Title

Selection of Native Wetland Plants for Water Treatment of Urban Runoff

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By

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TECHNICAL COMPLETION REPORT

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ABSTRACT

Field sampling was conducted in relatively undisturbed wetlands as well as in wetlands impacted by urban runoff to obtain information on ranges of biomass, nutrients and heavy metals accumulation in different type of common wetland plant species. The above ground biomass of erect emergent macrophytes, tules and cattails, (*Scirpus* spp., *Typha* spp.) ranged from 560 g to 3015 g of dry mass per square meter with the average nitrogen concentration of 0.9%. The creeping or soft emergent macrophytes such as water primrose, water cress and pennywort (*Ludwigia peploides, Nasturtium aquaticum, Hydrocotyle verticillata, Sagittaria latifolia*) usually reached significantly lower biomass (average of about 450 gm^{-2}) but the biomass was richer in nitrogen (3%). Representatives of the second group were also characterized by significantly faster decomposition rates. Methods of propagation of plants from rhizome and stem cuttings were elaborated. A greenhouse experiment carried out to determine the dependence of growth characteristics on water level showed that *Hydrocotyle verticillata* seemed to be most sensitive to low water levels followed by *Nasturtium aquaticum. Ludwigia peploides* grew well at all five tested water levels. Both *Hydrocotyle verticillata* and *Nasturtium aquaticum* were more sensitive to high nitrogen concentrations than *Ludwigia peploides.* The mesocosm experiment studying the effect of four different water levels on the growth and biomass allocation in tall erect emergents (*Scirpus californicus, S. acutus, Typha domingensis, Phragmites australis*) and short emergents (*Polygonum* sp., *Scirpus robustus, Sagittaria latifolia* and *Ludwigia peploides*) showed that with the exception of *Typha domingensis*, *Sagittaria latifolia* and *Scirpus robustus*, all other species allocated more biomass into belowground organs in the low water level treatment than in the high water treatment. Results of this experiment in combination with the observations from the field are crucial for proper species selection for various treatment purposes.

Five species, *Scirpus californicus, S. acutus, Typha domingensis, Sagittaria latifolia* and *Ludwigia peploides*, were grown in outdoor hydroponic cultures in a heavy metal experiment. Zinc, lead, cadmium and copper in the concentrations of 0.1, 1 and 10 ppm of were added to the nutrient solution in the cultures. After two weeks of exposure to the heavy metals, plants were measured, harvested, biomass was sorted into roots, rhizomes, stems and leaves, dried and analyzed for concentrations of individual metals. There were no statistically significant differences in the growth expressed as the percentage increment of total length between the control and all concentrations of all metals. However, there were species and organ specific differences in the accumulation of individual metals. Most metals were accumulated in roots, specifically adventitious roots. *Ludwigia peploides* seemed to be the most efficient in the accumulation of all metals tested.

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PROJECT NUMBER: W-769

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TITLE: Selection of Native Wetland Plants for Water Treatment of Urban Runoff

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PROBLEM AND RESEARCH OBJECTIVES

WRC project W-769 focused on obtaining data on the seasonal dynamics of growth, resource allocation, and pollutant allocation in selected wetland plant species grown under conditions of elevated pollution as compared to non-polluted habitats. Recent studies have indicated that pollution from urban runoff, especially storm water discharge, has caused major water quality problems in streams, lakes, and reservoirs, including nutrient enrichment, introduction of toxic materials, turbidity and heavy sediment deposition (Shutes et al. 1993).

Wetlands have the capacity to intercept storm runoff and store storm waters, simultaneously removing suspended solids, and some dissolved pollutants prior to discharge into waterways. Aquatic and semi-aquatic plants play an important role in promoting both nutrient transformation and nutrient removal in aquatic treatment systems. Extensive literature is available documenting many aspects of wastewater treatment using aquatic plants as summarized, e.g., by Moshiri (1993). Heavy metal uptake be wetland plants was documented by Simmers et al. (1981), Jamil et al. (1987), Lyngby (1987), Shutes et al. (1993), etc. Examples of storm water runoff treatment using wetlands are less numerous. Among the successful ones we can cite an artificial marsh constructed to remove suspended solids and nutrients from storm water runoff from the city of Tallahassee, FL (Tuavila et al. 1987).

