AD-A180 190 UPTAKE OF HEAVY METALS FROM CONTAMINATED SOILS BY SALT-MARSH PLANTS(U) DELTA INST FOR HYDROBIOLOGICAL RESEARCH YERSEKE (NETHERLANDS).. A H HUISKES ET AL. 1/1

UNCLASSIFIED DEC 86 R/D-4268R-EN DAJA45-83-C-0024 F/G 24/5 NL

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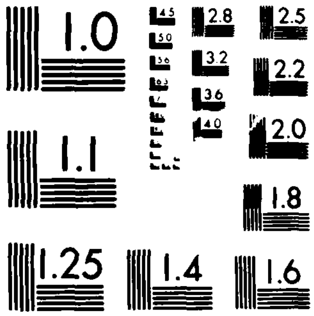

MICROCOPY RESOLUTION TEST CHART
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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A180190

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) R&D 4268R-EN
6a. NAME OF PERFORMING ORGANIZATION Delta Institute for Hydrobiological Research 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USARDSG-UK
6c. ADDRESS (City, State, and ZIP Code) Vierstraat 28 4401 EA Yerseke (Zeeland) The Netherlands	7b. ADDRESS (City, State, and ZIP Code) Box 65 FPO NY 09510-1500
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAE Waterways Experiment Station 8b. OFFICE SYMBOL (If applicable) WES-CW	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAJA45-83-C-0024
8c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102A	1L161102BH57	01	

11. TITLE (Include Security Classification)

(U) Uptake of Heavy Metals from Contaminated Soils by Salt-marsh Plants

12. PERSONAL AUTHOR(S)
Huiskes, A.H.L. and Nieuwenhuize, J.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 3/1983 TO 9/1986	1986 December	53

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	(U) Bioassay; (U) Heavy Metals; (U) Salt Marsh; (U) Contaminants; (U) Contaminated Soils
06	03, 01, 06		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Jerry C. Comati	22b. TELEPHONE (Include Area Code) 01-402-7331 22c. OFFICE SYMBOL AMXSN-RE

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. (continued)

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To compare heavy metal uptake by different plant species, buckets as used in the greenhouse experiment were dug in on a bank of a tidal creek in a Western Scheldt salt marsh. The buckets were filled with sediment of this location. Most of the tides inundated the pots. The following species were planted: *Spartina alterniflora*, *Spartina anglica*, *Aster tripolium* and *Puccinellia maritima*. In September 1985, 23 weeks after planting, the shoots were harvested and analyzed for metal contents. Differences were considered statistically significant at $p < 0.001$.

Levels of Cd, Pb, Fe, Cu, Zn and As did not differ significantly in *S. alterniflora* and *S. anglica*. Only for Mn a significant difference was found between these two related species. The levels of the various metals (except Mn) were lower in the *Spartina* spp. than in *A. tripolium* and *P. maritima*. Levels of Cd, Pb, Cu and Zn (but not Fe and Mn) were significantly higher in *Aster* than in the other species. *Puccinellia* metal levels had a variable position in the order of the various species. The results of the field experiment have been compared with the metal levels found in the experiments in the greenhouse.

The various statistical analyses (level of significance: $p < 0.001$; < 0.01; < 0.05 or < 0.1) showed similar results for the three plant species compared (*S. alterniflora*, *A. tripolium* and *P. maritima*). Pb, Fe, Cu and As levels generally were significantly higher in the field-grown specimens than in the plants grown in the greenhouse. Cd levels were also lower in the greenhouse plants, but the differences often were not significant. The Zn levels were not significantly different in *S. alterniflora*, but were significantly lower in the greenhouse specimens of *P. maritima* and *A. tripolium* (except for treatment low salinity, drained). In contrast, Mn levels were always higher in the greenhouse plants than in the specimens grown in the field.

Final Report dated December 1986.

Technical Report

Uptake of heavy metals from contaminated soils by salt-marsh plants

by

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Delta Institute for Hydrobiological Research,

Yerseke, The Netherlands

December 1986

Final Report

Approved for Public Release; Distribution unlimited

Prepared for Office, chief of Engineers, U.S. Army

Washington, D.C. 20314

Under Contract No. DAJA 45-83-C-0024

Monitored by Environmental Laboratory

U.S. Army Engineer Waterways Experiment Station

P.O. Box 631, Vicksburg, Miss. 39180

The research reported in this document has been made possible through the support and sponsorship of the U.S. Government through its European research Office of the U.S. Army.

This report is intended only for the internal management use of the Contractor and the U.S. Government.

Abstract

Spartina anglica, Puccinellia maritima and Aster tripolium, three common salt-marsh species in Western Europe, were grown in contaminated sediment from the port area of Antwerp (Belgium). Growth and levels of heavy metal contamination were compared with those of Spartina alterniflora, a common salt-marsh species from the United States. The plants were grown under waterlogged and drained soil conditons. In both cases was a high and a low soil salinity maintained.

The levels of heavy metals in the shoots of the plants were generally higher under drained conditions. The difference in salinity gave no obvious differences in metal levels in the shoots. Plants grown in the same sediment, after having allowed it to dry out and get aerated, had higher levels of heavy metals in their shoots.

The different plant species showed all different levels of metals in the shoots when grown under the same circumstances: P. maritima had the lowest levels, A. tripolium the highest. In A. tripolium there was also a significant difference in metal levels in leaf- and stem material.

In 1984 a greenhouse experiment was carried out with Spartina alterniflora, Aster tripolium and Puccinellia maritima. Uptake of heavy metals from contaminated soils dredged from the Western Scheldt estuary was measured in these plants. After the first harvest, the underground parts of the plants were left untouched to allow regrowth for an additional 90-days period. After this period the buckets were again harvested and the shoots analysed. During both the growth and regrowth phases, the plants were kept in buckets with different water and salinity regimes: inundated versus drained, high salinity versus low salinity. Each treatment had 5 replicates for each species.

Regrowth was very bad for Aster tripolium and for Puccinellia maritima at high salt conditions. Therefore only the results of P. maritima grown at low salt conditions and of S. alterniflora were statistically analysed.

Out of 42 comparisons between the first and the second harvest, with respect to Cd, Pb, Fe, Mn, Cu, Zn and As levels, 25 gave statistically significant differences (significance levels: $p < 0.001$; < 0.01; < 0.05; or < 0.1). Levels of Cd, Mn and Cu of the regrowth shoots of the second harvest were higher in general than of the first harvest. In contrast, levels of Fe generally were lower. Comparisons of Pb, Zn and As levels gave variable results.

To compare heavy metal uptake by different plant species, buckets as used in the greenhouse experiment were dug in on a bank of a tidal creek in a Western Scheldt salt marsh. The location was just across the spot where the sediment for the greenhouse experiment was dredged.
The buckets were filled with sediment of this location. Most of the tides the pots were inundated. The following species were planted: Spartina alterniflora, Spartina anglica, Aster tripolium and Puccinellia maritima. In September 1985, 23 weeks after planting, the shoots were harvested and analysed for metal contents (11-13 replicates for each plant species). Differences were considered statistically significant at $p < 0.001$.

Levels of Cd, Pb, Fe, Cu, Zn and As did not differ significantly in S. alterniflora and S. anglica. Only for Mn a significant difference was found between these two related species. The levels of the various metals (except Mn) were lower in the Spartina spp. than in A.tripolium and P. maritima. Levels of Cd, Pb, Cu and Zn (but not Fe and Mn) were significantly higher in Aster than in the other species. Puccinellia metal levels had a variable position in the order of the various species.

The results of the field experiment have been compared with the metal levels found in the experiments in the greenhouse.

The various statistical analyses (level of significance: $p < 0.001$; < 0.01; < 0.05 or < 0.1) showed similar results for the three plant species compared (S. alterniflora, A. tripolium and P. maritima). Pb, Fe, Cu and As levels generally were significantly higher in the field-grown specimens than in the plants grown in the greenhouse. Cd levels were also lower in the greenhouse plants, but the differences often were not significant. The Zn levels were not significanlty different in S. alterniflora, but were significantly lower in the greenhouse specimens of P. maritima and A. tripolium (except for treatment low salinity, drained). In contrast, Mn levels were always higher in the greenhouse plants than in the specimens grown in the field.

