Chapter 2

CHARACTERISTICS OF TRAMPLED MARSH SOIL AND POTENTIAL FOR REHABILITATION

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Introduction

There are several ways one can look at the Emeryville Crescent sculpture area. Some see it as a playground and bring their dogs and kids to romp around. Some see it as an area of unique art forms and come to contribute to or just appreciate the sculptures. These people are generally pleased. Others see the area as a valuable salt marsh habitat and are not pleased. This latter view is the one adopted by this paper.

As a marsh, the sculpture area is in serious trouble. Large areas of soil and vegetation have been trampled by foot traffic on the marsh, producing completely bare areas and trails that do not recover. The soil is compacted or allowed to erode away. Often the trampled areas are depressed enough to produce inadequate drainage, forming permanent ponds. In many areas where pickleweed does grow, its biomass is significantly below normal. Trampling has removed approximately 10% of the area of the sculpture marsh from production.

Recently, a public workshop sponsored by the California Coastal Conservancy designated restoration and enhancement of the Emeryville Crescent as a high priority project (CHNMB Associates, 1982). If the sculptures are removed and access to the marsh is regulated, such a project may include restoration of the trampled marsh soil. Several chemical and physical soil tests have been performed for this study and comparisons made between trampled and non-trampled areas, to determine the need and potential for restoration.

Significance of Habitat Loss Due to Trampling

There are several continuing detrimental effects on the wildlife at the Crescent due to the way the area is used by humans (see paper by Lisa Cohen). However, only effects that would remain after human access is restricted are considered here. Trampled marsh areas represent a complete loss of habitat, except for a few invertebrates found mainly in the ponded areas (Bailey, 1982, pers. comm.). Sixty species of waterbirds are found at the Crescent, including several endangered species: the California Brown Pelican, the California Least Tern, the Alameda Salt Marsh Song Sparrow, and the California Clapper Rail (Bodega Bay Institute, 1978). Recently, presence of the endangered Salt Marsh Harvest Mouse has been documented (see paper by David Olson). Many of these species have populations so low as to be subject to disruption of the gene pool by mutation. Every square meter of marsh habitat lost by trampling directly contributes to the decline of these species. Furthermore, the loss of marsh habitat lowers the influx of organic matter to the mudflats. This subsequently decreases the population of invertebrates that supports the birds. Finally, the Crescent is a unique wildlife area. It is the best and often only habitat for many bird species in the northern East Bay (Bailey, 1982, pers. comm.). The only place where the loss due to trampling can be fully replaced is at the Crescent itself.

Introduction to Methods

There are two limitations to this study that affect the choice of methods and the quality of the data. Both are constraints in time. First, the total amount of time available for research placed a limit on the number of samples and the variety of tests that could be done. When several methods were available for a given test, the simplest and least time-consuming was usually chosen. Some of the methods are "semi-quantitative," that is, they quantitatively determine a property of the soil but not the property that is desired. The desired property is related to the measured property in a consistent manner and must be calculated. Some tests that would have given useful information could not be done, including organic matter content and grain size distribution of the soil. No field tests of proposed rehabilitation procedures were possible.

The second constraint involves the time of year when samples could be collected, which was restricted to February and March. As will be shown, this limitation makes it difficult to determine exactly why the trampled areas remain bare but does allow the development of procedures to restore them. The tests were designed to give information on four factors suspected to prevent the growth of pickleweed in the trampled areas: salinity, alkalinity, soil compaction, and crust formation. Potential factors not addressed in this paper include the effects of tidal immersion, pond formation, soil erosion, and continued trampling.

Site Location and Selection

The Emeryville Crescent is an "L"-shaped tidal marsh and mudflat bounded on the south by the approach to the Oakland Bay Bridge, on the east by Interstate 80, and on the north by the Emeryville Marina landfill (for detailed site description see papers by Lisa Cohen and David Olson). FIGURE 1 shows the present area of the sculpture marsh and the sample localities. Sixteen sample sites were selected in pairs of trampled and nontrampled soil at approximately the same distance from the shoreline. Three of the sites (1A, 5A, 7A) were located by taking readings on distant landmarks with a Brunton compass. The other sites were located in relation to these three sites by compass readings and pacing of distances.

