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Distribution of riparian trees in tidal streams of the south San Francisco Bay

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DISTRIBUTION OF RIPARIAN TREES IN TIDAL STREAMS OF THE SOUTH SAN FRANCISCO BAY

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ABSTRACT

DISTRIBUTION OF RIPARIAN TREES IN TIDAL STREAMS OF THE SOUTH SAN FRANCISCO BAY

by Christine Kook

This thesis investigated the tolerance of *Salix spp.* and *Populus spp.* to potential increases in the soil and surface water salinity of lower Coyote Creek. Santa Clara Valley Water District hopes to discontinue use of a seasonal dam that prevents summer tidal waters from entering lower Coyote Creek. The District needs information on how discontinuing operation of the dam will affect the upstream riparian vegetation.

The thesis addressed this problem by answering an underlying question. What are the locations of mixed willow and cottonwood riparian associations at 3 control streams in the south San Francisco Bay region in relation to soil and water salinities?

The results indicated that transitions between riparian tree species correlate with gradations in soil and surface water salinity and indicate a downstream limit for riparian trees. The thesis concluded that removing the dam will compromise the long term sustainability of riparian trees along lower Coyote Creek.

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BACKGROUND TO THE PROBLEM

Introduction

This investigation will characterize the tolerance of *Salix spp.* and *Populus spp.* to the salinity of the soil and surface water and will assess whether or not the restoration of tidal action to Coyote Creek will affect the viability of those riparian streamside tree species which existed prior to 1982, as well as those riparian trees planted as a flood control project mitigation effort. This research is also relevant to the effects of sea level rise and our understanding of the location of the riparian zone in tidally influenced creeks.

Restoration of summer tidal flow to Coyote Creek will result if the Santa Clara Valley Water District (SCVWD) discontinues installation of a seasonal dam, Standish Dam, upstream from Dixon Landing Road in Milpitas. Standish Dam was emplaced by farmers in the early 1950s to create a freshwater pond for agricultural use. When the Alviso flood control project began in 1983 the riparian corridor extended downstream to Standish Dam. Downstream of the dam, the tidal channel supported primarily *Scirpus spp.* and other brackish marsh species. The California Department of Fish and Game (CDFG) has expressed concern that removing the dam will raise surface water and soil salinity levels and seriously compromise the viability of the riparian trees immediately upstream of Standish Dam (Dr. J. Smith, pers. comm. 1997).

Coyote Creek Revegetation Project occupies a 13 hectare site, and is mitigation by the Santa Clara Valley Water District (SCVWD) for the loss of nearly 2,000 trees on 5 hectares removed during the construction phase of lower Coyote Creek flood control project.

The project begins northwest of the intersection of Highway 880 and Highway 237 in Milpitas, and ends immediately south of Dixon Landing Road (Fig. 1). Currently, 7.08 hectares of riparian forest have been completed. The downstream reaches of the restoration project were planted in an attempt to lower water temperatures and provide shade for juvenile steelhead populations (*Onchorynchus mykiss irideus)* which had previously reared in the freshwater lake produced by Standish Dam (Linda Spahr, pers. comm. 1996). Trees, shrubs, and herbaceous species, at this lowermost site, were planted during the winters of 1991 and 1992, and their survival is of primary concern to the Water District (Table 1).

Table 1. Coyote Creek aquatic shade species planted at the Coyote Creek Restoration Project (Linda Spahr, pers. comm. 1996)

Botanical Name	Common Name	Aquatic Shade Species
Salix *Hindsiana* (on creek bank)	Willow	114
Salix Hindsiana (on bench)	Willow	37
Acer negundo (on bench)	Box Elder	19
Platanus racemosa (on bench)	Western Sycamore	15
Populus fremontii "Nevada" (on bench)	`Nevada' Cottonwood	59
Total		**249**

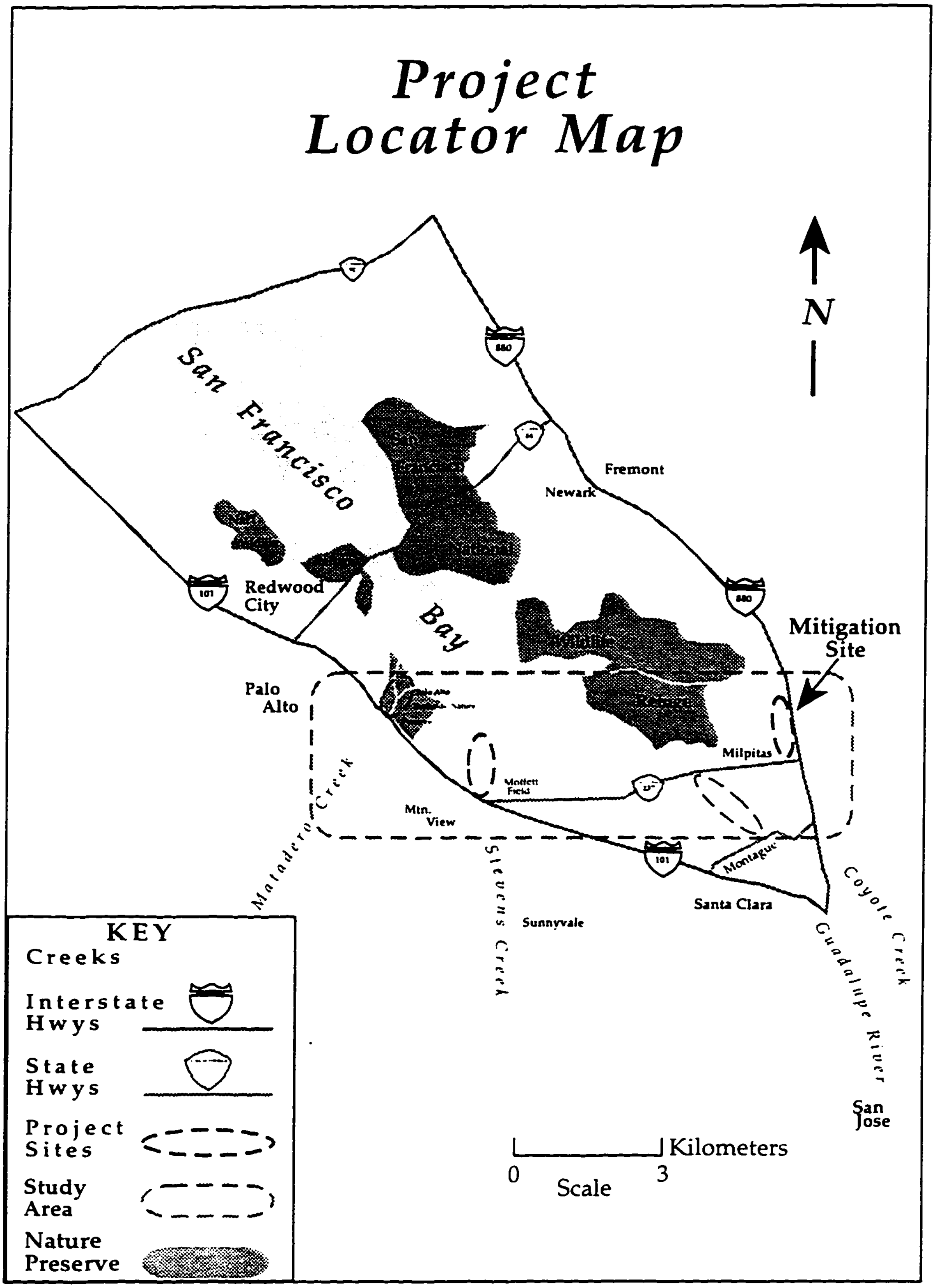

Fig. 1. Map of four project streams within the study area

Project site elevations range from 0.0 meters to 4.6 meters above mean sea level. Sea level begins southeast of Dixon Landing Road, and 4.6 kilometers upstream of where Coyote Creek empties into Coyote Slough (Fig. 2).

The Coyote Creek watershed. Coyote Creek has its headwaters in the Hamilton Range and drains an approximately 906 square kilometer watershed, flowing 193 kilometers through portions of San Jose, Alviso, and Milpitas and draining into San Francisco Bay. The upstream reaches of Coyote Creek have remained fairly undisturbed by humans, and the *Santa Clara County General Plan* allocates the upper watershed to open space. The section of the creek which flows through San Jose, Alviso and Milpitas has met a different fate. Constricted by development for homes, shopping centers, agriculture, and industry, the low lying section of Coyote Creek historically overflowed its banks approximately once in every eight years. Numerous Alviso residences, the San Jose/Santa Clara Pollution Control Plant, Agnews State Hospital, Newby Island Landfill, Leslie Salt Ponds, Highways 237 and 880, and agricultural lands all exist within the low lying portion of the Creek's floodplain. This portion of the creek is leveed by an extensive flood control system, and much of the pre-existing riparian corridor upstream of the re-vegetation project has been removed (Berger 1990, 112).

