibility to the selected quadrats for purposes of sediment sampling. Some quadrats could be reached only at MHHW and some only at MLLW, while the optimum time for collecting at others ranged between MHHW and MLLW.

On a few occasions at a few sample points, it was not physically possible to reach a quadrat for sediment collection because the tide was too low. On those occasions, the sediment core was taken as close as possible to the quadrat, generally within 1 m of the sample point stake.

Each sample was homogenized by hand prior to sediment pore (interstitial) water extraction and salinity analysis. Water was extracted from the sediment by two methods. In December, moisture was extracted by expressing the clay through a 20-cc syringe with three layers of #1 Whatman filter paper. This method was derived from Pacific Estuarine Research Laboratory (1990). Each syringe was filled with clay to 10 cc and the plunger depressed to obtain one to three drops of water. The extracted drop(s) were pipetted onto a Reichert salinity refractometer. Fresh filters were used for each sample and the syringe was cleaned thoroughly, rinsed with deionized water, and dried between each test. This method proved to be labor intensive and yielded very little moisture. For all subsequent tests (January through May), each homogenized clay sample was placed in a capped tube and run through an IEC Centra MP4R centrifuge for 10 minutes at 3,000 rpm and 25°C. A new tube and pipette were used for each sample. This method was derived from Ankley and Schubauer-Berigan (1994). Occasionally, samples required more than one spin to yield enough supernatant to pipette and place on the refractometer. The refractometer is generally considered to be accurate to within 0.5 ppt salinity (Arnold 1996).

Data Analysis

Based on the four sampling events in December 1995, two sampling events in January 1996, and two sampling events in February 1996, a monthly mean water salinity was calculated for each of the 32 sampling points. Sediment was sampled only once per month at each point, therefore no monthly mean was calculated. Mean salinity by zone, was determined by averaging the mean salinities for the eight sampling points within each zone.

Data from March through May 1996 were treated similarly, but with fewer samping events and sampling points. Based upon six sampling events, two each month, the mean monthly water salinity was calculated for each of sixteen sampling points.

Water and sediment salinity data were charted on histograms and found to have skewed distributions; therefore, the raw data were transformed using a logarithmic transformation to normalize the data prior to running parametric statistical tests.

Several null hypotheses were tested. Student's t-tests were used to determine the significance of the relationship between mean water and sediment salinities, mean water salinity and tide level, mean water salinity and depth, and mean water/sediment salinities and time. F-tests were used to determine whether the populations had equal variances prior to using the t-tests.

Pearson product-moment correlation coefficients were calculated to determine the correlation between vegetation cover and water and sediment salinities. This calculation was performed by study zone rather than by individual sampling point. The percent cover found at each of the eight points in each zone was averaged to obtain a percent cover for the entire zone.

RESULTS

Sampling Results

Both mean water salinities and sediment pore water salinities increased from the beginning of the slough to its confluence with Coyote Creek (Figure 3). Tables and graphs of salinities by individual sampling points are provided in Appendix A. Figures 4 and 5 depict the average water and sediment pore water salinities by zone for the entire study period.

Mean water salinity of the water column varied from 1.51 to 10.2 ppt in December, 1.75 to 3.69 in January, and 0.73 to 2.0 in February. Sediment pore water salinity ranged from 2.0 to 16.5 ppt in December, 1.0 to 14.0 in January, and 1.0 to 13.0 in February. Mean water salinity of the water column varied from 0.75 to 1.14 ppt in March, 0.70 to 1.81 in April, and 1.11 to 1.84 in May. Sediment pore water salinity ranged from 0 to 6.0 ppt in March, 0 to 11.5 in April, and 1.0 to 10.5 in May.

Comparison of Water and Sediment Pore Water Salinities

The first null hypothesis stated that (1) mean water and sediment pore water salinities in the Slough are not significantly different from each other and (2) mean water and sediment pore water salinities are not correlated with each other.

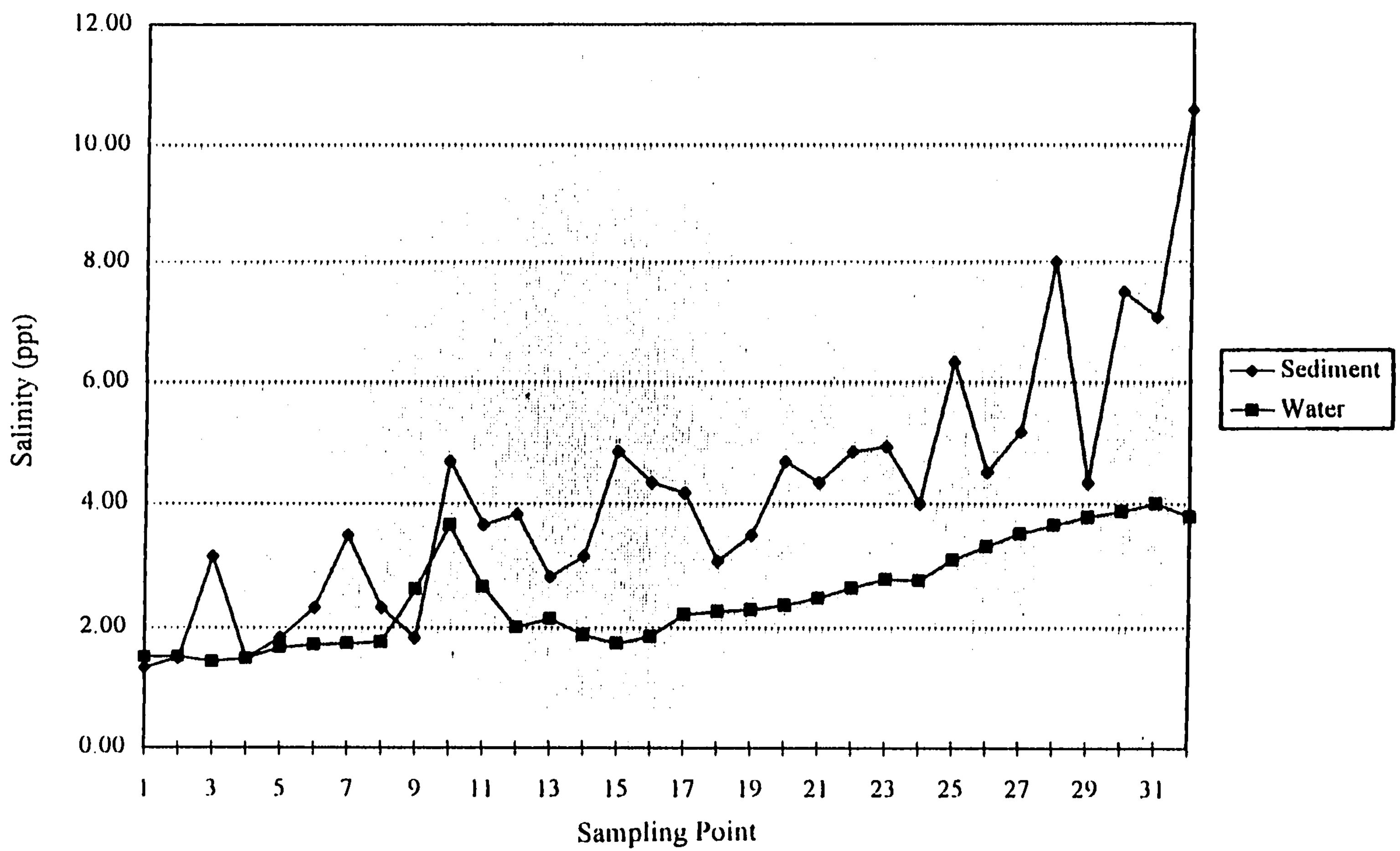

Figure 3. Mean Water and Sediment Pore Water Salinities by Sampling Point, December-May (6-month average)

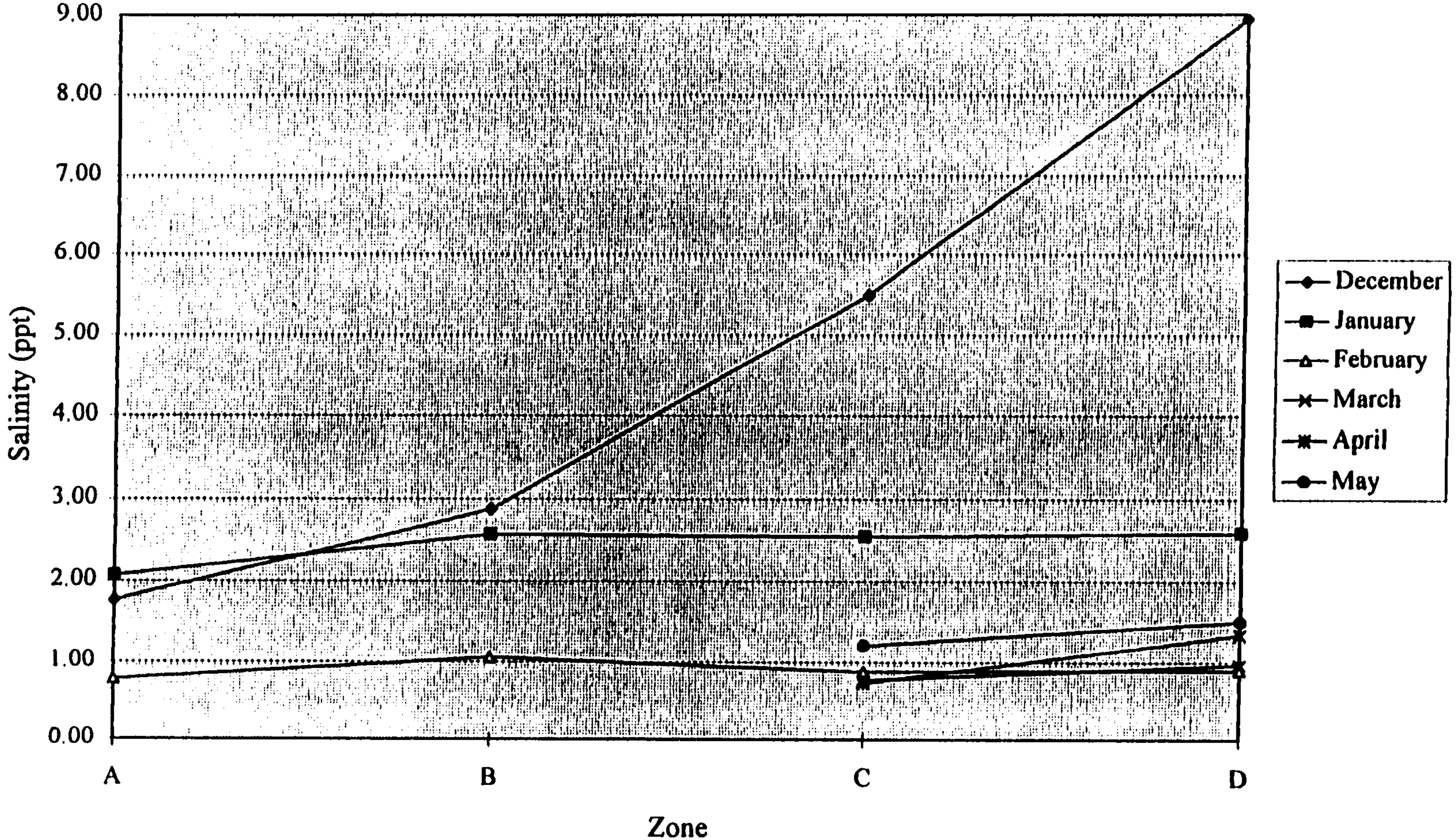

Figure 4. Mean Water Salinity by Zone, December-May (6-month average)