Due to the disrupted state of the area, use of a random sampling design was not feasible. Sites were selected according to the following criteria: Trampled areas had to be completely bare of vegetation and free of driftwood and other debris. The pickleweed and other vegetation in the nontrampled areas had to be healthy. The two sites of a trampled/nontrampled pair had to occur within about 30 feet of each other. Finally, ponded areas were generally avoided due to the difficulty in extracting samples and because the absence of vegetation could be explained solely on the basis of ponding. The two exceptions were site 6A, which was ponded, and site 8B, which was a composite of two healthy areas, one closer and one farther from the waterline than site 8A.

Methodology for Soil Tests

Saturation Percentage (SP): Soil samples for the salinity and alkalinity tests were taken on February 21 and 22, 1982. Samples were dug with a hand trowel and stored in plastic bags. Sample depth was chosen as the top 15 cm. of soil, since pickleweed roots are confined almost exclusively to this zone (Mahall and Park, 1976b). Soil samples were passed through a sieve with 3 mm openings to remove roots, pieces of wood and plastic and other debris. Distilled water was added to the soil until saturation was reached. Samples were allowed to stand for one hour, and then the criteria for saturation were rechecked and adjustments made (Doner, 1982). Samples were then oven-dried at 105°C to constant weight. The saturation percentage was calculated from the following formula (USSLS, 1954):

$$SP = \frac{(\text{loss in weight on drying})(100)}{(\text{weight of oven-dry soil})}$$

pH of Saturated Soil Paste: The pH of the soil paste was measured with a glass electrode, CHEMTRIX type 40 pH meter. The electrode was raised and lowered repeatedly and allowed to equilibrate until a representative reading was obtained (USSLS, 1954).

Electrical Conductivity (EC) of the Saturation Extract: The saturation extract was obtained from the saturated soil paste by suction filtration through Wattman #42

