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UPTAKE OF HEAVY METALS FROM
CONTAMINATED SEDIMENTS BY
SALT-MARSH PLANTS

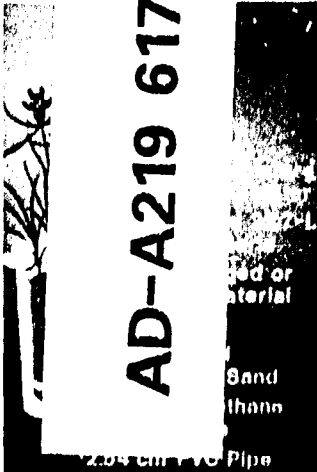
by

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US Army Corps
of Engineers



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19. ABSTRACT (Continued).

In 1984 the same experiment was carried out with *S. alterniflora*, *A. tripolium*, and *P. maritima*. After the first harvest, the underground parts of the plants were left untouched to allow regrowth for an additional 90-day period. After this period, the plants were harvested again, and the shoots analyzed.

The regrowth of *A. tripolium* and of *P. maritima* at high salinity was nil. Therefore, only the results of *P. maritima* grown at low salt conditions and of *S. alterniflora* were statistically analyzed.

Levels of Cadmium (Cd), manganese (Mn), and copper (Cu) in the regrowth shoots of the second harvest were in general higher than in shoots of the first harvest. In contrast, levels of iron (Fe) were generally lower. Comparisons of lead (Pb), zinc (Zn), and arsenic (As) levels gave variable results.

To compare heavy metal uptake by different plant species under field conditions, buckets as used in the greenhouse experiment were buried in the bank of a tidal creek in a Western Scheldt salt marsh. The location was just across from the spot where the sediment for the greenhouse experiment had been dredged.

Levels of Cd, Pb, Fe, Cu, Zn, and As did not differ significantly in *S. alterniflora* and *S. anglica*. A significant difference was found in the level of Mn in these two related species. The levels of the various metals (with the exception of Mn) were lower in the *Spartina* spp. than in *A. tripolium* and *P. maritima*. The results of the field experiment have been compared with the metal levels found in the experiments in the greenhouse.

Levels of Pb, Fe, Cu, As, Cd, and Zn were higher in the field-grown specimens than in the plants grown in the greenhouse. In contrast, Mn levels were always higher in the greenhouse plants than in the specimens grown in the field.

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PREFACE

This study was conducted by the Delta Institute for Hydrobiological Research, Yerseke, The Netherlands, and was monitored by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Funding was provided by the Long-Term Effects of Dredging Operations (LEDO) Program, which is sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). LEDO is managed within the Environmental Effects of Dredging Programs (EEDP). This research was conducted under Contract No. DAJA45-83-C-0024 as part of Work Unit No. 31776, "Toxic Substance Bioaccumulation in Plants." Dr. Bobby I. Folsom, Jr., Contaminant Mobility and Regulatory Criteria Group (CMRCG), EL, WES, was the Contracting Officer's Representative. HQUSACE Technical Monitors were Dr. Robert J. Pierce, Dr. William L. Klesch, and Mr. David B. Mathis.

Authors of this report and chief investigators for this study were Dr. A. H. L. Huiskes and Mr. J. Nieuwenhuize of the Delta Institute for Hydrobiological Research. This study was under the general supervision of Dr. Lloyd R. Saunders, Chief, CMRCG, EL, WES; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, EL; and Dr. John Harrison, Chief, EL. Dr. Robert M. Engler is the EEDP Program Manager. This report was edited by Ms. Lee T. Byrne of the WES Information Technology Laboratory.

COL Larry B. Fulton, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

	<u>Page</u>
PREFACE.....	1
PART I: INTRODUCTION.....	3
PART II: EXPERIMENTAL DESIGN.....	4
Greenhouse Experiments.....	4
Field Experiment.....	9
PART III: RESULTS.....	10
Sediment Analyses.....	10
Plant Analyses (Greenhouse Experiment).....	10
Plant Analyses (Field Experiment).....	15
PART IV: CONCLUSIONS AND RECOMMENDATIONS.....	17
Conclusions.....	17
Recommendations.....	19
REFERENCES.....	20
TABLES 1-10	
APPENDIX A: ANALYSIS RESULTS OF EIGHT SOIL SAMPLES TAKEN RANDOMLY FROM 1,000- μ CONTAMINATED MATERIAL.....	A1
APPENDIX B: ANALYSIS RESULTS OF FIVE SOIL SAMPLES TAKEN RANDOMLY FROM SITE OF FIELD EXPERIMENT IN SAEFTINGE SALT MARSH.....	B1
APPENDIX C: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>SPARTINA</i> <i>ALTERNIFLORA</i> (1983).....	C1
APPENDIX D: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>SPARTINA ANGLICA</i> (1983).....	D1
APPENDIX E: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>SPARTINA</i> <i>ALTERNIFLORA</i> (1984).....	E1
APPENDIX F: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>PUCCINELLIA</i> <i>MARITIMA</i> (1984).....	F1
APPENDIX G: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>ASTER TRIPOLIUM</i> LEAVES (1984).....	G1
APPENDIX H: HEAVY METAL CONCENTRATIONS AND YIELD OF <i>ASTER TRIPOLIUM</i> STEMS (1984).....	H1
APPENDIX I: INDIVIDUAL RESULTS OF METAL-ION CONCENTRATIONS OF SHOOTS OF <i>PUCCINELLIA MARITIMA</i> AND <i>SPARTINA ALTERNIFLORA</i>	I1
APPENDIX J: INDIVIDUAL RESULTS OF FIELD EXPERIMENT.....	J1
APPENDIX K: QUALITY CONTROL ANALYSIS METHOD.....	K1

UPTAKE OF HEAVY METALS FROM CONTAMINATED
SEDIMENTS BY SALT-MARSH PLANTS

PART I: INTRODUCTION

1. The boundaries between land and water have always been areas of major human activities. Large industrial complexes connected with harbor facilities are found everywhere in the world just in the interface between water and land as well as between sea and river. To keep the harbor basins open to shipping movements, large quantities of sediments have to be removed regularly. These sediments are often polluted with anthropogenic substances (heavy metals, organic compounds, pesticides, and oil residues) deliberately or inadvertently discharged into the water and partly adsorbed to the sediment particles. Depending on the levels of these pollutants, the sediments may be a health hazard when used to create arable land or natural environments. In the United States, one of the disposal alternatives is the creation of artificial marshes. Depending on the salinity of the dredged sediments and the disposal site, these marshes may be fresh, brackish, or saline.

2. The US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, is developing a bioassay to test the suitability of dredged material for use in marsh creation. In this study, the procedure for the plant bioassay has been applied to Dutch salt-marsh plant species growing in brackish, contaminated sediment; the North-American salt-marsh species *Spartina alterniflora* Loisel has been used as a reference. Greenhouse experiments were compared with similar experiments under field conditions. The specific objectives of the present study were:

- a. To evaluate the usefulness of the WES plant bioassay procedure by using other species and sediments.
- b. To investigate heavy metal uptake by a number of salt-marsh species.
- c. To compare the heavy metal uptake of the North-American *S. alterniflora* Loisel with the uptake of native salt-marsh species, namely *Puccinellia maritima* (Hudson) Parl., *Aster tripolium* L., and *Spartina anglica* Hubbard.
- d. To compare the results of the greenhouse experiments with results obtained in a field situation.

PART II: EXPERIMENTAL DESIGN

Greenhouse Experiments

3. The design of the greenhouse experiment was according to the bio-assay procedure as has been described by Folsom, Lee, and Bates (1981) and Folsom, Lee, and Preston (1981). Figure 1 shows a diagram of the experimental unit used. A small inner bucket rested on polyvinyl chloride (PVC) pipe inside a larger outer bucket. Six 6.35-mm-diam holes were drilled in the bottom of the inner bucket. These holes were covered with a 2.54-cm-thick polyurethane sponge overlaid with an approximately 2.54-cm layer of washed quartz sand. The sand and the sponge acted as filters to keep the sediment or soil from draining out of the bottom of the small bucket. The holes in the small bucket allowed water movement into and out of the sediment. The water level in the inner buckets was maintained by filling the space between the outer and inner bucket with water up to a certain height.

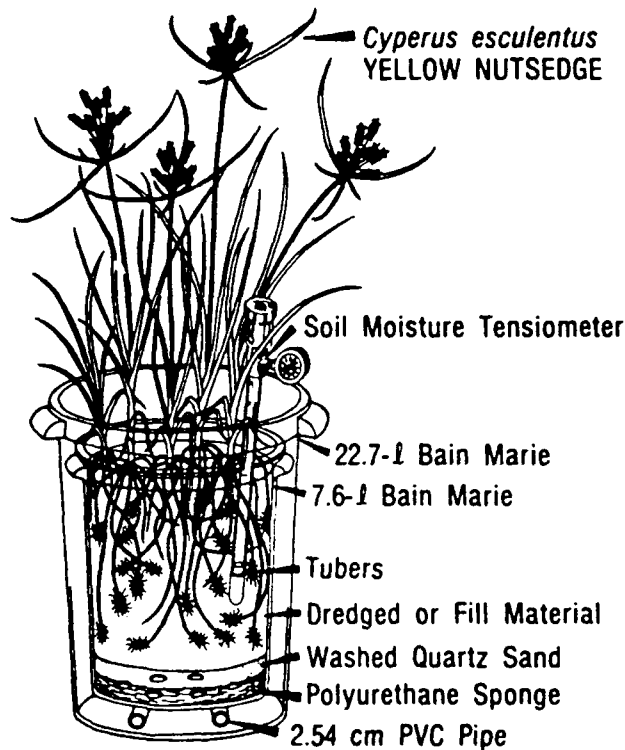


Figure 1. Diagram of the experimental unit used in the experiments (from Folsom, Lee, and Preston 1981)

Sediment preparation

4. The polluted sediment used in this study was dredged by the R. V. JAN VERWEY, a vessel of the Delta Institute for Hydrobiological Research, using a "Van Veen" grab. The dredging place was just outside the shipping lock "Zandvlietsluis" in the Belgian part of the Westerschelde estuary (Figure 2). This sediment is rather homogeneous in texture and concentrations of various substances, as it is well mixed by tugs towing iron bars across the