The Coyote Creek Riparian Station (CCRS), a non-profit group devoted to research and management of riparian ecosystems, has been contracted by SCVWD to monitor the re-vegetation project. Since 1982 they have been

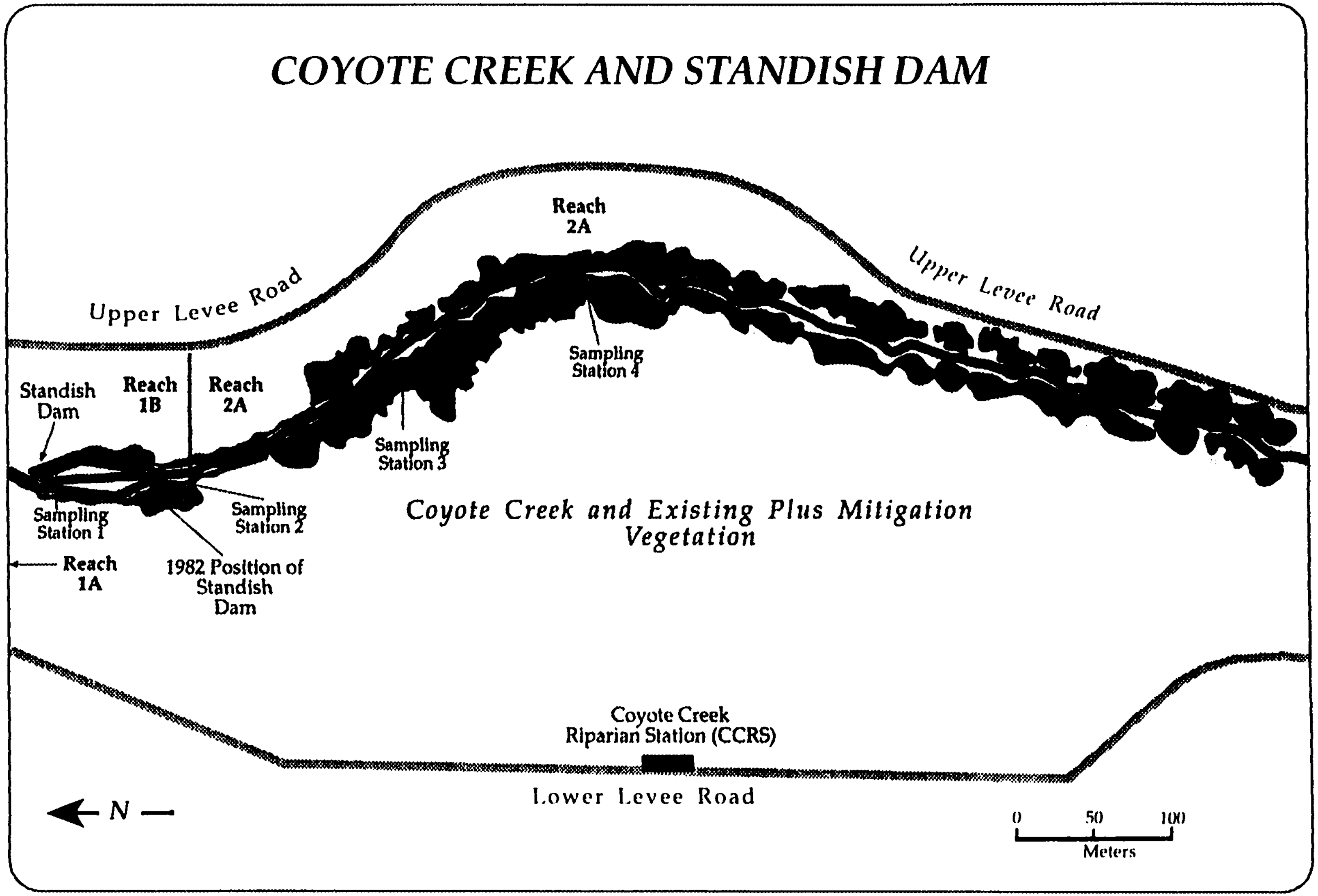

Fig. 2. Coyote Creek Revegetation Project showing reaches and Standish Dam

capturing birds and wildlife along the creek in order to assess how successfully the restored riparian system attracts and provides habitat for wildlife populations.

In order to comply with the Army Corps of Engineers (COE) and the United States Fish and Wildlife Service (USFWS), SCVWD must monitor wildlife use of the riparian habitat system for the life of the mitigation project (Berger 1990, 113). Otahal (1994) found that neotropical migratory songbirds, such as Wilson's Warblers (*Wilsonia pusilla*), use the Coyote Creek Restoration Project site as a vital rest stop on their journey to their breeding grounds in the Western United States (Chris Otahal, pers. comm. 1994).

The Removal of Standish Dam

The SCVWD has commissioned several studies in an attempt to determine the effect of the impoundment of fresh water behind Standish Dam on groundwater salinity levels and surface water temperatures. Standish Dam is a simple earthen dam installed each year in May and removed by October. Four culverts permit the outflow of fresh water during low tide, but during high water the force of the tides close the culverts automatically.

In 1993, the Habitat Restoration Group (HRG) and Jones and Stokes Associates monitored water quality along lower Coyote Creek (Jones and Stokes & HRG 1994). Testing took place along Reaches 1A (downstream of Standish

Dam - not shown in Fig. 2.), 1B, and 2A of Coyote Creek. Salinity and water level data were taken from 23 wells and compared with data taken following dam installation and removal. This work determined that the installation of the seasonal dam influences groundwater and salinity levels in section 1B and within 304 meters upstream of the dam's location. In this area the groundwater gradient adjacent to lower Coyote Creek varies with dam placement and removal. After placing the dam, a deep freshwater lake fills the channel and the gradient directs ground water away from the channel. Trapping fresh water lowers the salinity of well water within the section upstream of the dam during the summer. Conversely, with dam removal, groundwater flows into the channel, the lakebed channel is returned to tidal action, and the channel water becomes more saline. Salinity levels were also high in two wells, within section 2A, approximately one kilometer upstream of the dam (Tom Iwamura, pers. comm. May 1996) (Jones & Stokes Associates and HRG, Inc. 1994).

The Jones and Stokes report (1995) concludes that Standish Dam has no direct benefits for anadromous fishery resources; the shade plantings have failed as mitigation to restore lake temperatures to those present before the flood control project. Jones and Stokes & HRG (1995) have determined, however, that the dam may indirectly benefit riparian vegetation and wildlife in the following ways:

1. By diminishing the tidal influence from the Bay, the dam enhances

the chances of survival for the restored and existing riparian vegetation.

2. The wildlife habitat provided by the riparian vegetation improves as a function of time.
3. Soil moisture is made more available to vegetation by raising the water table for approximately 304 meters upstream of the dam.

The differences between the soils upstream and downstream of the dam have significant implications for the ability of the area to support tree species. The region upstream from the dam contains fine grained, nearly level, and generally well drained Mocho Loam soils. These highly fertile soils appear slightly sticky, plastic and calcareous. The pH is 8.0. Downstream of the dam, a clay substrate supports a shallow groundwater table. These Pacheco Loam, calcareous soils also have a pH of 8.0 (Tom Iwamura, pers. comm. May 1996).

<u>CDFG, USFWS, EPA Concerns Over Further Loss of Riparian Vegetation</u>

CDFG, the Environmental Protection Agency (EPA), and USFWS have expressed concerns that discontinuing the seasonal installation of Standish Dam may result in the loss of existing vegetation and of the Coyote Creek Restoration Project's streamside forest trees, especially *Salix* and *Populus* species. These agencies and the public are also very concerned about the loss of riparian habitat in the Bay Area in general. Today, only one half of one percent of the historical riparian habitat of California remains - approximately 140,427 hectares (Smith 1980). Agriculture, urban sprawl, and the resulting need for flood control projects have contributed to the loss of riparian habitat throughout the state of California.

The SCVWD is concerned with the protection of their mitigation project. The other resource agencies are interested in preserving the remaining riparian vegetation surrounding the San Francisco Bay Area. All of the agencies could use information quantifying the tolerance of streamside forest species to salinity and predicting the effects of returned tidal flow to the areas of concern within lower Coyote Creek. This research is designed to assist them in managing this riparian resource. This work will also provide baseline data on the salinity tolerance of *Salix spp.* and *Populus spp.* which may be valuable to other riparian restoration projects, and to the process of planning for and mitigating against rising sea levels which are expected from global warming (Williams 1985).

LITERATURE REVIEW

Introduction

This research specifically addresses two questions. First, at what soil and water salinities are riparian species, such as *Salix spp.* and *Populus spp.*, found along the tidal creeks and rivers surrounding the lower San Francisco Bay? Second, what effects will returning tidal flow to Coyote Creek have on riparian species, such as *Salix spp.* and *Populus spp.* previously growing or planted along stream banks within Reaches 1B and 2A of lower Coyote Creek? This section will review the importance of physical and chemical limiting factors on riparian species and describe how salinity affects the ability of various plant species to take in water and nutrients.

Physical and Chemical Limiting Factors

Chemical limiting factors combine with physical factors such as temperature and moisture to determine the distribution of plants throughout the environment (Krebs 1994, 119). Light, soil conditions or substrate structure, and fire also play a role. Studies have demonstrated that adaptations to a habitat result in ecological limitations. These adjustments to the environmental conditions inhibit the ability of a species to survive in other habitats. In other words, individual plant species cannot perform optimally in all environments (Krebs 1994, 119).

Physical factors which limit hydrophilic plant species. A diverse set of variables determine which vegetation types inhabit a typical, western river, including regional climate, net precipitation, landscape patterns, stream gradient, floodplain width, annual peak flood to mean flow rates, frequency and duration of flooding, water chemistry, and human impacts (Mitsch 1993, 460).

Landform and hydrologic gradients also result in the changing vegetation patterns within the riparian zone. The watershed process is four-dimensional in nature. The longitudinal (upstream-downstream), lateral (floodplain-upland), and vertical (groundwater zone-streambed channel) interact constantly, while continuously varying temporally (Doppelt, et al. 1993, *xxv*).

A critical limiting factor for riparian vegetation is surface water salinity. Rozema (1988) found that physiological stresses on plants resulting from sea water include, toxic ion excess, water stress from excess salinity, and anaerobic conditions. These effects vary with differing soil types (Krebs 1994, 131).

Salinity and Its Effects

The terms salinity, conductivity, and total dissolved solids all refer to the aggregate of all soluble mineral residues contained in the soil or water. Sea water contains various proportions of the cations sodium, calcium, potassium, and magnesium. These combine with anions to form *salts*, such as sulfates, chlorides, nitrates, carbonates, and bicarbonates. The mean salinity level for ocean water is 35 parts per thousand (Carter 1988, 12).

Conductance is measured in mhos. It is the reciprocal of the unit of resistance, the ohm. Since conductance is a property which depends on the dimensions of the conductor, it is often referenced in mhos per square centimeter ($mhos/cm^2$) or millimhos per square centimeter ($mmhos/cm^2$). Total dissolved solids (TDS) are measured in milligrams per liter (mg/l) or their equivalent parts per million (ppm). Salinity is measured in parts per thousand (ppt), and at high salinity levels most of the salts are sodium chloride and potassium chloride. Conversion factors can be used to convert conductivity to salinity.

Effects on agricultural species. Although a paucity of data exists concerning the effects of salinity on native tree species, the University of California at Davis and the United States Department of Agriculture (USDA) have accumulated a considerable body of research concerning the adverse impacts of salinity on agricultural tree crops. These data will provide a useful comparative tool for evaluating the implications of high soil salinity levels on such indicators of sustainability as reproductive success.