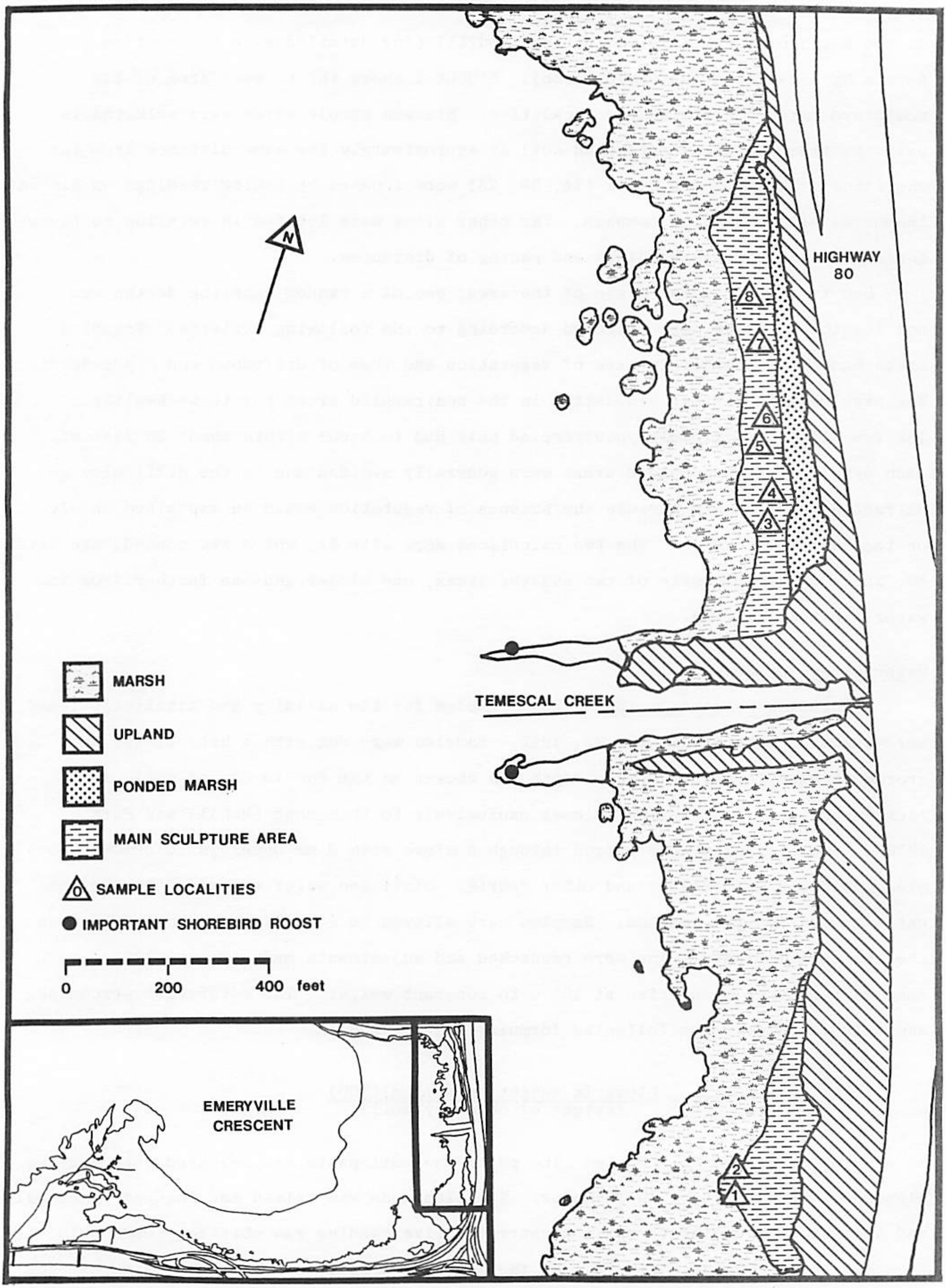

FIGURE 1. Sample Localities at the Emeryville Crescent Sculpture Marsh.
Sources: Bodega Bay Institute, 1978. Aerial photograph #SFB-38-14, U.S. Army Corps of Engineers, San Francisco, June 17, 1980.

filter paper in a Buchner funnel. Filtration was terminated when a sufficient amount of extract (5 to 10 ml) was obtained. The electrical conductivity was measured with a Beckman Model 16B2 Conductivity Bridge, using 0.01 N KCl as a standard reference solution. Readings were taken as resistance (R) and converted to EC at 25°C by the following formula (Doner, 1982):

$$EC(mmho/cm) = \frac{1.4118 \times R \text{ (of standard KCL)}}{R \text{ (of extract)}}$$

EC values were converted to percent salt in soil by making two assumptions. First, the total soluble cation concentration, in equivalents/liter of saturation extract, was approximated by EQ/L = 0.01 x EC (Doner, 1982). The second assumption concerns the exact composition of the solution salts. It has been shown that the salt breakdown in Suisun marsh soil is similar to that of sea water (TABLE 1) (Mall, 1969). Although differences may be expected due to their different locations, the salt composition of Suisun marsh soil was taken as the best available approximation for the soil at the Crescent. This composition corresponds to 57.16 gm/EQ. The amount salt in the soil was then calculated from the following equation:

$$\frac{\text{gm salt}}{\text{100gm soil}} = EC(mmho/cm) \times \frac{0.01\ EQ/L}{mmho/cm} \times \frac{57.16gm}{EQ} \times SP \text{ in } \frac{\text{gm water}}{\text{100 gm soil}} \times \frac{0.001\ L}{\text{gm water}}$$

EC values were converted to milliequivalents per liter (MEQ/L) at field moisture by assuming field moisture to be near its maximum value. Since this maximum occurs at about half the saturation level, the following formula was used (USSLS, 1954):

$$MEQ/L\ (FM) = 2 \times EC(mmho/cm) \times \frac{10\ MEQ/L}{mmho/cm}$$

IONS	SUISUN MARSH SOIL EXTRACTS	SEA WATER
Cl^-	18.87 gm/L	18.98 gm/L
Ca^{+2}	0.96	0.40
Mg^{+2}	1.87	1.27
Na^+	10.71	10.56
K^+	0.33	0.38

TABLE 1. Composition of Salt in Suisun Marsh Soil and Sea Water.
Source: Mall, 1969.