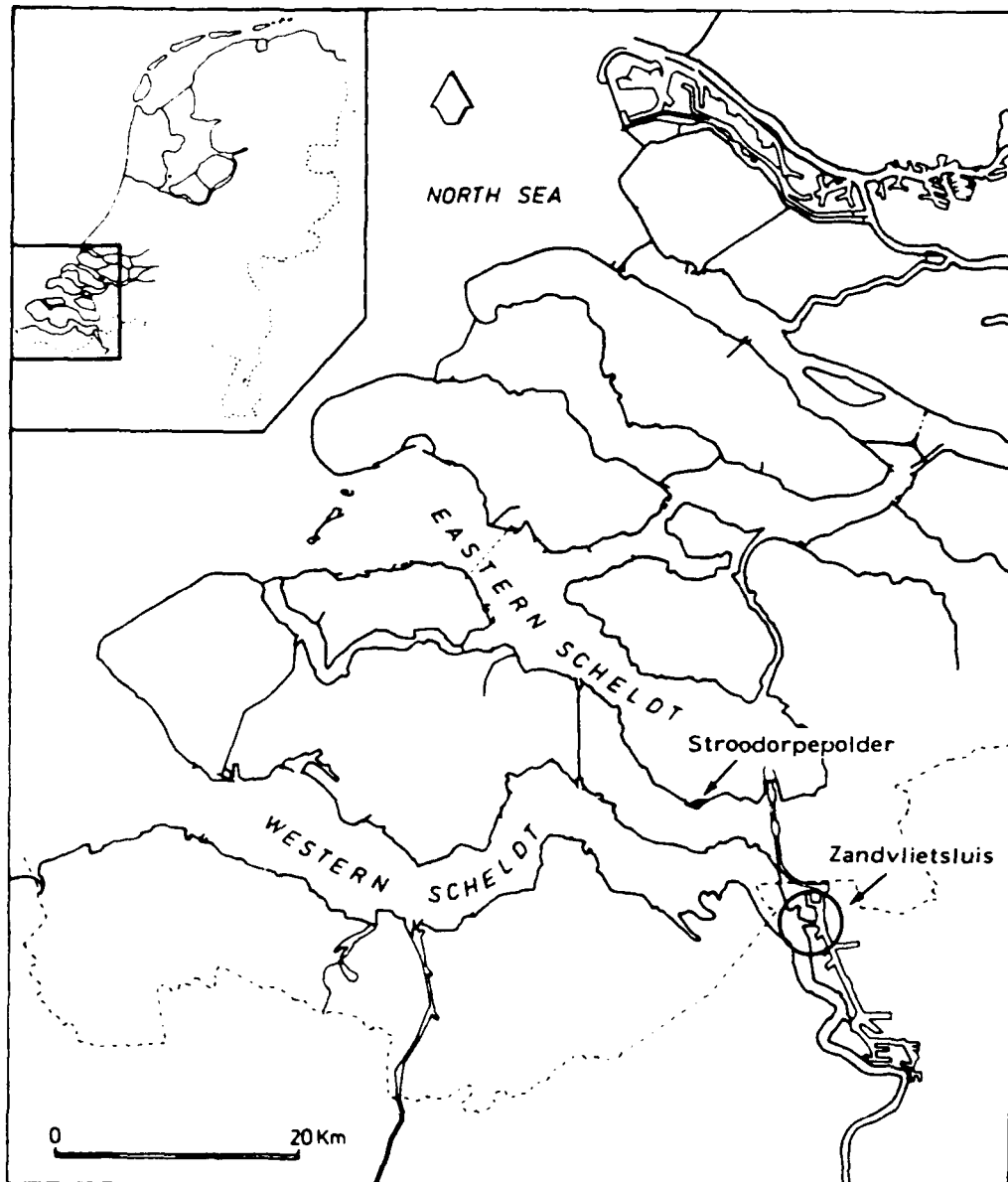


Figure 2. Map of the southwest Netherlands, with the positions of the dredging area and the field experiment (circle)

entrance of the lock in an attempt to resuspend the sediment and to subsequently remove it with the outgoing tides (see Appendix A).

5. Immediately after dredging, eight samples of the sediment were taken randomly for analysis for various heavy metals. The dredged sediment was transported in thoroughly cleaned plastic containers and spread out on large flats lined with PCV sheets to allow it to dry out. Excess water was siphoned off. After about 3 months, the water content of the sediment was 60.1 percent on wet weight basis.

Plant material

6. The experiment was divided in two parts for reasons of available space in the greenhouse. In the first year, an experiment was done using *S. alterniflora* and *S. anglica*. Seedlings of *S. alterniflora* were obtained from WES and transported by air to the institute. The plants were commercially grown from seeds and had four to five shoots, approximately 20 cm tall on arrival. *Spartina anglica* is the most abundant *Spartina* species in The Netherlands. It was imported by the Public Works Department from Great Britain in 1924 and 1925 for land reclamation purposes and has since spread naturally or by deliberate planting to almost all salt marshes in The Netherlands. For this experiment, cuttings of four to five shoots were taken in the field and transplanted to flats filled with potting compost to allow them to root. In the second year, an experiment was done with cuttings of *S. alterniflora*, *A. tripolium*, and *P. maritima*.

7. The inner buckets were filled with a known amount of sediment (approximately 7,000 g). In the first experiment, seedlings of *S. alterniflora* were planted, and in the second experiment, rooted cuttings. Three kinds of treatment were set up in the buckets, as follows:

- a. The outer bucket was filled with artificial seawater to a height just above the surface of the sediment in the inner bucket to maintain a waterlogged situation.
- b. The outer bucket was filled with artificial seawater that was 50 percent of the normal strength, to a height just above the surface of the sediment in the inner bucket.
- c. The outer bucket was filled to a height of 5 cm with artificial seawater that was 50 percent of the normal strength.

Each treatment had five replicates for each species. As a reference, *S. alterniflora* was also planted in buckets filled with a reference soil obtained from WES. This loamy soil was mixed with a fertilizer by WES. In the first

experiment, four buckets were kept waterlogged, and four buckets were kept under dry conditions with artificial seawater that was 50 percent of the normal strength. In the second experiment, only two buckets with WES soil were kept as a reference under dry conditions (i.e., the outer bucket was filled with 5 cm of artificial seawater that was 50 percent of the normal strength).

8. In the waterlogged treatment, the outer buckets were regularly adjusted to the level fixed at the start of the experiment with artificial seawater. In the other buckets, the level of 5 cm was maintained, but the plants in these buckets were also watered daily with demineralized water from the top, to prevent encrustation of the surface. Once a week, the watering was performed with artificial seawater to prevent desalinization of the upper soil layers.

Harvesting of plants

9. Ninety days after the start of the experiment, the shoots of the plants were harvested with a plastic knife to avoid metal contamination. All handling of plants and sediments was done with the researcher wearing plastic gloves. Almost all plants of *S. anglica* flowered after 90 days. The plants growing in the "upland" situation in the first experiment were harvested after 118 days, as the salinity levels in this treatment were established 4 weeks after planting. Also, one root sample and one soil sample were taken from a bucket per treatment and per species. This was done only in the first year as the buckets in the second year were kept intact for a regrowth experiment.

10. The shoots and roots were thoroughly rinsed with demineralized water and blotted dry with filter paper. The fresh weight of whole shoots was measured for *S. alterniflora*, *S. anglica*, and *F. maritima*. The shoots of *A. tripolium* were divided into stem, leaves, and inflorescences (if present). These divisions were separately weighed and subsequently analyzed. For *S. alterniflora* and *S. anglica*, the number of tillers and the total length of the shoots were also measured. The second greenhouse experiment was left in place to allow regrowth. This regrowth was harvested after another 90 days.

11. The results obtained from the root samples are not discussed in this report. The number of samples was too low, and the variation in metal levels too high to give any firm conclusions.

Analysis of plant samples

12. After the measurement of the fresh weight, the samples were kept at -20°C awaiting analyses. For the analyses, the samples were freeze-dried to constant weight. The dried samples (both plant and sediment) were then ground in an agate mill to avoid metal contamination. All handling of samples was done with the investigator wearing plastic gloves. The plant samples were subsequently digested with concentrated HNO_3 and H_2O_2 (30 percent). The destructure was brought to a volume of 50 ml by adding demineralized water. All elements were measured in this watery extract. Calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn) were measured by means of atomic absorption spectrometry. Sodium and potassium (K) were measured by means of flame-emission spectroscopy, using an air-acetylene flame. Lead, cadmium (Cd), and copper (Cu) were measured on the atomic absorption spectrophotometer in combination with a graphite furnace. Lead and cadmium were measured by means of the standard addition method. Arsenic was determined by hydride generation and atomic absorption spectrometry. All measurements were performed with a Perkin Elmer Model 2380 spectrophotometer.

Analysis of sediment samples

13. The sediment samples were freeze-dried to constant weight and ground in an agate mill before being sieved through a 2-mm sieve. Special care was taken to avoid heavy-metal contamination during the treatment of the samples. The chloride content of the samples was measured by potentiometric titration with AgNO_3 in a watery extract. CaCO_3 was measured by shaking 3 g of dry soil with 15-ml demineralized water and 7-ml HCl (25 percent). The CO_2 generated was measured volumetrically.

14. The particulate organic matter content was measured by pyrolysis of the sample and weighing of the produced CO_2 , adsorbed at an adsorption complex. P_2O_5 was determined colorimetrically by the vanadate method (Andersen 1975). Total nitrogen was measured as N_2 after pyrolysis in a Carlo Erba Model 1400 nitrogen analyzer. The pH was measured as pH KCl.

15. All metal ions were determined as total contents after digestion of the sample with a HCl-HNO_3 mixture (3:1) and a subsequent digestion with H_2O_2 (Schramel et al. 1982). All ions were analyzed in the destructure with the Atomic Absorption Spectrophotometer in combination with a graphite furnace. All results were statistically tested with an analysis of variance and a calculation of the least significant difference (LSD).

Field Experiment

16. On 15 April 1985, a field experiment was set up using the same buckets as in the greenhouse. These buckets were put in the nature reserve "Verdronken Land van Saeftinghe" on the bank of a tidal creek where they would be inundated during most of the tides. Permission for this experiment was obtained from the provincial trust "Het Zeeuwse Landschap" managing the reserve. The location was situated in a salt marsh along the Western Scheldt just across from the spot where the sediment had been dredged.

Sediment preparation

17. Fifty buckets were filled with sediment from a nearby creek matching the structure of the dredged sediment and placed in the creek bank. Additional soil samples were taken to be analyzed for heavy metals.

Plant material

18. Cuttings of *S. alterniflora*, *S. anglica*, *A. tripolium*, and *P. maritima* were planted in the pots, 12 replicates per species. Two pots with *S. alterniflora* were kept as a reserve since this species might have difficulty adjusting to an alien environment. After 1 month, the *Puccinellia* plants showed severe die-back, probably because of the flooding frequency that was unusually high for this species, which normally grows in higher parts of the marsh. Another 12 buckets with cuttings of this plant species were planted on a slightly higher level. The complete experiment was fenced off to exclude grazing damage and removal of plants by the tides.

Harvesting of the plants

19. The plants were harvested 5 months after the planting of the experiment. The shoots were cut with plastic knives and put in polyethylene bags that had been thoroughly rinsed with demineralized water. The bags were closed, labeled, and stored at -20° C while awaiting analysis.

Analysis of plant and soil samples

20. The plant samples were analyzed as reported in paragraph 12. The soil samples were analyzed as reported in paragraphs 13, 14, and 15.

PART III: RESULTS

Sediment Analyses

21. Immediately after dredging, eight soil samples were taken from a total mass of 1,000 ℓ of sediment dredged near Antwerp (Figure 1). The results are given in Table 1 (the individual results are given in Appendix A) together with the results of soil samples taken after the experiment with *S. altermiflora* and *S. anglica* in 1983. As these last figures are based on just one sample, no statistical treatment of the data could be performed, and they should be regarded as an indication.

22. The figures for the moisture content of the soil under waterlogged and drained conditions indicate that the drained soil was still very wet. Under drained conditions the salinity was low in both salinity treatments, while under waterlogged conditions the salinity was comparatively high in both treatments. The treatments applied were therefore waterlogged conditions coupled with high salinity and drained conditions coupled with low salinity. Although the results of the analyses of the plants will be presented as results for the four treatments, in the discussion this will be taken into account. In Table 2 the results of soil samples taken at the beginning of the field experiment are shown. Compared with the figures of the dredged sediment, there is only a slight difference. Appendix B gives the individual results of five soil samples.