Many communities outside California already use constructed wetlands for treatment of storm water effluent. Wetland systems are used for a number of reasons, including low maintenance costs and the potential to combine water treatment with habitat creation. However, regulatory agencies that would permit or comment on the establishment of these constructed wetlands (Regional Water Quality Control Boards, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers) are concerned about the potential for bioaccumulation of urban runoff pollutants. If wetlands are to be used for the treatment of urban runoff, an understanding of nutrient and pollutant cycling within wetland plants during the year is crucial. It will help wetland managers to design proper harvesting schemes for removing pollutants from the wetland environment. While many states and communities have experimented with urban effluent and wetlands to determine the most appropriate plant species and management, little work has been completed in California. Results obtained outside of the state can only partially assist in designing California storm water wetlands as plants, weather, and soil conditions differ significantly from those of other states. Consequently, significant interest has been generated in developing a useable information base which would be available to both communities and the state regulatory agencies when making decisions regarding storm water wetland management and design. Another important aspect of this problem is that urban runoff currently drains into existing wetlands, which are protected as waters of the United States by the Clean Water Act. It is important to know the effects and potential impacts that storm water is or may have on naturally occurring wetlands and to what extent pollutants are being concentrated in parts of plants that will be consumed by migratory or resident animals in the wetland environment.

In our project we focused primarily on obtaining data on seasonal dynamics of growth and resource allocation including heavy metals allocation in selected wetland plant species grown under conditions of elevated heavy metals. The obtained results provide a basis for using these species for wetland construction.

The specific objectives of our WRC grant were:

1. Assess the range of main nutrients (N,P) and heavy metals (Pb, Cu, Cd, Zn) in the biomass of selected wetland plant species and the respective sediment/water from natural, preferably undisturbed wetlands in the Sacramento Valley.

2. Define the ecological characteristics (nutrient uptake, biomass production, resource allocation, mortality rate and decomposition rate) of selected wetland species in response to elevated water pollution and water level fluctuation.

3. Determine the methods of propagation, management and harvesting of the selected species that will maximize their effectiveness in controlling urban runoff in constructed wetlands.

4. Design the plant composition for a constructed wetland and after plant establishment (time permitting) evaluate its efficiency with respect to water quality improvement.

In the third year of the project, we finished building the wetland cultivation facility (funded from other sources) in the Putah Creek Reserve area adjacent to the Institute of Ecology, UCD. This facility enabled us to conduct mesocosm scale controlled experiments on the heavy metals and biomass allocation by several representative species of wetland plants.

METHODOLOGY

Plant selection

The following species were selected for experiments at various stages of the project: *Hydrocotyle verticillata, Ludwigia peploides, Nasturtium aquaticum, Sagittaria latifolia* and *Polygonum hydropiperoides,* all representing a group of soft and/or creeping emergent macrophytes, and *Scirpus acutus, S. californicus, S. robustus, Typha latifolia, T. domingensis* and *Phragmites australis*, representing a group of erect emergent macrophytes. These species were selected because they are native to California with the exception of *Nasturtium aquaticum*, which is naturalized. According to our previous research and the literature data, they are robust primary producers and posses excellent reproductive capabilities. To obtain data on biomass production, the representative species were sampled at various location in the Central Valley. The above ground biomass was harvested from a 50 x 50 cm quadrat, dried and weighed. Methods of propagation of plants from rhizome and stem cuttings were elaborated (See Fig. 1). The rhizome propagation requires close monitoring of soil water as the rhizome cuttings are highly susceptible to both desiccation and drowning.

Greenhouse experiments

A greenhouse experiment was carried out to determine the dependence of growth characteristics on water level. Three species, *Hydrocotyle verticillata, Ludwigia peploides* and *Nasturtium aquaticum* were tested. Five different water depth in relation to soil surface were used: -10cm, -5cm, 0cm, +5cm, and +10 cm, each in five replicates. Individual plants were planted in pots with sand and placed in a large metal container with nutrient solution. Nitrogen concentration in the solution was checked at four day intervals and readjusted to 50ppm. The experiment lasted four weeks, at the end plants were harvested, divided into leaves, shoots and roots, dried and weighed.