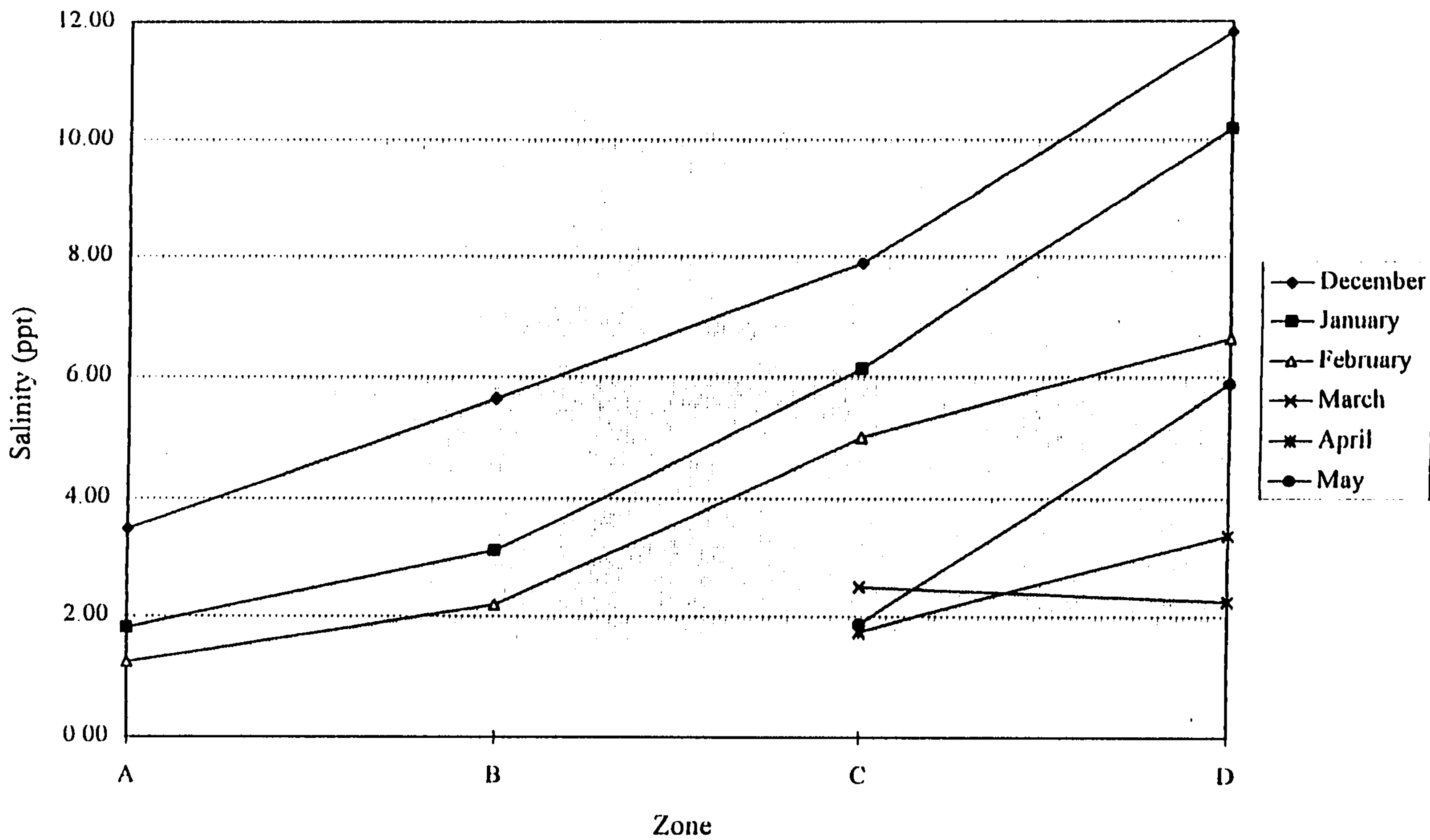

Figure 5. Sediment Pore Water Salinity by Zone, December-May (6-month average)

The mean water salinities for each month were compared to the sediment pore water salinities for the same month. A t-test assuming unequal variances was run on the December, January, and February data (Table 2). The results for each month were significant at $\alpha = 0.05$, showing a statistically significant difference between mean water and sediment pore water salinities.

Table 2.--Results of t-test on Water and Sediment Pore Water Salinities, December through February

Result	December 1995 water/sediment ($n = 32$)	January 1996 water/sediment ($n = 32$)	February 1996 water/sediment ($n = 32$)
mean ($\bar{x}$)	4.93/7.20 ppt	2.45/5.31ppt	0.91/3.77 ppt
sd (standard deviation)	2.87/3.74 ppt	0.39/3.59 ppt	0.22/3.06 ppt
df (degrees of freedom)	58	35	37
P (probability) (derived from log transformed data)	1.22E-04	9.3E-08	3.85E-17

Mean monthly water salinities for March, April, and May were compared to the sediment pore water salinities for the same month. A t-test assuming unequal variances was run on the March, April, and May data (Table 3). The results were significant ($\alpha = 0.05$) and the first half of the null hypothesis was rejected for all three months. Again, there was a statistically significant difference between mean water and sediment pore water salinities.

Table 3.--Results of t-test on Water and Sediment Pore Water Salinities, March through May

Result	March 1996 water/sediment (n = 16)	April 1996 water/sediment (n = 16)	May 1996 water/sediment (n = 16)
mean ($\bar{x}$)	0.87/2.38 ppt	1.04/2.57 ppt	1.36/3.88 ppt
sd (standard deviation)	0.13/1.84 ppt	0.43/2.79 ppt	0.20/2.72 ppt
df (degrees of freedom)	16	24	16
P (probability) (derived from log transformed data)	3.78E-06	5.7E-06	3.37E-04

Results correlating water and sediment pore water salinities (the second half of the null hypothesis) are shown on Table 4. December was the only month in which a strong correlation between water and sediment pore water salinities was found; therefore this was the only month for which the null hypothesis was rejected. It is interesting to note that the correlation between the two parameters became weaker during the rainy season in January and became stronger as the rainy season passed.

Table 4.--Correlation Between Water and Sediment Pore Water Salinities Based On Individual Sampling Points (r) (calculation performed with log transformed data)

December points 1-32	January points 1-32	February points 1-32	March points 17-32	April points 17-32	May points 17-32
0.88	0.52	0.12	0.11	0.34	0.35

Sediment Stratification. As an element of secondary interest to the research hypotheses, 17 sediment samples collected in May and 11 samples collected in April were analyzed in order to determine whether sediment in the root zone exhibited salinity stratification. The sediment cores ranged in length from 5 to 13 in. with an average of 8 in.

The salinities of pore water from the top of the core (closest to the water-sediment interface) were compared to the salinities from the bottom of the core. The top salinities ranged from 0 to 7.5 ppt. The bottom salinities ranged from 0.5 to 15.5 ppt. A t-test assuming unequal variances was performed on the top and bottom salinities (Table 5). The results were significant at $\alpha = 0.05$; therefore, it was concluded that there is a statistically significant difference between the top and bottom core salinities, with higher salinities being found at greater depth.

Table 5.--Results of t-test Comparing Sediment Core Top and Bottom Salinities

Result	Top ($n = 28$)	Bottom ($n = 28$)
Mean ($\bar{x}$)	2.2 ppt	4.3 ppt
sd (standard deviation)	2.1 ppt	3.7 ppt
df (degrees of freedom)	54	
P (probability) (derived from log transformed data)	1.002E-03	

Comparison of Salinity and Vegetation Cover

The second null hypothesis tested was that the percent cover of each species studied, California bulrush, alkali bulrush, peppergrass, pickleweed, cordgrass, and spearscale, was not correlated with mean water or sediment pore water salinities.

Pearson product-moment correlation coefficients were used to determine the strength of the relationship between percent cover of each plant species and the mean water and sediment pore water salinity readings. The data used for the correlation calculation are shown in Appendix B. The results for December, January, and February in all four zones are shown in Table 6. The results for December through May in zones C and D are shown in Table 7.

Correlations were stronger for the December through February period encompassing all four zones than they were during the March through May period on zones C and D only. California bulrush showed a very strong negative correlation with alkali bulrush (-0.90), peppergrass (-0.95), and cordgrass (-0.95), a strong negative correlation with sediment pore water salinity (-0.84) and pickleweed (-0.78), and a mild negative correlation with water salinity (-0.41).

Alkali bulrush showed very strong positive correlations with sediment pore water salinity (0.91), peppergrass (0.80), and cordgrass (0.86), and a strong positive correlation with water salinity (0.67). Peppergrass showed a strong positive correlation with cordgrass (0.86) and pickleweed (0.81). Pickleweed and cordgrass showed a strong

Table 6.--Results of Correlation Calculation on Vegetation and Salinity, Zones A through D, December through February

	Water ppt	Sediment pore water ppt	California bulrush %	Alkali bulrush %	Pepper-grass %	Pickle-weed %	Cord-grass %	Spear-scale %
Water ppt	1							
Sediment pore water ppt	0.72	1						
California bulrush %	-0.41	-0.84	1					
Alkali bulrush %	0.67	0.91	-0.90	1				
Peppergrass %	0.24	0.75	-0.95	0.80	1			
Pickleweed %	-0.13	0.47	-0.78	0.51	0.81	1		
Cordgrass %	0.36	0.75	-0.95	0.86	0.86	0.83	1	
Spearscale %	0.08	0.01	0.19	-0.23	-0.31	-0.18	-0.18	1

Table 7.--Results of Correlation Calculation on Vegetation and Salinity, Zones C and D, December through May

	Water ppt	Sediment pore water ppt	California bulrush %	Alkali bulrush %	Pepper-grass %	Pickle-weed %	Cord-grass %	Spear-scale %
Water ppt	1							
Sediment pore water ppt	0.78	1						
California bulrush %	-0.15	-0.38	1					
Alkali bulrush %	0.47	0.55	-0.81	1				
Peppergrass %	-0.05	0.29	-0.93	0.55	1			
Pickleweed %	-0.19	0.25	-0.75	0.35	0.85	1		
Cordgrass %	0.16	0.40	-1.00	0.80	0.93	0.78	1	
Spearscale %	0.17	0.23	-0.44	0.60	0.30	-0.02	0.39	1

positive correlation (0.83). Spearscale did not show a strong correlation with water salinity, sediment pore water salinity, or other vegetation species.

Appendix C provides charts comparing vegetation cover with water and sediment pore water salinities by zone for the December through February period. California bulrush was the predominant species in zones A and B (average 76.0 to 88.5% cover) where mean water salinities ranged from 0.79 to 3.52 ppt and sediment pore water salinities ranged from 1.25 to 5.63 ppt from December through February. The heron rookery is located in these zones. Points 10 and 11 in zone B were deep within the rookery near the apex of the triangular side channel (oxbow) where only California bulrush was observed. Salinities were consistently higher at these two points than in the rest of zone B on most sampling days (note the salinity spike in Figure 3), with surface water ranging from 0.79 to 5.36 ppt and sediment pore water ranging from 2 to 10 ppt.

In zone C, California bulrush was still the predominant species (average 66.38% cover); however, alkali bulrush and peppergrass began to replace it. Mean salinities ranged from 0.73 to 5.49 ppt for water and 1.75 to 7.88 ppt for sediment pore water from December through May (Appendix A). In zone D, the percent cover of California bulrush was substantially reduced (15.88 to 22.50% cover) and the predominant species were alkali bulrush and peppergrass. Salinities ranged from 0.90 to 8.95 ppt for water and 2.25 to 11.81 ppt for sediment pore water (Appendix A). Zone C was concluded to be the transition zone where freshwater vegetation began to be replaced by brackish vegetation species.

Comparison of Salinity and Tide Levels

The third null hypothesis tested was that mean water salinities are not significantly different between low tide and high tide.

The mean water salinities in the Slough were skewed; therefore, the raw data were transformed using a logarithmic transformation to normalize the data. The data prior to transformation is shown in Appendix D.

Salinity readings at all sites for four low tides from December 1995 through February 1996 were compared to the readings at four high tides for the same period. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between high and low tide salinities; therefore, the null hypothesis was rejected (Table 8).

Table 8.--Results of t-test Comparing High and Low Tide Water Salinities

Result	December, January, February (high/low) (*n* = 124)	March, April, May (high/low) (*n* = 48)
mean ($\bar{x}$)	5.48/0.90 ppt	1.40/0.75 ppt
sd (standard deviation)	5.23/0.42 ppt	0.70/0.12 ppt
df (degrees of freedom)	144	56
P (probability) (derived from log transformed data)	1.03E-30	3.63E-08

Salinity readings for three low tides from March through May 1996 were compared to the readings for three high tides for the same period. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between high and low tide salinities and the null hypothesis was rejected (Table 8).

Evaluation of Stratification

Depth at which the slough bottom was reached with the salinity meter probe varied with tide level from 1 to 5 m. It appeared that, in general, salinities of surface water were lower than the salinities at depth. The null hypothesis tested was that mean water salinities at the surface of the Slough channel were not significantly different from those at the bottom.

Appendix E shows the surface and bottom salinity readings. The log transformed surface salinity readings from December 1995 through February 1996 were compared to the bottom readings for the same period. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between surface and bottom salinities and the null hypothesis was rejected (Table 9).

The log transformed surface salinity readings for points 17 through 32 from March through May 1996 were compared to the bottom readings for the same period. A t-test assuming unequal variances did not show a significant difference ($\alpha = 0.05$) between surface and bottom salinities; therefore, the null hypothesis was supported for these three months (Table 9).

Table 9.--Results of t-test Comparing Surface and Bottom Water Salinities

Result	December, January, February (surface/bottom) ($n = 247$)	March, April, May (surface/bottom) ($n = 96$)
mean ($\bar{x}$)	2.54/4.07 ppt	0.98/1.27 ppt
sd (standard deviation)	3.82/5.41 ppt	0.49/1.11 ppt
df (degrees of freedom)	470	149
P (probability) (derived from log transformed data)	5.19E-04	2.23699E-01

These results partially support the idea that stratification exists in the Slough. Fresh water is believed to occupy the surface layer of the channel. The less dense fresh water floats on top of the heavier, more saline, water (Arnold 1995; Josselyn 1983). This was found to be true during three of the six study months.