Plant Analyses (Greenhouse Experiment)

Growth parameters

23. The data presented in Figure 3 show the fresh weight of the shoots of *S. altermiflora* in the 1983 and 1984 experiments, both on dredged sediment and on WES soil. There is a difference in average fresh weight per plant between plants grown on WES soil and plants grown on dredged sediment; this difference could be due to a difference in soil fertility. No significant difference could be found between the various treatments over the 2 years (analysis of variance). The results obtained from plants grown on WES soil were not statistically treated, as they were too few and too different from the results on the dredged material. The individual results are given in

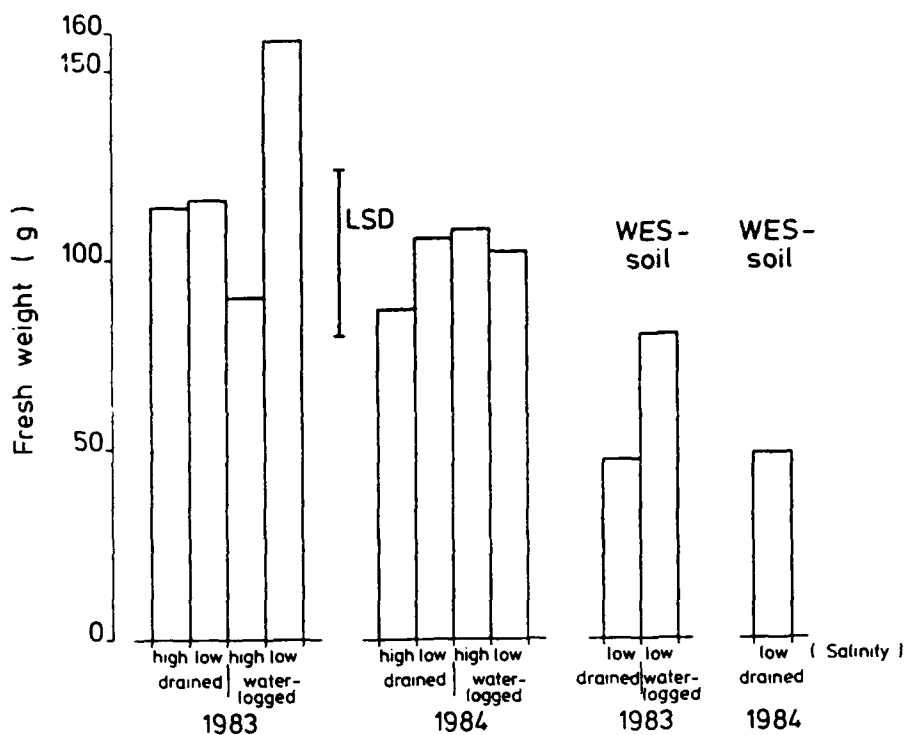


Figure 3. Total fresh weight of shoots per pot of *S. alterniflora* grown in 1983 and 1984 under different treatments

Appendix C. The average amount of tillers produced per plant is shown in Figure 4. There is a significant difference between the average number of tillers produced in 1983 and 1984, and in 1983 a significant difference between drained and waterlogged circumstances. The difference in tiller production could be due to the fact that in 1983 the plants were grown from seedlings and in 1984 from cuttings.

24. The number of tillers of *S. anglica*, the European *Spartina*, is also shown in Figure 4. The difference between the two species is obvious, as is the difference between the number of tillers under drained and under waterlogged conditions. All plants of *S. anglica* were flowering at the end of the experiment.

25. The average fresh weight of the two *Spartina* species grown in 1983 is compared in Figure 5. An analysis of variance showed a significant difference between the two species, but no significant difference between the treatments. Appendices C and D give the individual results.

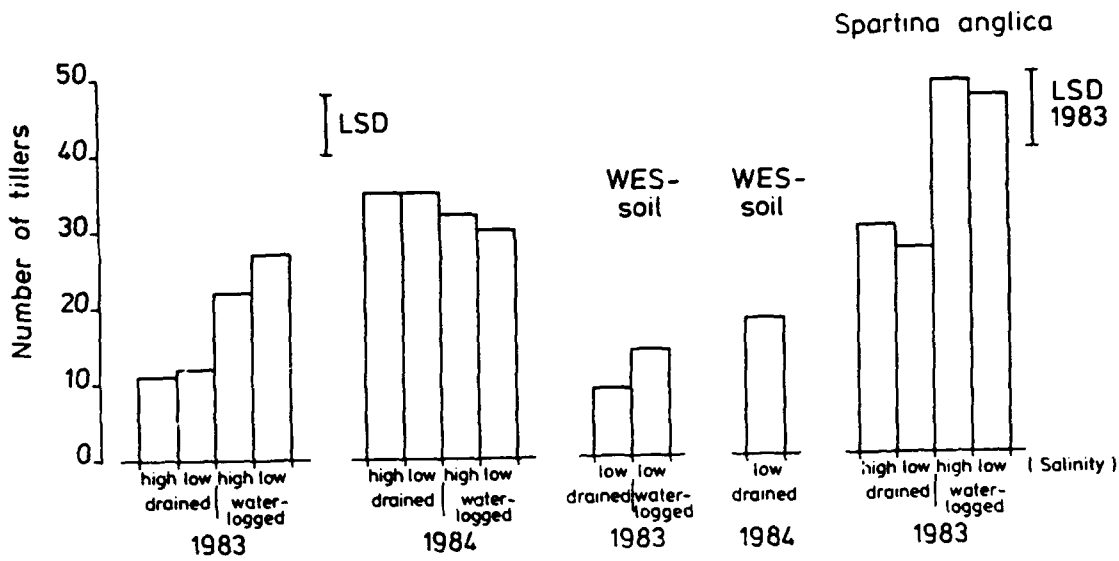


Figure 4. Number of tillers per pot of *S. alterniflora* and *S. anglica* grown in 1983 and 1984 under different treatments

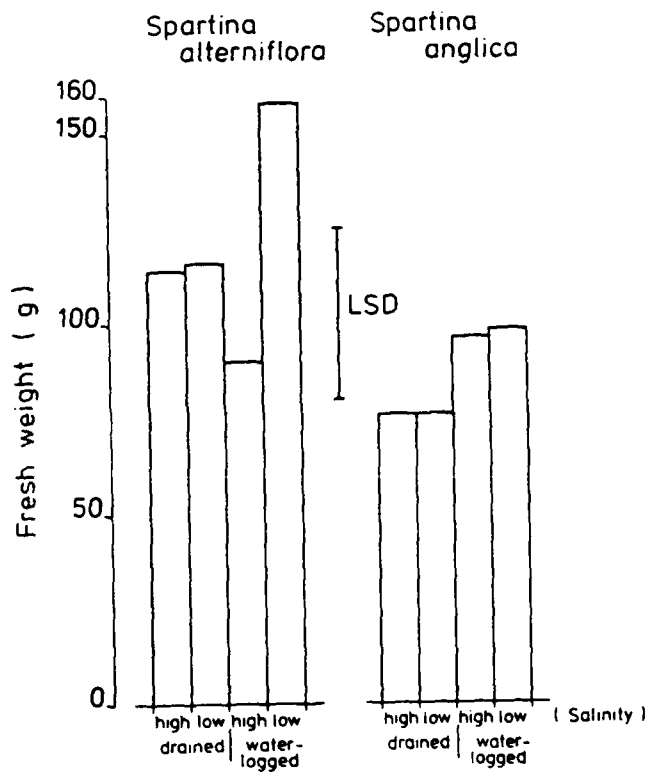


Figure 5. Total fresh weight of shoots per pot of *S. alterniflora* and *S. anglica* grown under different treatments in 1983

26. The data presented in Figure 6 show the average fresh weight of the part of the experiment performed in 1984. The species studied were *S. alterniflora*, *P. maritima*, and *A. tripolium*. Comparison of the results is questionable as the species are not as closely related as the *Spartinas* are (same genus). Moreover, *A. tripolium* is a forb with a completely different growth form as compared with the other two species, which are grasses. The latter two species produce, for instance, a negligible amount of stem material, contrary to *A. tripolium*. Stem material and leaf material of *A. tripolium* were processed separately, both chemically and statistically. No significant difference between the results from the various treatments could be found. There is a significant difference between the species, however.

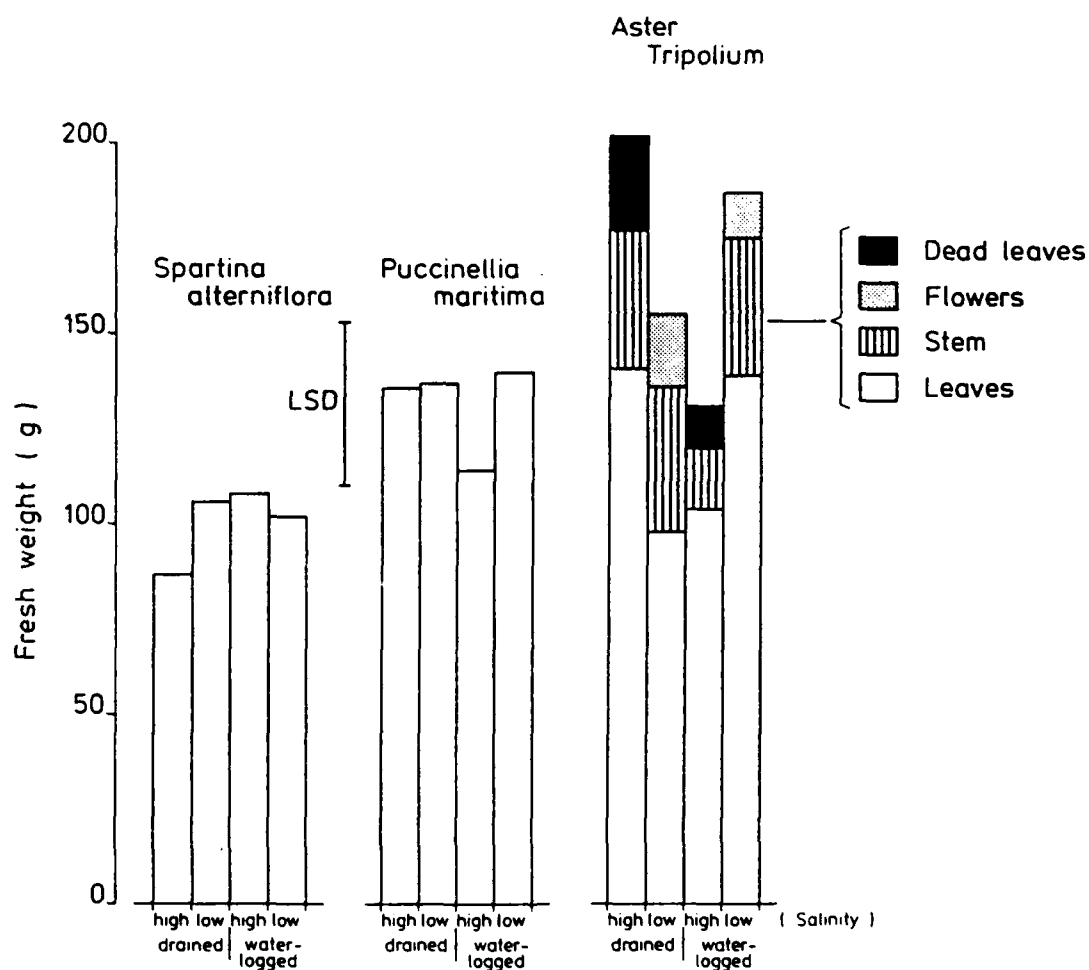


Figure 6. Total fresh weight of shoots per pot of *S. alterniflora*, *P. maritima*, and *A. tripolium* grown under different treatments in 1984

This is not surprising as the stem fraction was treated statistically as a separate species. The weights of this fraction, though, were substantially lower as compared with the leaf fraction or the shoots of the grasses. The results of *A. tripolium* show a clear difference in behaviour under the various treatments. Under low-salinity conditions, the plants flowered, which did not occur under high-salinity conditions. Under high-salinity conditions, the plants formed a substantial amount of dead leaves, while the amount of fresh leaves did not differ significantly. The turnover rate of leaves must therefore be higher under high-salinity conditions. This has been shown for other halophytes as well (Waisel 1972). The difference between the results from high- and low-salinity treatments for *A. tripolium* could indicate that in 1984 the two salinity levels might have been established properly, contrary to the results shown for 1983 (Table 1). This fact, however, could not be checked, as no soil samples were taken because the buckets with their contents were saved for a regrowth experiment.

Plant analyses

27. The average amounts of metal ions in shoots of plants grown in 1983 and 1984 are shown in Tables 3 and 4 and in Appendices E, F, G, and H. The results of the experiment performed in 1983 (Table 3) are the means of samples from five replicate treatments. The results for *S. anglica* grown under high-salinity and waterlogged conditions are the means of three samples, however, as two plants showed a strongly reduced growth as compared with all other plants. In Table 4, the significance of the individual figures is shown.

28. Although considerable overlaps occur in the significant differences, some general tendencies are shown. Under inundated circumstances Mn, Na, Ca, and Mg were taken up in higher amounts, while under drained conditions Cu, As, K, and, to a certain extent, Zn were taken up in higher quantities.

29. Cadmium showed a tendency to be taken up more by *S. alterniflora*, while Fe seemed to be taken up in higher amounts by *S. anglica*. The pattern for Pb is not clear. The difference in high- and low-salinity treatments is unclear. Table 5 shows the results of the experiment performed in 1984. *Spartina alterniflora* was used in this experiment for comparison with the findings in 1983.