Contents

Preface

This study was conducted at the Delta Institute for Hydrobiological Research, Yerseke, The Netherlands. It started in March 1983 with Dr. A.H.L. Huiskes, dept. of Experimental Botany and Mr. J. Nieuwenhuize, dept. of Soil Chemistry, as chief investigators.

The study is one of a number of investigations and monitoring programs of the Delta Institute for Hydrobiological Research on the dynamics of anthropogenic substances in the environment. It also links up with the experiments performed at the US Army Corps of Engineers Waterways Experiment Station, Vicksburg, USA, to develop a bioassay procedure to assess the level of contamination of dredged sediments.

The project was financed by the U.S. Army Corps of Engineers Field Verification Program, Mr. Charles C. Calhoun, Program manager. At various stages of the project assistance was received from various persons. We like to thank:

Drs. C.R. Lee, B.L. Folsom and J.E. Simmers of WES for the numerous discussions on matters related to the project and the hospitality, they and their families extended to us during our stays in the U.S.A. Mr. R.G. Rhett and the late Mrs. K.M. Preston-Garner for providing us with various shipments of materials, plants and reference soils.

Mr. C.M. de Rooy and Mr. J.A. van Sprundel for dredging the polluted estuarine sediments with the R.V. "Jan Verwey". Mr. J. van Soelen en Mr. M.M. Markusse for their assistance during the growth and the harvesting of the experiment. Mr. J.M. van Liere, Mr. A. Goud and Mrs. C.H. Poley for the chemical analyses of the samples. Mr. L.J. Goud and Mr. J.C. Ruissen for taking care of the administration of the project. Dr. W.G. Beeftink and Dr. E.K. Duursma for reviewing the text and providing valuable additions and revisions. Mrs. M.J. van Leerdam, Mr. J.A. van den Ende and Mr. A.A. Bolsius for typing and for processing the text and the figures.

Our families for allowing us to make regular journeys to the United States and for entertaining our foreign colleagues working in the same program.

1. Introduction

The boundaries between land and water have always been areas of major human activities. Large industrial complexes connected with harbour 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 harbour 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 of America one of the disposal alternatives is the creation of artifical marshes. Depending on the salinity of the dredged sediments and the disposal site these marshes may be fresh, brackish or saline.

The U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, is developing a bioassay for testing the quality of the dredged material, which in turn will provide evidence for the decision in what way the sediment will be disposed off.

In this study the procedure for the plant bioassay has been applied in experiments with some Dutch salt-marsh plant species growing in brackish contaminated sediment and using the North-American salt-marsh species *Spartina alterniflora* Loisel as a reference. The greenhouse experiments were compared with a similar experiment under field conditions. The specific objectives of the present study were:

a. To evaluate the usefulness of the Waterways Experiment Station 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 _Spartina alterniflora_ Loisel with the uptake of native salt-marsh species, _viz._ _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.

2. Experimental design

2.1. Greenhouse experiments

The design of the greenhouse experiment was according to the bioassay procedure as has been described by Folsom et al. (1981a, b).

Figure 1 shows a diagram of the experimental unit used in the experiments. A small inner bucket rested on polyvinyl chloride (PVC) pipe inside a larger outer bucket. Six 6.35 mm diameter holes were drilled in the bottom of the inner bucket. These holes were covered with a 2.54 cm thick polyrethane sponge overlaid with a 2.54 cm (approximately) layer of washed quartz sand. The sand and the sponge acted as a filter to keep the sediment/soil from draining out 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 up to a certain height with water.

2.1.1. Sediment preparation

The polluted sediment used in this study was dredged by one of the institute's research vessels R.V. "Jan Verwey" using a "Van Veen" grab. The dredging place was just outside the big shipping lock "Zandvlietsluis" in the Belgian part of the Westerschelde estuary (Fig. 2). This sediment is rather homogenous in texture and concentrations of various substances, as it is well mixed by tugs towing iron bars across the entrance of the lock in attempt to resuspend the sediment and a subsequent removal of it with the outgoing tides.

Immediately after dredging 8 samples of the sediment were taken randomly to analyse the sediment for the various heavy metals. The dredged sediment, transported in thoroughly cleaned plastic containers, was spread out on large flats lined with PVC sheets to let it dry out. Excess water was siphoned off. After about three months, the water content of the sediment was 60.1% on weight basis.

2.1.2. Plant material

The experiment was divided in two parts for reasons of available space in the greenhouse. The first year an experiment was done with S. alterniflora and S . anglica. S . alterniflora was obtained from WES transported by air. The plants were commercially grown from seeds and had 4 to 5 shoots, approximately 20 centimers high. S . anglica is at present 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 spread since then naturally or by deliberate planting to almost all salt marshes in the Netherlands. For the exeriment cuttings of 4 to 5 shoots were taken in the field and transplanted to flats filled with potting compost to allow them to root. The second year an experiment was done with S. alterniflora-cuttings and cuttings of A. tripolium and P. maritima. The inner buckets were filled with a known amount of sediment (7000 g approximately). In the sediment the rooted cuttings were planted (or in the first experiment seedlings of S. alterniflora). The water and salinity regime in the buckets was:

a. The outer bucket filled with artifical seawater to a height just above the surface of the sediment in the inner bucket to maintain a waterlogged situation.

b. The outer bucket filled with artificial seawater of 50% of the normal strength, to a height just above the surface of the sediment in the inner bucket.

c. The outer bucket filled to a height of 5 cm with artifical seawater of 50% of the normal strength.

Each treatment had 5 replicates for each species. As a reference S. alterniflora was also planted in buckets filled with a reference soil, obtained from WES. This is a loamy soil, which 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 artifical seawater of 50% 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 filled with 5 cm of artificial seawater of 50% of the normal strength).

In the waterlogged situation the outer buckets were regularly adjusted to the level fixed at the start of the experiment with artifical seawater. In the other buckets the level of 5 cm was kept constant too but the plants in these buckets were daily watered with demineralized water from the top. Once a week the watering was performed with artificial seawater.

2.1.3. Harvesting of the plants

Ninety days after the start of the experiment the shoots of the plants were cut at the soil surface with a plastic knife to avoid metal contamination. All handling of plants and sediments was done wearing plastic gloves. Almost all plants of S. anglica flowered after ninety days. The plants growing in the "upland" situation in the first experiment were harvested four weeks later, as the salinity levels in these containers were established four weeks after planting. Per treatment were for each species also one root sample and one soil sample taken from a bucket. This was only done in the first year as the buckets in the second year were kept intact for a regrowth experiment.

The shoots and roots were thoroughly rinsed with demineralized water and blotted dry with filter paper. Fresh weight of whole shoots was measured for S. alterniflora, S. anglica and P. maritima. The shoots of A. tripolium were divided into stem, leaves and - if present - inflorescences. These fractions were separately weighted and subsequently analysed. For S. alterniflora and S. anglica also the number of tillers and the total length of the shoots were measured.

The second greenhouse experiment was left in place to allow regrowth. This regrowth was harvested after another ninety days.

The results of the roots 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.

2.1.4. Analysis of various components in plant samples

After the measurement of the fresh weight the samples were kept at -20°C (-4°F) awaiting analyses. For the analyses the samples were freeze-dried to constant weight. The dried samples - both plant and sediment samples - were then ground in a agate mill to avoid metal contamination. All handling of samples was done, using plastic gloves. The plant samples were subsequently digested with HNO_3 conc. and H_2O_2 (30%). The destruate was brought to a volume of 50 ml by adding demineralized water. This volume contained still 2 ml HNO_3. All elements were measured in this watery extract. Ca, Mg, Fe, Mn and Zn were measured by means of atomic absorption spectrometry, using an air-acetylene flame. Na and K were measured by means of flame - emission spectroscopy using also an air - acetylene flame.

Pb, Cd and Cu were measured on the atomic absorption spectro-photometer in combination with a graphite furnace. Pb and Cd were measured by means of the standard addition method.

As was determined by hydride generation and atomic absorption spectrometry. All measurements were performed with a Perkin Elmer model 2380 instrument.

2.1.5. Analysis of various components in sediment samples

The sediment samples were freeze-dried to constant weight and ground in an agate mill. The samples were sieved through a 2 mm sieve. Due 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%). The produced CO_2 was measured volumetricly.