Evaluation of Temporal Salinity Patterns

To determine if mean salinities change over time, the null hypothesis was tested that water and sediment pore water salinities in the Slough do not change significantly over a six-month period.

Water Salinity. The mean December water salinity readings for points 1 through 32 (zones A through D) were compared to the mean February water salinity readings for the same points. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between December and February salinities; therefore, the null hypothesis was rejected (Table 10).

The mean December water salinity readings for points 17 through 32 (zones C and D) were compared to the mean May water salinity readings for the same points. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between December and May salinities and the null hypothesis was rejected (Table 10).

Table 10.--Results of t-test on Temporal Water Salinities

Result	December/February ($n = 32$)	December/May ($n = 16$)
mean ($\bar{x}$)	4.93/0.90 ppt	7.22/1.36 ppt
sd (standard deviation)	2.87/0.22 ppt	2.00/0.20 ppt
df (degrees of freedom)	36	22
P (probability) (derived from log transformed data)	4.6678E-15	8.45468E-16

Sediment Pore Water Salinity. The mean December sediment pore water salinity readings for points 1 through 32 (zones A through D) were compared to the mean February readings for the same points. A t-test assuming unequal variances showed a significant difference ($\alpha = 0.05$) between December and February salinities and the null hypothesis was rejected (Table 11).

The mean December sediment pore water salinity readings for points 17 through 32 (zones C and D) were compared to the May readings for the same points. A t-test showed a significant difference ($\alpha = 0.05$) between December and May salinities and the null hypothesis was rejected (Table 11).

Table 11.--Results of t-test on Temporal Sediment Pore Water Salinities

Result	December/February ($n = 32$)	December/May ($n = 16$)
mean ($\bar{x}$)	7.20/3.77 ppt	9.84/3.88 ppt
sd (standard deviation)	3.74/3.06 ppt	3.00/2.72 ppt
df (degrees of freedom)	61	20
P (probability) (derived from log transformed data)	2.42E-05	4.27E-07

It was found that salinities were the highest in December, decreased in subsequent months and began to elevate again in May. Rainfall and changes in WPCP discharge could have influenced salinity during the study period (Table 12). Table 13 gives the results of a Pearson product-moment correlation coefficient calculation for these factors. Both water and sediment pore water salinity showed a strong negative correlation with cumulative rainfall and with wastewater discharge.

Table 12.--Rainfall, Wastewater Discharge, and Salinities by Month

Month	Rainfall[1] (inches)	Cumulative Rainfall During Study Period (inches)	Average Discharge[2] (mgd)	Mean Water Salinity (ppt) of Entire Slough	Mean Sediment Pore Water Salinity (ppt) of Entire Slough
December	3.94	3.94	128	4.77	7.20
January	2.95	6.89	130	2.45	5.31
February	2.87	9.76	145	0.90	3.77
March	1.30	11.06	142	0.97	2.38
April	0.47	11.53	134	1.04	2.84
May	0.91	12.44	133	1.36	3.88

[1] Source: Santa Clara Valley Water District. Guadalupe Slough weather station.
[2] Source: San Jose/Santa Clara Water Pollution Control Plant.

Table 13.--Results of Correlation Calculation for Rainfall, Wastewater Discharge, and Salinities

	Cumulative Rainfall	Discharge	Water Salinity	Sediment Pore Water Salinity
Cumulative Rainfall	1			
Discharge	0.53	1		
Water Salinity	-0.91	-0.73	1	
Sediment Pore Water Salinity	-0.91	-0.70	0.95	1

Summary

These results showed that water and sediment pore water salinities were significantly different, but that in December they were strongly correlated. Only alkali bulrush was found to correlate strongly with water salinity. Other species correlated more strongly with sediment pore water salinity than with water salinity. Water salinities differed significantly between low and high tide. Stratification was evident from December through February, but not from March through May. Both water and sediment pore water salinities changed significantly over a six-month period. Water and sediment pore water salinities were negatively correlated with cumulative rainfall and wastewater flows.

DISCUSSION

How does one balance the habitat requirements of one wildlife species over another, particularly if both are protected by law? Moore (1995) summarized the conflict between protecting salt marsh habitat for the endangered clapper rail and salt marsh harvest mouse and protecting tall bulrush (brackish marsh) habitat that has been shown to be important to heron species. Moore also touches on the conflict between different environmental laws, in this case, endangered species versus water reuse regulations. The WPCP is faced with the challenge of protecting two habitats that are affected by the same water body, but have very different requirements.

Previous data on water salinity in Artesian Slough have been scant; however, available information was summarized by H. T. Harvey & Associates in a 1995 Preliminary Ecological Risk Assessment. These data are shown on Table 14 with data collected from December 1995 through May 1996 during the present study. Sampling points listed in the risk assessment are shown on Figure 6. These studies varied in methods and duration, making statistical comparisons impossible. A qualitative comparison indicates that, since 1980, average salinity has changed little near the WPCP discharge point, while it has increased slightly near the rookery and decreased slightly just downstream of the rookery. It appears that salinity has decreased near the

Table 14.--Comparative Artesian Slough Salinity Data

Approximate sample location (see Figure 3)	Comparable sample location from present study (see Figure 2)	Average of salinity (ppt) values from 6/24-8/6/80 (measured weekly)[1]	Average salinities (ppt) (surface/bottom) from June-Oct. 1982-1986 (measured weekly)[2]	Mean annual salinity (ppt) ranges: 1980-1986 (measured monthly)[3]	Salinity (ppt) (mean/range) from present study, 12/4/95-5/24/96 (measured 2-4 times monthly)
1	none	-	0.8/0.9	-	-
2	1	0.5	-	1.0-1.5	1.5/0.60-3.03
3	13	0.8	-	0.9-1.7	2.2/0.70-6.17
4	15, 16	-	2.3/3.3	-	2.0/0.70-6.67
5	26	7.0	6.5/7.0	1.3-3.0	3.2/0.7-15.57
Mean annual flow (mgd) from WPCP		106	110-121	106-121	135 (based on 6 study months)

[1] San Jose State University 1981
[2] San Francisco Bay Bird Observatory 1987
[3] Larry Walker Associates Inc. 1987

Source: H. T. Harvey & Associates, South Bay Water Recycling Artesian Slough Heron Rookery Preliminary Ecological Risk Assessment. (Alviso: H. T. Harvey & Associates, 1995), 9.

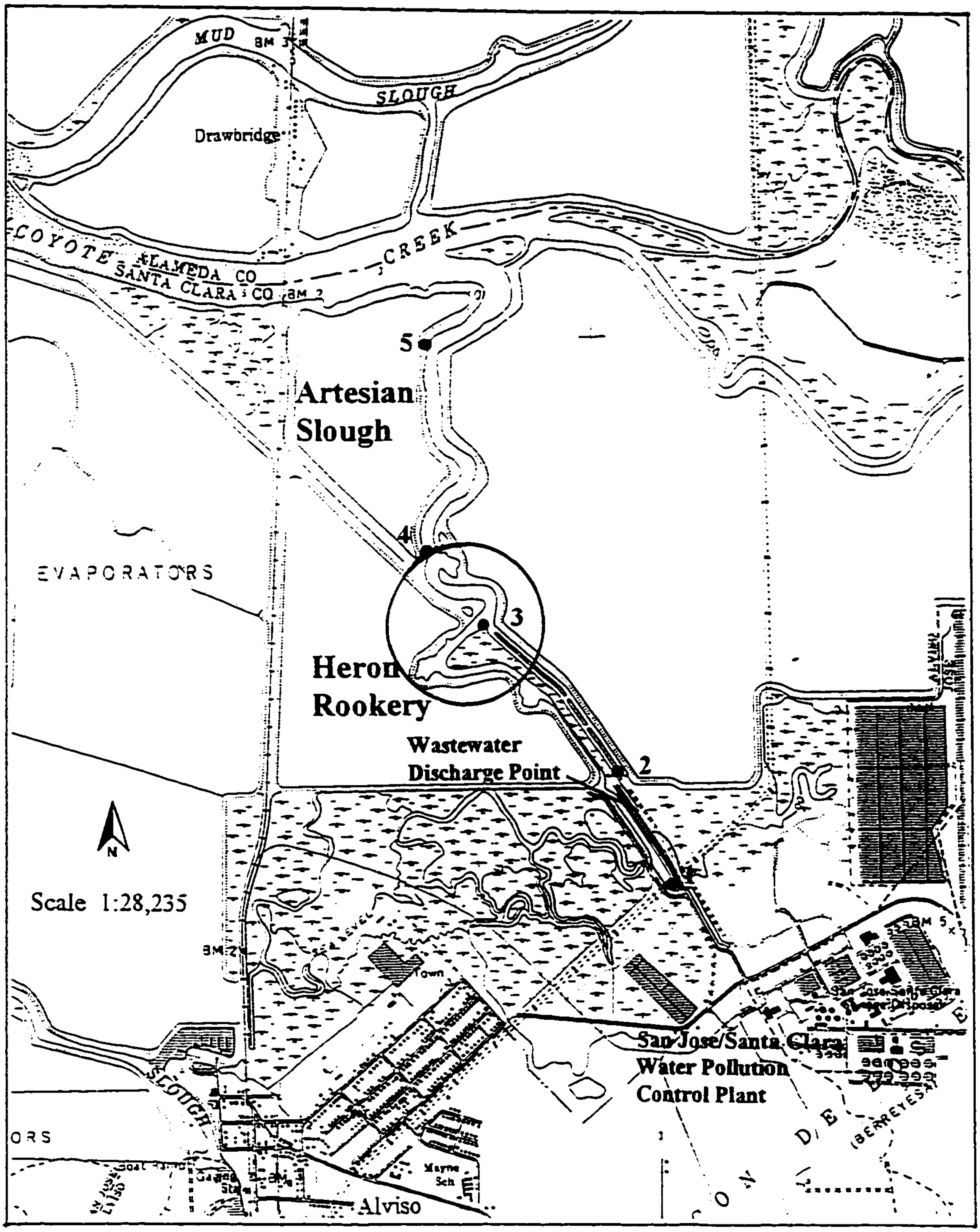

Figure 6. Artesian Slough Historic Sampling Point Locations

Source: H. T. Harvey & Associates. South Bay Water Recycling Artesian Slough Heron Rookery Preliminary Ecological Risk Assessment. (Alviso: H. T. Harvey & Associates. 1995). 10.

confluence of Artesian Slough with Coyote Creek when compared with the San Jose State University and San Francisco Bay Bird Observatory studies, but has increased slightly compared with the Larry Walker Associates study (Table 14).

Comparison of Water and Sediment Pore Water Salinities

This study found a strong correlation between water and sediment pore water salinity in December, a finding that is supported by the literature. Correlations decreased into the winter months and began to increase again in the spring. Rollins (1973) found that soil pore water salinity was 1.3 to 2 times that of water salinity. There was sufficient variability in the results of the present study, with mean soil pore water salinities ranging from 1 to 7 times that of water salinities, that it would be advisable for future monitoring programs to collect data on both soil and water salinities.

Comparison of Salinity and Vegetation Cover

Sediment pore water salinity was found to be a more important predictor of vegetative species and cover than water salinity, a finding also supported by the literature (Mall 1969). This study supports the contention by Cain (1979) that soil salinity is a major factor influencing plant growth and distribution.

Previous research suggests that soil salinities below 10 ppt will give a competitive advantage to California bulrush (H. T. Harvey & Associates 1995). This study indicates that, for this Slough, 6 ppt was the highest observed value at which California bulrush had a clear competitive advantage. This study also indicates that California bulrush dominates (at least 80% cover) where mean water salinities remain below 4 ppt. Above these salinities, alkali bulrush and peppergrass begin to compete successfully.

Both California bulrush and alkali bulrush are rhizomatous perennials which primarily reproduce vegetatively. Alkali bulrush rhizomes occur in the top 15 cm of soil (H. T. Harvey & Associates 1995). California bulrush rhizomes were observed during this study to occur in the top 15 to 30 cm of soil, although this was not quantified. California bulrush may be competitively superior to alkali bulrush in fresh water because of its larger root structure, faster growth, and taller canopy. Habitat partitioning is evidenced by alkali bulrush occupying higher elevations where sediment salinities would be expected to be higher and may exceed those tolerated by California bulrush. Sediment salinity increases with increasing elevation due to longer periods of exposure and evaporation (Josselyn 1983).

Zone C was the transition zone between freshwater and brackish habitat, a transition that occurs further downstream than has been seen in the past (H. T. Harvey & Associates 1995). In this zone, alkali bulrush and peppergrass were beginning to replace California bulrush in sediment pore water salinities that ranged from 1.75 to 7.88 ppt (winter-spring zone average), higher than the 2.19 to 5.63 ppt range in zone B that was almost entirely California bulrush. In zone D, alkali bulrush and peppergrass predominated at sediment pore water salinities ranging from 2.25 to 11.81 ppt.