30. The significant differences between the species and between the treatments are presented in Table 4. The stem-fraction and the leaf-fraction of *A. tripolium* are treated as separate species. The highest metal levels are

found in the leaves of *A. tripolium* (Appendix G). The grasses have significantly lower levels of Cd, Cu, Zn, Fe, and Na in their shoots as compared with the forb *A. tripolium*. The As, K, and Ca levels differed significantly between all species. The levels of Mn and Mg were significantly lower in the stems of *A. tripolium* and in *P. maritima* shoots, while Pb seemed to be accumulated especially in the stem of *A. tripolium*. Under drained circumstances Cd, Cu, and Zn were taken up more. The levels of As differed significantly between all treatments. The Pb, Fe, Mn, Mg, Na, K, and Ca levels showed no obvious difference.

31. An analysis of variance performed on the results of the experiment of 1983 and 1984 with *S. alterniflora* showed significantly higher levels of Fe, Mn, Na, K, and Ca in 1984. The levels of Cu and As were lower in 1984.

Plant analyses (regrowth)

32. A comparison of the first and the second harvest of the greenhouse experiment is given in Table 7 (full results in Appendix I). *Aster tripolium* did not have any regrowth at all, probably because of the harvesting method, as most of the axillary buds were harvested as well. *Puccinellia maritima* had regrowth only under the low-salinity treatment. The level of metals in the shoot at the second harvest was significantly different from that at the first harvest. This might be due to the increased soil ripening process by the root system of the plant. Significantly higher concentrations of Cd, Cu, Na, and Mg were shown in the second harvest. For Fe, As, and K, the values were lower at the second harvest. There was a difference in Mn content between inundated and drained treatments of the two harvests. Regrowth of *S. alterniflora* occurred in all treatments. Levels of Cd were higher in the second harvest and even more so under drained circumstances. Levels of Pb, Fe, As, Na, and K did not differ significantly. Levels of Mn were higher in the second harvest, as were Cu, Ca, and Mg. The Zn concentrations in the shoots of the second harvest were higher in the drained treatments and lower in the inundated treatments.

Plant Analyses (Field Experiment)

33. The average values of metal ions in the shoots of the various plant species grown under field circumstances are presented in Table 8. There are two sets of data for *P. maritima* (as mentioned in paragraph 18). After

1 month, another set of buckets with *P. maritima* was planted, as the first set did not grow very well. Eventually, the first set of plants started to grow as well, and at the time of harvesting, there was no visible difference between the two sets. Levels of Fe, Mn, Cu, and K showed significant differences, however, between the two sets of plants (Table 9). This difference could have been caused by a slight difference in aeration of the soil in the buckets planted at a higher level.

34. *Aster tripolium* had, in general, higher metal concentrations in the shoot as compared with the grasses, with the exception of *Puccinellia*, which had higher levels of Fe and As. The two *Spartina* species generally had lower levels of metal ions in the shoot except for Mn, Na, K, Ca, and Mg. *Puccinellia maritima* also tended to have lower levels of Mn, Na, K, Ca, and Mg. The individual results of the experiment are given in Appendix J. The significant differences between the various species for the individual metals are given in Table 9. The quality control analysis method is included in Appendix K.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

35. The division of the total greenhouse experiment into two parts spread over 2 consecutive years may have obscured some of the differences in plant uptake of heavy metals and the influence of the four treatments on the uptake. First, different plant material was used for *S. alterniflora* in 1983 and 1984. In 1983 young plants grown from seedlings were used; in 1984 the plants were grown from cuttings taken from older plants. This may explain the difference in tiller production in 1983 and 1984. In 1983 there was a significant difference in tiller production under drained and waterlogged conditions (Figure 4). In 1984, however, no significant difference was found, and the mean number of tillers was generally higher. This was also the case with the plants grown on the reference soil obtained from WES.

36. Second, there was a difference in the type of sediments used in 1983 and 1984. In 1983 the sediment used had been dredged only 2-1/2 months before the start of the experiment, while in 1984 the same sediment was used and had then had about 15 months to settle and ripen. The sediment, however, never dried out even after 15 months. At the start of the experiment in 1984, it was still a "mousse."

37. These features were the reason that the experiments for the 2 years were discussed separately. The higher levels of Mn and Fe in the shoots of *S. alterniflora* in 1984 (Tables 3 and 5) could have been due to the difference in soil conditions in 1983 and 1984. It is known that a lower redox potential may result in a higher availability of these metal ions (Rozema and Roosenstein 1985). The differences in levels of other metals did not show a clear pattern.

38. The differences between high- and low-salinity treatments were not clear. Analyses of salinity in 1983 showed that the high-salinity, drained treatment had a lower salinity than the high-salinity, waterlogged treatment (Table 1). This was undoubtedly due to the watering of the pots with tap water to prevent serious desiccation of the top layer of soil in the pots. This watering apparently washed down the salts, although once a week the pots were watered with artificial seawater. Although in 1984 the drained pots were watered more often with artificial seawater, the results (Table 5) showed that

the difference in the two treatments was still not clear. As the pots were used for a sequential regrowth experiment, no soil samples were taken. This watering resulted effectively in three treatments: high-salinity, waterlogged; low-salinity, waterlogged; and low-salinity, drained.

39. In the regrowth experiment, the results for Fe and Mn were completely different. This is in accordance with the findings of Rozema, Luppens, and Broekman (1985). It is very difficult to decide whether this is due to the ripening-aeration process in the soil, enhanced by the rooting of the plants, to mere soil processes or for that matter plant processes. Probably it is a complex of factors in which the inundation or drainage is also involved. The results showed, however, that increased aeration of the soil by drainage may alter the availability of heavy metals. Inundation may retard this process, as the results in Tables 3 and 5 indicate. The results show that inundation may lower the uptake of Cd, Zn, and probably Pb, As, and Cu, but increased levels of Mn were seen in *Spartina* shoots, and lower levels in *A. tripolium*. For Fe, this pattern is less clear. The levels of Fe in the shoots of *P. maritima* differ from both *A. tripolium* and the *Spartina* species. The salinity level may play a role in the uptake of Fe and Mn. In general, it may be concluded that drainage and aeration resulted in higher levels of Cd, Zn, Pb, As, Cu, and Mn in some cases, while Fe tended to occur in higher levels under less ripened soil conditions (higher salinity and less aeration). The regrowth results with respect to levels of Cd, Cu, Mn, and As support this conclusion. Lead concentrations were not significantly different in the two harvests, and Fe levels were higher only in the first harvest of *P. maritima*.

40. How do all these results relate to the real situation in the field? In Table 10 a comparison is made between the greenhouse results and the results of the field experiment. For a better comparison, the results from the drained treatment with low salinity was used as these circumstances were closest to the field situation (Table 1). Lower concentrations of Pb, Fe, Cu, As, and Mg were found in the shoots of three of the species tested in the greenhouse experiment, whereas Mn and K concentrations were higher than in the field. These figures coincide with the soil analyses. In general, the greenhouse experiment gave a good picture of the reactions of the plants under field conditions, which means that in this research project the bioassay procedure could be used as a model of the field situation.

41. The differences in heavy-metal uptake for the different plant species is apparent, especially in the experiment of 1984. For a bioassay procedure, it is imperative to make a choice of only one standard species. The best American species may be *S. Alterniflora*, but in the Dutch environment with a greater species diversity in the salt marsh, it may be difficult to make a choice. *Spartina anglica* is a dominant species in the Dutch salt marsh and may therefore qualify, but so are *P. maritima*, known as a low accumulator, and *A. tripolium*, which is a high accumulator of heavy metals (Beeftink et al. 1982). *Aster tripolium* is eaten as a vegetable in The Netherlands and is therefore subject to the standard for heavy-metal contamination as established by the Ministry of Agriculture. It is tempting to use this standard for the *A. tripolium* bioassay to decide whether a soil is contaminated or not, but there is no jurisdiction with respect to this matter.

Recommendations

42. The bioassay procedure developed at WES provides a good method to assess the contamination level of a certain amount of dredged material. It has to be decided, however, which species should be used as a European test organism, as different species accumulate heavy metals in different amounts.

43. It is clear from the 2-year test results that the time between dredging, bioassay, and harvesting is a decisive factor in determining the availability of the various metal ions. It is therefore imperative that this time be taken into account when the results of a bioassay procedure are analyzed.

44. Further research has to be performed to study the pathway of the contaminants in the food chains of the ecosystem. Studies on herbivorous and detrital fauna should be of first priority.

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Table 1
 Analysis Results of Soil Samples Taken Immediately from Dredged Sediment and Taken After the Sediment Was Left to Dry
 Out in Plants Grown in It for 90 Days

Soil Sample	CaCO ₃ %	Na meq per 100 g Dry Soil	K meq per 100 g Dry Soil	Moisture % per 100 g Dry Soil	NaCl g per 100 g Dry Soil	NaCl g per 100 g Water	P ₂ O ₅ mg per 100 g Dry Soil	pH (KCl) Soil	POC % Dry Soil	N-total % Dry Soil	Moisture % per 100 g Field Moisture	Clay Particles <16 μm %	Cd ppm	Pb ppm	Fe %	Cu ppm	Zn ppm	Cr ppm
Mean values of eight samples from dredged material	14.2	31.3	2.23	173.7	1.61	9.26	129	7.0	4.9	0.32	63.5	40.8	10.6	138	2.96	90	506	201
<i>S. anglica</i> high salinity waterlogged	14.8			86.1	1.80	20.94	132	7.6	4.5	0.31	46.3		10.8	139	3.77	87	471	
<i>S. anglica</i> high salinity drained	13.5			66.3	0.35	5.22	125	7.7	3.6	0.27	49.9		10.7	150	3.67	88	480	
<i>S. anglica</i> low salinity waterlogged	14.9			87.2	2.43	27.92	119	7.7	4.7	0.29	46.6		11.0	140	3.80	74	471	
<i>S. anglica</i> low salinity drained	14.6			87.3	0.26	2.92	110	7.7	3.8	0.29	46.6		11.6	151	4.21	101	501	
<i>S. alterniflora</i> high salinity waterlogged	14.3			95.2	3.44	36.16	122	7.8	4.8	0.30	48.8		11.0	123	3.53	84	453	
<i>S. alterniflora</i> high salinity drained	13.8			76.8	0.43	5.62	119	7.6	3.8	0.27	43.4		11.7	138	3.65	97	462	
<i>S. alterniflora</i> low salinity waterlogged	14.8			99.9	2.12	21.29	126	7.6	4.7	0.29	46.6		11.3	142	3.90	91	483	
<i>S. alterniflora</i> low salinity drained	13.8			62.0	0.21	3.39	128	7.5	3.5	0.26	38.3		10.7	118	3.59	>1	462	
WFS reference soil <i>S. alterniflora</i> low salinity waterlogged	0.65			36.5	0.04	1.15	22	6.8	0.9	0.07	26.8		1.4	112	1.23	5	37	
WFS reference soil <i>S. alterniflora</i> low salinity drained	0.47			30.9	0.07	2.18	21	7.4	0.4	0.05	23.6		1.6	104	1.51	8	42	

Table 2

Analysis Results of Soil Samples Taken from Sediment Used in
the Field Experiment*

CaCO ₃ %	Na	K**	Moisture	NaCl	NaCl	P ₂ O ₅			
	meq per 100 g <u>Dry Soil</u>	meq per 100 g <u>Dry Soil</u>	% per 100 g <u>Dry Soil</u>	g per 100 g <u>Dry Soil</u>	g per l Soil <u>Water</u>	mg per 100 g <u>Dry Soil</u>	pH (KCl)		
13.4	16.5	26.6	105.9	0.500	4.73	134	7.5		
POC %	N-total %	Moisture % per 100 g Field <u>Moist Soil</u>	Clay Particles <16 μm %	Cd <u>ppm</u>	Pb <u>ppm</u>	Fe %	Cu <u>ppm</u>	Zn <u>ppm</u>	C/N <u>Ratio</u>
3.6	0.31	51.0	49.0	13.5	153	3.97	93	505	14.8

* Data are averages of five values.