The USDA has defined saline soil as a soil which contains concentrations of soluble salts in the range known to impair agricultural productivity. The excess salts hinder plant growth and development by limiting the absorption of water and nutrients. The conductivity of the soil controls the osmotic pressure (OP) of the soil solution, and OP affects the way in which plants exchange nutrients through the root system. The higher the conductivity of various single-salt solutions, the higher their osmotic pressure. Highly saline solutions reverse the osmotic pressure gradient and cause needed water to flow away from the plant's root system (USDA 1954, 16).

A comparison of salt tolerant halophytic species with salt-sensitive glycophytic species illustrates the way in which various plants respond to saline environments. Halophytes have adapted to high levels of salinity by accumulating sodium and chloride in their leaves. They use this store of ions for osmotic pressure adjustment. Further, the plants isolate these salts in the cytoplasm or organelles. In this way, the species prevent interference with metabolic processes and enzyme functions. These sophisticated adaptive mechanisms require outstanding transport mechanisms in order to maintain steep solute gradients. The mechanisms for adjusting to saline environments require energy and, as a result, lower growth rates (Lauchi et al. 1984, 18).

Glycophytes are plant species with minimal tolerance for saline environments. When grown in relatively low salt concentrations (below 6 ppt), they exclude salts by moving sodium, chloride, or both at slow rates from the roots upward. Most of these species do not have transport mechanisms capable of maintaining osmotic adjustments and wilt when exposed to these environments. Salt sensitive species, including trees, cannot control salt uptake, and lack the ability to compartmentalize these ions. The resultant high internal saline concentrations lead to tissue injury, and result in ion toxicity (Lauchi et al. 1984, 19).

Salinity tolerance levels. Plants vary considerably in the range of salinity they can tolerate. The USDA has published guidelines concerning expected plant conditions given soil salinity levels (Table 2).

Table 2. Salinity (ppt) effects on crops (USDA 1954, 9)

Effects Negligible	Sensitive Species Experience Reduced Yields	Yields of Many Crops Restricted	Salt Resistant Crops Only	Outside Range of Tolerance for Most Crops
0 - 1.27	1.28 - 2.55	2.56 - 5.11	5.12 - 10.23	10.24

The Salinity Laboratory in Riverside, California reported salt tolerances with yield decreases above these thresholds. Common crop trees, such as those found in the *Rosaceae* family, plum (*Prunus spp.*), orange (*Citrus spp.*), and grapefruit (*Citrus spp.*) all experienced yield loss when soil salinities exceeded 0.96 - 1.15 ppt (Maas 1984, 21).

Effects of the tidal environment on native plant species. Willoughby & Davilla (1981) found that water salinity and subsequent increases in soil salinities represented a limiting factor in the establishment and survival of vascular plants located 1.7 kilometers upstream of the Sacramento/San Joaquin estuary in the lower Sacramento River. Two primary variables restricted the distribution of vascular plants in the lower Sacramento River. First, elevation defined the distance between soil surfaces and tide levels, controlled the moisture content of the soil, and the frequency and depth of plant submergence. Second, the salinity of the surface water determined the salinity of the soil which had an important influence on the diversity of species distribution (Willoughby & Davilla 1981, 643).

Willoughby & Davilla (1981, 643) found that there were large variations between surface water salinities during normal rainfall years and drought years. They studied gauging station data taken at Collinsworth, California, and showed that mean monthly surface water salinity values, averaged over a period of thirteen years, varied between 0.5 and 2.0 ppt. Salinities during the 1977 drought year varied between 4.5 and 6.0 ppt.

Species in the zone of tidal influence distribute themselves from the shoreline to the top of the stream bank. Willoughby & Davilla (1981) found that rhizomatous herbs gained advantage over all other species in the zone between the river channel and the riparian woodland because of their high reproductive capacity. Arroyo willow (*Salix lasiolepis*) was the only woody species capable of sufficient vegetative reproduction to exist within this portion of the tidal streambank community. Of the seventy eight species present in the riparian zone, above the areas that were inundated by high tides, only ten percent were tree species (Willoughby & Davilla 1981, 645).

Physiological tolerances of *Salix* and *Populus spp*. *Salix spp*. and *Populus spp*. exist as the dominant tree species in the riparian woodlands which grow along the downstream reaches of Coyote Creek and other South Bay creeks.

Munz (1959) and Sawyer and Keeler-Wolf (1995) classified riparian woodlands as seasonally flooded wetlands. Sawyer and Keeler-Wolf (1995, 216) included in their classification system several series in which either *Salix spp*., or *Populus spp*. are important components:

1. A *Populus spp*. dominant
    - Black cottonwood (*P. balsamifera* = *P. trichocarpa*) series dominant
    - Fremont cottonwood (*P. fremontii*) series dominant
2. A *Salix spp*. dominant
    - Arroyo willow series
    - Pacific willow (*S. lasiandra*) series
    - Red willow (*S. laevigata*) series
    - Mixed willow series

These series are consistent with the riparian woodland vegetation in lower elevations surrounding the southern portion of the San Francisco Bay

(Sawyer and Keeler-Wolf 1995, 278). The *Populus fremontii* series and the mixed willow series are the most common associations in northern Santa Clara County streams. Within these two series, either *Populus spp.* or *Salix spp.* dominate, or they thrive in relatively equal numbers. These vegetation types and others exist within freshwater floodplains or in low-lying floodplains along the rivers of the Central Coast. The general location of these associations in relation to tidal effects is shown in figure 3 (Mitsch and Gosselink 1993, 268).

The genera *Salix* and *Populus* are part of the willow family (*Salicaceae*) (Jepson 1993, 988). Streambanks throughout California provide habitat for the red willow and the pacific or yellow willow. Both of these species, as well as the arroyo willow, require high soil moisture content and tolerate inundation during episodic storm events. They can survive in a variety of soil types including clay hardpan, and shallow and sandy soil, but cannot endure soils which swell and contain heavy plastic clays. Seeds mature in the summer, but only retain their viability for a few days. All species have shallow, long, invasive roots which can extend to between 3.7 and 4.6 meters in their search for groundwater. They can survive within the active channel and thrive along the lower and middle slope of river floodplains (Kusler et al. 1990, 359).

The Sacramento River Valley and the western hills bordering the valley, the Sierra Foothills in Southern California, and the riparian woodlands of the Mojave Desert comprise the native range of the Fremont cottonwood. These

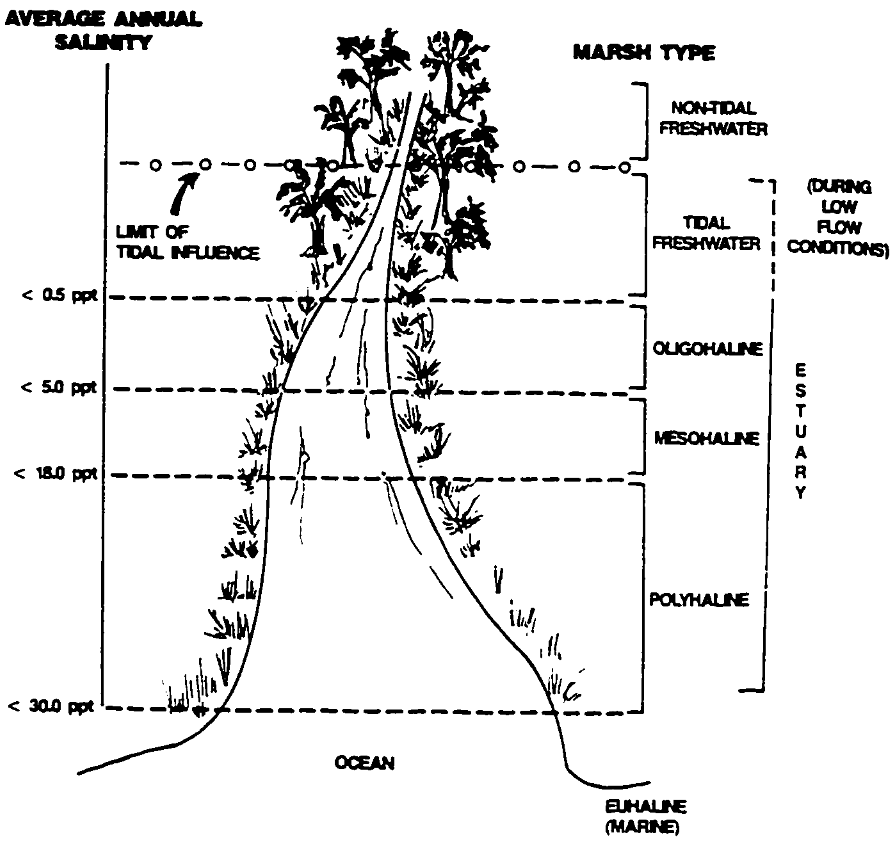

Fig. 3. Illustration of the gradient of decreasing salinity as a function of distance from the ocean or bay: Source: Mitsch & Gosselink. 1993

open crowned, 12 to 27 meter deciduous trees have deep invasive roots, and thrive in flatlands, and along the lower, middle, and upper slopes of riverine floodplains. Fremont cottonwoods tolerate many soil types, but prefer the sandy, humus of river bottoms. They require constant moisture, and their roots can travel 5.5 meters in search of a good underground water source (Waxman 1996, F-12).

Black cottonwoods are common throughout the state along streams below 2,700 meters. These tall, majestic cottonwoods have shallow root systems compared with those of the Fremont cottonwood. Locally, they exist as a part of the riparian ecosystems of Central Coast rivers and streams. Fremont cottonwood and black cottonwood hybridize along Stevens Creek (Linda Spahr, pers. comm. June 1996). *Populus* tolerates inundation caused by flooding, but their tolerance to saline soils is unknown (Waxman 1996, F-13).

Adaptations of *Scirpus californicus* and *Scirpus robustus*. Bulrushes *(Scirpus spp.)* are typically found downstream from the *Salix spp.* and *Populus spp.* zone in tidal streams such as Coyote Creek. California bulrush *(Scirpus californica)* and alkali bulrush *(Scirpus robustus)* are perennial sedges found commonly in freshwater and brackish marshes throughout California. Alkali bulrush does best at lower elevations and requires frequent shallow inundation. This species endures moderately strong wave action when surface water salinities are below 20 ppt. California bulrush thrives between 1.2 meters above mean low low water and mean high high water and tolerates moderate wave action and considerable submergence. Soil salinities below 15 ppt provide optimal growth and reproductive habitat (Waxman 1996, F-107).