Table 15 compares the California bulrush transition zone observed in this study with reported transition areas noted in previous studies. Zone C, point 18, approximately 2.1 kilometers from the WPCP outfall, was where California bulrush began to be replaced by alkali bulrush and peppergrass. This comparison indicates that the beginning of the transition zone has moved approximately 1.3 kilometers downstream between 1980 and 1996. If mean annual flows return to roughly 102 to 106 mgd (near the 1980 flow rate), it is possible that the transition zone could eventually recede to zone B. Such flows would probably support the well-established California bulrush community in the rookery. It is possible that such flows would also protect existing salt marsh habitat in Coyote Creek from further conversion.

Table 15.--Comparison of Transition Zones Over Time

Year	Approximate Distance from Outfall (km)	Corresponding Point (see Figure 2)	Zone
1980	0.8	9-10[1]	B
1983	1.2	14[2]	B
1987	1.5	16[2]	B
1995-1996	2.1	18	C

[1] Point location estimated based on data from H. T. Harvey & Associates (1995).
[2] Point location extrapolated from vegetation mapping (H. T. Harvey & Associates 1995).

The relationship between salinity and wastewater flow and vegetation has been established by previous research and it is expected that future flow changes will result in some vegetation change. H. T. Harvey & Associates (1995) has suggested that if projected changes result in flows greater than 100 mgd, conditions under which

California bulrush has historically thrived, then California bulrush communities should not be threatened. This study suggests that a minimum discharge of 100 mgd would be required to protect the California bulrush community within the main rookery area, but that such a reduced flow could possibly cause California bulrush communities further downstream to begin being replaced by other species.

It should be noted that this study only examined vegetation within 2 m of the vegetation at the water's edge. Vegetation further up the bank was not examined. California bulrush occupies areas from MLLW to MTL; alkali bulrush generally occupies higher elevations, MTL to MHHW; therefore, species distributions beyond the 2-m quadrats and at higher elevations could be significantly different from those observed in this study.

It is interesting to note that the oxbow portion of zone B, where much of the rookery exists, does appear to exhibit slightly higher salinities than the main channel portion of zone B. This assessment is based on readings taken at points 10 and 11 within the oxbow. There may be several reasons for this higher salinity. The oxbow fills with water at high tide; some of this saline water may remain in deeper pockets during lower tides due to reduced water circulation caused by the higher elevation or "sill" of the mouth of the oxbow where it meets the main channel. In this area, higher sediment salinities could be a factor of higher elevation and increased evaporation, and reduced flushing from the wastewater discharge during medium to low tides. Mean water salinities at points 10 and 11 ranged from 1.15 to 5.88 ppt, and sediment pore water salinities ranged from 2.00 to 10.00 ppt, compared with overall zone B averages of 1.06 to 3.52 ppt for water and 2.19 to 5.63 ppt for sediment pore water (Appendix A). While these two points are not necessarily representative samples of the entire oxbow, this finding suggests that, for some reason, in this area California bulrush tolerates higher salinities without losing its competitive advantage.

It was also found that alkali bulrush and peppergrass appear to share the same habitat and salinity tolerances. California bulrush significantly loses its competitive advantage to these two species in mean water salinities ranging from 1 to 9 ppt and sediment pore water salinities ranging from 2 to 12 ppt. Peppergrass also shares habitat with pickleweed and cordgrass, indicating that its salinity tolerance may be even higher than that of alkali bulrush.

Wastewater diversion is planned to occur during the summer months, a season when salinities are naturally higher due to reduced rainfall and increased evaporation. If diversion, hence increased salinity, occurs after the spring growth spurt of the bulrush, then vegetation decreases would not be anticipated (Zedler et al. 1990; Cain 1979; Mall 1969). It should be remembered, however, that any changes that might be caused by diversion might not be apparent for years.

Salinity is only one of several environmental factors known to affect vegetation distribution. Others variables that have been noted in the literature include elevation, length of soil submergence, and soil characteristics (Atwater and Hedel 1976; Latham 1991; Mall 1969). While the strong correlation found between vegetation and salinities does not tell us causative factors, salinity does appear to be a potential limiting influence. Further study of these other variables would shed additional light on the tolerances of California bulrush.

Current vegetation distribution patterns cannot be explained solely by current salinity patterns; vegetation at a particular location also reflects historical environmental factors (Rankin 1995; Zedler 1995). While tidal cycles and seasons in the future can be reasonably expected to remain similar to conditions during the past few years, salinity and water depth in the Slough channel may change once diversion begins. It should be remembered, however, that any changes that might be caused by diversion might not be apparent for years.

Evaluation of Stratification

Significant stratification was found in the water column during the first three months, but not during the last three months of the study. Further study might reveal whether stratification is correlated with tide cycle or season.

Temporal Salinity Characteristics

The data show that water and sediment pore water salinities in the Slough change significantly over time regardless of discharge volumes from the WPCP. Seasonal changes in precipitation and evaporation would account for these changes. This study did not include observations during the driest, warmest months of the year, from June through October, when mean salinities are expected to be higher due to increased evaporation, higher evapotranspiration by vegetation, and reduced freshwater inflow from runoff (Josselyn 1983). To understand the full range of annual fluctuations, it would be necessary to collect data during an entire year and for several years. Vegetation responds to long-term conditions, and especially to conditions during germination in spring.

December salinities were the highest of any study month, probably because they were reflecting the long, dry summer and fall of 1995, when there had been no rain since June. Decreasing salinities during subsequent months were attributable to two main factors: 1) increased rainfall and 2) increased wastewater flows. This rainfall effect is well supported by the literature (Schemel 1971; Zedler et al. 1990; H. T. Harvey & Associates 1995).

Water and sediment pore water salinities were found to decrease over time as the rainy season progressed. Rainfall appears to have a cumulative dilution effect over time, with salinities correlated to total rainfall rather than to the rainfall for the particular month in which they were measured (refer to Tables 12 and 13). In summer, sediment salinities will increase due to decreased precipitation and increased evaporation. The data also suggest that salinities decrease as discharge increases. The relative importance of rainfall and discharge to salinity values is a more complicated question that requires a full year's worth of data for a more thorough investigation.

RECOMMENDATIONS

Management Recommendations

The results of this study suggest three primary recommendations for management of Artesian Slough: (1) establish baseline salinity conditions during dry months, (2) manage wastewater flows to maintain low salinity conditions in the rookery, and (3) conduct regular monitoring after wastewater diversion begins.

Establish baseline salinity conditions during dry months. Salinity varies with the seasons, as established by previous research and as validated by this study. It is necessary to have at least one year's worth of baseline data on salinity conditions throughout Artesian Slough, as recommended by the RWQCB (Moore 1995). The present study, which covered the period from December through May, should be augmented by a study of water and sediment salinities from June through November. It is important that sediment be included in the monitoring regime since vegetation distribution was found in this study to correlate more strongly with sediment pore water salinity than with water salinity. This continued research should be conducted in 1997 before the wastewater diversion begins.

It is especially important to know the baseline conditions during the summer, which is naturally the time of highest salinities and is also the time during which the most wastewater diversion is anticipated. This study covered the winter and spring when lower salinities are important factors in the reproductive success of California bulrush. The literature indicates that higher salinities are tolerated in the summer if the bulrush population has become well established during the lower salinities periods of winter and spring. More data are necessary to define the summer salinity range that is tolerated by a healthy California bulrush community.

September, October, and November data could be gathered throughout the entire length of the Slough. From June through August, study could proceed in zones C and D by gaining access to Artesian Slough from Coyote Creek. This would be especially useful because zone C is the transition zone where freshwater and brackish habitats merge.

During the heron nesting season, one alternative for obtaining salinity data would be to install permanent monitoring stations with remote access such as a wireless communications link for downloading data. An advantage of such stations is that they could collect data on water salinity and tide height in zones A and B during the breeding season when boat access to the rookery is not permitted. The disadvantage is that they could not monitor sediment salinity.

Manage wastewater flows to maintain low salinities in the rookery. It is recommended that once the wastewater diversion program begins, the WPCP control its discharge volume in a manner that maintains the salinity conditions in zones A and B that are necessary for the healthy California bulrush population upon which the rookery depends. Based upon this study, the conditions that should be maintained in these zones during the peak germination and growth months of February through May are 1 ppt for water and 2 ppt for sediment pore water. During December and January, water salinities ranging from 1 to 4 ppt and sediment pore water salinities ranging from 1 to 6 ppt appear to be well tolerated. These should enable California bulrush to continue outcompeting alkali bulrush in these zones.

Conduct regular monitoring after diversion begins. In light of anticipated changes to freshwater flows and the sensitivity of the freshwater, brackish, and salt marsh habitats in and near Artesian Slough, continued monitoring is warranted. Both water and sediment salinities should be monitored closely once diversion begins, particularly in the spring when California bulrush is germinating and in the summer when higher salinities could reach its limits of tolerance. Vegetation is an important component of any monitoring regime in order to determine if any changes in species distributions are occurring and to correlate any such changes with salinities. Determination of vegetative species should be accomplished by estimating percent cover or by another noninvasive method. Continued monitoring will enable evaluation of possible transition zone changes.

It is understood that even under the best conditions, it is not possible to control all factors affecting marsh habitat and the rookery. Two such factors mentioned by H. T. Harvey & Associates (1995) are ongoing sedimentation and the potential for bird colony abandonment for unknown reasons. However, a solid foundation of knowledge regarding Slough ecosystem dynamics will assist in evaluating any proposed changes in WPCP discharge.

Research Needs

The results of this study suggest several lines of research in order to strengthen the knowledge needed to predict effects of future changes.

The relationship between salinity and wastewater flow and vegetation has been established by previous research and it is expected that future flow changes will result in some vegetation change.

The germination requirements of California bulrush and peppergrass have received little or no study; therefore, controlled experiments on seed germination and seedling survival would be useful in determining tolerances.

Previous research has identified length of submergence as an important variable in vegetation distribution (Mall 1969; Cain 1979). Submergence was not evaluated during this study, and is a potential subject for further review.

A computer simulation model was developed by CH2M Hill to investigate the relationship between salinity and wastewater flows from the WPCP (CH2M Hill 1990). This predictive model was based on an outfall dye study of dilution patterns in South San Francisco Bay and a database of currents, salinities, and other information. Additional computer modeling could be conducted using the specific salinity data collected during this study to develop a more accurate model.

Continued monitoring of all habitats of concern, salt, brackish, and freshwater marsh, will enable evaluation of the effects of human activities on sensitive wildlife species and help prevent negative impacts from wastewater management.

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APPENDIX A

WATER AND SEDIMENT PORE WATER SALINITY DATA AND GRAPHS

Table A-1.--Mean* Water Salinities (ppt) by Point and Month

Point	Dec. 1995	Jan. 1996	Feb. 1996	March 1996	April 1996	May 1996	Average. Dec.-Feb.	Average. Dec.-May
1	1.65	1.89	0.73				1.42	
2	1.82	1.85	0.75				1.47	
3	1.67	1.89	0.75				1.44	
4	1.51	1.75	0.75				1.34	
5	1.70	2.23	0.80				1.58	
6	2.03	2.15	0.80				1.66	
7	1.87	2.20	0.85				1.64	
8	1.88	2.56	0.85				1.76	
Zone A	1.77	2.07	0.79				1.54	
9	2.18	2.48	0.83				1.83	
10	5.88	3.69	1.15				3.57	
11	5.88	3.35	2.00				3.74	
12	2.23	2.16	0.85				1.75	
13	2.88	2.00	0.88				1.92	
14	2.82	2.13	0.80				1.92	
15	3.09	2.42	1.00				2.17	
16	3.17	2.42	1.00				2.20	
Zone B	3.52	2.58	1.06				2.39	
17	4.31	2.59	0.90	0.75	0.70	1.25	2.60	1.75
18	4.92	2.77	0.90	0.75	0.70	1.25	2.86	1.88
19	4.73	2.58	0.90	0.76	0.73	1.15	2.74	1.81
20	5.21	2.58	0.90	0.76	0.73	1.15	2.90	1.89
21	5.38	2.41	0.85	0.76	0.73	1.11	2.88	1.88
22	5.96	2.52	0.85	0.80	0.76	1.30	3.11	2.03
23	6.48	2.36	0.85	0.80	0.73	1.30	3.23	2.09
24	6.96	2.56	0.85	0.80	0.78	1.20	3.46	2.19
Zone C	5.49	2.55	0.88	0.77	0.73	1.21	2.97	1.94
25	7.24	2.61	0.90	0.80	0.79	1.35	3.58	2.28
26	8.05	2.57	0.80	0.85	0.83	1.38	3.81	2.41
27	8.55	2.56	0.90	0.91	1.11	1.40	4.00	2.57
28	8.88	2.57	0.90	1.00	1.58	1.45	4.12	2.73
29	9.23	2.57	0.90	0.98	1.61	1.48	4.23	2.80
30	9.56	2.59	0.92	1.04	1.81	1.54	4.36	2.91
31	9.85	2.61	0.92	1.05	1.27	1.68	4.46	2.90
32	10.20	2.69	0.93	1.14	1.80	1.84	4.61	3.1
Zone D	8.95	2.60	0.90	0.97	1.35	1.52	4.15	2.71

* December mean reflects four sample events, two at high tide and two at low tide. January through May means reflect two sample events each month, one at high tide and one at low tide.