** Determined by total destruction instead of shaking with acid. Total destruction gives 10 ± 2 times higher values.

Table 3

Amounts of Metal Ions in Shoots of *S. anglica* and *S. alaterniflora*
Grown Under Different Salinities and Soil Moisture Conditions*

Metal	<i>S. anglica</i>						<i>S. alaterniflora</i>						Least Significant Difference
	High Salinity		Low Salinity		High Salinity		Low Salinity		High Salinity		Low Salinity		
	Inundated	Drained	Inundated	Drained	Inundated	Drained	Inundated	Drained	Inundated	Drained	Inundated	Drained	
Cd	0.130	0.118	0.112	0.074	0.214	0.284	0.170	0.228	0.144				
Pb	0.522	0.474	0.286	0.482	0.388	0.490	0.368	0.510	0.176				
Fe	74.2	62.8	62.6	69.8	59.8	52.0	59.8	56.6	11.5				
Mn	117.0	92.6	104.0	80.0	116.2	90.8	100.2	82.6	24.6				
Cu	3.30	4.00	3.50	4.96	3.44	5.38	2.58	5.30	1.37				
Zn	14.2	20.6	17.6	26.4	23.2	36.4	16.6	26.4	11.2				
As	0.162	0.282	0.158	0.258	0.152	0.306	0.154	0.266	0.077				
Na	33.88	23.04	31.46	20.66	24.94	16.06	22.28	14.60	3.71				
K	8.52	13.86	8.92	13.62	12.62	15.98	10.18	15.20	3.05				
Ca	3.10	2.32	2.78	2.08	2.84	2.54	2.70	2.36	0.52				
Mg	3.70	1.94	3.54	1.82	2.18	1.86	2.34	1.72	0.51				

* Cd, Pb, Fe, Mn, Cu, Zn, and As in mg·kg⁻¹ on dry weight basis; Na, K, Ca, and Mg in mg·g⁻¹.

Table 4

Least Significant Differences in Heavy-Metal Concentrations in Shoots
of *S. anglica* and *S. alterniflora* (P < 0.001)*

<u>Metal</u>	<u>Treatment</u>								<u>Metal</u>	<u>Treatment</u>							
Cd	4	3	2	1	7	5	8	6	As	5	7	3	1	4	8	2	6
	_____									_____							
Pb	3	7	5	2	4	6	8	1	Na	8	6	4	7	2	5	3	1
	_____									_____							
Fe	6	8	5	7	3	2	4	1	K	1	3	7	5	4	2	8	6
	_____									_____							
Mn	4	8	6	2	7	3	5	1	Ca	4	2	8	6	7	3	5	1
	_____									_____							
Cu	7	1	5	3	2	4	8	6	Mg	8	4	6	2	5	7	3	1
	_____									_____							
Zn	1	7	3	2	5	4	8	6		_____							
	_____									_____							

* The numbers 1 through 8 represent the various treatments:

<i>S. anglica</i>	high salinity	inundated	1
		drained	2
	low salinity	inundated	3
		drained	4
<i>S. alterniflora</i>	high salinity	inundated	5
		drained	6
	low salinity	inundated	7
		drained	8

Table 5

Amounts of Metal Ions in Shoots of *S. alterniflora*, *P. maritima*, and *A. tripolium* (Leaves and Stem)
Grown Under Different Salinities and Soil Moisture Conditions*

Metal	<i>S. alterniflora</i>		<i>P. maritima</i>		<i>A. tripolium</i> (Leaves)		<i>A. tripolium</i> (Stem)	
	High Salinity Inundated	Low Salinity Inundated	High Salinity Inundated	Low Salinity Inundated	High Salinity Inundated	Low Salinity Inundated	High Salinity Inundated	Low Salinity Inundated
Cd	0.186	0.362	0.114	0.194	0.222	0.580	0.260	0.228
Pb	0.380	0.368	0.712	0.504	0.520	0.640	1.354	0.500
Fe	253.0	153.6	75.4	92.2	259.6	208.2	523.6	185.8
Mn	126.6	100.0	69.6	68.2	81.0	130.8	29.2	29.2
Cu	3.40	3.08	4.22	5.18	5.18	7.60	13.24	10.18
Zn	20.4	21.4	11.4	13.4	29.0	37.0	23.4	20.6
As	0.200	0.144	0.230	0.228	0.096	0.030	0.298	0.136
Na	24.62	19.86	14.08	6.04	60.06	57.42	10.14	20.28
K	14.16	25.12	27.84	18.86	28.84	29.68	6.12	7.98
Ca	3.28	3.58	1.58	1.14	4.92	5.18	2.02	3.12
Mg	2.24	1.74	1.84	0.93	2.12	2.12	1.70	1.26

* Cd, Pb, Fe, Mn, Cu, Zn, and As in $\text{mg}\cdot\text{kg}^{-1}$ on dry weight basis; Na, K, Ca, and Mg in $\text{mg}\cdot\text{g}^{-1}$.

Table 6
Least Significant Difference in
Heavy-Metal Concentrations

<u>Metal</u>	<u>Species*</u>				<u>Treatments**</u>			
Cd	<u>2</u>	<u>1</u>	<u>4</u>	<u>3</u>	<u>C</u>	<u>D</u>	<u>A</u>	<u>B</u>
Pb	<u>1</u>	<u>3</u>	<u>2</u>	<u>4</u>	<u>D</u>	<u>A</u>	<u>B</u>	<u>C</u>
Fe	<u>3</u>	<u>1</u>	<u>2</u>	<u>4</u>	<u>D</u>	<u>B</u>	<u>A</u>	<u>C</u>
Mn	<u>4</u>	<u>2</u>	<u>1</u>	<u>3</u>	<u>C</u>	<u>A</u>	<u>D</u>	<u>B</u>
Cu	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>D</u>	<u>B</u>	<u>C</u>	<u>A</u>
Zn	<u>2</u>	<u>1</u>	<u>4</u>	<u>3</u>	<u>C</u>	<u>D</u>	<u>A</u>	<u>B</u>
As	<u>3</u>	<u>1</u>	<u>4</u>	<u>2</u>	<u>D</u>	<u>A</u>	<u>B</u>	<u>C</u>
Na	<u>2</u>	<u>1</u>	<u>4</u>	<u>3</u>	<u>B</u>	<u>A</u>	<u>C</u>	<u>D</u>
K	<u>4</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>D</u>	<u>B</u>	<u>C</u>	<u>A</u>
Ca	<u>2</u>	<u>4</u>	<u>1</u>	<u>3</u>	<u>C</u>	<u>A</u>	<u>B</u>	<u>D</u>
Mg	<u>2</u>	<u>4</u>	<u>1</u>	<u>3</u>	<u>B</u>	<u>A</u>	<u>D</u>	<u>C</u>

* *S. alterniflora* = 1; *P. maritima* = 2; *A. tripolium* leaves = 3; *A. tripolium* stems = 4.

** High-salinity, drained = A; low-salinity, drained = B; high-salinity, inundated = C; low-salinity, inundated = D. The underlined symbols do not differ significantly from each other (P < 0.001).

Table 7

Average Values of Metal-Ion Concentrations* in Two Subsequent Harvests of Shoots of *P. maritima* and *S. alterniflora*

Harvests	mg·kg ⁻¹							
	Cd		Pb		Fe		Mn	
	I**	II	I	II	I	II	I	II
<i>P. maritima</i>								
Low salinity								
drained	0.30	0.53†	1.06	0.42	481	54†	71	66
inundated	0.11	0.19	0.38	0.39	168	90†	61	73†
<i>S. alterniflora</i>								
Low salinity								
drained	0.21	0.95†	0.43	0.30	161	170	116	265†
inundated	0.16	0.23†	0.21	1.03	176	99	106	221†
High salinity								
drained	0.36	1.07	0.37	0.30	154	172	100	191†
inundated	0.19	0.25	0.38	0.30	253	108	127	328†
Harvests	mg·kg ⁻¹							
	Cu		Zn		As			
	I	II	I	II	I	II	I	II
<i>P. maritima</i>								
Low salinity								
drained	3.6	4.9†	14	11	0.35		0.03†	
inundated	3.1	5.2†	10	13	0.16		0.09	
<i>S. alterniflora</i>								
Low salinity								
drained	3.4	3.6	23	34†	0.19		0.18	
inundated	3.2	3.9†	20	14†	0.12		0.21†	
High salinity								
drained	3.1	4.2†	21	37†	0.14		0.18	
inundated	3.4	3.5	20	15†	0.20		0.20	

(Continued)

* Cd, Pb, Fe, Mn, Cu, Zn, and As in mg·kg⁻¹ on dry weight basis; Na, K, Ca, and Mg in mg·g⁻¹.

** I = first harvest, II = second harvest.

† Significant difference (P < 0.05).

Table 7 (Concluded)

Harvests	$\text{mg}\cdot\text{g}^{-1}$							
	Na		K		Ca		Mg	
	I	II	I	II	I	II	I	II
<i>P. maritima</i>								
Low salinity								
drained	6.6	8.4	19.8	14.5†	1.4	1.5	1.1	1.5
inundated	8.7	16.1†	15.5	11.1†	1.2	2.1	1.3	2.7†
<i>S. alterniflora</i>								
Low salinity								
drained	19.4	21.1	12.0	14.1	3.5	7.1†	2.2	3.6†
inundated	22.2	25.1	12.3	11.4	3.4	6.8†	2.1	4.4†
High salinity								
drained	19.9	21.4	25.1	13.0†	3.6	7.1†	1.7	3.3†
inundated	24.6	25.9	14.2	15.1	3.3	7.1†	2.2	4.5†

* Cd, Pb, Fe, Mn_1 , Cu, Zn, and As in $\text{mg}\cdot\text{kg}^{-1}$ on dry weight basis; Na, K, Ca, and Mg in $\text{mg}\cdot\text{g}^{-1}$.

** I = first harvest, II = second harvest.

† Significant difference ($P < 0.05$).

Table 8

Amounts of Metal Ions on Dry Weight Basis in Shoots of *P. maritima*,
A. tripolium, *S. anglica*, and *S. alterniflora* Grown in
Buckets in a Salt Marsh near Antwerp*

Parameters**	As	Cd	Pb	Fe	Mn	Cu	Zn	Na	K	Ca	Mg
<i>P. maritima</i>											
(second planting)											
metal ions	0.67	0.46	2.5	632	60	10.1	26	12.9	11.5	1.9	2.0
SD(n-1)	0.19	0.15	1.9	226	14	1.5	3	1.7	1.4	0.5	0.4
% CV	29.0	32.7	76.5	35.7	23.3	14.5	11.3	13.5	11.9	29.2	20.4
n	11	13	13	13	13	12	12	13	13	13	13
<i>P. maritima</i>											
(first planting random)											
metal ions	0.74	0.29	3.4	882	49	8.1	26	11.5	8.4	1.7	1.7
SD(n-1)	0.18	0.07	1.2	257	9	1.1	5	0.9	1.3	0.3	0.2
% CV	25.0	24.0	34.9	29.1	18.0	13.7	19.8	8.0	15.6	17.0	12.6
n	11	11	11	11	11	11	11	11	11	11	11
<i>A. tripolium</i>											
metal ions	0.53	0.89	3.6	566	68	13.1	55	38.3	14.7	5.4	3.9
SD(n-1)	0.29	0.45	1.5	286	15	4.4	14	12.3	2.8	1.4	0.8
% CV	55.6	50.9	42.0	50.5	21.7	33.7	25.0	38.3	19.3	26.4	20.0
n	11	12	12	12	12	12	12	12	12	12	12
<i>S. anglica</i>											
metal ions	0.41	0.10	1.1	303	60	3.9	21	24.1	11.8	2.3	2.3
SD(n-1)	0.09	0.03	0.4	47	8	0.8	5	2.3	1.5	0.2	0.2
% CV	21.5	30.8	34.2	15.4	14	20.8	22.3	9.5	12.8	8.2	8.5
n	12	11	12	12	12	12	12	12	12	12	12
<i>S. alterniflora</i>											
metal ions	0.41	0.23	1.1	300	70	4.4	21	19.6	9.6	2.7	1.8
SD(n-1)	0.10	0.12	0.3	63	11	0.8	6	2.0	1.4	0.4	0.2
% CV	25.5	52.3	29.7	21.0	15.1	18.1	26.1	10.3	15.1	13.9	12.8
n	13	13	13	13	13	13	13	13	13	13	13

* As, Cd, Pb, Fe, Mn, Cu, Zn, and Na are given in $\text{mg}\cdot\text{kg}^{-1}$; Na, K, Ca, and Mg are given in $\text{mg}\cdot\text{g}^{-1}$.