Total Exchangeable Cations (TEC): Exchangeable cations were determined by an equilibrium pH method in which the cations are replaced by an excess of H^+. To 2.0 gm of air-dry soil was added 25 ml of 1 N HOAc (acetic acid). The suspension was shaken intermittently for one hour, then the pH was determined with a CHEMTRIX type 40 pH meter. TEC values in milliequivalents/100 gm soil were then read from a standard graph relating the pH of the HOAc solution to total exchangeable metallic cations in the soil (Jackson, 1958).

TEC values were converted to exchangeable sodium percentage (ESP) and exchangeable sodium (ES) values by making several assumptions. First, the composition of the soluble salts was again taken to be that of Suisun marsh soil. This corresponds to 69.84% Na^+, 7.13% Ca^{+2}, and 22.88% Mg^{+2} in terms of percent of total MEQ/L. Next the equation MEQ/L (soluble salts) = 10 X EC(mmho/cm) was assumed. The soluble sodium, calcium, and magnesium concentrations for the saturation extract of each sample were then calculated by the following equation:

$$\text{Specific cation concentration (MEQ/L)} = \text{EC(mmho/cm)} \times \frac{10\ \text{MEQ/L}}{\text{mmho/cm}} \times \%\ \text{specific cation}$$

The ESP was estimated from the specific soluble cation concentrations by the following standard equations (USSLS, 1954):

$$\text{ESP} = \frac{100(-0.0126 + 0.01475x)}{1 + (-0.0126 + 0.01475x)}, \text{ where } x = \frac{Na^+}{(Ca^{+2} + Mg^{+2})/2}, \text{ all concentrations}$$

in MEQ/L. Finally, TEC values were taken to be equivalent to cation exchange capacity (i.e., all the exchange sites in the soil are occupied). This is a reasonable assumption for saline-alkali soils (Doner, 1982, pers. comm.). ES values were then calculated from the following formula:

$$\text{ES(MEQ/L)} = \frac{\text{EXP x TEC(MEQ/L)}}{100}$$

Bulk Density: Samples for the bulk density test were taken on March 6, 1982. Soil cores having field structure were obtained by thrusting plastic tubes of 0.95 cm diameter into the soil by hand. Core depth varied from 4-6 cm. Volume was determined by direct measurement of the length of the soil core. The samples were then dried to constant weight at 105°C.

Soil Crust Density: Samples for the soil crust density test were taken on April 18, 1982. Since crust pieces were generally not available directly on the

SOIL PROPERTY	SATURATION PERCENTAGE	pH OF SATURATED SOIL PASTE	ELECTRICAL CONDUCTIVITY	AMOUNT SALT IN SOIL	SALINITY AT FIELD MOISTURE	TOTAL EXCHANGEABLE CATIONS	EXCHANGEABLE SODIUM	EXCHANGEABLE SODIUM PERCENTAGE	BULK DENSITY	SOIL CRUST DENSITY
SOIL FACTOR	Salinity	Alkalinity	Salinity	Salinity	Salinity	Alkalinity	Alkalinity	Alkalinity	Soil Compaction	Crust Formation
UNITS	per cent	pH	mmho/cm	gm salt / 100gm soil	MEQ/L	MEQ / 100gm soil	MEQ / 100gm soil	per cent	gm/cm3	gm/cm3
1 A*	68.5	7.30	53.0	2.08	1060	7.5	2.8	37.5	1.14	1.14
1 B	162.5	6.40	22.3	2.07	446	8.1	2.3	27.8	0.84	
2 A	36.1	7.72	36.5	0.75	730	4.5	1.5	33.2	0.83	
2 B	58.9	7.06	8.6	0.29	172	4.8	0.91	19.0	0.60	
3 A	129.1	7.03	30.8	2.27	616	8.0	2.5	31.2	0.86	1.26
3 B	204.3	6.93	18.0	2.10	360	7.5	1.9	25.6	0.47	
4 A	73.3	7.30	42.9	1.80	858	9.6	3.4	35.0	0.90	
4 B	196.0	6.68	31.7	3.56	634	14.5	4.5	31.2	0.38	
5 A	138.1	7.65	49.2	3.88	984	9.8	3.6	36.6	0.71	1.49
5 B	212.2	6.95	17.0	2.06	340	7.5	1.9	25.0	0.64	
6 A	106.4	7.95	31.5	1.92	630	10.9	3.4	31.5	0.64	
6 B	279.3	7.05	19.2	3.07	384	6.1	1.6	26.3	0.47	
7 A	74.2	8.57	63.0	2.67	1260	18.8	7.4	39.6	0.79	1.32
7 B	171.2	6.90	19.9	1.95	398	9.1	2.4	26.6	0.67	
8 A	49.1	8.42	70.8	1.99	1416	14.4	5.9	41.0	1.35	
8 B	116.2	7.10	13.8	0.92	276	7.5	1.7	23.1	0.66	
RANGE A	36.1-138.1	7.03-8.57	30.8-70.8	0.75-3.89	616-1416	4.5-18.8	1.5-7.4	31.2-41.0	0.64-1.35	1.14-1.49
RANGE B	58.9-279.3	6.40-7.10	8.6-31.7	0.29-3.56	172-634	4.8-14.5	0.91-4.5	19.0-31.2	0.38-0.84	
MEAN A	84.4	7.74	47.2	2.17	944	10.4	3.8	35.7	0.90	1.30
MEAN B	175.1	6.88	18.8	2.00	376	9.3	2.2	25.6	0.60	