The particulate organic matter content was measured by pyrolysis of the sample ad 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.

All metal-ions were determined as total contents after destruction of the sample with a HCl-HNO_3 mixture (3:1) and a subsequent destruction with H_2O_2 (Schramel et al., 1982). All ions were analysed in the destruate with the Atomic Absorption Spectrophotometer in combination with a graphite furnace. All results are statistically tested with an analysis of variance and a calculation of the Least Significant Differece.

2.2. The Field Experiment

On 15 April 1985 a field experiment using the same buckets as used in the greenhouse were dug in in the nature reserve "Verdronken Land van Saeftinghe" on the bank of a tidal creek where they would be inundated most of the tides. Permission for this experiment was asked and obtained from the provincial trust "Het Zeeuwse Landschap" managing the reserve. With the help of officers of this body the location was chosen. This location is situated in a salt marsh along the Western Scheldt just across the spot where the sediment was dredged.

2.2.1. Sediment preparation

The inner buckets of the bioassay design were used in this experiment. The buckets were filled with sediment from a nearby creek globally matching the structure of the dredged sediment. 50 Buckets were dug in in the creek bank. Additional soil samples were taken to be analysed for heavy metals.

2.2.2. Plant material

Cuttings of *S. alterniflora*, *S. anglica*, *A. tripolium* and *P. maritima* were planted in the pots, per species 12 replicates were planted. Two pots with *S. alterniflora* were kept as a reserve. This not native species might suffer from the alien environment. After 1 month the *Puccinellia* plants showed severe die-back, probably due to the flooding frequency which was unusually high for this species: it 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.

2.2.3. Harvesting of the plants

On September 16th, five months after the planting of the experiment the plants were harvested. The shoots were cut with plastic knives and put in polythene bags, which were thoroughly rinsed with demineralized water. The bags were closed and labeled and put at -20°C awaiting analysis.

2.2.4. Analysis of the plant samples

The plant samples were analysed as reported in section 2.1.4.

2.2.5. Analysis of the soil samples

The soil samples were analysed as reported in section 2.1.5.

3. Results

3.1. Sediment analyses

Immediately after dredging 8 soil samples were taken from total mass of 1000 litres of sediment dredged near Antwerp (Fig. 1). The results are given in Table I (the individual results are given in Appendix A). Also in Table I are shown the results of soil samples taken after the experiment with S. alterniflora and S. anglica in 1983. As these figures are based on just one sample no statistical treatment of the data could be performed and they have to be treated as an indication.

The figures for the moisture content of the soil and the salinity under waterlogged and drained conditions and the high and low salinity levels may indicate that the envisaged treatments were not very well maintained. Under drained conditions the salinity was low at both salinity levels, while under waterlogged conditions the salinity was comparatively high at both levels. This means that with the interpretation of the results the fact has to be kept in mind that the treatments applied were 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 the data will be related to the above mentioned findings. In Table II the results of soil samples taken at the beginning of the field experiment are shown. These figures when compared with those of the dredged sediment, are slightly different. In general the heavy metal contents are higher. Appendix B gives the individual results of five soil samples.

3.2. Plant analyses (greenhouse experiment)

As there are at certain points significant differences between the data of S. alterniflora plants grown in 1983 and plants grown in 1984, the results of the two parts of the experiment are presented separately with S. alterniflora as a reference.

3.2.1. Growth parameters

Figure 3 shows the fresh weight of the shoots for S. alterniflora in the experiments of 1983 and 1984, 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 could be due to a difference in soil fertility. No significant difference could be found between the various treatments and the two 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 appendix C. Figure 4 shows the average amount of tillers produced per plant. There is a significant difference between the average number of tillers produced in 1983 and in 1984 and also a significant difference in 1983 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.

In Figure 4 the number of tillers of S. anglica, the European Spartina, is also shown, together with the LSD (= least significant difference) of the findings of both Spartina species in 1983. The difference between the two species is obvious together with 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.

In Figure 5 the average fresh weight of the two Spartina species grown in 1983 is compared. An analysis of variance showed a significant difference between the two species, but no significant difference was found due to the four treatments. Appendices C and D gives the individual results.

Figure 6 shows 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 between the results is questionable as the species are not as closely related as the Spartina's 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 a negligible amount of stem material as compared with A. tripolium. For A. tripolium stem material and leaf material are 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. 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 leaves 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 form a substantial amount of dead leaves, while the amount of fresh leaves does 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 I). This fact however could not be checked, as no soil samples were taken, for the reason that the buckets with their contents were saved for a regrowth experiment.

3.2.2. Plant analyses

The Tables III and V show the average results of the analyses of the shoot material of the experiments of 1983 and 1984 respectively. The results of the experiment performed in 1983 (Table III) are the means of samples from five replicate treatments. The results shown for S. anglica grown under high salinity and waterlogged conditions are the means of three samples, as two plants showed a strongly reduced growth as compared with all other plants. In Table IV the significance of the individual figures is shown.

Although Table IV shows considerable overlaps in significant differences there are some general tendencies. The influence of inundation or drainage is present for Mn, Cu, As, Na, K, Ca and Mg and to a lesser extent for Zn. Mn, Na, Ca and Mg were taken up more under inundated circumstances, while Cu,As, K and to a certain extent Zn were taken up in higher quantities under drained conditions.

Cd 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 as was already suggested in section 5.1. Tabe V shows the results of the experiment performed in 1984 S. alterniflora was mainly used in this experiment to link it up with the findings in 1983.

Table VI gives the significant differences between the various results. The table presents the significant differences between the species

- whereby the stem - samples of A. tripolium are treated as a separate species - and between the treatments, which gives a better survey in this case as compared with the method used in Table IV. For most metal - levels the leaves of A. tripolium score highest. In a number of cases are these differences significant. The grasses have significantly lower levels of Cd in their shoots as compared with the forb A. tripolium. This is also the case for Cu, Zn and to a lesser extent for Fe and Na. As, K and Ca levels show significant differences for all species. Mn and Mg levels are significantly lower in the stems of A. tripolium, and in P. maritima-shoots, while Pb seems to be accumulated especially in the stem of A. tripolium. No significant differences due to the treatments were found in levels of Pb, Fe, Mn and Mg. Cd, Cu and Zn were taken up more under drained circumstances. The levels of As differed significantly between all treatments. Na, K and Ca levels showed no obvious difference.

An analysis of variance performed on the results of S. alterniflora of 1983 and 1984 showed significant differences between the two experiments for levels of Fe, Mn, Cu, As, Na K and Ca. The shoots of S. alterniflora had in 1984 significantly higher levels of Fe, Mn, Na, K and Ca. The levels of Cu and As were lower in 1984.

3.2.3. Plant analyses (regrowth)

Table VII gives a comparison between the first harvest of the greenhouse experiment and the second harvest. (Full results in Appendix J). A. tripolium did not give any regrowth at all. This was probably due to the harvesting method as most of the axillary buds were harvested as well. P. maritima gave only regrowth under the low salinity treatments; again a sign that in the second experiment the treatments were better established than in the first. The metal levels in the shoot of the second harvest were different from those of the first harvest. This might be due to the increased soil ripening process by the root system of the plant. Cd, Cu, Na and Mg showed higher concentrations in the second harvest. For Fe, As and K the values were lower while there was a difference in Mn-content between inundated and drained treatments of the two harvests.

S. alterniflora produced in all cases regrowth. Cd-levels were higher in the second harvest and even more so under drained circumstances. Pb, Fe, As, Na and K levels did not differ significantly. Mn levels were higher in the second harvest so were Cu, Ca and Mg levels. The Zn concentrations in the shoots of the second harvest were higher in the drained treatments and lower in the inundated treatments.

3.3. Plant analyses (field experiment)

Table VIII shows the average values of metal ions in the shoots of the various plant species. There are two sets of data for P. maritima. As mentioned in section 2.2.2. after one month another set of buckets with P. maritima was planted as the first set did not seem to grow very well. Eventually however 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. In tabel IX can be seen however that for some metal concentrations significant differences occur. This is the case for Fe, Mn, Cu and K. This difference could have been caused by a slight difference in aeration of the soil in the buckets planted at a higher level.