PROBLEM STATEMENT AND OBJECTIVES

On April 18, 1996, SCVWD began a one year study of the question of whether discontinuing Standish Dam will have adverse effects on existing vegetation and on selected sections of the Coyote Creek Revegetation Project. Lake water quality and fish sampling studies have not substantiated the value of the dam to existing fishery resources (Jones and Stokes and HRG 1994). The Water District needed more complete data concerning the effects of discontinuing the dam on riparian vegetation in order to determine whether the revegetated and naturally occurring riparian species of lower Coyote Creek would be preserved if the dam was removed permanently. The primary question this thesis will consider is: to what extent will increased salinity caused by renewed summer tidal influx affect the viability of tree species that previously existed or were planted along lower Coyote Creek.

In order to address this problem, the thesis work will focus on two questions. Question 1) What are the locations of mixed willow and cottonwood riparian associations at 3 control streams in the south San Francisco Bay region in relation to soil and water salinities? Specifically, this thesis will statistically test this question: Do transitions between streamside tree species clearly correlate with gradations in the salinity of soils and surface waters and indicate a downstream limit for riparian tree species? None of these streams have a downstream dam, such as Standish Dam on Coyote Creek. Question 2) These data will then be compared to the location of riparian associations along lower Coyote Creek and the soil and water salinities there. These comparisons will allow an assessment of the question: How will reinstating the tidal flow to the lower section of Coyote Creek affect the tree species growing along the lower Coyote Creek?

METHODS

Establishment of Sampling Stations on the Control Streams

The four sampling locations delimit a range along the control creeks, Stevens Creek, Matadero Creek, and the Guadalupe River, which begins where riparian vegetation dominates and ends where only saline-tolerant marsh vegetation, such as *Scirpus spp.*, persists.

Along the Guadalupe River and Stevens Creek, tidal marsh species dominate in the area closest to the Bay. On both streams the transitional area dominated by California bulrush and alkali bulrush continues for approximately one kilometer upstream. Station number one was established in this brackish zone. The second study site corresponded with the next upstream zone in which arroyo willow began to occur. Along Stevens Creek a large proportion of non-native, ruderal species also exist in this section. There were no red willow, Pacific or yellow willow, or *Populus spp.* present in this section of either stream. Further upstream from the Bay, both water bodies are dominated by *Salix spp.* and *Populus spp.*, although California bulrush also persists. On both streams, the third station marked the downstream limit for Fremont cottonwoods, and the fourth station was located where a full stand of riparian tree species first occurred (Fig. 4 and 5).

The third control stream in the study area, Matadero Creek, provided an informative contrast. Near the Bay, the creek becomes part of the Palo Alto Marsh Enhancement Project (PAMEP). The PAMEP was established in 1987, and has created a freshwater marsh using reclaimed water from the Palo Alto Regional Water Quality Control Plant and a salt water marsh by restoring tidal water to the nature preserve via culverts from the Bay. Both fresh and salt water are pumped into Matadero Creek (Fig. 5). Soil and surface water sampling also took place at four stations along Matadero Creek. The first station characterized the soil and surface water salinity present in a brackish marsh dominated by bulrushes. The next sampling station measured the soil and surface water salinity of a zone dominated by red willow, pacific or yellow willow, and arroyo

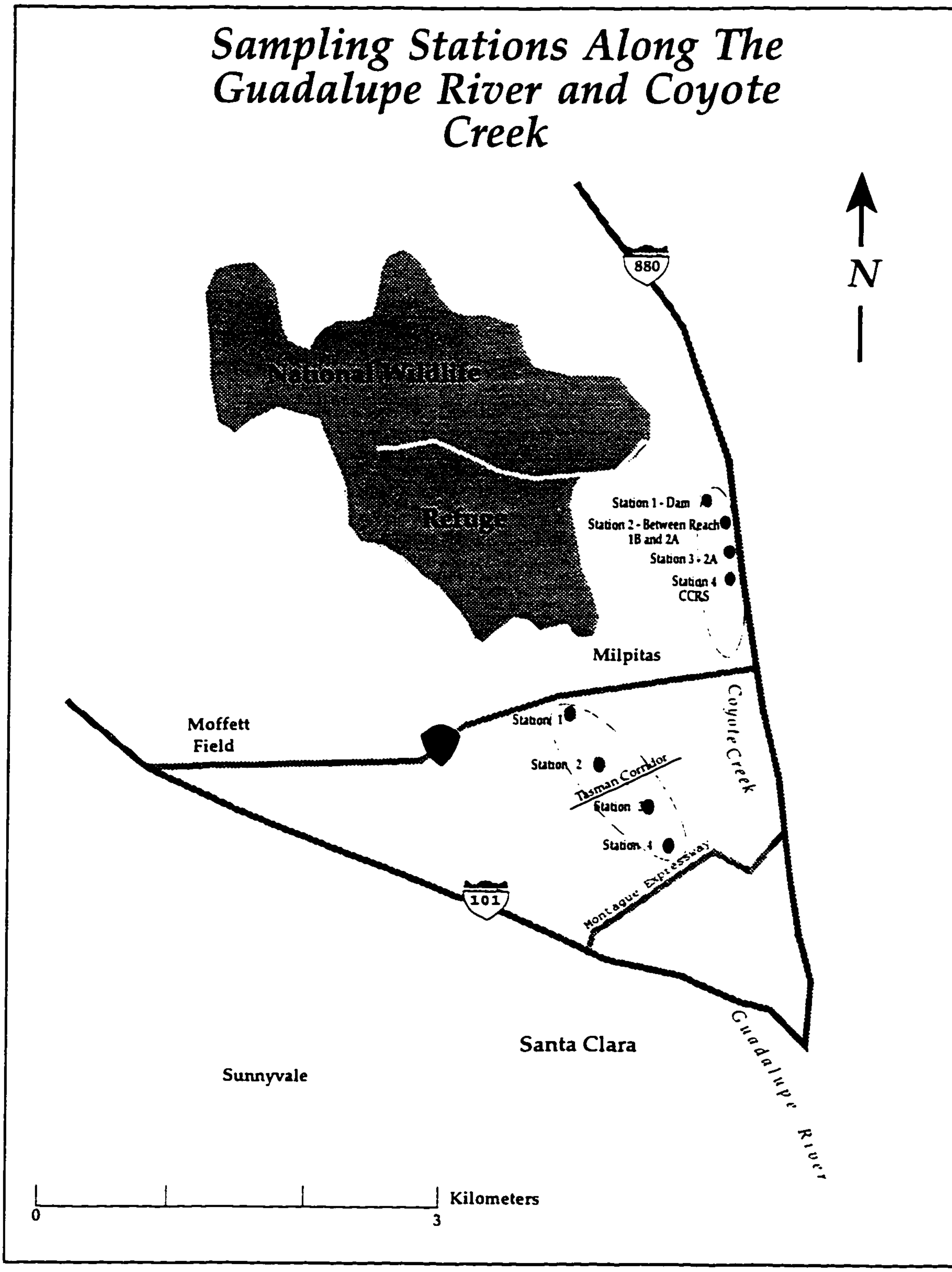

Fig. 4. Map of Guadalupe River and Coyote Creek sampling locations

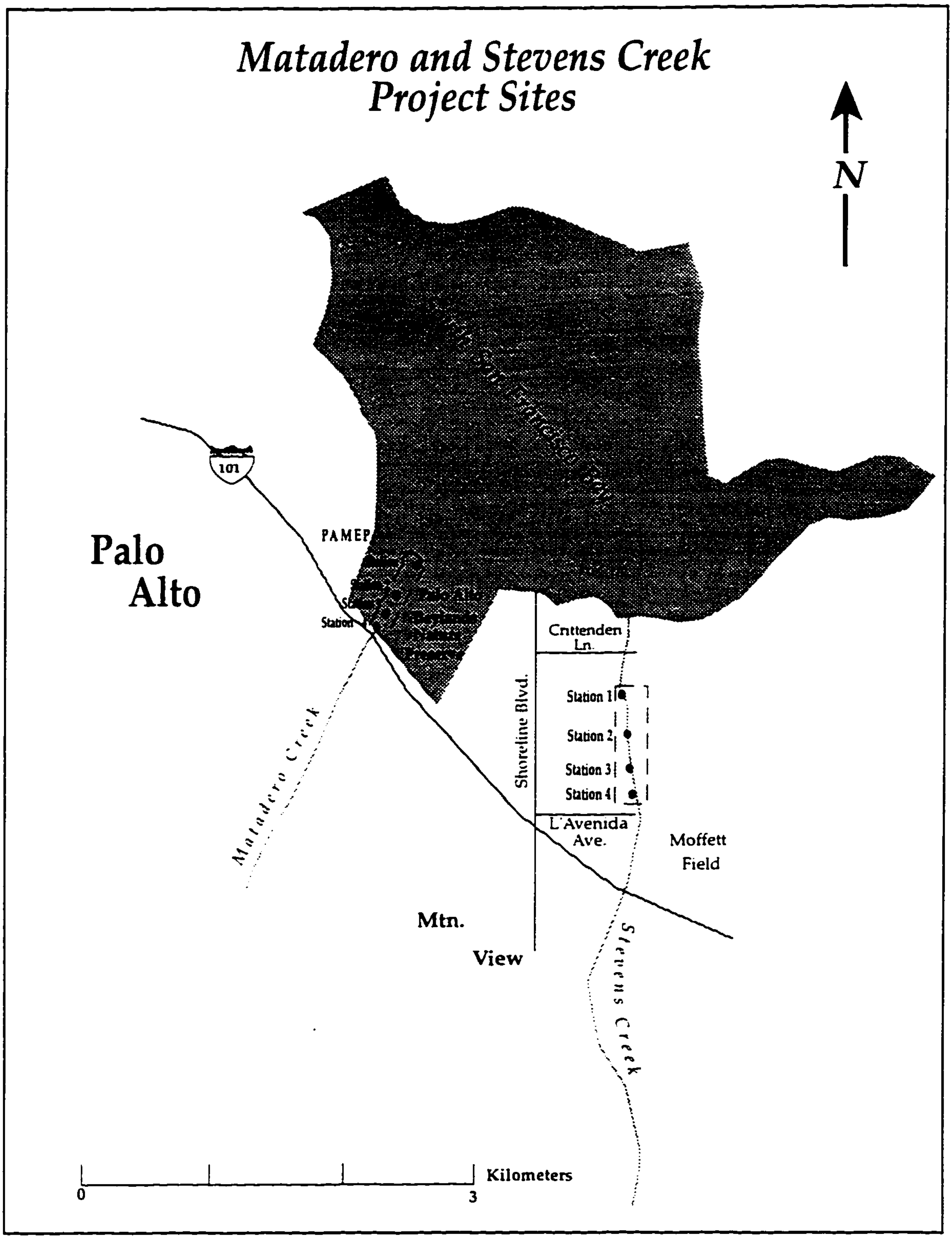

Fig. 5. Map of Stevens and Matadero Creek sampling locations

willow, although a few black walnuts (*Juglans hindsii*) have established themselves upland of the willows. Water from the salt marsh is pumped into the creek approximately 500 meters downstream, and the streamside vegetation is less diverse than the forest immediately upstream. Fresh water flows through a culvert into the upper portion of the study area, and this section contains a diverse riparian community of California buckeye (*Aesculus californicus*), black walnut, box elder (*Acer negundo*), red willow, pacific or yellow willow, arroyo willow and California bulrush. Two sampling stations were set up at roughly equal intervals in this section.