Table 2. Data From Six Soil Experiments
*Note: Sample pairs are numbered 1 to 8. A indicates the trampled area, B indicates the nontrampled area.

sample sites, four sample areas were chosen that encompassed sites 1 and 2, 3 and 4, 5 and 6, and 7 and 8. Crust pieces were picked by hand from these areas and stored in plastic bags. The moisture content of the samples was determined by drying representative crust pieces to constant weight at 105°C. Several crust pieces were weighed, corrected for moisture content, and dropped in a water-filled 1000 ml graduated cylinder to determine volume by water displacement. Absorption of water by the crust pieces was minimized by taking volume readings within a few seconds of immersion.

Presentation of Data

The results of the six soil tests and associated calculations are compiled in TABLE 2. In addition to the laboratory tests, several observations were made at the marsh. The vegetation of sites 1B to 4B consisted solely of pickleweed, while that of sites 5B to 8B mainly of pickleweed, with some salt grass and other marsh grasses. On March 6, visible salt crusts were observed at all trampled sites except 6A, which was submerged. On April 17, soil crusts were observed on or within 15 feet of all trampled sites. The size of the soil crusts ranged from 1 to 16 square inches. Pickleweed seedlings, ranging up to 2.5 inches tall, were observed at all trampled sites. Except for one area of approximately 10 ft^2 near sites 1 and 2, these seedlings were seen only within about a foot of the edge of the bare areas. The seedlings grew both between and directly through soil crust pieces.

Salinity Tolerance of Pickleweed

Pickleweed is a low-growing, leafless, succulent-stemmed halophyte of the genus Salicornia (Bodega Bay Institute, 1978). The specific species at the Crescent is usually called Salicornia pacifica Standl (Atwater, 1979), or Salicornia virginica L. (Mahall and Park, 1976a). However, it is likely that these two species and others (S. herbacea, S. europa, S. stricta) are not actually separate species but simply different races of the same species adapted to the environmental conditions at different locations (Kadlec and Wentz, 1975). Pickleweed grows only during the spring and summer months, but maintains a perennial above-ground system throughout the winter. The tidal range of pickleweed extends from mean high water to the highest high tides (Mahall and Park, 1976a). Species of Salicornia are among the most salt-tolerant plants in the world and are termed facultative halophytes, meaning that optimal growth is obtained in a saline soil (Barbour, 1970). The upper limit of salinity that pickleweed can survive is not precisely determined, since the various studies often widely disagree (TABLE 3). No published data for the tolerance of pickleweed to soil alkalinity were found.

TYPE OF PLANT MATERIAL	SPECIES[1]	UPPER LIMIT OF SALINITY TOLERANCE[2]	MEQ/L[3]	SOURCE
Mature	S. herbacea	4.5% salt	787	Barbour, 1970
Mature	S. europa	9.0% salt	1575	Barbour, 1970
Mature	S. virginica	81 gm/liter salt	1417	Mall, 1969
Mature	S. stricta	4.25% salt	744	Chapman, 1960
Seedlings	S. herbacea	very poor growth at 5.0% NaCl	855	Barbour, 1970
Seedlings	S. virginica	zero growth at 2.2% salt	385	Barbour and Davis, 1970
Seeds	S. europa	8% germination at 5.0% NaCl	855	Ungar, 1962
Seeds	S. stricta	12% germination at 10% salt	1749	Chapman, 1960
Seeds	S. herbacea	0.4 M NaCl	400	Waisel, 1972

TABLE 3. Salinity Tolerance of Pickleweed.