A. tripolium has in almost all cases higher metal concentrations in the shoot as compared with the grasses. Puccinellia has significantly higher levels of Fe and As. The two Spartina-species have generally spoken lower levels of metal-ions in the shoot except for Mn (where P. maritima scores lowest) Na, K, Ca and Mg, where P. maritima also tends to have lower levels. The individual results of the experiment are given in Appendix K. Table IX shows the significant differences between the various species for the individual metals.

4. Discussion and recommendations

4.1. Discussion

The division of the total greenhouse experiment into two parts, spread over two consecutive years may have obscured some of the differences in plant uptake of heavy metals and in the influence of the four treatments. Firstly the plant material of S. alterniflora was different in the two years. 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 (Fig. 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 the Waterways Experiment Station.

Secondly, another difference between the experiment of 1983 and of 1984 was that in 1983 sediment was used which had been dredged only two and a half months before the start of the experiment, while in 1984 the same sediment was used which by then had had about fifteen months to settle and ripen. The sediment, even over these fifteen months, never dried out; at the start of the experiment in 1984 it was still a "mousse".

These features were the reason why the experiments of the two years were discussed separately. An indication for the difference in soil conditions in 1983 and 1984 might be the higher levels of especially Mn and Fe in the shoots of S. alterniflora in 1984 (Table III and V). 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.

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 I). 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 artifical sea water. Although in 1984 the drained pots were watered more often with artifical sea water, the results (Table V) 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.

In the regrowth results a discrepancy between Fe and Mn came about. This is in accordance with the findings of Rozema et al (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 would be a complex of factors in which also the inundation or drainage is involved. The results showed however that increase of aeration of the soil by drainage may alter the availability of heavy metals. Inundation may retard this process (compare

Tables III and V). This inundation may lower the uptake of Cd, Zn and probably Pb, As and Cu, but it gave increased levels of Mn 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. As concerned with Fe and Mn the salinity level may play a role in the uptake of metal ions. In general may be concluded that the processes connected with drainage and aeration:oxidation, and lowering of the redox potential 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.

These conclusions may also be drawn from the regrowth results when Cd, Cu, Mn and As concentrations are observed. Pb concentrations are not significantly different between each other, and Fe levels are higher only in the first harvest of *P. maritima*.

How do all these results relate to the real situation in the field. In table X a comparison is made between the greenhouse results and the results of the field experiment. For a good comparison the results from the drained treatment with low salinity was used as these circumstances were closest to the field situation (Table I). Pb, Fe, Cu, As and Mg in three of the four species gave lower concentrations in the shoots in the greenhouse experiment while Mn and K gave higher concentrations 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.

The differences in heavy-metal levels between the different plant species is apparent, especially in the experiment of 1984. For a bioassay procedure it is imperative to make a choice for one single standard species. This may be _S. alterniflora_ in the American situation, but in the Dutch situation with, in general, a greater species diversity in the salt marsh it may be difficult to make a choice. _S. anglica_ is a dominant species in the Dutch salt marsh and could therefore qualify. _P. maritima_ is known as a low accumulator, while _A. tripolium_ is a high accumulator of heavy metals (Beeftink _et al._, 1982). The last species is eaten as a vegetable in the Netherlands and is in that quality subject to the standard of heavy metal contamination of the Ministry of Agriculture. It is tempting to use these standards for the bioassay with _A. tripolium_, to decide whether a soil is contaminated or not, but there is no jurisdiction with respect to this matter.

4.2. Recommendations

The bioassay procedure, developed at Waterways Experiment Station, 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.

It is clear from the results over the two years that the time between dredging and bioassay procedure and the harvest time are decisive for the availability of the various metal ions. It is therefore imperative to take this time into account when the results of a bioassay procedure are analysed.

Further research has to be performed to study the pathway of the contaminants in the food chains of the ecosystem. Studies on herbivorous an detrital fauna comes first.

5. References

Andersen, J.M. (1975). An ignition method for determination of total phosphorus in lake sediments. Water reseach 10: 329-331.

Beeftink, W.G., J. Nieuwenhuize, M. Stoeppler and C. Mohl (1982). Heavy-metal accumulation in salt marshes from the Western and Eastern Scheldt. The Science of the Total Environment 25: 199-223.

Folsom, B.L., C.R. Lee and K.M. Preston (1981a). Plant Bioassay of materials from the Blue River dredging project. Miscellaneous Paper EL-81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Folsom, B.L., C.R. Lee and D.J. Bates (1981b). Influence of disposal environment on availability and plant uptake of heavy metals in dredged material. Technical Report EL-81-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Rozema, J., Luppes, E. and R. Broekman (1985). Differential response of salt-marsh species to variation of iron and manganese. Vegetatio 62: 293-301.

Rozema, J. and J. Roosenstein (1985). Effects of zinc, copper and cadmium on the growth and mineral composition of some salt-marsh halophytes. In: Beeftink, W.G., J. Rozema and A.H.L. Huiskes (eds.). Ecology of Coastal Vegetation: 551-553. Junk, Dordrecht.

Schramel, P., Li-Qiang, A. Wolff and S. Hasse (1982). ICP-Emissions-spektroskopie: Ein analytisches Verfaren zur Klärschlamm und Bodenüberwachung in der Routine. Fresenius Z. Anal. Chem. 313: 213-216.

Waisel, Y. (1972). Biology of Halophytes. Academic Press, New York.

Figures

Figure 1. Diagram of the experimental unit, used in the experiments (derives from Folsom et al. 1981a).

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

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

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

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

Figure 6. Total fresh weight of shoots per pot of *Spartina alterniflora*, *Puccinellia maritima* and *Aster tripolium* grown under different treatments in 1984.

Fig. 1

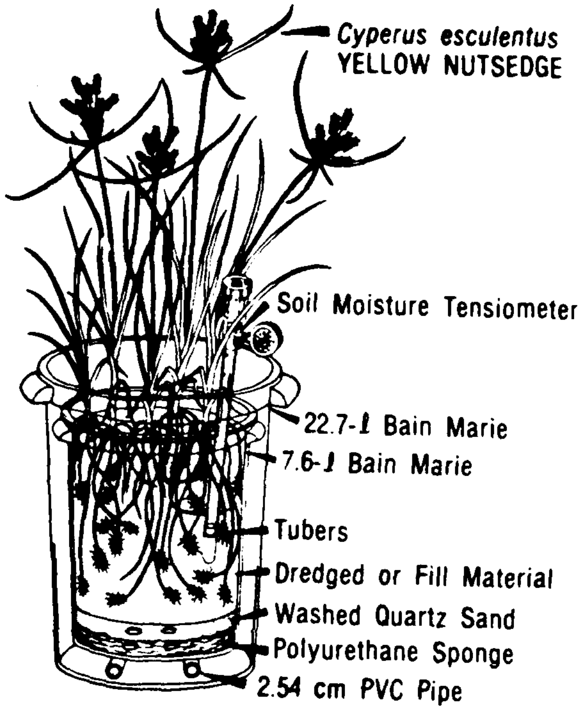

Cyperus esculentus
YELLOW NUTSEDGE
Soil Moisture Tensiometer
22.7-l Bain Marie
7.6-l Bain Marie
Tubers
Dredged or Fill Material
Washed Quartz Sand
Polyurethane Sponge
2.54 cm PVC Pipe