Salinity Sampling

Sampling took place once a week from late July until the end of November 1996, at 4 sampling stations set up along each stream. A YSI model salinity meter was used to measure surface water salinity. When sampling in an heterogeneous environment, accounting for spatial variability becomes important. The surface water was tested at a distance of one meter from the shoreline, and at four 0.30 meter increments vertically. Readings were averaged for that sampling location (Dr. Rhea Williamson, Pers. Comm. 1996). Sampling took place over a range of tidal conditions between high high water (HHW) and high low water (HLW). The highest tides during the sampling period were 2.07 meters (6.8 feet).

Composite soil samples were taken from the root zone of adjacent relevant tree species at a depth of between six and fifteen centimeters below the crust. Four samples, randomly selected around each tree, comprised the composite. The collection points varied each time (USDA 1954, 83).

Preparation of a soil saturation extract was done in accordance with USDA instructions (USDA 1954, 84). A Kelway salinity "direct indicating bridge" was used to measure the electrical conductivity of soil solutions. The conductivity cell reads directly from 0.06 to 6.4 ppt, and is operated by alternating current. This method is useful when taking numerous soil samples, and is considered accurate enough (1% full scale) for diagnostic purposes (USDA 1954, 89).

When soil conductivity fell near the upper range of the Kelway meter, the samples were sent to Perry Laboratory in Watsonville. This well regarded laboratory uses a Beckman Solubridge for analysis of electrical conductivity. This direct indicating bridge is accurate to 0.006 ppt.

Taking data from late July through November allowed for analysis of summer to fall variations. Throughout the sampling period surface water salinity was high due to low stream flow rates. The sampling period also coincided with the time when the dam restricts tidal flow in Coyote Creek.

Vegetation Sampling

The diversity and abundance of tree species at the four sites on each creek were determined by running a belt transect perpendicular to the creek at each of the monitoring stations. Trees growing within 5 meters on either side of the line were counted. Seedlings (plants under one half meter in height) were tallied separately to provide baseline information concerning the health and recruitment of the trees established under current conditions (Krebs 1994, 155).

Coyote Creek Methods

The strategy for assessing the potential effects of reinstating the summer tidal flow to lower Coyote Creek required data upstream and downstream of the dam. When the dam was removed in October, the soil and surface water salinity of the water upstream of Standish Dam was measured at 4 sampling locations spaced at intervals beginning 30 meters upstream of the dam and ending at a station adjacent to the CCRS. The positions of the sampling stations were marked during a 1.8 meter tidal cycle, and coincided with drops in surface water salinity of approximately 2 ppt per station beginning at the dam and ending at the station adjacent to CCRS. These testing sites accounted for both existing trees and those planted as mitigation. Soil samples were taken within 4.6 meters of the shoreline. The water salinity was also measured 30 meters downstream of the dam weekly from late July to the end of November.

ANALYSIS

Question One

A Pearson's correlation coefficient was used to test whether or not soil and surface water salinities at each station were related. Student t-tests compared mean soil salinities from each of the four stations at each creek to each other. Student t-tests were also used to determine if soil salinity measurements taken along each control creek were statistically different from the mean values taken at corresponding stations at other control creeks. The mean soil salinity values measured at the four monitoring stations on the control creeks were compared with the diversity and abundance of tree species located adjacent to these various monitoring stations.

Question Two

Finally, the investigation assessed the potential adverse effects of removing Standish Dam and restoring summer tidal flow to Coyote Creek. I compared mean soil salinity values from each station along Coyote Creek with the more downstream stations (brackish species only) of each of the reference streams, and progressed to upstream stations until no statistical differences were found.

RESULTS

Mean surface water salinity declined as sampling moved upstream in all four streams (Tables 3 and 5). These declines were paralleled by decreases in soil salinity moving upstream in all four streams (Tables 4 and 5). Within each stream the soil and surface water were significantly correlated (Table 6) with r^2 values of 0.36 - 0.8. Highest correlations were for Stevens Creek and Guadalupe River which were unmodified by dams and culverts.

Table 3. -- Mean +/- standard deviation of surface water salinity (ppt) at Stevens Creek, Matadero Creek and the Guadalupe River

	Station #1 - No Trees	Station # 2 *Salix spp.* begin	Station # 3 *Populus spp.* begin	Station # 4 Full Stand
Stevens Creek	5.4 +/- 1.9	1.0 +/- 1.1	0.5 +/- 0.2	0.3 +/- 0.4
Matadero Creek	5.7 +/- 1.0	3.8 +/- 1.4	1.9 +/- 1.1	0.8 +/- 0.3
Guadalupe River	2.4 +/- 0.6	1.0 +/- 0.3	0.4 +/- 0.1	0.3 +/- 0.1

Table 4. -- Mean +/- standard deviation of soil water salinity (ppt) at Stevens Creek, Matadero Creek and Guadalupe River

	Station #1 - No Trees	Station # 2 *Salix spp.* begin	Station # 3 *Populus spp.* begin	Station # 4 Full Stand
Stevens Creek	1.7 +/- 0.3	0.8 +/- 0.3	0.9 +/- 0.3	0.6 +/- 0.2
Matadero Creek	1.3 +/- 0.3	0.9 +/- 0.3	0.6 +/- 0.2	0.6 +/- 0.2
Guadalupe River	1.4 +/- 0.3	0.7 +/- 0.3	0.7 +/- 0.2	0.6 +/- 0.3

Table 5. -- Mean +/- standard deviation of surface water and soil water salinity (ppt) at Coyote Creek

	Station #1 - Dam	Station # 2	Station # 3 2A	Station # 4 CCRS
Coyote Creek Surface Water	6.7 +/- 1.9	4.4 +/- 1.9	3.2 +/- 2.3	1.1 +/- 0.9
Coyote Creek Soil	5.9 +/- 5.1	5.1 +/- 2.6	4.6 +/- 6.1	0.9 +/- 0.4

Table 6. -- Results of Pearson's Correlation Coefficient between surface water mean salinity and soil water salinity

Stream	r Value	P
Stevens Creek - r (*df* - 63)	0.92	< 0.001
Matadero Creek - r (*df* - 63)	0.64	< 0.001
Guadalupe River - r (*df* - 63)	0.94	<0.001
Coyote Creek - r (*df* - 63)	0.57	<0.001

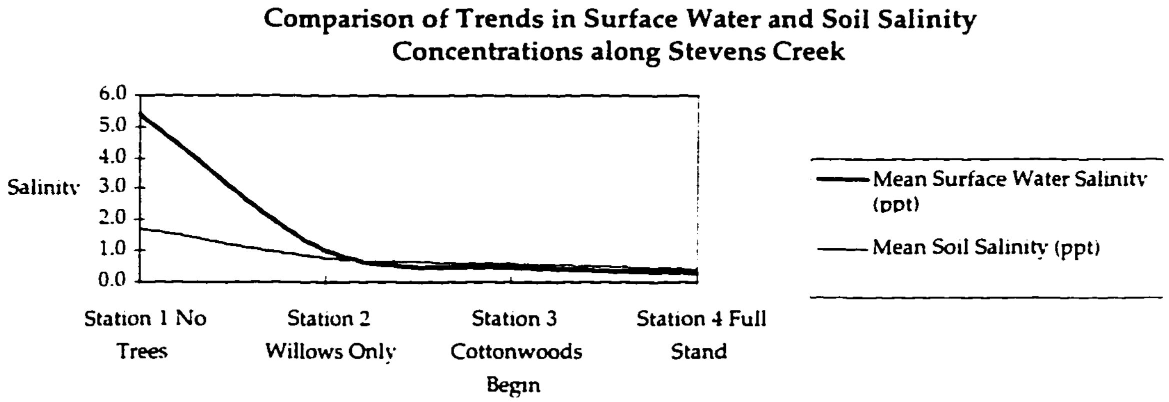

Fig. 6. Mean surface water and soil salinities along Stevens Creek (ppt)

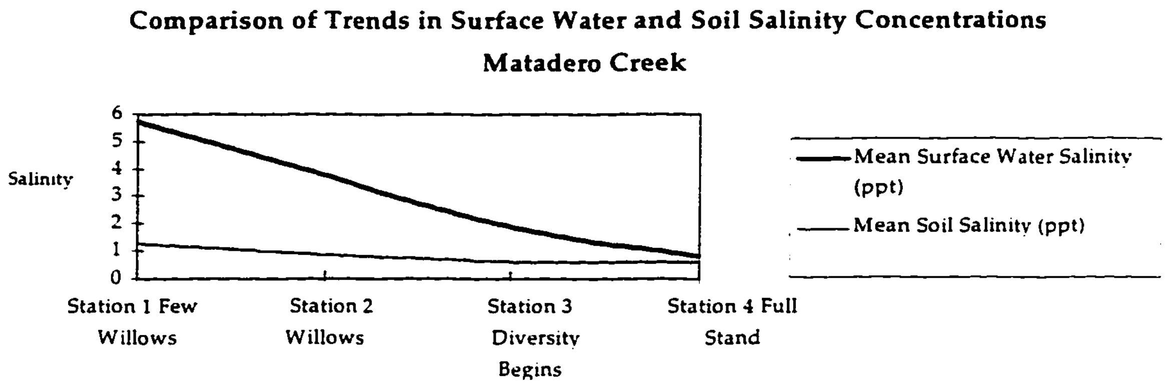

Fig. 7. Mean surface water and soil salinities along Matadero Creek (ppt)