** SD = standard deviation; % CV = percentage covariance; n = number of samples.

Table 9
Least Significant Differences in Heavy-Metal
Concentrations in Shoots of Four Salt-Marsh
Species Grown Under Field Conditions*

<u>Metal</u>	<u>Treatment</u>					<u>Probability</u>
Cd	4	5	2	1	3	<0.001
Pb	4	5	1	2	3	<0.001
Fe	5	4	3	1	2	<0.001
Mn	2	1	4	3	5	<0.001
Cu	4	5	2	1	3	<0.001
Zn	4	5	2	1	3	<0.001
As	4	5	3	1	2	<0.001
Na	2	1	5	4	3	<0.001
K	2	5	1	4	3	<0.001
Ca	2	1	4	5	3	<0.001
Ng	2	5	1	4	3	<0.001

* 1 = *P. maritima* (second planting)
 2 = *P. maritima* (first planting)
 3 = *A. tripolium*
 4 = *S. anglica*
 5 = *S. alterniflora*

Table 10

Comparison of Results of Field Experiment (I) with *S. anglica*,
S. alterniflora, *P. maritima*, and *A. tripolium* (Leaves) with
Results of Greenhouse Experiment Under Drained and
Low-Salinity Conditions (II)

Species	$\text{mg} \cdot \text{kg}^{-1}$							
	Cd		Pb		Fe		Mn	
	I	II	I	II	I	II	I	II
<i>S. anglica</i> (1983 experiment)	0.10	0.07	1.1	0.5*†	303	70*†	60	80*†
<i>S. alterniflora</i>	0.23	0.21	1.1	0.4*†	300	161*†	70	116*†
<i>P. maritima</i>	0.29	0.30	3.4	1.1*†	880	481*†	50	71*†
<i>A. tripolium</i> (leaves)	0.89	1.48	3.6	0.6*†	566	80*†	68	168*†

Species	$\text{mg} \cdot \text{kg}^{-1}$					
	Cu		Zn		As	
	I	II	I	II	I	II
<i>S. anglica</i> (1983 experiment)	3.9	5.0*†	21	26	0.41	0.26*†
<i>S. alterniflora</i>	4.4	3.4*†	21	23	0.41	0.19*†
<i>P. maritima</i>	8.1	3.6*†	26	14*†	0.74	0.35*†
<i>A. tripolium</i> (leaves)	13.1	6.4*†	55	80	0.53	0.07*†

Species	$\text{mg} \cdot \text{g}^{-1}$							
	Na		K		Ca		Mg	
	I	II	I	II	I	II	I	II
<i>S. anglica</i> (1983 experiment)	24.1	20.7*†	11.8	13.6	2.3	3.1	2.3	1.8*†
<i>S. alterniflora</i>	19.6	19.4	9.5	12.0*†	2.7	3.5*†	1.8	2.2*†
<i>P. maritima</i>	11.5	6.6*†	8.4	19.8*†	1.8	1.4	1.7	1.1*†
<i>A. tripolium</i> (leaves)	38.3	48.7*†	14.7	29.4*†	5.4	7.6*†	3.9	2.1*†

NOTE: The asterisks mark a significant difference at the level $P < 0.05$. The arrows indicate significantly lower or higher values in the greenhouse experiment.

APPENDIX A: ANALYSIS RESULTS OF EIGHT SOIL SAMPLES TAKEN
RANDOMLY FROM 1,000- ℓ CONTAMINATED MATERIAL*

Lab	CaCO ₃ %	Na meq per 100 g Dry Soil	K meq per 100 g Dry Soil	Moisture % per 100 g Dry Soil	NaCl g per 100 g Dry Soil	NaCl g per ℓ Soil Water
27096	14.1	30.4	2.35	174.4	1.73	9.91
27097	14.5	32.3	2.31	173.4	1.69	9.77
27098	13.2	29.7	2.19	174.8	1.59	9.13
27099	13.7	29.9	2.15	174.1	1.38	7.91
27100	14.6	33.2	2.26	175.5	1.64	9.35
27101	15.8	34.0	2.23	173.8	1.52	8.76
27102	14.3	30.1	2.15	171.8	1.64	9.55
27103	13.2	29.5	2.17	171.7	1.66	9.68
mean	14.2	31.3	2.23	173.7	1.61	9.26
S.D.	3.8	1.8	0.08	1.4	0.11	0.66

	P ₂ O ₅ mg per 100 g Dry Soil	pH	POC %	N %	Moisture (100 g wet) ⁻¹ %	Clay % <16 μ m
27096	132	6.9	4.3	0.318	63.6	44.9
27097	130	7.1	4.5	0.323	63.4	39.9
27098	126	7.0	4.7	0.321	63.6	40.0
27099	132	7.0	5.4	0.323	63.5	38.3
27100	124	7.1	4.6	0.318	63.7	40.5
27101	125	7.0	5.5	0.321	63.5	41.2
27102	133	7.0	4.9	0.329	63.2	40.0
27103	132	7.1	5.1	0.324	63.2	41.2
mean	129	7.0	4.9	0.322	63.5	40.8
S.D.	4	0.1	0.4	0.004	0.2	1.9

	Cd ppm	Pb ppm	Fe %	Cu ppm	Zn ppm	Cr ppm	C/N ratio
27096	10.1	145	2.95	86	498	197	13.5
27097	10.6	135	3.46	92	510	100	13.9
27098	10.7	136	2.76	95	498	203	14.6
27099	10.7	136	3.06	93	498	200	16.7
27100	10.8	140	3.09	88	519	201	14.5
27101	10.8	139	2.79	88	507	201	17.1
27102	10.7	137	2.46	89	510	203	14.9
27103	10.6	137	3.13	90	504	204	15.7
mean	10.6	138	2.96	90	506	201	15.1
S.D.	0.2	3	0.30	3	8	2	1.3

* Samples were taken with the "van Veen" grab near the Zandvlietsluis (Antwerp), 6 January 1983. Calculated on dry basis except if mentioned.

APPENDIX B: ANALYSIS RESULTS OF FIVE SOIL SAMPLES TAKEN RANDOMLY
FROM SITE OF FIELD EXPERIMENT IN SAEFTINGE SALT MARSH*

Lab	CaCO ₃ % ³	Na meq per 100 g <u>Dry Soil</u>	K meq per 100 g <u>Dry Soil</u>	Moisture % per 100 g <u>Dry Soil</u>	NaCl g per 100 g <u>Dry Soil</u>	NaCl g per l Soil Water
30378	13.2	16.5	24.5	88.1	0.418	4.74
30379	14.0	16.5	27.1	114.7	0.557	4.86
30380	13.6	17.4	26.6	108.2	0.514	4.75
30381	12.7	18.7	27.6	131.5	0.596	4.53
30382	13.6	13.9	27.1	86.9	0.414	4.76
mean	13.4	16.6	26.6	105.9	0.500	4.73
S.D.	0.49	1.8	1.2	18.8	0.082	0.12

	P ₂ O ₅ mg per 100 g <u>Dry Soil</u>	pH KCl	POC %	N %	Moisture (100 g wet) ⁻¹	Clay % <16 μm
30378	132	7.5	4.3	0.31	46.9	47.8
30379	126	7.4	4.9	0.34	53.3	54.5
30380	137	7.6	4.5	0.33	52.0	49.9
30381	138	7.6	5.0	0.29	56.8	51.3
30382	136	7.5	4.3	0.29	45.8	41.6
mean	134	7.5	4.6	0.31	51.0	49.0
S.D.	4.9	0.06	0.33	0.023	4.58	4.81

	Cd <u>ppm</u>	Pb <u>ppm</u>	Fe %	Cu <u>ppm</u>	Zn <u>ppm</u>	Mn <u>ppm</u>	As <u>ppm</u>
30378	12.2	149	3.72	85.3	465	962	34.6
30379	14.8	149	3.90	92.9	530	1070	47.4
30380	13.2	158	3.99	98.0	510	1038	42.6
30381	13.9	168	4.30	101.7	542	1145	49.3
30382	13.4	144	3.94	89.2	480	980	41.1
mean	13.5	153	3.97	93.4	505	1039	43.0
S.D.	0.95	9.3	0.21	6.6	32	73	5.8

* The values are calculated on dry weight basis.

APPENDIX C: HEAVY METAL CONCENTRATIONS AND YIELD OF *SPARTINA*
ALTERNIFLORA (1983)

Pot No.	Fresh Weight Shoot, g	No. of Tillers	mg·kg ⁻¹							mg·g ⁻¹			
			Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>													
26	118.77	10	0.37	0.48	48	113	5.1	46	0.27	17.4	16.0	2.9	1.7
27	121.40	8	0.11	0.41	56	96	5.9	27	0.44	16.5	13.6	3.1	2.2
28	89.60	10	0.69	0.32	54	67	6.1	65	0.14	15.9	15.1	3.0	2.1
29	158.87	15	0.13	0.29	45	105	4.1	26	0.31	16.6	13.0	2.2	1.9
30	81.31	10	0.12	0.95	57	73	5.7	18	0.37	13.9	22.2	1.5	1.4
<u>Drained, Low Salinity</u>													
36	132.06	13	0.24	0.53	50	82	5.1	30	0.23	16.7	14.1	2.3	1.7
37	112.48	14	0.15	0.44	66	56	5.7	18	0.31	14.5	16.7	1.9	1.4
38	91.52	11	0.19	0.60	62	67	5.8	20	0.31	12.8	15.9	2.6	1.9
39	152.72	14	0.42	0.51	44	130	5.4	41	0.22	13.1	15.7	3.3	2.2
40	93.69	9	0.14	0.47	61	78	4.5	23	0.26	15.9	13.6	1.7	1.4
<u>Inundated, High Salinity</u>													
21	85.50	15	0.17	0.57	64	74	4.6	30	0.21	21.6	10.7	2.7	2.7
22	131.91	22	0.32	0.29	67	133	5.2	27	0.18	24.5	13.0	2.9	2.0
23	55.84	10	0.17	0.30	61	153	2.9	22	0.13	33.8	13.2	3.1	3.0
24	139.86	33	0.29	0.43	55	122	2.4	18	0.14	24.7	12.7	2.7	1.6
25	38.99	29	0.12	0.35	52	99	2.1	19	0.10	20.1	13.5	2.8	1.6
<u>Inundated, Low Salinity</u>													
31	155.28	23	0.09	0.32	63	109	2.2	16	0.15	24.3	9.5	2.9	2.3
32	99.90	27	0.19	0.29	71	105	2.5	14	0.16	23.1	9.5	3.0	2.3
33	119.32	24	0.15	0.49	66	83	2.2	17	0.16	22.6	11.3	2.2	1.6
34	158.11	27	0.19	0.48	63	108	2.9	17	0.17	22.6	9.5	3.0	2.4
35	258.83	32	0.23	0.26	46	96	3.1	19	0.13	19.8	11.1	2.4	2.1

APPENDIX D: HEAVY METAL CONCENTRATIONS AND YIELD OF *SPARTINA ANGLICA* (1983)