Fig. 2

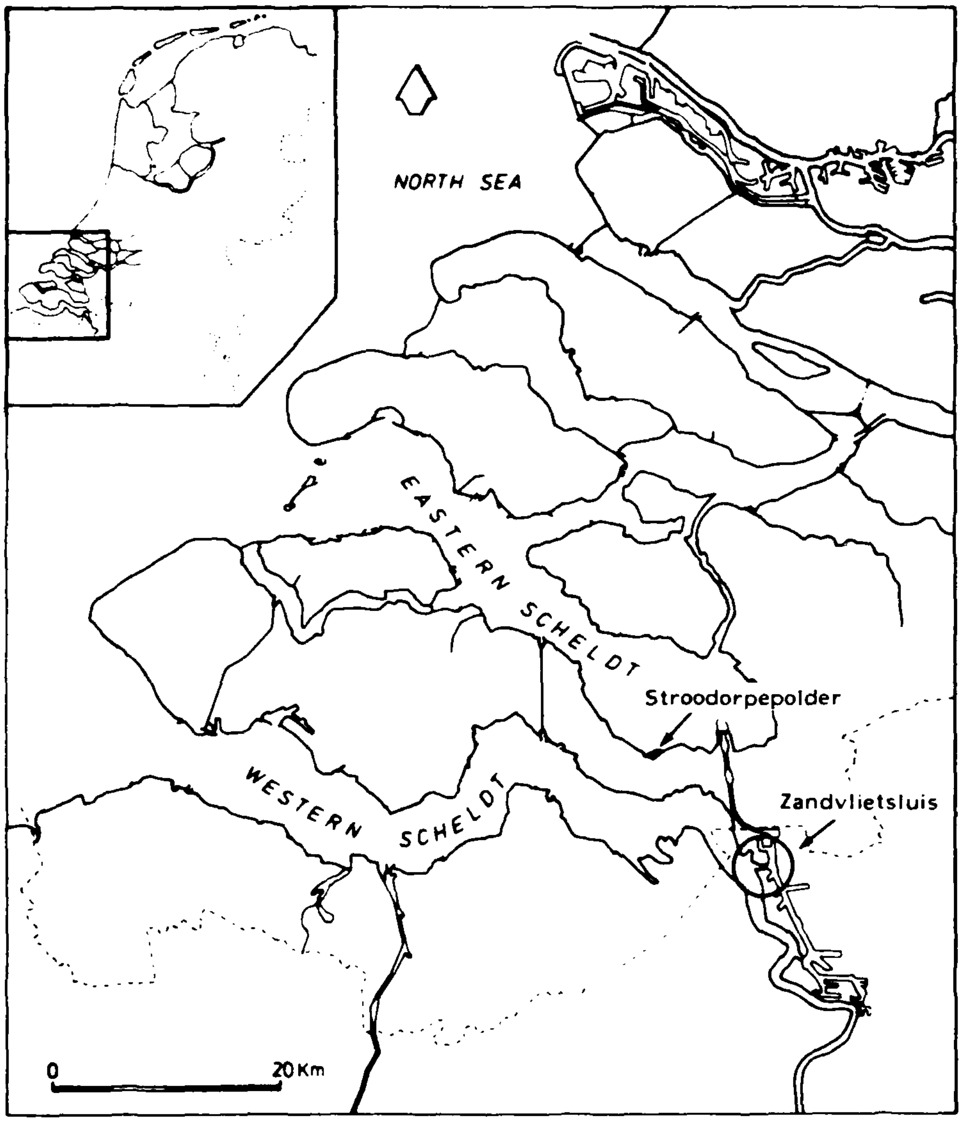

NORTH SEA
EASTERN SCHELDT
WESTERN SCHELDT
Stroodorpepolder
Zandvlietsluis
0
20 Km

Fig. 3

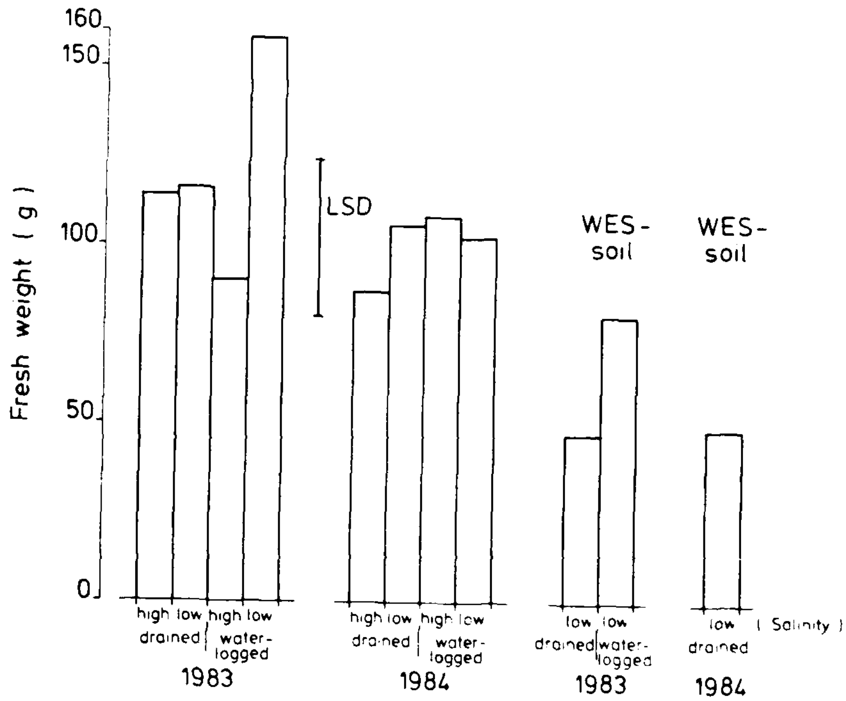
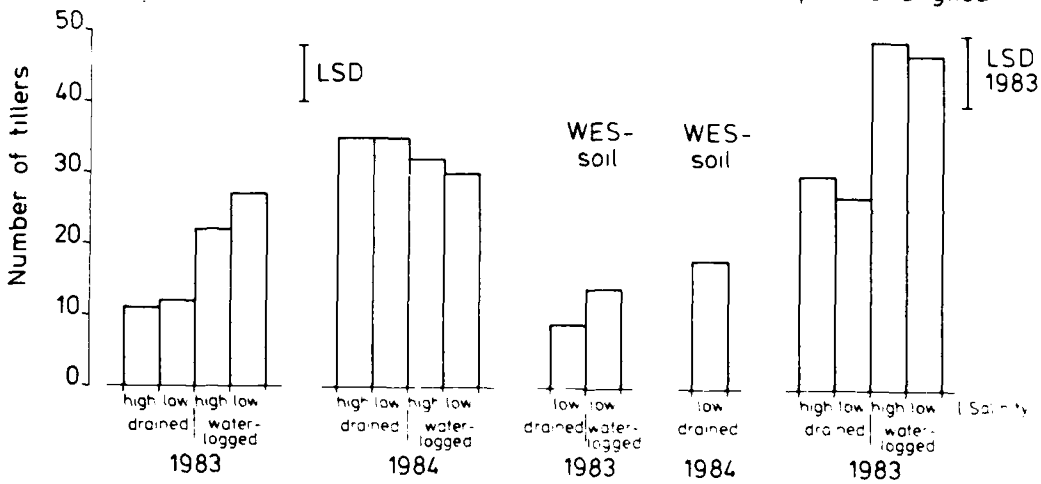

160
150
100
50
0
Fresh weight (g)
LSD
WES-
soil
WES-
soil
high low high low
drained water-
logged
1983
high low high low
drained water-
logged
1984
low low
drained water-
logged
1983
low
drained
1984
(Salinity)

Fig. 4.