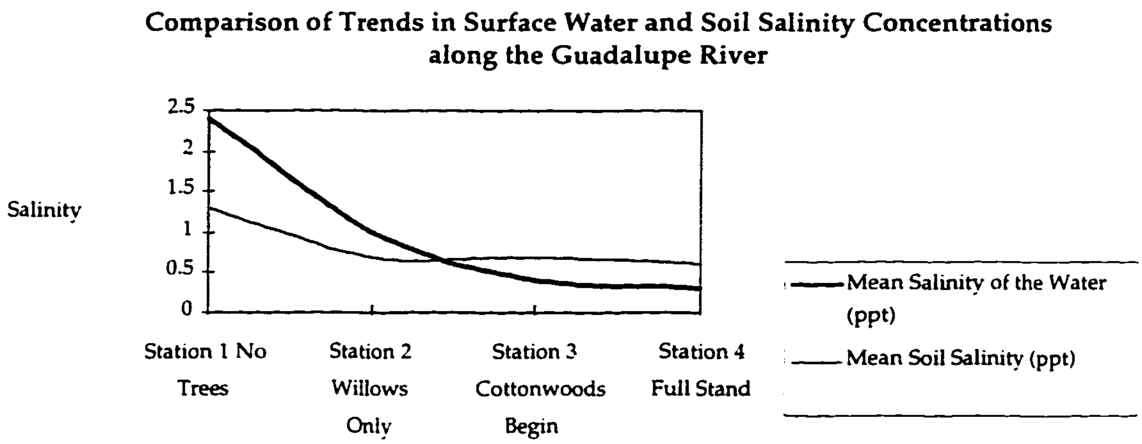

Fig. 8. Mean surface water and soil salinities along the Guadalupe River (ppt)

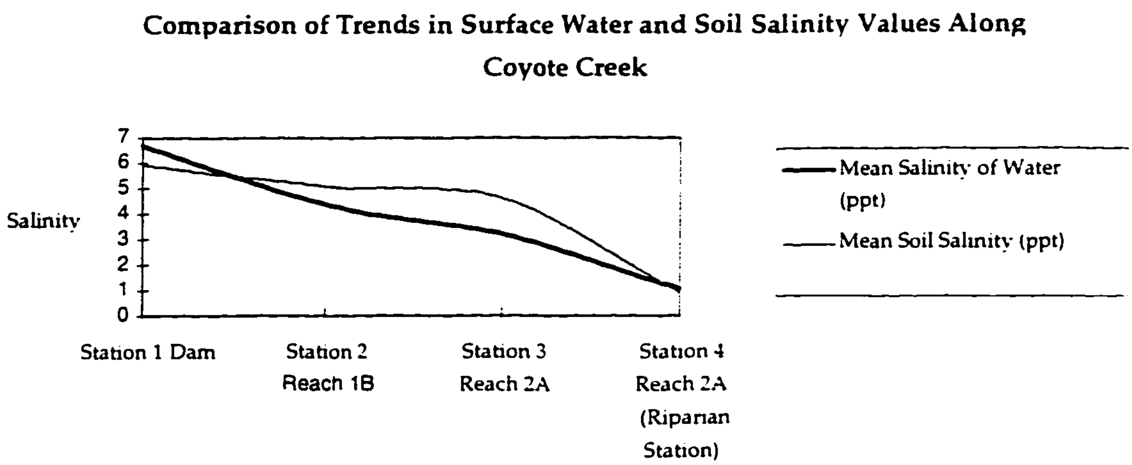

Fig. 9. Mean surface water and soil salinities along the Coyote Creek (ppt)

The t tests compared mean soil salinity data from all four stations within the three reference streams and determined that station 1, which lacked trees, was significantly higher in soil salinity than adjacent upstream stations. Mean soil salinity at station 2 on Matadero Creek was significantly higher than at station 3, and soil salinity at station 2 on Stevens Creek was significantly higher than at station 4 (Table 7).

Soil salinity values for comparable stations on the three control streams were then compared with student t-tests to see if there were significant differences between corresponding stations across streams. The three upstream stations showed no significant differences from their counterparts on the other streams, except for stations 4 on Stevens Creek and Matadero Creek. Means for station 1 were significantly different in comparisons for all 3 streams (Table 8).

Table 7. - Results from student t tests comparing means soil salinity between sites within each control stream

	Observed t	Critical t and Significance level	H_0 rejected or upheld
Stevens Creek Comparison Between Stations: (*df* - 30)			
Station 1 versus 2	7.00	3.646 (0.001)	rejected
Stations 2 versus 3	1.84	2.042 (0.05)	upheld
Station 3 versus 4	2.041	2.042 (0.05)	upheld
Station 1 versus 4	15.30	3.646 (0.001)	rejected
Station 2 versus 4	3.32	2.750 (0.01)	rejected
Combined stations 3 and 4 versus station 1 *df* - 46	12.29	3.505 (0.001)	rejected
Combined stations 3 and 4 versus station 2 *df* - 46	2.84	2.682 (0.01)	rejected
Matadero Creek Comparison Between Stations: (*df* - 30)			
Station 1 versus 2	3.81	3.646 (0.001)	rejected
Station 2 versus 3	2.80	2.042 (0.05)	rejected
Station 3 versus 4	0.00	2.042 (0.05)	upheld
Station 1 versus 4	6.73	3.646 (0.001)	rejected
Station 3 and 4 combined versus 1 (*df* - 46)	7.23	3.505 (0.001)	rejected
Station 3 and 4 combined versus 2 (*df* - 46)	3.11	3.505 (0.001)	rejected
Guadalupe River Comparison Between Stations: (*df* - 30)			
Station 1 versus 2	6.00	3.46 (0.001)	rejected
Station 2 versus 3	0.33	2.042 (0.05)	upheld
Station 3 versus 4	1.42	2.042 (0.05)	upheld
Station 1 versus 4	7.54	3.646 (0.001)	rejected
Station 2 versus 4	1.225	2.042 (0.05)	upheld
Station 2, 3 and 4 combined versus 1 (*df* - 62)	7.84	3.46 (0.001)	rejected

Table 8 - Results from student t tests comparing mean soil salinity for corresponding stations on the control creeks

	Observed t	Critical t and Significance level	H_o rejected or upheld
Stevens Creek Comparison With the Guadalupe River			
Stevens Creek 3 and 4 versus Guadalupe River 2, 3 and 4 (*df* - 78)	4.07	3.640 (0.001)	rejected
Stevens Creek 3 and 4 versus Guadalupe River 3 and 4 (*df* - 62)	2.89	2.660 (0.01)	rejected
Stevens Creek Station 4 versus Guadalupe River Station 4 (*df* - 30)	1.58	2.042 (0.05)	upheld
Stevens Creek Station 3 versus Guadalupe River Station 3 (*df* - 30)	1.73	2.042 (0.05)	upheld
Stevens Creek Station 2 versus Guadalupe River Station 2 (*df* - 30)	0.53	2.042 (0.05)	upheld
Stevens Creek Station 1 versus Guadalupe River Station 1 (*df* - 30)	2.80	2.750 (0.01)	rejected
Stevens Creek Comparison With the Matadero Creek: (*df* - 30)			
Station 4 versus Station 4	3.11	2.750 (0.01)	rejected
Station 3 versus 3	1.73	2.042 (0.05)	upheld
Station 2 versus 2	1.05	2.042 (0.05)	upheld
Station 1 versus 1	2.50	2.042 (0.05)	rejected
Guadalupe River Comparison With the Matadero Creek: (*df* - 30)			
Station 4 versus 4	0.71	2.042 (0.05)	upheld
Station 3 versus 3	0.87	2.042 (0.05)	upheld
Station 2 versus 2	1.75	2.042 (0.05)	upheld
Station 1 versus 1	0.0	2.042 (0.05)	upheld

Table 9 gives the abundance of trees by species counted in the 10 meter transects at each of the stations along the three reference creeks. Station 1 contained only one tree, a willow. Station 2 was dominated by *Salix spp.*, and included two *S. spp.* seedlings. At station 3, *S. spp.* was most abundant, however, other tree species, such as *Populus spp.* and their seedlings, were also common. Along Stevens Creek and the Guadalupe River station 4 was dominated by *P. spp.* A diverse stand of riparian tree species, including box elder and California buckeye, dominated station 4 along Matadero Creek.

Table 9. -- Tree species (seedlings) counted along transects at four stations along Stevens Creek, the Guadalupe River, and Matadero Creek

	Station 1 Downstream	Station 2	Station 3	Station 4 Upstream
Stevens Creek				
Salix spp.		5	4	
Populus spp.			4 (4)	11 (2)
Guadalupe River				
Salix Spp		2	5 (4)	6
Populus spp.			1	12 (3)
Matadero Creek				
Salix Spp	1	5 (2)	6	2
Populus spp.				
Other Tree Species		1	5	7 (2)

Mean soil salinity values for the entire data set ranged between 0.4 ppt and 1.7 ppt. The range was arbitrarily divided into four roughly equal intervals to assess the distribution of tree species relative to mean soil salinity values. With the exception of one *Salix spp.*, all trees fell between 0.4 ppt and 0.99 ppt. Twenty one of the twenty two *Populus spp.* occurred below 0.69, as did thirteen of the fourteen trees of other species (Table 10) (Fig. 10).