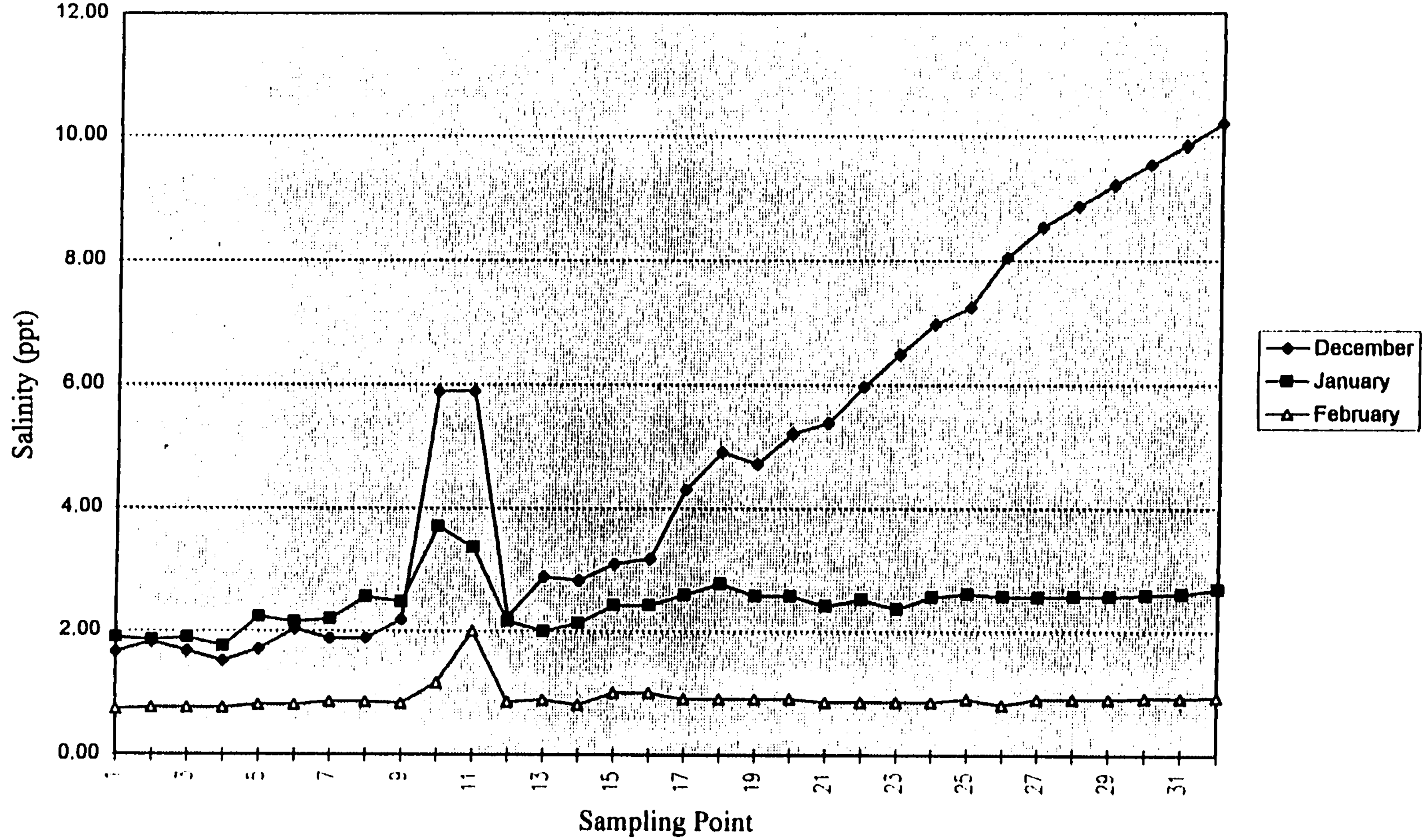

Figure A-1. Mean Water Salinity by Sampling Point, December-February

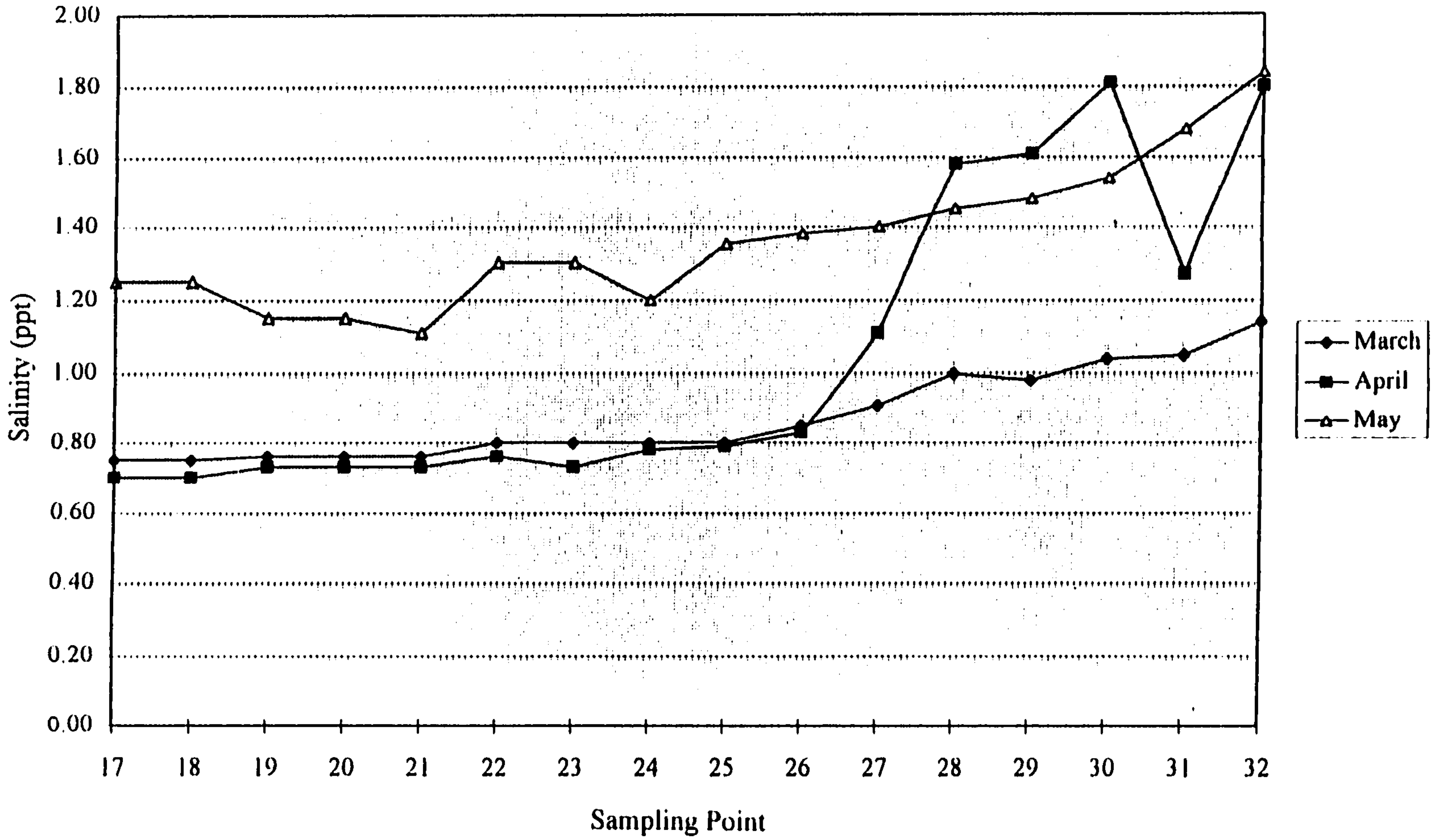

Figure A-2. Mean Water Salinity by Sampling Point, March-May

Table A-2.--Sediment Pore Water Salinity (ppt) by Point and Month*

Point	Dec. 1995	Jan. 1996	Feb. 1996	March 1996	April 1996	May 1996	Average, Dec.-Feb.	Average, Dec.-May
1	2.0	1.0	1.0				1.33	
2	2.5	1.0	1.0				1.50	
3	7.5	1.0	1.0				3.17	
4	2.0	1.0	1.5				1.50	
5	3.5	1.0	1.0				1.83	
6	4.5	1.5	1.0				2.33	
7	4.0	5.0	1.5				3.50	
8	2.0	3.0	2.0				2.33	
Zone A	3.50	1.81	1.25				2.19	
9	3.0	1.0	1.5				1.83	
10	10.0	2.0	2.0				4.67	
11	5.0	4.0	2.0				3.67	
12	4.5	4.5	2.5				3.83	
13	5.0	2.0	1.5				2.83	
14	4.5	2.0	3.0				3.17	
15	7.5	5.0	2.0				4.83	
16	5.5	4.5	3.0				4.33	
Zone B	5.63	3.13	2.19				3.65	
17	6.5	5.0	4.0	3.5	4.0	2.0	5.17	4.17
18	8.0	5.0	3.0	0.0	0.5	2.0	5.33	3.08
19	5.5	6.5	4.0	2.0	2.0	1.0	5.33	3.50
20	10.0	8.0	8.0	0.0	0.0	2.0	8.67	4.67
21	8.5	5.5	5.5	2.5	2.0	2.0	6.50	4.33
22	7.5	6.5	6.5	5.0	1.0	2.5	6.83	4.83
23	9.5	5.5	6.0	4.0	2.0	2.5	7.00	4.92
24	7.5	7.0	3.0	3.0	2.5	1.0	5.83	4.00
Zone C	7.88	6.13	5.00	2.50	1.75	1.88	6.33	4.19
25	8.5	8.5	8.0	2.5	4.0	6.5	8.33	6.33
26	9.5	9.0	4.5	1.5	0.5	2.0	7.67	4.50
27	9.0	10.0	3.0	0.0	2.5	6.5	7.33	5.17
28	14.0	14.0	2.5	6.0	5.0	6.5	10.17	8.00
29	10.5	8.0	3.5	0.0	0.5	3.5	7.33	4.33
30	16.5	11.0	6.5	2.0	2.5	6.5	11.33	7.50
31	14.0	9.0	12.0	2.0	0.5	5.0	11.67	7.08
32	12.5	12.0	13.0	4.0	11.5	10.5	12.50	10.58
Zone D	11.81	10.19	6.63	2.25	3.38	5.88	9.54	6.69

*Sediment was collected and analyzed once per month at each point.