[1]Data for several species are included because of the uncertainty concerning the speciation of Salicornia.

[2]Some values are field tests and some are hydroponic laboratory tests, but all refer to the salinity of the water or soil-water actually experienced by the roots or seeds.

[3]Conversion of values to MEQ/L was made using 57.16 gm/MEQ for "salt" and 58.5 gm/MEQ for NaCl.

Discussion of Data

Salinity: The EC of the saturation extract is generally regarded as the best measurement of soil salinity in relation to plant response. The salt concentration of the soil solution experienced by the plant depends not only on the amount of salt present but on the amount of water present. Therefore, two soil samples (such as 1A and 1B) can have the same amount of salt present and still exhibit a large difference in salinity (EC) due to the difference in their ability to hold water as measured by the saturation percentage (USSLS, 1954). The EC values for the trampled areas are consistently higher than those for the corresponding nontrampled areas, with little overlap in the range of values.

The breakdown into gm salt/100gm soil and SP explains why these differences exist. Partly it is because there is commonly more salt in the trampled areas, sometimes over twice as much as in the corresponding nontrampled area (sites 2 and 8).

However, this trend is not completely consistent, being sharply reversed for sites 4 and 6. The more consistent and more significant trend is the saturation percentage. SP values for the nontrampled areas are consistently higher than the corresponding trampled areas and are often very high in magnitude. While the correlation with soil grain size distribution remains to be tested, the most likely explanation for the SP differences is a much higher organic matter content for the nontrampled areas (Doner, 1982, pers. comm.). Organic matter in high concentration can make soil act like a sponge, soaking up more than twice its weight in water (USSLS, 1954).

It is not certain whether the salinity in the trampled areas exceeds the tolerance of pickleweed. The concentration of soluble salts at field moisture for trampled areas averaged 944 MEQ/L. This value exceeds some, but not all, of the salinity limits in TABLE 3. But there is one more thing to consider. Marsh soil salinities are at their lowest point during the winter, due to the flushing of salts from the soil by rainfall. Salinity can be expected to increase significantly throughout the summer because of increased evaporation of the tidal water on the marsh (Chapman, 1960). For example, the Suisun marsh increases in average salinity by 87% in the pickleweed zone between April and September (Mall, 1969). Furthermore, it is probable that salinity would increase more during the summer for the trampled areas than for the healthy areas because the presence of vegetation reduces the evaporation rate of tidal water, and the healthy areas have much better drainage and permeability to water than the bare areas (Chapman, 1960). If salinity at the Crescent is assumed to increase by 87% over the summer (an uncertain comparison, since the Suisun marsh is more brackish than the Crescent), the average summer value for the trampled areas, 1765 MEQ/L, would exceed all of the salinity limits. While data for late summer are needed for confirmation, excessive salinity appears to be a major deterrent to the growth of pickleweed in the trampled areas.

Alkalinity: Soil particles adsorb cations due to electrical charges on the surfaces of the particles. These cations are chemically bound to the soil and are therefore not soluble. They can be replaced by other cations in the soil solution, however, hence the term exchangeable. Alkalinity refers to the percent of the total exchange sites occupied by sodium ions. The main effect of high alkalinity is on the structure of the soil. As alkalinity increases, the soil becomes more dispersed, resulting in low permeability and the formation of soil crusts upon drying. High alkalinity can also disturb the nutritional balance of plants by removing calcium from plant tissues (USSLS, 1954).

The soil pH shows a consistent trend toward higher values in trampled areas. The usual interpretation of pH is in terms of H^+ concentration, but the exact property measured by soil pH is unknown. The pH data are useful mainly as a check on the ESP values, since higher soil pH values are commonly correlated with higher ESP values (USSLS, 1954). Thus the pH test increases confidence in the ESP calculations.