Table 10. -- Distribution of trees on Stevens Creek, Matadero Creek, and the Guadalupe River by soil salinity (ppt)

Range of Mean Soil Salinity Values	*Salix Spp.* Within That Range	*Populus Spp.* Within That Range	Other Tree Species Within That Range
0.4 - 0.69	14	21	13
07 - 0.99	17	1	1
1.0 - 1.29			
1.3 - 1.6	1		

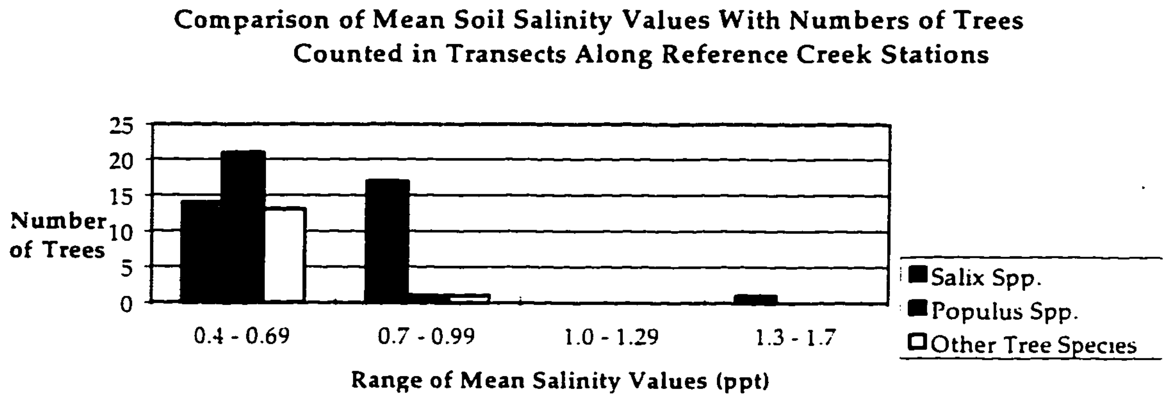

Fig. 10. -- Frequency distribution of tree species relative to mean soil salinity values

Soil salinity values acted as a good predictor of aggregate tree species distribution along Matadero Creek, as there were strong negative correlations between soil salinity and tree abundance (Table 11).

Table 11. - Pearson's Correlation Coefficients for soil salinity versus tree abundance for sites on three reference streams

Stream	r	p
Stevens Creek - r (*df* - 3)	-0.61	< 0.05
Matadero Creek - r (*df* - 3)	-0.96	< 0.01
Guadalupe River - r (*df* - 3)	-0.80	< 0.05

Coyote Creek Results

Whether reinstating tidal flow to the lower section of Coyote Creek will have adverse effects on the *Salix spp.* and *Populus spp.* that existed or were planted, can be assessed by comparing Coyote Creek salinity values to those of the control creeks.

The analysis examined whether significant statistical differences existed between the mean values of soil samples taken from station 1, with the highest soil salinity at each of the control creeks, and the mean values of soil samples taken from all four stations along Coyote Creek. The student t test was used when the F test demonstrated that variances were not significantly different. When variances were significantly different the Wilcoxon T test was used.

The mean soil salinity values for all three downstream sites along Coyote Creek were higher than the means of the most downstream station along each of the control creeks, even though the downstream stations used for comparison had sufficient salinity to preclude trees. The soil salinity at Station 4 on Coyote Creek, adjacent to CCRS, corresponded to the stations along the three reference creeks which contain only *Salix spp* . Thus, the data show that even at the most upstream station of Coyote Creek, the soils were significantly more saline than the soils surveyed at locations where full stands of *Populus spp.* and other diverse riparian tree species were found. All 4 stations along Coyote Creek contained a full stand of *Populus spp.* and *Salix spp.* similar to the stands existing at station 4 of the reference sites, even though soil salinities at the 3 downstream sites contained only *Scirpus spp.* on the 3 reference streams (Table 12).

Table 12. - Results from student t and Wilcoxon T-tests comparing differences between mean soil salinity values taken from control creeks with mean soil salinity values taken along Coyote Creek

	Observed T (F or t when stated)	Critical Factors and α levels	H_o rejected or upheld
Stevens Creek Comparison With the Coyote Creek: (*df* - 9)			
Stevens Creek 1 and Coyote Creek 1 (Dam)	1	1 (0.01)	rejected
Stevens Creek 1 and Coyote Creek 2 (1B)	0	1 (0.01)	rejected
Stevens Creek 1 and Coyote Creek 3 (2A-1)	4	5 (0.05)	rejected
Stevens Creek 1 and Coyote Creek 4 (CCRS) (*df* =23)	F = 0.3	2.64 (0.05)	upheld
Stevens Creek 1 and Coyote Creek 4 (CCRS) (*df* = 23)	6.9 (t-test)	3.646 (0.001)	rejected
Stevens Creek 2 and Coyote Creek 4 (CCRS) (*df* = 23)	1.2	2.042 (0.05)	upheld

Table 12. continued

Matadero Creek Comparison With the Coyote Creek: (*df* - 9)			
Matadero Creek 1 and Coyote Creek 1 (Dam)	1	1 (0.01)	rejected
Matadero Creek 1 and Coyote Creek 2 (1B)	0	1 (0.01)	rejected
Matadero Creek 1 and Coyote Creek 3 (2A-1)	4	5 (0.05)	rejected
Matadero Creek 1 and Coyote Creek 4 (CCRS) (*df* = 23)	F = 0.3	2.64 (0.05)	upheld
Matadero Creek 1 and Coyote Creek 4 (CCRS) (*df* = 23)	4.1 t-test	3.646 (0.001)	rejected
Matadero Creek 2 and Coyote Creek 4 (CCRS) (*df* = 23)	0.0	2.042 (0.05)	upheld
Guadalupe River Comparison With the Coyote Creek: (*df* - 9)			
Guadalupe River 1 and Coyote Creek 1 (Dam)	1	1 (0.01)	rejected
Guadalupe River 1 and Coyote Creek 2 (1B)	0	1 (0.01)	rejected
Guadalupe River 1 and Coyote Creek 3 (2A-1)	3	5 (0.05)	rejected
Guadalupe River 1 and Coyote Creek 4 (CCRS) (*df* = 23)	F = 0.56	2.042 (0.05)	upheld
Guadalupe River 2 and Coyote Creek 4 (CCRS) (*df* = 23)	1.9 t-test	2.042 (0.05)	upheld

Summary

Significant differences existed between the soil salinities surveyed in upstream stations inhabited by *Populus spp.* and other diverse tree species, and the salinity of the soils in which *Scirpus spp.* dominate. Along Stevens and Matadero Creeks, *Salix spp.* demonstrated a tolerance to significantly higher salinity than *Populus* and other tree species. The data established that a negative correlation exists between the abundance of *Populus* trees and soil salinity, especially along Matadero Creek. Gradations in the salinity of soil and surface waters did correlate with floristic transitions, and did indicate a downstream limit for riparian tree species. No riparian trees were found at soil salinity values greater than 1.34 ppt, or water salinity values greater than 5.7 ppt. Sixty seven of the sixty eight trees counted (98.5%) were found at soil salinity values less than 0.99 ppt, and surface water salinities less than 3.8 ppt.

Statistically significant differences were found to exist between the mean values of soil samples taken from the stations along the control sites, and the mean values of soil samples taken from three of the four stations along Coyote Creek. However, the relationship of soil salinity to vegetation was different between the control streams and Coyote Creek (Table 13).

Table 13. -- Comparison of mean soil salinity values (ppt) and vegetation types on control streams and on Coyote Creek

	Control Streams	Coyote Creek (Dam, 1B, 2A)	Coyote Creek (CCRS)
Diverse Tree Species and *Populus spp.*	0.4 - 0.8 ppt	4.6 - 5.9 ppt	0.9 ppt
***Salix spp.* only**	0.3 - 0.9 ppt		

DISCUSSION

Introduction

The primary question addressed by this thesis was: How will reinstating the tidal flow to the lower section of Coyote Creek affect the tree species, such as *Salix spp.* and *Populus spp.*, that were planted as mitigation or grow naturally along the lower Coyote Creek?

The answer to this question requires considering the tolerances of these species to the more saline conditions which will be created when the dam is removed.

The literature review described the problems glycophytic species experience when subjected to saline conditions. These species do not have the transport mechanisms of salt tolerant halophytic species. They cannot maintain osmotic adjustments in these environments and, as a result, plant cells lose rigidity due to insufficient water.

An interesting relationship exists between the tolerance values for soil conductivity values reported by USDA for agricultural tree species and the frequency distribution of tree species relative to mean soil salinity found in this research (USDA 1954, 9). The salinity of the soils in which the diverse tree species and pure stands of *Populus spp.*, and *Salix spp.* live on the control creeks falls between 0.4 - 0.8 ppt. These salinities lie in the range of values for the USDA's *most benign* category. Between 0.0 and 0.6 ppt, agricultural plant species experience no negative effects. Tree species in the family *Rosaceae*, plum (*Prunus spp.*), orange (*Citrus spp.*), and grapefruit (*Citrus spp.*) trees all fell into this categories. For fruit trees, the maximum soil salinity without yield loss varied between 0.96 and 1.2 ppt (Maas 1984, 21). The range also describes the tolerance level of riparian tree species in the South San Francisco Bay, as sixty seven of the sixty eight trees counted were found at soil salinity values less than 0.99 ppt.

Two primary variables restrict the distribution of vascular plants in the tidal riverine systems: elevation and surface water salinity. Elevation defines the distance between the soil surface and water levels, controls the moisture content of the soil, and controls the frequency and depth of plant submergence. Typically, tree species only exist on islands or creek banks above the active channel. In the tidal zone, their exposure to inundation is minimal during the low flow conditions of the spring and summer months. The salinity of the surface water determines the salinity of the soil which has an important influence on the diversity of species distribution (Willoughby & Davilla 1981, 643).

Mitsch and Gosselink (1993) used a classification system for the Atlantic Coast which divided the estuary into zones representing the mean salinity of the surface water. They stated that this classification system most accurately represents low flow conditions, and depicts a downstream limit for the riparian tree species in this eastern system of less than 0.5 ppt. in surface water. Summer rains along the Atlantic Coast may influence the relationship between surface water and soil salinities. Differing variables, such as rainfall patterns, limit the conclusions that can be drawn from studies conducted outside the south San Francisco Bay Area. Salinity levels found along Coyote Creek, however, are higher than expected based on the community description of Fremont cottonwood and mixed willow series (Sawyer and Keeler Wolf, 1995), and higher than studies reported by Mitsch and Gosselink (1993) would predict. The values for the vegetated stations on the three control streams fall within the tidal freshwater and oligohaline (0.5 - 5.0 ppt) zones (Table 14). The surface water salinity values where Coyote Creek's diverse tree species and *Populus spp.* exist fall between the oligohaline and the mesohaline (5.0 - 18.0 ppt) estuarine regions (Table 15).