Spartina anglica



Fic. 5

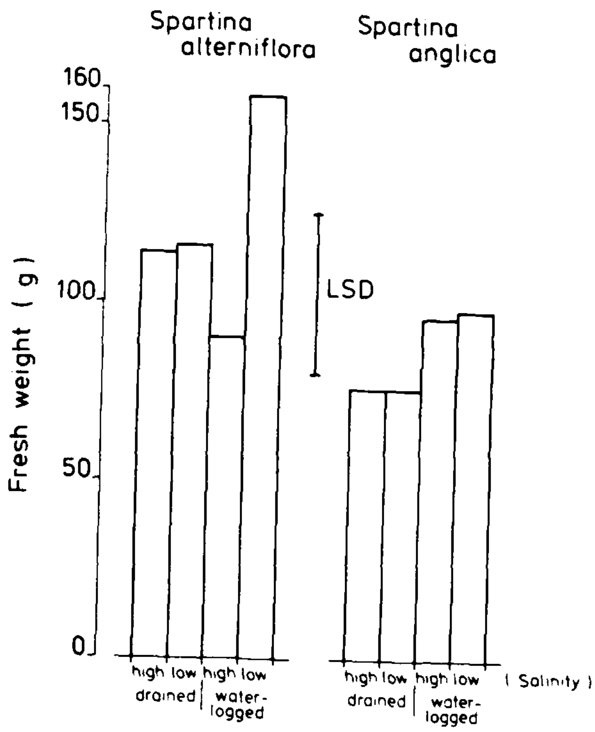
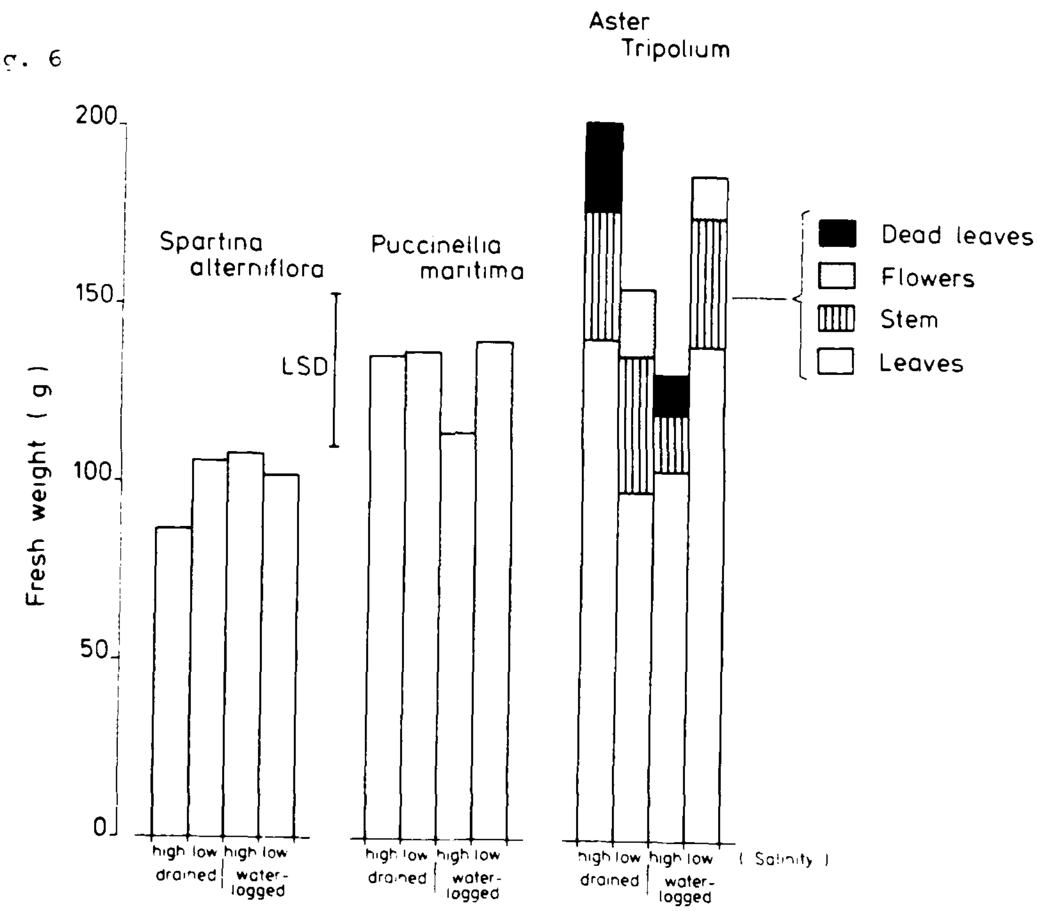

Spartina alterniflora
Spartina anglica
Fresh weight (g)
160
150
100
50
0
LSD
high low high low
drained water-logged
high low high low
drained water-logged
(Salinity)

Fig. 6


Aster
Tripolium
Spartina
alterniflora
Puccinellia
maritima
LSD
Fresh weight (g)
200
150
100
50
0
Dead leaves
Flowers
Stem
Leaves
high low high low
drained
water-
logged
(Salinity)

'able 1. Analysis results of soil samples taken immediately from the dredged sediment and taken after the sediment was left tot dry out en plants were grown in it for ninety 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 l soil water	P_2O_5 mg per 100 g dry soil	pH (KCl)	POC % dry soil	N-total % dry soil	moisture % per 100 g field moist soil	clay particles < 16 µm %	Cd ppm	Pb ppm	Fe %	Cu ppm	Zn ppm	Cr ppm	C/N ratio
mean values of 8 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	15.1
Spartina anglica 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		
Spartina anglica high salinity drained	13.5			66.3	0.35	5.22	125	7.7	3.6	0.27	39.9		10.7	150	3.67	88	480		
Spartina anglica 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	94	471		
Spartina anglica low salinity drained	14.6			87.3	0.26	2.92	110	7.7	3.8	0.29	46.6		13.6	151	4.21	101	501		
Spartina alterniflora high salinity waterlogged	14.3			95.2	3.44	36.16	122	7.8	4.8	0.30	48.8		12.0	123	3.53	84	453		
Spartina alterniflora 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		
Spartina alterniflora 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		
Spartina alterniflora 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		
WES reference soil																			
WES ref. soil *Spartina alterniflora* 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		
WES ref. soil *Spartina alterniflora* 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 II. Analyses results of soil samples taken from the sediment used in the field experiment. The data are averages of 5 values.

$CaCO_3$ %	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 1 soil water	P_2O_5 mg per 100 g dry soil	pH (KCl)
13.4	16.5	26.6	105.9	0.500	4.73	134	7.5

POC % dry soil	N-total % dry soil	moisture % per 100 g field moist soil	clay particles < 16 µm %	Cd ppm	Pb ppm	Fe %	Cu ppm	Zn ppm	C/N ratio
3.6	0.31	51.0	49.0	13.5	153	3.97	93	505	14.8

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

Table III. Amounts of metal ions (in $mg.kg^{-1}$ on dry weight basis) in shoots of <u>Spartina</u> <u>anglica</u> and <u>Spartina</u> <u>alterniflora</u> grown under different salinities and soil moisture conditions. The levels of Na, K, Ca and Mg are given in $mg.g^{-1}$.

	Spartina anglica				Spartina alterniflora				
	high salinity		low salinity		high salinity		low salinity		L.S.D.
	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	[illegible].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

availability of heavy metals. Inundation may retard this process (compare

Table IV. Least significant differences (LSD) in heavy-metal concentrations in shoots of Spartina anglica and Spartina alterniflora ($P < 0.001$).

The figures 1 to 8 represent the various treatments:

Spartina anglica	high salinity	inundated	1
		drained	2
	low salinity	inundated	3
		drained	4
Spartina alterniflora	high salinity	inundated	5
		drained	6
	low salinity	inundated	7
		drained	8

The underlined figures differ not significantly of each other.

Cd	4	3	2	1	7	5	8	6
Pb	3	7	5	2	4	6	8	1
Fe	6	8	5	7	3	2	4	1
Mn	4	8	6	2	7	3	5	1
Cu	7	1	5	3	2	4	8	6
Zn	1	7	3	2	5	4	8	6
As	5	7	3	1	4	8	2	6
Na	8	6	4	7	2	5	3	1
K	1	3	7	5	4	2	8	6
Ca	4	2	8	6	7	3	5	1
Mg	8	4	6	2	5	7	3	1

Table V. Amounts of metal ions (in $mg \cdot kg^{-1}$ on dry weight basis) in shoots of Spartina alterniflora, Aster tripolium (leaves and stem) and Puccinellia maritima grown under different salinities and soil moisture conditions. The levels of Na, K, Ca and Mg are given in $mg \cdot g^{-1}$.