Pot No.	Fresh Weight Shoot, g	No. of Tillers	mg·kg ⁻¹							mg·g ⁻¹			
			Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>													
6	73.66	25	0.09	0.59	77	86	4.9	24	0.30	24.5	13.4	1.9	1.7
7	87.38	24	0.29	0.46	56	122	2.4	19	0.15	27.6	16.0	2.9	2.2
8	73.30	23	0.07	0.30	67	89	3.6	18	0.35	18.9	13.9	2.0	1.6
9	87.91	53	0.03	0.46	47	90	2.6	12	0.32	23.2	7.8	2.7	2.4
10	59.34	24	0.11	0.56	67	76	6.5	30	0.29	21.0	18.2	2.1	1.8
<u>Drained, Low Salinity</u>													
16	116.30	34	0.05	0.41	59	64	3.5	20	0.18	20.0	8.8	2.1	1.0
17	56.14	24	0.06	0.63	69	79	5.9	31	0.25	21.5	17.0	2.3	1.8
18	79.50	20	0.11	0.33	72	83	7.2	36	0.23	24.5	15.9	2.0	2.0
19	62.68	26	0.05	0.35	83	85	3.7	18	0.34	18.6	13.4	1.7	1.6
20	63.11	31	0.10	0.69	66	89	4.5	27	0.29	18.7	13.0	2.3	1.8
<u>Inundated, High Salinity</u>													
1	18.14	18	0.29	1.4	229	91	6.4	32	0.30	39.8	10.2	4.2	4.8
2	3.12	2	0.23	1.2	244	64	8.9	21	--	43.9	10.4	4.1	5.5
3	93.83	51	0.14	0.49	69	122	3.5	12	0.16	34.6	8.8	3.6	3.6
4	63.24	34	0.13	0.50	75	127	3.6	18	0.17	37.7	9.4	3.2	4.3
5	131.82	62	0.12	0.58	79	102	2.8	13	0.16	29.3	7.4	3.1	3.2
<u>Inundated, Low Salinity</u>													
11	127.17	57	0.11	0.21	46	112	3.3	14	0.14	33.1	8.7	3.0	3.5
12	105.82	58	0.04	0.21	53	90	2.8	15	0.11	31.7	7.7	2.6	3.6
13	120.06	47	0.14	0.40	74	98	3.0	17	0.19	28.7	7.9	2.7	4.0
14	46.19	27	0.16	0.26	75	122	4.6	26	0.22	32.7	11.1	2.8	3.4
15	89.96	46	0.11	0.35	65	98	3.8	16	0.13	31.1	9.2	2.8	3.2

APPENDIX E: HEAVY METAL CONCENTRATIONS AND YIELD OF
SPARTINA ALTERNIFLORA (1984)

Pot No.	Fresh Weight Shoot, g	No. of Tillers	mg·kg ⁻¹							mg·g ⁻¹			
			Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>													
41	125.47	33	0.42	0.46	183	116	3.4	17	0.17	21.5	23.5	3.4	1.9
42	66.65	26	0.28	0.30	131	78	2.8	17	0.11	18.5	24.3	3.1	1.5
43	84.34	37	0.40	0.54	158	101	3.3	25	0.15	18.0	27.0	3.5	1.8
44	92.59	43	0.39	0.36	159	107	3.4	28	0.12	22.0	26.8	4.0	1.9
45	67.84	37	0.32	0.18	137	98	2.5	20	0.17	19.3	24.0	3.9	1.6
<u>Drained, Low Salinity</u>													
46	99.69	37	0.35	0.42	189	124	3.6	28	0.22	17.3	11.9	3.9	2.0
47	107.30	40	0.22	0.36	137	116	4.2	23	0.17	22.4	12.7	4.3	2.5
48	84.40	37	0.35	0.54	161	94	3.0	25	0.20	17.0	14.6	3.2	1.6
49	100.90	31	0.12	0.64	226	101	3.0	23	0.25	22.3	12.6	2.9	2.2
50	136.12	32	0.03	0.20	91	144	3.3	16	0.13	18.2	8.1	3.1	2.6
<u>Inundated, High Salinity</u>													
51	107.83	39	0.19	0.16	104	124	3.7	22	0.11	26.5	22.0	3.7	2.8
52	126.88	44	0.26	0.20	172	114	3.1	23	0.12	20.8	10.8	2.8	2.0
53	91.47	22	0.17	0.30	203	139	3.3	21	0.14	24.0	13.0	3.1	2.0
54	94.24	23	0.12	0.38	282	122	3.4	18	0.26	27.8	13.5	3.4	2.2
55	119.73	32	0.19	0.86	504	134	3.5	18	0.37	24.0	11.5	3.4	2.2
<u>Inundated, Low Salinity</u>													
56	58.29	21	0.11	0.40	128	106	3.6	24	0.12	26.3	15.6	3.9	2.5
57	112.41	26	0.11	0.20	365	103	3.0	16	0.12	21.4	9.7	3.3	2.1
58	124.77	39	0.20	0.24	167	143	2.9	19	0.11	21.0	12.1	3.5	1.9
59	95.57	36	0.13	0.10	117	91	3.0	20	0.11	21.2	12.5	3.0	1.9
60	120.58	28	0.23	0.12	104	87	3.3	21	0.15	21.3	10.7	3.1	2.0

APPENDIX F: HEAVY METAL CONCENTRATIONS AND YIELD OF
Puccinellia maritima (1984)

Pot No.	Fresh Weight Shoot, g	mg·kg ⁻¹						mg·g ⁻¹				
		Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>												
21	130.21	0.17	0.58	210	62	4.4	14	0.29	4.8	16.0	0.9	0.8
22	134.87	0.35	1.20	450	79	5.7	16	0.43	6.8	17.3	1.5	1.1
23	127.23	0.13	0.16	117	65	5.3	11	0.11	7.3	21.5	1.3	1.1
24	141.88	0.13	0.24	88	66	6.2	13	0.12	5.5	19.5	0.9	0.8
25	147.49	0.19	0.34	176	69	4.3	13	0.19	5.8	20.0	1.1	0.9
<u>Drained, Low Salinity</u>												
26	141.02	0.25	1.32	829	77	3.5	15	0.57	6.3	20.6	1.3	1.0
27	127.32	0.39	2.54	1000	78	4.3	19	0.75	11.0	22.6	2.3	1.8
28	124.00	0.29	0.46	204	77	3.9	12	0.18	5.8	22.1	1.1	0.9
29	155.77	0.28	0.66	259	54	3.7	12	0.15	5.3	16.6	1.1	0.9
30	137.00	0.29	0.30	115	71	2.8	10	0.12	4.8	17.6	1.0	0.9
<u>Inundated, High Salinity</u>												
31	97.27	0.06	0.14	97	63	3.6	11	0.07	9.0	16.3	1.2	1.5
32	132.59	0.19	1.06	343	75	5.2	14	0.31	13.3	18.8	1.9	1.8
33	109.13	0.10	0.54	126	54	3.8	12	0.14	16.0	17.0	1.6	2.4
34	124.62	0.09	0.86	426	64	4.0	10	0.39	11.3	38.3	1.4	1.4
35	104.78	0.13	0.96	306	92	4.5	10	0.24	20.8	48.8	1.8	2.1
<u>Inundated, Low Salinity</u>												
36	122.93	0.24	0.60	230	64	2.9	11	0.21	8.4	15.6	1.3	1.3
37	116.24	0.05	0.34	131	56	2.6	10	0.18	8.5	18.1	1.2	1.3
38	175.10	0.19	0.52	149	57	2.7	11	0.20	9.0	13.6	1.3	1.4
39	158.79	0.06	0.26	226	65	4.2	9	0.14	9.9	15.8	1.3	1.3
40	127.23	0.03	0.20	104	65	3.1	9	0.07	7.9	14.2	1.0	1.1

APPENDIX G: HEAVY METAL CONCENTRATIONS AND YIELD OF
ASTER TRIPOLIUM LEAVES (1984)

Pot No.	Fresh Weight Shoot, g	mg·kg ⁻¹							mg·g ⁻¹			
		Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>												
1	144.84	0.59	0.54	95	139	7.7	46	0.04	72.3	36.6	5.2	2.4
2	168.03	0.78	0.76	60	120	5.3	45	0.01	46.4	24.8	4.1	2.0
3	0.0	--	--	--	--	--	--	--	--	--	--	--
4	156.18	0.51	0.84	153	144	7.5	27	0.05	65.0	28.3	6.2	2.3
5	96.67	0.44	0.42	61	120	9.9	30	0.02	46.0	29.0	5.2	1.8
<u>Drained, Low Salinity</u>												
6	51.68	0.83	0.48	118	181	8.4	98	0.15	53.0	25.1	6.6	2.1
7	161.13	0.52	0.36	72	87	5.2	31	0.04	45.2	26.1	5.5	1.8
8	156.93	0.59	0.60	68	70	6.6	29	0.04	43.7	44.4	5.1	2.2
9	57.36	3.14	0.70	72	281	5.1	138	0.06	52.5	24.6	11.2	2.4
10	61.00	2.33	0.70	69	225	6.7	103	0.06	49.2	26.6	9.6	2.2
<u>Inundated, High Salinity</u>												
11	95.76	0.17	0.54	55	81	5.5	33	0.04	58.8	23.8	4.9	1.3
12	71.79	0.37	0.72	67	40	3.6	24	0.10	45.0	35.5	3.6	4.6
13	93.18	0.24	0.52	81	106	5.4	32	0.12	60.5	25.5	5.9	1.7
14	154.00	0.17	0.32	96	102	5.8	25	0.09	63.6	27.0	4.8	1.4
15	105.28	0.16	0.50	78	76	5.6	31	0.13	72.4	32.4	5.4	1.6
<u>Inundated, Low Salinity</u>												
16	90.69	0.26	0.52	180	163	5.6	45	0.11	58.0	14.8	8.4	1.9
17	157.82	0.18	0.52	58	65	5.6	18	0.01	65.0	25.1	6.6	2.1
18	218.58	0.36	0.80	48	112	6.8	22	0.05	80.6	23.3	8.1	2.5
19	212.38	0.19	0.44	57	71	3.4	22	0.03	54.2	26.9	5.1	1.5
20	15.26	2.04	1.76	375	294	5.5	120	0.36	87.9	22.6	14.2	3.6

APPENDIX H: HEAVY METAL CONCENTRATIONS AND YIELD OF
ASTER TRIPOLIUM STEMS (1984)

Pot No.	Fresh weight Stem, g	ppm							mg·g ⁻¹			
		Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<u>Drained, High Salinity</u>												
1	103.68	0.27	0.12	152	31	7.6	17	0.13	17.6	13.8	1.4	0.9
2	27.12	0.43	0.46	124	21	16.3	27	0.05	6.4	4.3	1.2	1.5
3	6.53	1.10	2.38	842	75	29.2	68	--	54.5	23.0	5.4	5.5
4	18.24	0.54	1.00	477	36	19.0	23	0.33	7.5	4.0	1.8	1.0
5	23.19	0.49	1.02	434	38	22.9	35	0.46	10.8	9.8	2.5	1.4
<u>Drained, Low Salinity</u>												
6	77.67	0.63	0.60	146	35	4.7	25	0.20	32.4	17.6	2.6	1.2
7	8.99	0.59	0.70	94	20	17.4	21	0.12	9.3	4.3	2.1	1.3
8	3.68	0.59	0.70	94	20	17.4	21	0.12	9.3	4.3	2.1	1.3
9	52.24	1.57	0.14	50	42	6.7	30	0.08	15.6	15.1	3.5	1.3
10	48.76	1.14	0.20	42	37	8.2	28	0.07	18.1	18.1	3.4	1.2
<u>Inundated, High Salinity</u>												
11	21.66	0.09	0.22	146	14	10.9	16	0.12	8.8	7.8	1.4	1.4
12	5.24	0.68	4.06	1561	66	14.6	31	--	11.0	6.8	3.0	2.1
13	18.38	0.16	0.86	149	16	14.5	21	0.21	8.0	4.0	1.5	1.3
14	21.33	0.14	0.83	397	21	13.2	18	0.35	6.4	6.8	1.6	1.4
15	17.79	0.23	0.80	365	29	13.0	31	0.51	16.5	5.2	2.6	2.3
<u>Inundated, Low Salinity</u>												
16	85.90	0.18	0.48	218	62	5.1	21	0.11	31.6	12.6	5.4	1.2
17	14.71	0.17	0.64	301	21	13.4	17	0.16	13.6	4.0	2.4	1.0
18	23.37	0.22	0.50	142	23	12.8	19	--	16.3	4.3	2.7	1.2
19	18.55	0.16	0.32	120	17	11.8	15	0.13	9.8	3.4	2.3	1.3
20	38.14	0.41	0.56	148	33	7.8	31	0.14	30.1	15.6	2.8	1.6

APPENDIX I: INDIVIDUAL RESULTS OF METAL-ION CONCENTRATIONS OF SHOOTS
OF *Puccinellia maritima* AND *Spartina alterniflora**