Table 14. -- Mean surface water salinity (ppt) for all three reference streams

Range of Mean Values	**Diverse Tree Species and *Populus spp.* (Stations 3 and 4)**	***Salix spp.* (Station 2)** (Excluding single *Salix spp.* found at PAMEPS station 1)
Reference Sites	0.3 to 0.9	0.4 to 3.8

Table 15. -- Mean surface water salinity (ppt) for Coyote Creek

	Diverse Tree Species and *Populus* and *Salix spp.* (Downstream Stations 1 - 3)	**Diverse Tree Species and *Populus spp.* and *Salix spp.* (Upstream - Station 4)**
Coyote Creek	3.2 - 6.7	1.1

Tree species in the wetland environment establish themselves either on islands or on the floodplain and are not affected by frequent tidal inundation. Their elevation minimizes their exposure to the highly saline, anaerobic conditions halophytes must endure.

During the period of study, the benches adjacent to stations 3 and 4 along the Guadalupe River were only inundated by 1.8 meter (6.0 feet) HHW and higher tidal events. The trees along Coyote, Stevens, and Matadero Creeks were never flooded by the tides during the period of observation.

Although, during the low flow period, the riparian tree species present along Coyote Creek do not endure the frequent tidal inundation and wave actions that wetland species experience in the lower elevations, they do experience relatively high soil salinity levels. To counteract the effects of these conditions, plants use energy which might otherwise be used for reproduction or fighting disease. Such stresses may shorten the lives of these trees.

The Salinity of Surface Waters Downstream from Standish Dam

The effects of salinity increase during times of drought. As a part of their research along the lower Sacramento River, Willoughby & Davilla (1981) used mean monthly surface water salinity values, averaged over a period of thirteen years. The normal variation fell between 0.5 and 2.0 ppt. Salinities during the 1977 drought year, however, rose to between 4.5 and 6.0 ppt. This indicates that the mean surface water salinities during a wet rainfall year might be lower than values that would be observed during a drought. This research project was conducted during an average rainfall year. If the salinity of the surface waters and the soils rose as a result of low rainfall, the potentially negative effects on the tree species present in the tidal zone would also increase (Willoughby & Davilla 1981, 643).

In this study, the mean salinity of the tidal water was tested approximately 50 meters downstream of Standish Dam to assess these values before they were diluted and could no longer be compared with upstream values. Surface water salinities downstream from the dam were significantly higher than at the stations above the dam site on Coyote Creek (Table 16). A 1.3 kilometer meander was removed from the section of Coyote Creek immediately downstream of Standish Dam as a part of the flood control project. Removing this meander diminished the time and the distance that tidal waters take to travel to the project site, and extended the upstream limit of tidal action (Dr. J. Smith, pers. comm. 1997). Saline surface water potentially intrudes further upstream than it did in 1986, and surface water salinity will increase once the dam is removed.

Table 16. -- Comparison of mean surface water salinity values from the four stations with the surface waters downstream of Standish dam (ppt)

Sampling Location	Mean Values (ppt)
Downstream of Standish Dam (n=19)	14.7
Coyote Creek - Station 1 (Dam) (n = 9)	6.7
Coyote Creek - Station 2 (1B) (n = 9)	4.4
Coyote Creek - Station 3 (2A) (n = 9)	3.2
Coyote Creek - Station 4 (CCRS) (n = 9)	1.1

A 1994 study by Jones and Stokes and HRG indicated that the installation of the seasonal dam influences groundwater and salinity levels in section 1B and within 300 meters upstream of the dam's location. Their research concluded that Standish Dam lowers the salinity of the groundwater in Section 1B and the groundwater, in turn, keeps the surface water salinity from increasing. These data show that the groundwater gradient varies with dam placement and removal. With the dam in place, the freshwater lake directs the groundwater gradient away from the channel and lowers the salinity of wells within the section upstream of the dam during the summer. Conversely, with dam removal, the channel water becomes more saline. The 1994 report further states that the dam enhances the chances of survival of the restored vegetation by raising the water table and making soil moisture more available to vegetation. Thus, the dam plays an important role in protecting the riparian vegetation immediately upstream. The dam blocks the tides, lowers the salinity of the soils, and raises the groundwater level. Especially during a drought, the dam could diminish stress by reducing the salinity of surface and groundwater and by increasing water available to the vegetation in Reach 1B (Jones & Stokes Associates, Inc. and HRG 1994) (Jones & Stokes Associates, Inc. and HRG 1995).

All the above information leads to the conclusion that without Standish Dam the increased influence of salinity will compromise the long term sustainability of the *Salix spp.* and *Populus spp.* historically present and planted along Reaches 1B and the lower portions of 2A and within 4.6 meters of the creek

The findings of my research also support this conclusion. The soils sampled at stations in the control creeks which represented the downstream limit of *Salix spp.* and *Populus spp.* were all significantly less saline than the mean soil values of the stations at Coyote Creek where these species were planted or existed as a result of the dam's presence. The pre-existing trees located along the lower Coyote Creek streambanks may already be in jeopardy and are showing such signs of stress as dead tree tops. The mean values of the soil samples taken from the reference sites were all within the range in which USDA found no adverse effects. This thesis research found that *Populus spp.*, especially, showed a preference for freshwater conditions. In addition, the soils taken from Coyote Creek Stations 1 (Dam), 2 (1B), and 3 (2A) and within 4.6 meters of the creek all showed salinity levels at which only salt resistant crops grow (Maas 1984).

The mean surface water salinity values present along the Coyote Creek test section correspond with zones which support species associated with transitional marsh environment. The elevation of the stream bank above the active channel mitigates this problem somewhat by protecting the *Salix spp.* and *Populus spp.* from inundation by the saline waters. However, the mean salinity of the surface water influences the salinity of the soil, and even the current range of these values will induce stress.

Previous studies conducted by Jones and Stokes and HRG (1995) indicated that removing the dam will increase the salinity of both the groundwater and surface water. Over time this may increase the already high soil salinity levels.

Salinity values of the tidal waters taken downstream of Standish Dam indicate that the salinity of the surface waters in the study area would increase significantly during drought years, and during the late summer when the dam has been in place. At these times, near the dam section and sections 1B and 2A, the historic stand of *Populus spp.* and *Salix spp.* and the revegetation project area will be particularly vulnerable. Even as far upstream as the station adjacent to CCRS, the *Populus spp.* would experience stress if the salinity of the soils rose because of the increased ratio of tidal to freshwater. MacDonald et al. (1984, 23) found that stresses such as elevated salinity levels increased plant root's susceptibility to disease. This effect was increased during times of drought.

In 1982, when the SCVWD began to consider the need for increased flood protection in Alviso, the downstream limit for riparian tree species in Coyote Creek extended to Standish Dam. At that time, the dam was located upstream, above the present split channel. Later the SCVWD revegetated the reaches upstream as a mitigation for trees removed by the District to control flooding. The lake upstream of Standish Dam has been the source of fresh water that is critical to the survival of lower Coyote Creek's riparian tree species. The two series planted, Fremont cottonwood and mixed willow, are generally found in fresh water floodplains. The data indicate that without the dam, the *Populus spp.* will be most at risk in this environment.

Finally, this research is also relevant to the effects of sea level rise. Carbon dioxide and other upper atmosphere gasses trap long wave radiation emanating from the earth's surface, and reflect it back into the atmosphere. Human activity has caused a significant accumulation of these *greenhouse gasses* in the atmosphere, and these are expected to increase global temperatures by as much as 2-3^0 C over the next fifty to one hundred years. Melting glacial and sea ice and thermal expansion of ocean water result from increases in temperature, and will cause a dramatic rise in sea levels (Williams 1985, 4).

Williams (1985) evaluated the effects of sea level rise on the San Francisco Bay. Sea levels normally rise 0.15 meters per century (Williams 1985, 6). Recently conducted studies predict that over the next century, global warming has a 50% chance of causing sea levels to rise 0.3 meters and a 1% chance of causing a rise of 1.2 meters (Titus and Narayanan, 1996). Williams estimates that if sea levels rise within this range the perimeter of the Bay will expand (Philip Williams, pers. comm. 1997).

An increase in marginal area would also expand the tidal prism of the Bay. Williams predicts a significant shift in the areal distribution of habitat types (Williams 1985, 27). As salt water intrudes farther into streams, *Populus spp.* and *Salix spp.* will retreat until soil and water salinity levels do not exceed their tolerances. Preservation of environmental resources such as riparian tree species will require management objectives which account for the sensitivity of these species to changes in salinity levels, in light of rising water levels. Long term planning for the preservation of important wetland resources would require the identification of appropriate substitute restoration areas around the Bay which will withstand the effects of sea level rise.

RECOMMENDATIONS

Management Recommendations

Discussion of alternatives. If the District no longer installs Standish Dam during the spring and summer months, CDFG wants the SCVWD to mitigate for the loss of both historic and planted tree species. The District will have to replace planted trees on a one to one basis, but the requirement for replacing existing vegetation is unclear.

The riparian forest which exists in reaches 1B and 2A was planted to improve the habitat potential provided by the freshwater lake behind Standish Dam. These trees may also be at risk. Elevation relative to tide levels is another important limiting factor. During tidal events equal to or greater than 1.8 meters HHW, the surface waters extend to within a few centimeters of the top of the bench which was created for the purposes of erosion control. The SCVWD should seek out a nearby reference site with similar conditions and use it as a model for revegetating this area. *Scirpus spp.* could survive along the lower edge of the streambank. Replacements for *Salix spp.* and *Populus spp.* could be planted upstream of CCRS and in an upland location. All these strategies will be somewhat experimental and should be monitored for at least ten years.

Finally, if the District decides to protect existing *Salix spp.* and *Populus spp.*, they might consider either continuing the dam placement as it has been or moving the dam to its former location at the top of the trifurcated channel. This was the former downstream limit of established riparian trees and would protect this forest. At a minimum, the District might consider installing the dam during times of drought, although this may not be sufficient to protect the existing and planted trees.

Research Needs

The Coyote Creek mitigation site will continue as an interesting research area. These research projects will assist environmental professionals in planning for and mitigating against the effects of salt water intrusion due to sea level rise:

1. Surveying the salinity of the soil upstream of Standish Dam from May to October when the Dam is in place.
2. Monitoring the alterations in the composition of the streamside forest.

3. Monitoring increases in the salinity of the surface waters, and minor stream flow effects relative to changes in weather patterns.
4. Monitoring the salinity of the soil as it relates to increased salinity of the surface waters.
5. Monitoring the salinity of the groundwater near Reach 1B.
6. Observing faunal changes as they relate to changes in salinity and vegetation type.

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