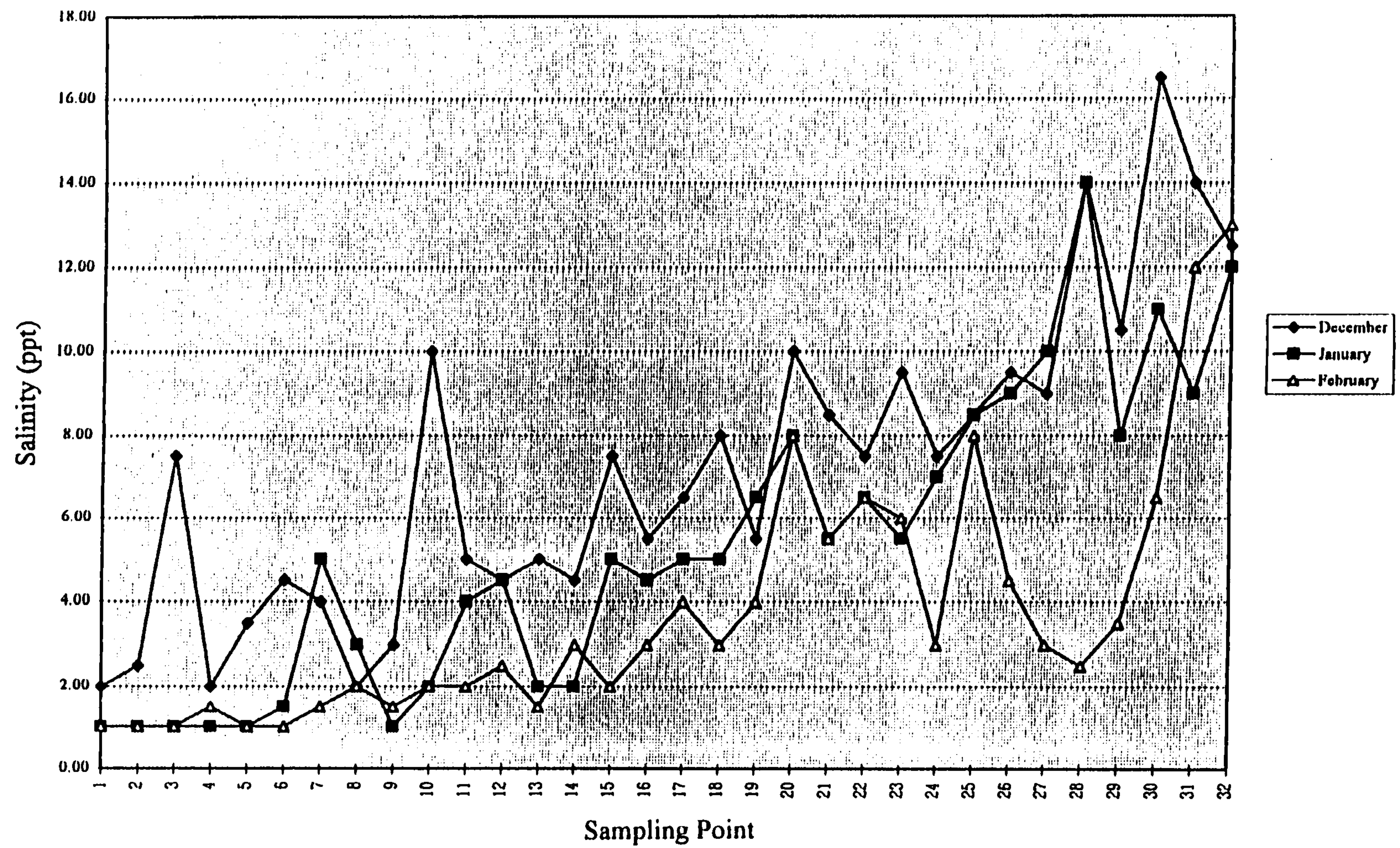

Figure A-3. Sediment Pore Water Salinity by Sampling Point, December-February

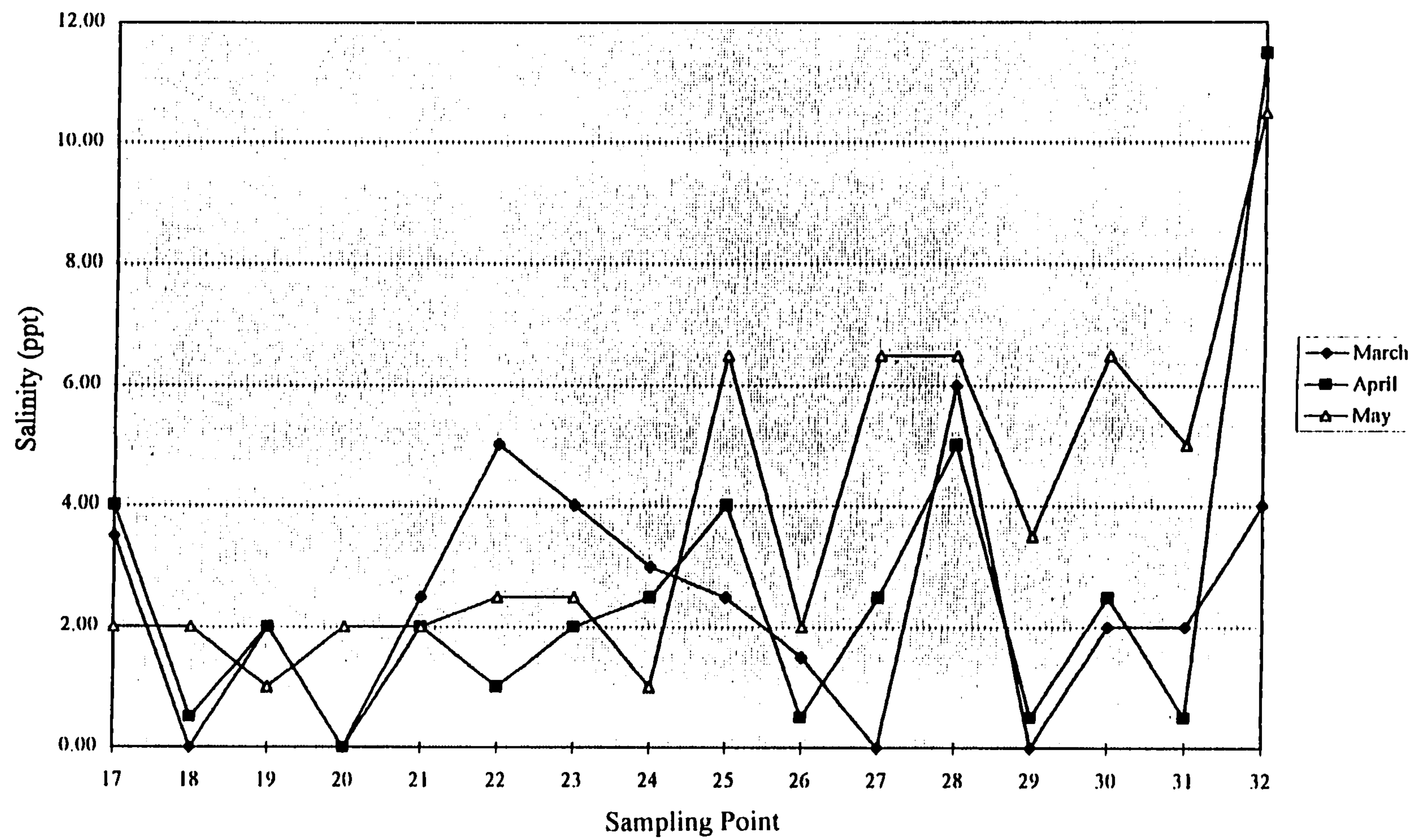

Figure A-4. Sediment Pore Water Salinity by Sampling Point, March-May

APPENDIX B

DATA FOR SALINITY AND VEGETATION CORRELATION CALCULATION

Table B-1.--Summary of Salinity and Vegetation Data for Correlation Calculation

Zone	Month	Mean Water ppt[1]	Mean Sediment ppt[2]	California bulrush % cover[3]	Alkali bulrush % cover[3]	Pepper-grass % cover[3]	Pickle-weed % cover[3]	Cord-grass % cover[3]	Spear-scale % cover[3]
A	December	1.77	3.50	88.50	0.06	0	0	0	0
A	January	2.07	1.81	88.50	0.06	0.06	0	0	0
A	February	0.79	1.25	88.50	0	0	0	0	0
B	December	3.52	5.63	79.75	0	0	0	0	11.06
B	January	2.58	3.13	76.00	0	2.31	0	0	2.31
B	February	1.06	2.19	76.00	0.38	4.81	0	0	0
C	December	5.49	7.88	66.38	7.94	15.88	0	0	0
C	January	2.55	6.13	66.38	11.06	13.38	0	0	0
C	February	0.88	5.00	66.38	7.13	19.00	0	0	0
C	March	0.77	2.50	66.38	2.31	19.00	0	0	0
C	April	0.73	1.75	66.38	15.88	9.63	0	0	0
C	May	1.21	1.88	66.38	5.19	15.88	0	0	0
D	December	8.95	11.81	20.50	34.75	26.94	0.75	11.06	0.75
D	January	2.60	10.19	22.50	22.88	33.19	7.13	11.44	0
D	February	0.90	6.63	19.00	14.88	41.13	7.13	11.06	0
D	March	0.97	2.25	22.13	16.25	33.19	7.13	11.06	0
D	April	1.35	3.38	19.38	23.63	33.56	2.69	11.06	0
D	May	1.52	5.88	15.88	29.63	33.56	2.38	11.06	2.31

[1] The water salinity (ppt) is the mean of the samples taken each month at eight sampling points within each zone.
[2] The sediment pore water salinity (ppt) is the mean of the samples taken each month at eight sampling points within each zone.
[3] The vegetation % cover is the mean of the observations made each month at eight sampling points within each zone.

APPENDIX C

BAR CHARTS COMPARING SALINITY AND VEGETATION COVER

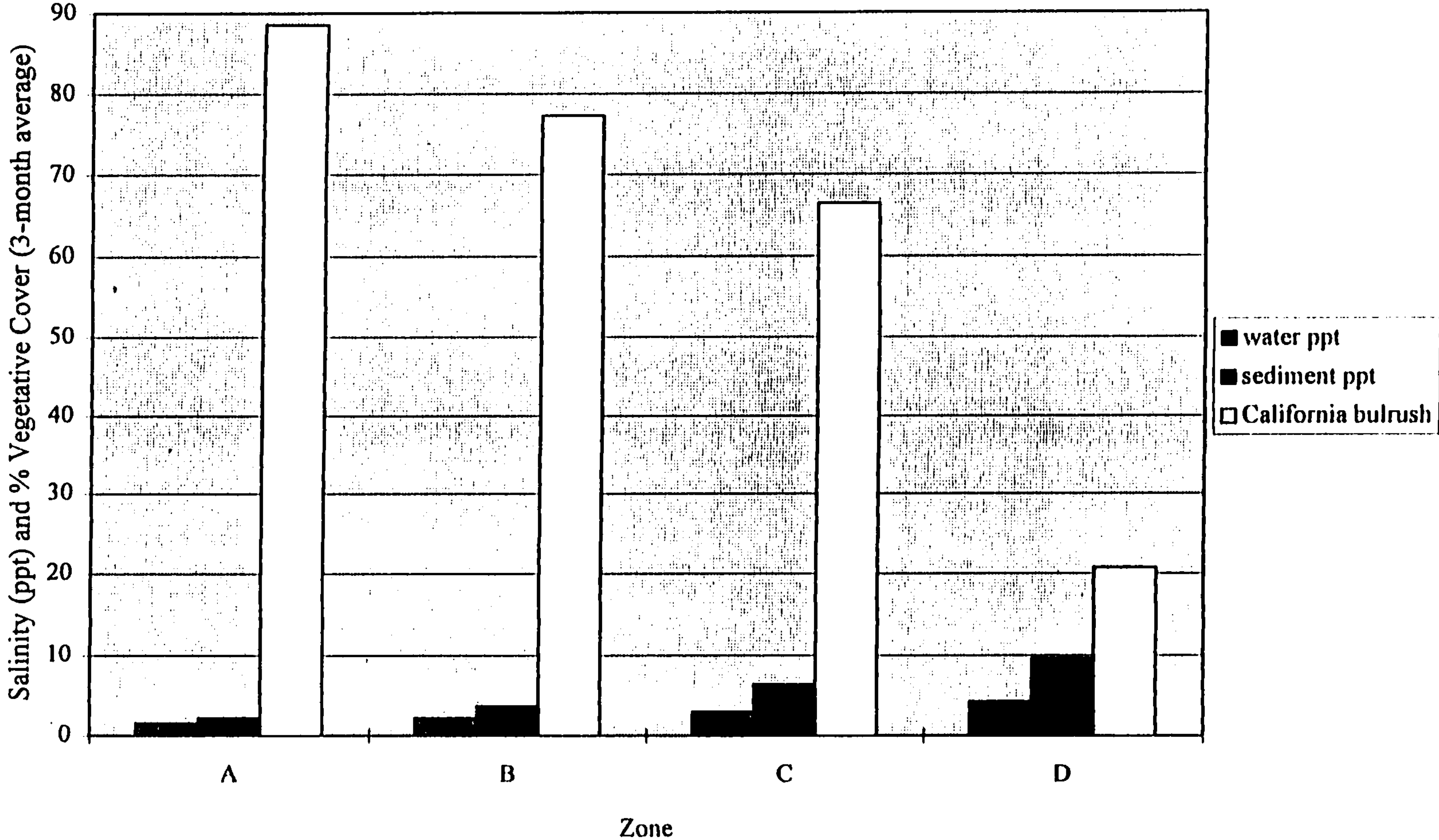

Figure C-1. Comparison of California Bulrush and Mean Salinities by Zone, December-February