Treatment	Pot No.	mg·kg ⁻¹							mg·g ⁻¹			
		Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
<i>Puccinellia maritima</i>												
Low salinity drained	26	0.53	<0.3	43	64	4.4	12	0.04	9.2	14.7	1.5	1.5
	27	0.41	0.37	57	69	5.6	10	0.04	10.3	14.8	1.6	1.8
	28	0.88	0.67	65	48	5.1	14	0.01	8.0	19.2	1.4	1.3
	29	0.40	0.46	40	80	4.8	9	0.01	6.5	12.7	1.4	1.3
	30	0.44	<0.3	63	71	4.4	11	0.06	8.0	11.0	1.5	1.5
Low salinity inundated	36	0.20	0.47	80	69	5.4	12	0.12	12.5	9.1	1.5	1.8
	37	0.37	0.54	112	86	5.0	16	--	24.3	9.6	3.7	5.0
	38	0.10	<0.3	123	76	5.1	12	0.06	15.5	16.6	2.2	2.5
	39	0.16	0.36	57	63	5.8	9	0.04	14.4	11.5	1.5	2.1
	40	0.12	<0.3	80	70	4.8	16	0.13	13.8	8.9	1.6	2.2
<i>Spartina alterniflora</i>												
Low salinity drained	46	0.69	<0.3	107	261	3.5	33	0.09	22.4	13.6	8.0	3.8
	47	1.65	<0.3	104	312	3.3	36	0.19	19.5	14.3	8.1	3.8
	48	1.01	<0.3	127	249	3.8	40	0.21	22.5	15.7	7.0	3.1
	49	0.67	<0.3	106	249	3.8	34	0.20	20.8	14.3	6.1	3.6
	50	0.71	<0.3	90	256	3.8	26	0.22	19.7	12.4	6.5	3.5
Low salinity inundated	56	0.18	0.69	106	140	4.3	18	0.20	24.5	14.4	4.7	2.9
	57	0.19	<0.3	91	240	3.7	12	0.20	22.7	9.7	7.7	4.7
	58	0.24	2.7	98	254	3.4	13	0.22	23.5	12.1	7.2	4.6
	59	0.25	0.71	116	251	4.0	14	0.21	25.8	9.7	7.0	4.4
	60	0.31	0.77	86	220	4.1	11	0.23	28.9	11.1	7.5	5.4
High salinity drained	41	2.2	<0.3	70	215	4.5	21	0.12	19.8	12.1	6.8	3.1
	42	0.48	<0.3	122	151	4.2	43	0.19	25.2	13.5	6.9	3.8
	43	1.29	<0.3	87	236	4.3	50	0.22	19.3	15.2	7.6	3.2
	44	0.72	<0.3	419	174	4.2	34	0.24	20.9	12.4	7.5	3.3
	45	0.65	<0.3	160	181	4.0	35	0.14	21.8	11.7	6.7	3.0
High salinity inundated	51	0.18	<0.3	91	321	2.4	15	0.23	23.6	13.3	6.8	3.9
	52	0.23	<0.3	135	281	3.0	14	0.21	27.5	13.3	7.0	4.3
	53	0.17	<0.3	113	414	4.1	19	0.17	26.5	17.9	7.5	6.1
	54	0.31	<0.3	102	312	4.0	13	0.19	25.3	14.2	7.2	4.2
	55	0.38	<0.3	98	314	4.0	15	0.18	26.7	16.7	6.9	4.0

* After a regrowth of 90 days following the first harvest.

APPENDIX J: INDIVIDUAL RESULTS OF FIELD EXPERIMENT

Treatment	Pot No.	mg·kg ⁻¹							mg·g ⁻¹				
		Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg	
<i>Puccinellia maritima</i> (row)	0-1	0.47	2.4	958	68	13.6	32	1.0	14.7	10.4	2.4	2.5	
	0-2	0.90	8.7	1236	99	93.6*	104*	*	15.8	9.9	3.5	3.2	
	0-3	0.48	2.4	722	62	9.9	29	1.0	13.7	10.3	1.9	2.1	
	0-4	0.38	2.4	590	51	9.7	26	0.71	13.6	12.1	1.8	1.9	
	0-5	0.38	2.3	572	58	10.2	26	*	15.3	14.0	1.7	2.1	
	0-6	0.29	1.9	538	63	8.2	22	0.58	10.9	12.0	1.7	1.9	
	0-7	0.56	2.3	505	58	11.5	28	0.63	12.4	11.1	1.6	2.0	
	0-8	0.48	1.7	607	54	11.7	24	0.60	11.5	11.5	1.7	1.9	
	0-9	0.48	2.0	550	51	10.0	31	0.67	10.9	10.9	1.6	1.6	
	0-10	0.40	2.1	512	62	9.8	26	0.71	11.8	12.7	1.6	1.7	
	0-11	0.43	2.1	552	58	9.1	24	0.34	13.2	10.9	1.5	1.9	
	0-12	0.30	0.85	411	58	8.8	24	0.56	10.6	10.1	1.5	1.7	
	0-13	0.49	1.4	468	37	9.3	26	0.54	14.0	14.0	1.7	2.0	
<i>Puccinellia maritima</i> (random)	1-1	0.28	2.2	542	42	7.4	24	0.63	10.5	8.5	1.5	1.5	
	1-5	0.24	2.7	791	42	7.2	24	0.74	10.8	8.9	1.8	1.4	
	1-9	0.28	3.5	871	45	9.0	22	0.80	12.6	11.4	2.1	1.8	
	2-2	0.38	4.9	1388	67	9.8	25	0.68	11.3	8.9	2.3	2.0	
	3-4	0.27	3.4	1000	54	9.0	37	0.95	11.4	8.8	2.0	1.8	
	3-8	0.36	6.0	868	50	7.8	30	1.1	11.4	7.5	1.7	1.6	
	4-2	0.32	3.0	845	52	6.9	29	0.82	10.5	6.9	1.5	1.5	
	4-6	0.40	3.4	859	43	7.7	26	0.61	13.3	9.3	1.7	1.9	
	4-10	0.16	2.1	640	40	6.4	20	0.51	11.2	8.5	1.4	1.5	
	5-3	0.30	4.1	1260	63	9.4	25	0.79	12.7	7.0	1.9	2.0	
	5-7	0.24	2.4	617	47	8.6	19	0.48	11.2	7.0	1.4	1.7	
<i>Aster tripolium</i>	1-4	0.68	2.2	645	74	16.7	60	0.66	29.8	13.1	4.4	3.5	
	1-8	1.2	3.4	735	75	17.8	68	0.54	47.7	16.6	6.9	4.3	
	2-1	1.1	4.2	853	84	14.1	63	1.1	50.0	17.7	6.9	4.3	
	2-5	1.2	6.9	1185	86	15.0	73	*	45.	15.0	7.5	4.8	
	2-9	1.5	4.7	726	67	20.1	66	0.93	52.6	18.2	6.8	4.8	
	3-3	0.46	2.2	437	70	8.2	40	0.74	25.8	11.5	4.8	3.5	
	3-7	0.41	3.2	528	51	8.7	40	0.40	22.1	10.6	4.0	3.0	
	4-1	0.19	5.6	119	36	4.7	31	0.18	17.1	11.6	2.6	2.1	
	4-5	1.7	2.8	357	74	16.1	65	0.27	49.0	18.8	5.7	4.1	
	4-9	0.76	2.0	256	53	12.8	59	0.35	36.2	13.8	4.9	3.6	
	5-2	0.75	3.4	461	80	11.7	42	0.36	48.9	13.0	5.8	4.3	
	5-6	0.75	2.2	494	66	11.6	49	0.30	34.6	16.8	5.0	3.9	
	<i>Spartina anglica</i>	1-2	0.07	0.90	352	75	3.1	21	0.33	20.8	12.2	2.5	2.4
1-6		0.08	1.1	325	49	4.7	26	0.33	24.7	14.0	2.1	2.0	
1-10		0.06	1.8	317	70	3.6	20	0.40	26.2	11.9	2.3	2.3	
2-3		0.16	1.7	342	53	5.4	28	0.57	25.9	9.7	2.6	2.7	
2-7		0.07	1.0	267	51	3.3	18	0.29	23.8	12.1	2.1	2.3	
3-1		0.09	0.75	245	57	3.4	18	0.44	23.5	11.4	2.2	2.3	
3-5		0.12	0.94	241	65	4.6	17	0.34	27.0	13.6	2.2	2.3	
3-9		0.12	0.80	270	55	3.5	17	0.46	22.6	9.8	2.5	2.2	
4-3		0.14	1.1	383	71	3.6	22	0.40	26.4	12.1	2.5	2.5	
4-7		0.11	1.1	306	55	3.2	17	0.37	22.7	12.6	2.4	2.2	
5-4		0.11	1.4	333	59	3.4	17	0.56	25.9	12.6	2.0	2.4	
5-8		0.45	0.54	254	63	5.2	30	0.43	19.9	9.2	2.3	2.0	
<i>Spartina alterniflora</i>		1-3	0.12	1.1	218	55	4.0	16	0.23	18.3	11.3	1.8	1.7
		1-7	0.27	0.60	211	76	4.8	25	0.31	17.8	8.3	3.2	1.9
		2-4	0.21	0.90	325	65	4.1	17	0.43	21.9	10.7	2.8	1.8
	2-8	0.15	1.4	276	61	3.9	14	0.40	22.0	8.7	2.8	1.7	
	3-2	0.33	1.3	344	75	6.4	32	0.52	16.3	9.3	2.6	1.8	
	3-6	0.55	0.68	252	75	3.7	28	0.38	20.0	8.8	2.8	2.0	
	3-10	0.15	0.66	333	60	4.0	19	0.43	17.7	8.5	2.7	1.8	
	4-4	0.12	1.2	271	70	4.4	15	0.42	19.3	9.0	3.1	1.6	
	4-8	0.20	1.1	322	78	5.4	26	0.54	18.8	9.0	2.9	1.8	
	5-1	0.22	1.4	431	84	3.7	27	0.58	20.0	9.3	3.0	2.1	
	5-5	0.26	0.90	249	53	3.7	20	0.36	18.6	9.3	2.2	1.4	
	5-9	0.32	1.6	373	86	4.6	20	0.47	20.2	8.6	2.9	2.1	
	5-10	0.11	1.4	300	67	5.1	20	0.26	23.6	13.4	2.5	2.3	

* Odd or missing value.

APPENDIX K: QUALITY CONTROL ANALYSIS METHOD

Parameters	Fe	Zn	Mn	Cu	Pb	Cd	Cr	Ca(%)	K(%)	Mg(%)
Standards	752	64	237	9.5	6.5	3.1	5.0	2.90	4.56	0.68
	705	57	228	9.3	5.5	3.4	5.0	2.93	4.21	0.63
	700	60	244	9.9	5.6	3.5	4.9	3.11	4.58	0.68
	739	62	238	10.3	5.6	3.7	4.9	3.03	4.30	0.66
	722	61	239	9.4	5.2	3.5	5.2	2.95	4.46	0.66
	745	59	244	9.9	6.3	3.2	5.0	3.00	4.51	0.68
	700	61	244	9.8	6.3	3.3	5.0	3.06	4.46	0.68
\bar{x}	723	60	239	9.7	5.9	3.4	5.0	3.00	4.44	0.67
Standard deviation	22.2	2.22	5.78	0.351	0.471	0.177	0.105	0.07	0.137	0.019
Standard error	8.40	0.84	2.19	0.133	0.178	0.067	0.040	0.028	0.052	0.0071
Coefficient of variation	3.1	3.7	2.4	3.6	8.1	5.2	2.1	2.5	3.1	2.8
95% confidence	20	2	5	0.35	0.45	0.15	0.10	0.07	0.13	0.01
Limits of detection limit*	0.45	0.05	0.04	0.57	2.2	0.06	2.8	0.03	0.01	0.01
NBS 1573 (certified values)	690±25	62±6	238±7	11±1	6.3±0.3	(3)	4.5±0.5	3.00±0.3	4.46±0.03	(0.7)

Note: Samples are analyzed according to the analysis methods of the Soil Science Laboratory DIHO, 1984; 15 February 1985, Soil Science Laboratory.

* Standard deviation $\times 3$ (n = 6) Fe, Zn, Mn, Ca, K, Mg in ppm and Cu, Pb, Cd, Cr in ppb; data in parentheses are noncertified values, information only.