The ES and ESP values show a consistent trend, those in the trampled areas being higher than in the healthy areas by varying amounts. The differences in ESP (especially at sites 7 and 8) would be significant for a non-halophyte, but the effect of such high alkalinity on pickleweed is not known. Higher alkalinity in the trampled areas would most likely produce an additional stress on pickleweed plants, but assigning a magnitude to this stress awaits further research.

Soil Compaction: The effect of soil compaction, as measured by bulk density, includes prevention of root penetration and seedling emergence and decreased ability of the soil to conduct water. Drainage difficulties can be expected at bulk densities of about 1.7 gm/cm^3. Difficulties in root penetration and seedling emergence begin at bulk densities of about 1.8 gm/cm^3 (USSLS, 1954). None of the bulk densities tested reach these limits, the highest (8A) being 1.35 gm/cm^3. However, the trend toward higher bulk densities in the trampled areas is consistent, and one trampled area (4A) has a bulk density over twice as high as its corresponding healthy area. As shown by the SP test, the nontrampled areas generally have much more organic matter than the trampled areas. Since organic matter is much lighter than soil particles, most of the bulk density difference is probably due to the difference in organic matter content, rather than soil compaction. Soil compaction is probably not restrictive to the recolonization of pickleweed in the trampled areas. Any lesser detrimental effect cannot be determined from these data.

Crust Formation: Hard surface crusts can develop due to high exchangeable sodium, low organic matter, and the wetting of soil to zero tension. All of these occur in the bare areas at the Crescent. The main effect of soil crusts on plants is as a barrier to seedling emergence (USSLS, 1954). Even the highest soil crust density measured for a trampled area (1.49 gm/cm^3 at sites 5 and 6), lies well below the 1.7 gm/cm^3 limit expected to cause major problems for seedlings. This is supported by the observation of seedlings growing directly through the crust pieces. It is likely that the problem will worsen as the summer progresses, but as of April, crust formation was not sufficient to prevent recolonization of the trampled soil.

Marsh Rehabilitation: A Definition

The creation of marsh habitat is usually described as "marsh restoration." The situation at the sculpture marsh is quite different, and the term "marsh rehabilitation" is preferable. Marsh restoration refers to creating marsh where it does not presently exist, whereas the areas needing rehabilitation at the Crescent are surrounded by healthy marsh. Therefore, marsh restoration techniques may not necessarily be applicable. For instance, the entire sculpture marsh cannot be diked off while restoration work is being done, because this would kill the 90% of the marsh that is healthy. Furthermore, marsh rehabilitation has some unique problems, such as the possible interference of work by the tides and the fact that most of the work must be done by hand, not machine. In view of the variation in the values for the soil tests in TABLE 2, marsh rehabilitation could be a very detailed procedure. The amounts of any amendments added to the soil would vary widely from site to site. Although the sculpture marsh is a unique situation in some ways, the following rehabilitation methods could be used in other marshes trampled by human or animal traffic. These procedures may also be useful when a marsh restoration procedure partially fails, and undesired salt pans are produced.

The Need for Rehabilitation

The desirability of a rehabilitation effort at the Crescent depends on how long it would take for the marsh to recover naturally. For the ponded areas, natural recovery in any foreseeable time period is unlikely. Sedimentation may eventually fill the ponded areas, but it might aggravate the problem instead, since most of the sediments would be trapped by the surrounding vegetation (Pestrong, 1972). Since natural drainage channels haven't formed over the last 15 years, there is little reason to expect them to do so in the future. Recolonization by pickleweed seedlings at the rate observed in the spring of 1982 would take decades to complete. Some recolonization will probably occur in a few years if access to the area is restricted, but total recovery to pre-trampled productivity levels for the entire sculpture marsh would most likely take 50 years or more (Bailey, 1982, pers. comm.).

Methods for Marsh Rehabilitation

The February data in this paper is ideal as a basis for developing rehabilitation methods, because a rehabilitation effort should certainly begin at the end of winter when soil salinity is at a minimum. The basic goal is to change the values for the trampled areas given in TABLE 2 to match those for the corresponding nontrampled areas. The following methods should be considered only as informed suggestions, since the actual procedures must be determined by field trials.