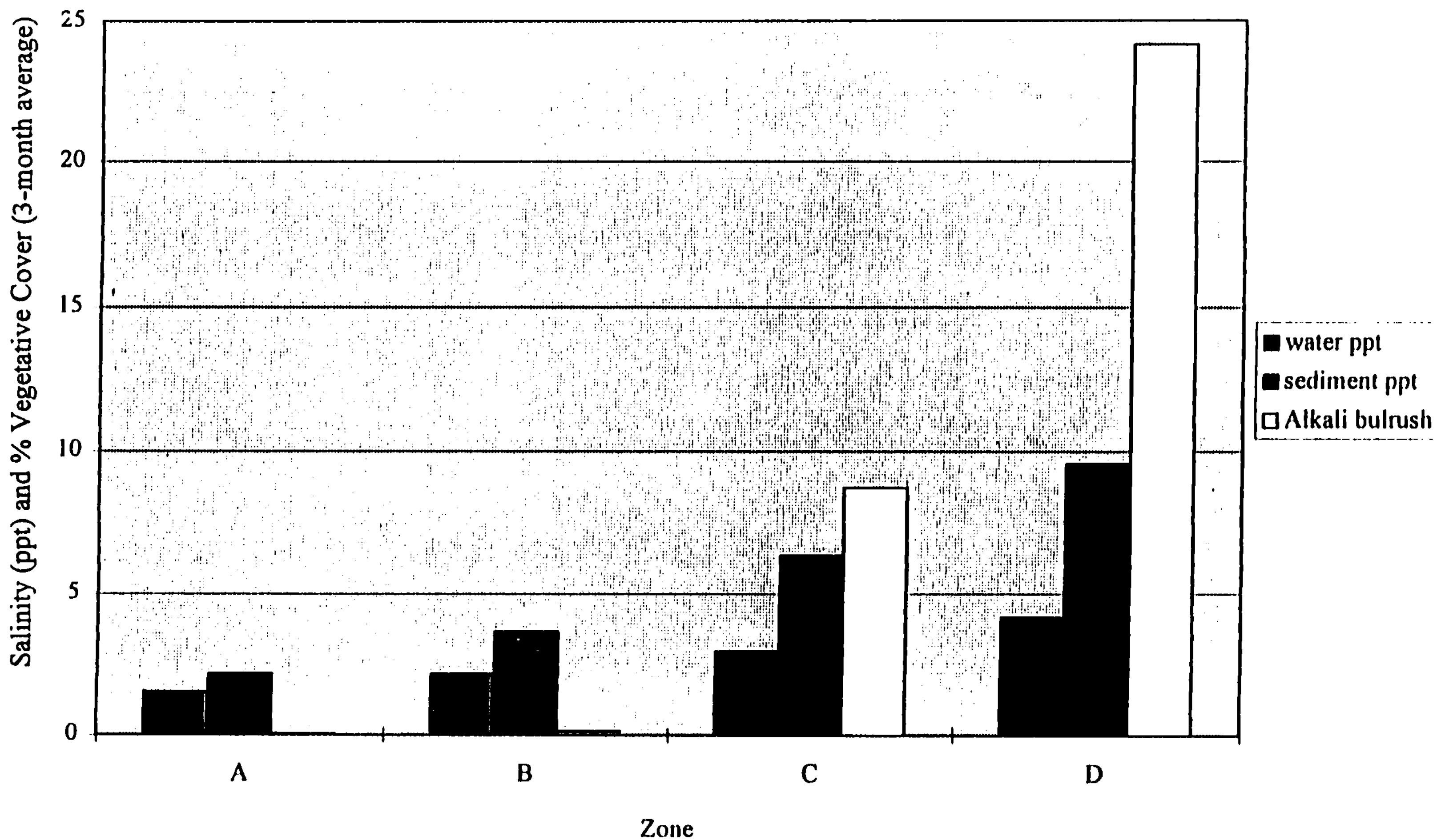

Figure C-2. Comparison of Alkali Bulrush and Mean Salinities by Zone, December-February

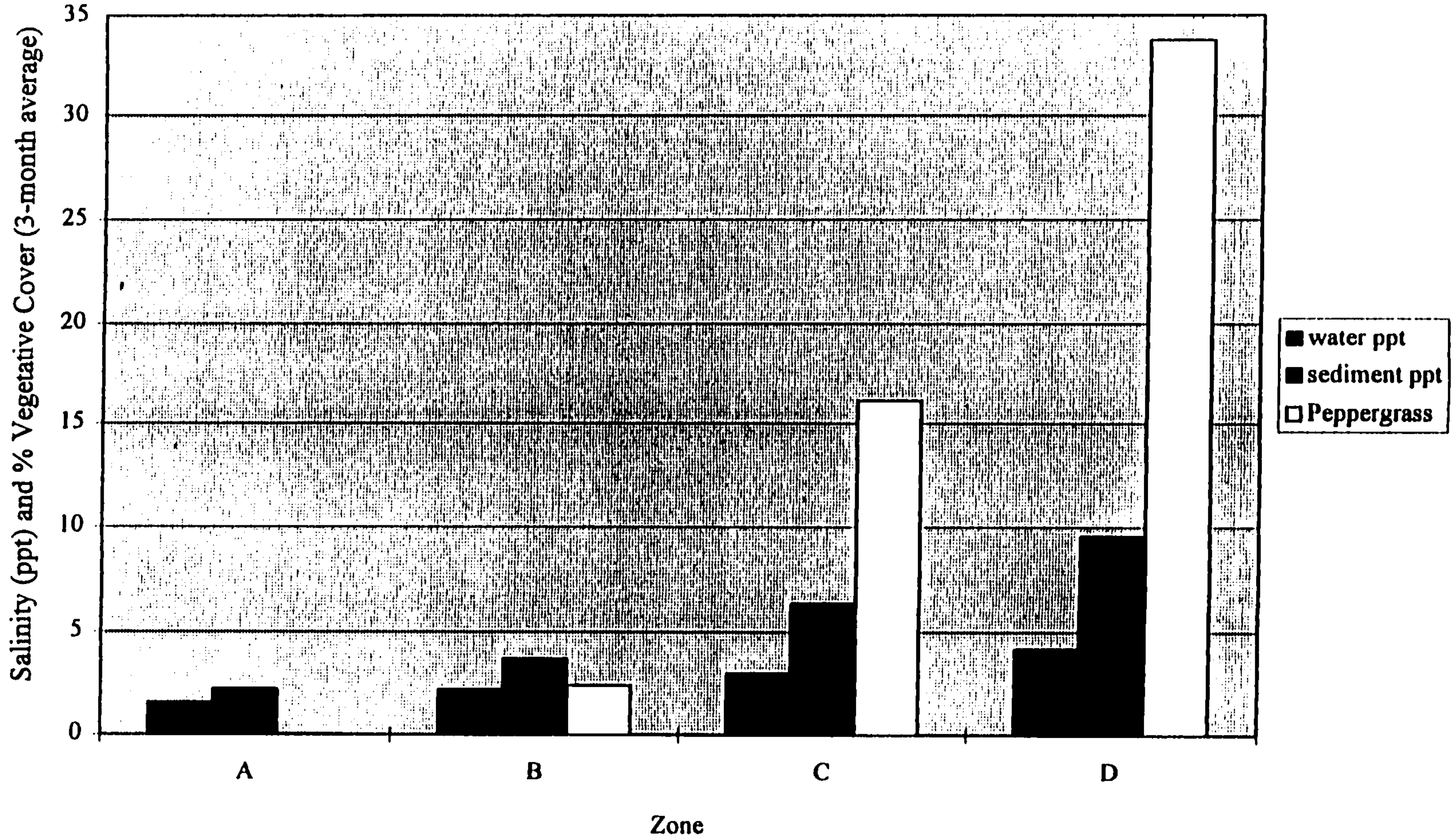

Figure C-3. Comparison of Peppergrass and Mean Salinities by Zone, December-February

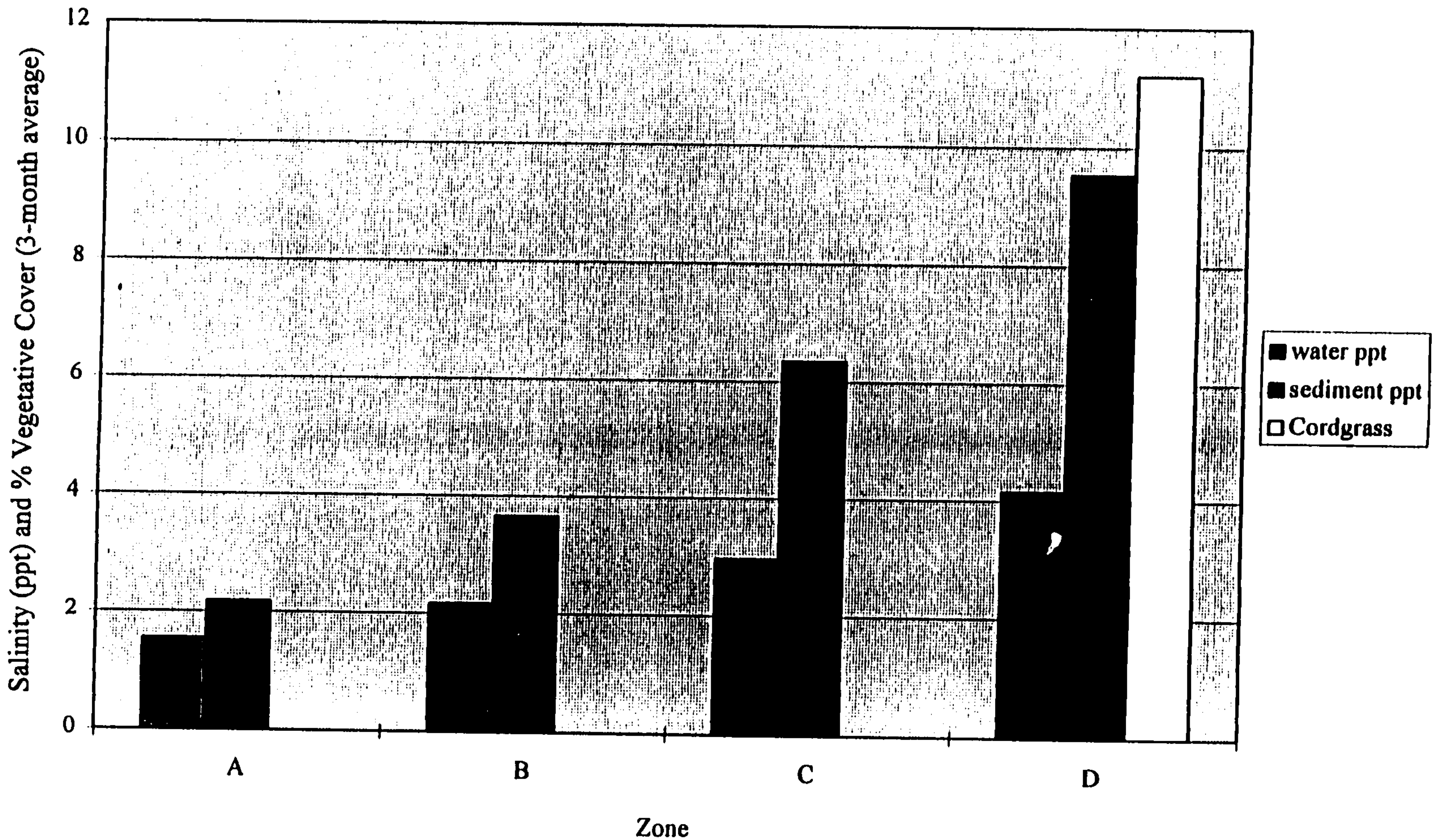

Figure C-4. Comparison of Cordgrass and Mean Salinities by Zone, December-February

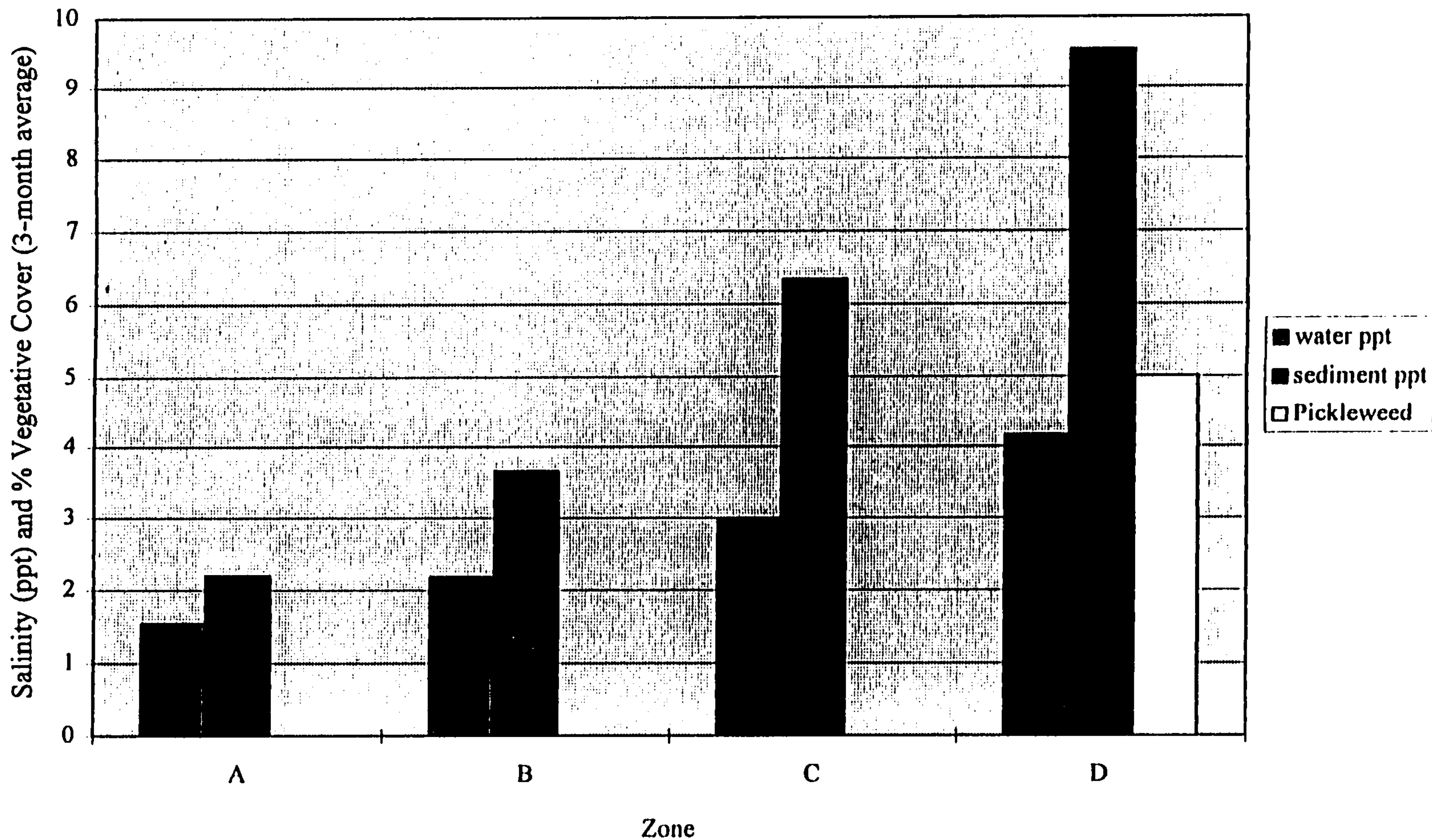

Figure C-5. Comparison of Pickleweed and Mean Salinities by Zone, December-February