	Spartina alterniflora				Puccinellia maritima				Aster tripolium (leaves)				Aster tripolium (stem)			
	high salinity		low salinity		high salinity		low salinity		high salinity		low salinity		high salinity		low salinity	
	inundated	drained	inundated	drained	inundated	drained	inundated	drained	inundated	drained	inundated	drained	inundated	drained	inundated	drained
Cd	0.186	0.362	0.156	0.214	0.114	0.194	0.114	0.300	0.222	0.580	0.606	1.482	0.260	0.566	0.228	0.904
Pb	0.380	0.368	0.212	0.432	0.712	0.504	0.384	1.056	0.520	0.640	0.808	0.568	1.354	0.996	0.500	0.468
Fe	253.0	153.6	176.2	160.8	75.4	92.2	143.6	79.8	259.6	208.2	168.0	481.4	523.6	405.8	185.8	85.2
Mn	126.6	100.0	106.0	115.8	69.6	68.2	61.4	71.4	81.0	130.8	141.0	168.8	29.2	40.2	29.2	30.8
Cu	3.40	3.08	3.16	3.42	4.22	5.18	3.10	3.64	5.18	7.60	5.38	6.40	13.24	19.00	10.18	10.88
Zn	20.4	21.4	20.0	23.0	11.4	13.4	10.0	13.6	29.0	37.0	45.4	79.8	23.4	34.0	20.6	25.0
As	0.200	0.144	0.122	0.194	0.230	0.228	0.160	0.354	0.096	0.030	0.112	0.070	0.298	0.242	0.136	0.118
Na	24.62	19.86	22.24	19.44	14.08	6.04	8.74	6.64	60.06	57.42	69.14	48.72	10.14	19.36	20.28	16.94
K	14.16	25.12	12.32	11.98	27.84	18.86	15.46	19.90	28.84	29.68	22.54	29.36	6.12	10.98	7.98	11.88
Ca	3.28	3.58	3.36	3.48	1.58	1.14	1.22	1.36	4.92	5.18	8.48	7.60	2.02	2.46	3.12	2.74
Mg	2.24	1.74	2.08	2.18	1.84	0.93	1.28	1.10	2.12	2.12	2.32	2.14	1.70	2.06	1.26	1.26

Table VI. Least significant differences (LSD) in heavy-metal concentrations. The figures 1 to 4 represent the plant species. The letters A to D represent the treatments. Spartina alterniflora = 1; Puccinellia maritima = 2; Aster tripolium-leaves = 3; Aster tripolium-stems = 4. High salinity, drained = A, Low salinity, drained = B, High salinity, inundated = C, Low salinity inundated = D.The underlined symbols differ not significantly from each other ($P < 0.001$).

	Species				Treatments			
Cd	2	1	4	3	C	D	A	B
Pb	1	3	2	4	D	A	B	C
Fe	3	1	2	4	D	B	A	C
Mn	4	2	1	3	C	A	D	B
Cu	1	2	3	4	D	B	C	A
Zn	2	1	4	3	C	D	A	B
As	3	1	4	2	D	A	B	C
Na	2	1	4	3	B	A	C	D
K	4	1	2	3	D	B	C	A
Ca	2	4	1	3	C	A	B	D
Mg	2	4	1	3	B	A	D	C

Table VII. Average values of metal-ion concentrations (in $mg \cdot kg^{-1}$ on dry weight basis) in two subsequent harvests of shoots of *Puccinellia maritima* and *Spartina alterniflora*. The concentrations of Na, K, Ca and Mg are given in $mg \cdot g^{-1}$. I = first harvest; II = second harvest. The asterisks mark a significant difference ($P < 0.05$).

	Cd ($mg \cdot kg^{-1}$)		Pb		Fe		Mn		Cu		Zn		As		Na ($mg \cdot g^{-1}$)		K		Ca		Mg	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Puccinellia maritima																						
low salinity drained	0.30	0.53*	1.06	0.42	481	54*	71	66	3.6	4.9*	14	11	0.35	0.03*	6.6	8.4	19.8	14.5*	1.4	1.5	1.1	1.5
inundated	0.11	0.19	0.38	0.39	168	90*	61	73*	3.1	5.2*	10	13	0.16	0.09	8.7	16.1*	15.5	11.1*	1.2	2.1	1.3	2.7*
Spartina alterniflora																						
low salinity drained	0.21	0.95*	0.43	0.30	161	170	116	265*	3.4	3.6	23	34*	0.19	0.18	19.4	21.1	12.0	14.1	3.5	7.1*	2.2	3.6*
inundated	0.16	0.23*	0.21	1.03	176	99	106	221*	3.2	3.9*	20	14*	0.12	0.21*	22.2	25.1	12.3	11.4	3.4	6.8*	2.1	4.4*
high salinity drained	0.36	1.07	0.37	0.30	154	172	100	191*	3.1	4.2*	21	37*	0.14	0.18	19.9	21.4	25.1	13.0*	3.6	7.1*	1.7	3.3*
inundated	0.19	0.25	0.38	0.30	253	108	127	328*	3.4	3.5	20	15*	0.20	0.20	24.6	25.9	14.2	15.1	3.3	7.1*	2.2	4.5*

Table VIII. Amounts of metal ions (in $mg.kg^{-1}$ on dry weight basis) in shoots of Spartina anglica, S. alterniflora, Puccinellia maritima and Aster tripolium grown in buckets in a salt marsh near Antwerp (B). The levels of Na, K, Ca and Mg are given in $mg.g^{-1}$. Also is given the standard deviation and the percentage covariance. n = number of samples.

	mg.kg^{-1}						mg.g^{-1}			
	As	Cd	Pb	Fe	Mn	Cu	Zn	Na	K	Ca	Mg
Puccinellia maritima (second planting)											
x	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
Puccinellia maritima (first planting random)											
x	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
Aster tripolium											
x	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
Spartina anglica											
x	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
Spartina alterniflora											
x	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

Table IX. Least significant differences in heavy-metal concentrations in shoots of four salt-marsh species grown under field conditions.

1 = Puccinellia maritima (second planting)
2 = do. (first planting)
3 = Aster tripolium
4 = Spartina anglica
5 = Spartina alterniflora

The underlined figures differ not significantly of each other.

Cd	4	5	2	1	3	$p < 0.001$
Pb	4	5	1	2	3	$p < 0.001$
Fe	5	4	3	1	2	$p < 0.001$
Mn	2	1	4	3	5	$p < 0.001$
Cu	4	5	2	1	3	$p < 0.001$
Zn	4	5	2	1	3	$p < 0.001$
As	4	5	3	1	2	$p < 0.001$
Na	2	1	5	4	3	$p < 0.001$
K	2	5	1	4	3	$p < 0.001$
Ca	2	1	4	5	3	$p < 0.001$
Ng	2	5	1	4	3	$p < 0.001$

Table X. Comparison of the results of a field experiment (I) with *Spartina alterniflora*, *Puccinellia maritima* and *Aster tripolium* (leaves) with the results of a greenhouse experiment under drained and low salinity conditions (II). The asterisk marks a significant difference at the level $P < 0.05$. The arrow indicates significantly lower or higher values in the greenhouse experiment.

	mg.kg^{-1}							
	Cd		Pb		Fe		Mn	
	I	II	I	II	I	II	I	II
Spartina anglica (1983 experiment)	0.10	0.07	1.1	0.5*↓	303	70*↓	60	80*↑
Spartina alterniflora	0.23	0.21	1.1	0.4*↓	300	161*↓	70	116*↑
Puccinellia maritima	0.29	0.30	3.4	1.1*↓	880	481*↓	50	71*↑
Aster tripolium (leaves)	0.89	1.48	3.6	0.6*↓	566	80*↓	68	168*↑

	mg.kg^{-1}					
	Cu		Zn		As	
	I	II	I	II	I	II
Spartina anglica (1983 experiment)	3.9	5.0*↓	21	26	0.41	0.26*↓
Spartina alterniflora	4.4	3.4*↓	21	23	0.41	0.19*↓
Puccinellia maritima	8.1	3.6*↓	26	14*↓	0.74	0.35*↓
Aster tripolium (leaves)	13.1	6.4*↓	55	80	0.53	0.07*↓

	mg.g^{-1}							
	Na		K		Ca		Mg	
	I	II	I	II	I	II	I	II
Spartina anglica (1983 experiment)	24.1	20.7*↓	11.8	13.6	2.3	3.1	2.3	1.8*↓
Spartina alterniflora	19.6	19.4	9.5	12.0*↑	2.7	3.5*↑	1.8	2.2*↑
Puccinellia maritima	11.5	6.6*↓	8.4	19.8*↑	1.8	1.4	1.7	1.1*↓
Aster tripolium (leaves)	38.3	48.7*↑	14.7	29.4*↑	5.4	7.6*↑	3.9	2.1*↓

8. Appendices

A. Analyses of the eight soil samples taken randomly, immediately after dredging.

B. Analyses of 5 soil samples taken randomly from the site of the field experiment.

C. Heavy metal concentrations and yield of *Spartina alterniflora* (1983).

D. Heavy metal concentrations and yield of *Spartina anglica* (1983).

E. Heavy metal concentrations and yield of *Spartina alterniflora* (1984).

F. Heavy metal concentrations and yield of *Puccinellia maritima* (1984).

G. Heavy metal concentrations and yield of *Aster tripolium* leaves (1984).

H. Heavy metal concentrations and yield of *Aster tripolium* stems (1984).

J. Heavy metal concentrations of *Puccinellia maritima* and *Spartina alterniflora* after a regrowth experiment.

K. Individual results of the field experiment.

L. Quality control analyses-method.

Appendix A. Analysis results of 8 soil samples, chosen at random, from 1000 litres contaminated material, samples with the "van Veen" grab near the Zandvlietsluis (Antwerp) - 6th January 1983. Calculated on dry basis except if mentioned.