Soil salinity can be reduced either by removing salt or by increasing the ability of the soil to hold water (SP). The only practical way to remove salt from the trampled areas would be surface flushing with large quantities of water. This would involve pumping sea water to the trampled areas to provide a continual flow. Sea water would be effective in removing salt, even though it is quite salty itself. The salinity of the soil solution in the trampled areas averaged 944 MEQ/L, while that of sea water is only 218 MEQ/L (Mall, 1969). Since the salinity of sea water lies within the salinity range found in the healthy marsh areas, there should be no serious detrimental effect on the healthy areas due to the flushing process. The high water table in the marsh should prevent any undesired downward movement of salt during flushing.

The effectiveness of flushing can be determined only by doing it, but it is likely that flushing would need to be supplemented by a second method: the addition of organic matter to increased the saturation percentage. The EC values that the trampled areas would have if the SP equalled that of the corresponding nontrampled area are given in TABLE 4, column 1. All but one of these values (5A) fall below the highest EC value of a nontrampled area. The SP value required to reduce the EC of the trampled areas to that of the corresponding nontrampled area is given in column 2. All of these values except that for site 5A are attainable (USSLS, 1954). The ideal type of organic matter to use would be green organic matter, such as grass clippings, because of its high nitrogen content. The next choice would be peat moss. Dry organic matter, such as straw, could be used as long as attention is paid to its effect of lowering the nitrogen content of the soil, and nitrogen is added if necessary (Doner, 1982, pers. comm.). Any sites not correctable by flushing and organic matter addition could probably be

SAMPLE NUMBER	EC IF SP = THAT OF HEALTHY AREA 1	SP REQUIRED TO REDUCE EC TO HEALTHY AREA EC 2
1A	22.4	163.2
2A	22.3	152.9
3A	19.4	220.0
4A	16.1	99.3
5A	32.0	400.3
6A	12.0	174.9
7A	27.3	234.7
8A	30.0	252.3

TABLE 4. Effectiveness of Decreasing Salinity by Increasing the Saturation Percentage.

saved by the addition of fill. Fill will be required anyway because of the poor drainage of many of the trampled areas, and soil could be traded between problem areas and easily-corrected areas if necessary. The fill should be silty clay in order to have a good water-holding ability.

The usual method for reducing alkalinity in soils is by replacement of the exchangeable sodium with calcium. This is done by adding a chemical amendment such as gypsum, sulfur, or limestone. However, it is not known whether this method is applicable in this case because the tides may wash away the chemicals and the high concentration of soluble sodium may interfere with the replacement of exchangeable sodium. Furthermore, since it has been shown that the addition of organic matter can counteract the unfavorable effects of exchangeable sodium (USSLS, 1954), it is possible that the alkalinity problem would be solved as a "side-effect" of the solution to the salinity problem. And, as previously discussed, it is not known whether the high ESP values of the trampled areas need correction at all. Clearly, more research is needed in this area.

The remaining soil problems are more easily corrected. The addition of organic matter should reduce the bulk density of the trampled soil considerably. Mechanically breaking up the soil, using a mechanical rototiller or just shovels, would be all the additional work needed to correct the bulk density values. Since soil crusts form because of high alkalinity and low organic matter content, no further treatment beside that described above should be needed to prevent crust formation. Finally, once the osil has been rehabilitated, recolonization of pickleweed should occur quickly even without transplants (Hinde, 1954). However, transplantation of S. virginica has been shown to be easily accomplished, with 100% survival for plants transplanted within the same tidal zone (Batson and Stalter, 1969). With abundant sources of mature plants within a few feet of the trampled areas, this procedure would be both quick and effective. Seeds and seedlings found in the marsh could be collected, stored and then planted after the soil has been prepared for them.

Conclusion

The above arguments demonstrate both the need for and feasibility of marsh rehabilitation at the Emeryville Crescent sculpture marsh. However, whether such a project becomes a reality depends on political, economic, and social decisions yet to be made. It is hoped that these decisions will be made soon, because the sculptures are steadily spreading. At the southern end of the marsh is an incredibly authentic-looking driftwood replica of the Lunar Module. Unfortunately, the surrounding landscape is just as authentic-looking, a perfect replica of the bare and lifeless moon. One small step for man........

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