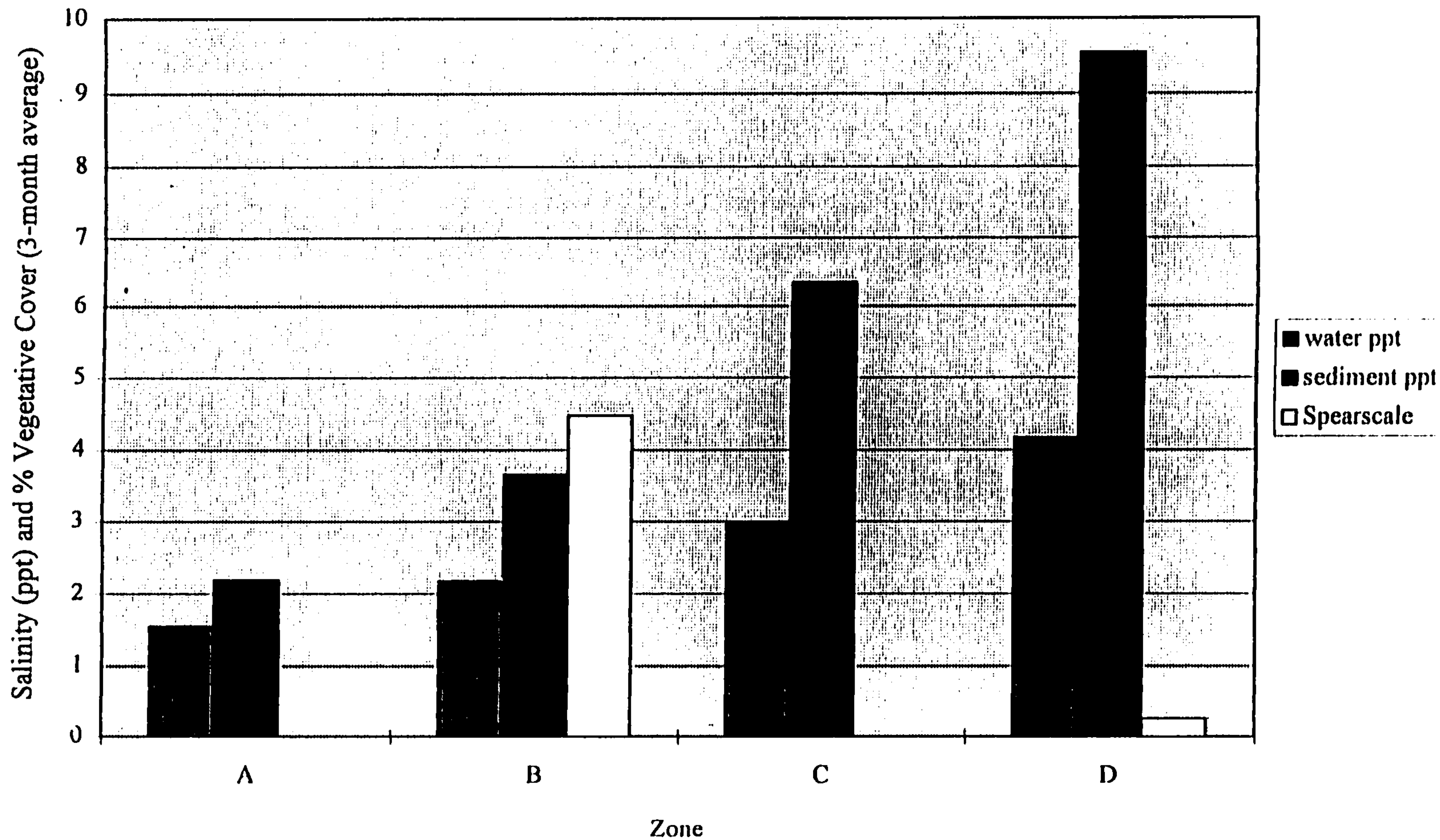

Figure C-6. Comparison of Spearscale and Mean Salinities by Zone, December-February

APPENDIX D

WATER AND SEDIMENT PORE WATER SALINITIES BY TIDE LEVEL

Table D-1.--Mean* Water Salinities (ppt) by Tide Level, December through February

Point	December high	December low	January high	January low	February high	February low
1	2.42	0.88	2.85	0.93	0.60	0.85
2	2.72	0.93	2.74	0.97	0.60	0.90
3	2.42	0.93	2.82	0.97	0.60	0.90
4	2.07	0.95	2.53	0.97	0.60	0.90
5	2.39	1.03	3.45	1.00	0.60	1.00
6	3.00	1.05	3.30	1.00	0.60	1.00
7	2.68	1.05	3.44	0.97	0.70	1.00
8	2.82	0.95	3.85	1.27	0.70	1.00
9	3.47	0.90	4.05	0.90	0.67	1.00
10	5.89	**	3.58	3.80	0.80	1.50
11	5.89	**	4.00	2.70	0.80	3.20
12	3.55	0.90	3.48	0.83	0.80	0.90
13	5.02	0.75	3.30	0.70	0.87	0.90
14	4.94	0.70	3.55	0.70	0.70	0.90
15	5.49	0.70	4.14	0.70	1.20	0.80
16	5.49	0.85	4.14	0.70	1.20	0.80
17	7.82	0.80	4.48	0.70	1.10	0.70
18	9.04	0.80	4.83	0.70	1.10	0.70
19	8.67	0.80	4.47	0.70	1.10	0.70
20	9.62	0.80	4.47	0.70	1.10	0.70
21	10.00	0.75	4.12	0.70	1.00	0.70
22	11.15	0.78	4.34	0.70	1.00	0.70
23	12.20	0.75	4.02	0.70	1.00	0.70
24	13.12	0.80	4.42	0.70	1.00	0.70
25	13.69	0.80	4.42	0.80	1.10	0.70
26	15.27	0.83	4.40	0.73	0.90	0.70
27	16.25	0.85	4.32	0.80	1.10	0.70
28	16.90	0.85	4.34	0.80	1.10	0.70
29	17.60	0.85	4.34	0.80	1.10	0.70
30	18.22	0.90	4.38	0.80	1.13	0.70
31	16.90	0.85	4.34	0.80	1.10	0.70
32	17.60	0.85	4.34	0.80	1.10	0.70

*December mean reflects two high tide and two low tide sample events. January and February means reflect one high and one low tide each month.

**Data not collected.

Table D-2.--Water Salinities (ppt) by Tide Level, March through May*

Point	March high	March low	April high	April low	May high	May low
17	0.60	0.90	0.70	0.70	1.80	0.70
18	0.60	0.90	0.70	0.70	1.80	0.70
19	0.62	0.90	0.75	0.70	1.80	0.50
20	0.62	0.90	0.75	0.70	1.80	0.50
21	0.62	0.90	0.75	0.70	1.72	0.50
22	0.70	0.90	0.83	0.70	1.90	0.70
23	0.70	0.90	0.77	0.70	1.90	0.70
24	0.70	0.90	0.85	0.70	1.70	0.70
25	0.70	0.90	0.88	0.70	2.00	0.70
26	0.80	0.90	0.95	0.70	2.05	0.70
27	0.93	0.90	1.53	0.70	2.10	0.70
28	1.10	0.90	2.45	0.70	2.20	0.70
29	1.06	0.90	2.53	0.70	2.25	0.70
30	1.15	0.93	2.93	0.70	2.38	0.70
31	1.10	0.90	2.45	0.70	2.20	0.70
32	1.06	0.90	2.53	0.70	2.25	0.70

*Data reflects one high tide and one low tide reading each month.

APPENDIX E

WATER SALINITY DATA BY DEPTH

Table E-1.–Mean* Water Salinities by Depth, December through February

Point	December surface	December bottom	January surface	January bottom	February surface	February bottom
1	0.88	2.95	0.80	2.45	0.70	0.75
2	0.95	3.40	0.80	2.60	0.75	0.75
3	0.95	2.93	0.85	2.60	0.75	0.75
4	0.98	2.48	0.90	2.65	0.75	0.75
5	1.08	2.80	0.95	2.95	0.80	0.80
6	1.15	3.58	1.00	3.15	0.80	0.80
7	1.20	3.03	1.00	3.10	0.80	0.90
8	1.18	3.10	0.95	3.25	0.80	0.90
9	1.23	3.65	0.95	3.30	0.80	0.85
10	5.60**	5.25**	3.20	4.10***	1.15	0.80***
11	5.60**	5.25**	2.65	5.70***	2.00	0.80***
12	1.28	3.43	0.95	3.25	0.80	0.90
13	1.40	4.40	1.15	3.00	0.85	0.90
14	1.43	4.83	1.10	3.10	0.80	0.80
15	1.75	4.83	1.25	3.25	1.00	1.00
16	1.83	4.90	1.25	3.25	1.00	1.00
17	2.78	7.00	1.75	3.15	0.90	0.90
18	3.28	6.98	1.75	3.10	0.90	0.90
19	3.33	6.90	1.95	3.00	0.90	0.90
20	3.73	7.23	1.95	3.00	0.90	0.90
21	3.90	7.50	2.05	2.85	0.85	0.85
22	4.60	7.63	2.05	2.95	0.85	0.85
23	4.93	8.25	2.05	2.45	0.85	0.85
24	5.38	8.75	2.20	2.80	0.85	0.85
25	5.05	9.18	2.25	2.85	0.90	0.90
26	6.28	9.53	2.50	2.60	0.80	0.80
27	7.18	9.70	2.45	2.75	0.90	0.90
28	7.88	9.95	2.50	2.60	0.90	0.90
29	8.58	10.00	2.50	2.60	0.90	0.90
30	9.00	10.10	2.55	2.60	0.90	0.90
31	9.23	10.25	2.65	2.60	0.90	0.90
32	10.10	10.30	2.60	2.55	0.90	0.95

*December mean reflects four sample events. January and February means reflect two sample events each month.

**Reflects two sample events.

***Reflects one sample event.

Table E-2.–Mean* Water Salinities by Depth, March through May

	March	March	April	April	May	May
Point	surface	bottom	surface	bottom	surface	bottom
17	0.75	0.75	0.70	0.70	1.25	1.25
18	0.75	0.75	0.70	0.70	1.25	1.25
19	0.75	0.80	0.70	0.80	1.20	1.00
20	0.75	0.80	0.70	0.80	1.20	0.95
21	0.75	0.80	0.70	0.80	1.25	0.80
22	0.80	0.80	0.70	0.85	1.30	1.30
23	0.80	0.80	0.70	0.80	1.30	1.30
24	0.80	0.80	0.70	0.85	1.30	1.35
25	0.80	0.80	0.70	0.85	1.35	1.35
26	0.80	0.90	0.75	0.85	1.35	1.40
27	0.85	1.00	0.85	1.75	1.40	1.40
28	0.85	1.10	0.85	2.95	1.40	1.50
29	0.85	1.10	0.90	3.00	1.45	1.50
30	0.95	1.20	0.85	3.40	1.45	1.55
31	0.95	1.15	0.85	2.50	1.60	1.70
32	1.05	1.20	0.95	3.05	1.60	2.05

*December mean reflects two sample events.