Labnr.	$CaCO_3$	meq $(100\ g)^{-1}$ Na	meq $(100\ g)^{-1}$ K	moisture $(100\ g\ dry)^{-1}$ A	g NaCl $(100\ g)^{-1}$ dry B	g NaCl l^{-1} C	mg $(100\ g)^{-1}$ P_2O_5	pH	% POC	% N
27096	14.1	30.4	2.35	174.4	1.73	9.91	132	6.9	4.3	0.318
27097	14.5	32.3	2.31	173.4	1.69	9.77	130	7.1	4.5	0.323
27098	13.2	29.7	2.19	174.8	1.59	9.13	126	7.0	4.7	0.321
27099	13.7	29.9	2.15	174.1	1.38	7.91	132	7.0	5.4	0.323
27100	14.6	33.2	2.26	175.5	1.64	9.35	124	7.1	4.6	0.318
27101	15.8	34.0	2.23	173.8	1.52	8.76	125	7.0	5.5	0.321
27102	14.3	30.1	2.15	171.8	1.64	9.55	133	7.0	4.9	0.329
27103	13.2	29.5	2.17	171.7	1.66	9.68	132	7.1	5.1	0.324
mean	14.2	31.3	2.23	173.7	1.61	9.26	129	7.0	4.9	0.322
S.D.	3.8	1.8	0.08	1.4	0.11	0.66	4	0.1	0.4	0.004

Labnr.	moisture $(100\ g\ wet)^{-1}$ %	% clay ≤ 16 µm	ppm Cd	ppm Pb	% Fe	ppm Cu	ppm Zn	ppm Cr	C/N ratio
27096	63.6	44.9	10.1	145	2.95	86	498	197	13.5
27097	63.4	39.9	10.6	135	3.46	92	510	100	13.9
27098	63.6	40.0	10.7	136	2.76	95	498	203	14.6
27099	63.5	38.3	10.7	136	3.06	93	498	200	16.7
27100	63.7	40.5	10.8	140	3.09	88	519	201	14.5
27101	63.5	41.2	10.8	139	2.79	88	507	201	17.1
27102	63.2	40.0	10.7	137	2.46	89	510	203	14.9
27103	63.2	41.2	10.6	137	3.13	90	504	204	15.7
mean	63.5	40.8	10.6	138	2.96	90	506	201	15.1
S.D.	0.2	1.9	0.2	3	0.30	3	8	2	1.3

Appendix. B. Analysis results of 5 soil samples, taken at random, from the soil used for the field experiment in the Saeftinge salt marsh. The values are calculated on dry weight basis.

Labnr.	$CaCO_3$ %	Na (total) meq $(100\ g)^{-1}$	K (total) meq $(100\ g)^{-1}$	moisture $(100\ g\ dry)^{-1}$	g NaCl dry soil	g NaCl l^{-1}	P_2O_5 mq $(100\ g)^{-1}$	pH KCl	POC %
30378	13.2	16.5	24.5	88.1	0.418	4.74	132	7.5	4.3
30379	14.0	16.5	27.1	114.7	0.557	4.86	126	7.4	4.9
30380	13.6	17.4	26.6	108.2	0.514	4.75	137	7.6	4.5
30381	12.7	18.7	27.6	131.5	0.596	4.53	138	7.6	5.0
30382	13.6	13.9	27.1	86.9	0.414	4.76	136	7.5	4.3
mean	13.4	16.6	26.6	105.9	0.500	4.73	134	7.5	4.6
S.D.	0.49	1.8	1.2	18.8	0.082	0.12	4,9	0.06	0.33

Labnr	N %	moisture $(100\ g\ wet)^{-1}$	clay % < 16 µm	Cd ppm	Pb ppm	Fe %	Cu ppm	Zn ppm	Mn ppm	As ppm
30378	0.31	46.9	47.8	12.2	149	3.72	85.3	465	962	34.6
30379	0.34	53.3	54.5	14.8	149	3.90	92.9	530	1070	47.4
30380	0.33	52.0	49.9	13.2	158	3.99	98.0	510	1038	42.6
30381	0.29	56.8	51.3	13.9	168	4.30	101.7	542	1145	49.3
30382	0.29	45.8	41.6	13.4	144	3.94	89.2	480	980	41.1
mean	0.31	51.0	49.0	13.5	153	3.97	93.4	505	1039	43.0
S.D.	0.023	4.58	4.81	0.95	9,3	0.21	6.6	32	73	5.8

Appendix C. Heavy metal concentrations and yield of <u>Spartina alterniflora</u> (1983).

Pot nr.	Fresh weight shoot	Nr. of tillers	Cd ($mg.kg^{-1}$)	Pb ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)	Cu ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	As ($mg.kg^{-1}$)	Na ($mg.g^{-1}$)	K ($mg.g^{-1}$)	Ca ($mg.g^{-1}$)	Mg ($mg.g^{-1}$)
drained, high salinity													
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
drained, low salinity													
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
inundated, high salinity													
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
inundated, low salinity													
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 nr.	Fresh weight shoot	Nr. of tillers	mg.kg^{-1}							mg.g^{-1}			
			Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
drained, high salinity													
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
drained, low salinity													
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
inundated, high salinity													
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
inundated, low salinity													
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 nr.	Fresh weight shoot	Nr. of tillers	Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
			$mg.kg^{-1}$							$mg.g^{-1}$			
drained, high salinity													
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
drained, low salinity													
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
inundated, high salinity													
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
inundated, low salinity													
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	13.1	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 <u>Puccinellia maritima</u> (1984).

Pot nr.	Fresh weight shoot	Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
		mg·kg^{-1}							mg·g^{-1}			
drained, high salinity												
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
drained, low salinity												
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
inundated, high salinity												
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
inundated, low salinity												
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 (1984).

Pot nr.	Fresh weight shoot	Cd ($mg.kg^{-1}$)	Pb	Fe	Mn	Cu	Zn	As	Na ($mg.g^{-1}$)	K	Ca	Mg
drained, high salinity												
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
drained, low salinity												
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
inundated, high salinity												
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
inundated, low salinity												
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 nr.	Fresh weight stem	Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
		ppm							$mg.g^{-1}$			
drained, high salinity												
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
drained, low salinity												
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
inundated, high salinity												
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
inundated, low salinity												
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 J. Individual results of metal-ion concentrations of shoots of *Puccinellia maritima* and *Spartina alterniflora* after a regrowth of 90 days after the first harvest (values are in $mg\ kg^{-1}$ except for Na, K, Ca, Mg these are in $mg{\cdot}g^{-1}$, both on dry weight basis.

		$mg{\cdot}kg^{-1}$							$mg{\cdot}g^{-1}$			
	Potnr.	Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
Puccinellia maritima												
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
Spartina alterniflora												
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

Appendix K. Individual results of the field experiment. * odd or missing value.

	Pot nr.	Cd	Pb	Fe	Mn	Cu	Zn	As	Na	K	Ca	Mg
		$mg.kg^{-1}$							$mg.g^{-1}$			
Puccinellia maritima (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
Puccinellia maritima (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
Aster tripolium												
	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
Spartina anglica												
	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	0.5?	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
Spartina alterniflora												
	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

Appendix L. Quality control analyses-method.

	Fe	Zn	Mn	Cu	Pb	Cd	Cr	Ca(%)	K(%)	Mg(%)
	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±0,03	4.46±0.03	(0.7)

* standard deviation x 3 (n=6) Fe, Zn, Mn, Ca, K, Mg in ppm en Cu, pb, Cd, Cr in ppb
(   ) = non-certified values, information only

Samples are analysed according to the analysis methods of the soil science laboratory DIHO, 1984.

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