To determine the dependence of growth of *Hydrocotyle verticillata* and *Nasturtium aquaticum* and its tissue nitrogen concentration on the concentration of nitrogen in water, we planted individual plants in 500 ml Erlenmeyer flasks (*Nasturtium*) or plastic holders placed in buckets (*Hydrocotyle*) in 1/2-strength Hoagland nutrient solution with 1.4, 7, 14, 35, 70, and 140 ppm of nitrogen added as $CaNO_3$. (The same experiment using *Ludwigia peploides* was carried on previously and its results are described in the Final report for WRC-727 project.) The nutrient solution was changed every second day. The experiment lasted 25 days.

Field survey of heavy metals in sediments, water and plant material

In the second year of the project, four wetlands receiving urban runoff and two control sites were selected for analyses. Two of the runoff retention basins, Octo Inn (OI) and Rancho Solano (RS), are located in Fairfield, California, two, the North Pond (NP) and West Pond (WP) are in Davis, California. A small natural wetland in the Cosumnes River Preserve (CP), together with a marsh at Calhoun Slough (CS) at the Jepson Prairie Reserve represent the non-polluted habitats. Plant and sediments were collected in the fall and winter. Water was sampled in January, February and March, 1992, following the rain events. All samples were analyzed for lead, zinc, and copper; sediment samples were also analyzed for molybdenum and cadmium. Metals analysis was conducted using Ionized Coupled Plasma Atomic Emission Spectroscopy (ICPAES).

Wetland cultivation facility

During winter and spring of 1992 a wetland cultivation facility was built in the Putah Creek Reserve area adjacent to the Institute of Ecology, UCD. It includes three sets of fiberglass or plastic containers. The first set consists of 24 round fiberglass tanks (5' diameter, 3' high). Each tank is divided into four compartments by plywood partitions and filled with soil. These tanks were used for studying the effect of different water levels on the growth of wetland plants. The second set includes 80 small plastic containers that were used for experiments assessing the effect of elevated concentrations of heavy metals on plant growth.

Heavy metals experiment

Propagules of five wetland plant species, native to California's Central Valley, were collected in the winter of 1991-1992. *Scirpus acutus* (S.a.), *S. californicus* (S.c.), and *Typha domingensis* (T.d.), were collected and propagated from rhizomes. *Ludwigia peploides* (L.p.) was propagated from stem cuttings and *Sagittaria latifolia* (S.l.) was propagated by tubers.

Each plant propagule was planted individually into a #6 nursery pot. Washed sand was used as a substrate. A pot with each species was then put into a large tub and the water level was raised to saturation (30 L). Once the plants had sprouted and established themselves, Hoagland's nutrient solution, without micro-nutrients, was added and nitrate levels were kept as close to 40 ppm as possible. This was to ensure good plant growth at the time of exposure to the metals. The tubs were then flooded with another 10 L of water to ensure flooded conditions.

A randomized complete block design was used for the layout. There were five blocks, each with twelve tubs. Treatments were randomly assigned to the twelve tubs. The four metal salts, mentioned above (Cd, Cu, Pb and Zn), were administered at three treatment levels: 0.1, 1.0 and 10.0 parts per million (ppm).. There were ten control tubs that had no metals added to the water. Prior to treatment, all plants were measured for length or leaf area. The tubs were treated as batch reactors, according to the design layout. The plants were allowed to grow for an additional two weeks after metal treatment. After this time, the plants were harvested, remeasured, separated into leaves, rhizomes, roots, adventitious roots, tubers and the original propagule stock. Each part was dried at 80° C for 48 hours and then weighed. Once weighed, the samples were ground and submitted to the University of California's Department of Agriculture and Natural Resources Laboratory for metals analysis. Metals analysis was conducted using Ionized Coupled Plasma Atomic Emission Spectroscopy (ICPAES).

Growth, as a function of biomass increase was determined by using correlations of shoot length to dry weight biomass for *Scirpus acutus, S. californicus* and *Typha domingensis*. Stem length and number of branches over 10 cm were used to get relationships for biomass in *Ludwigia peploides*, and leaf area was used for biomass correlations in *Sagittaria latifolia.* These correlation relationships were obtained by destructive sampling in accordance with Vymazal et al. 1993.

Nitrate measurements were taken with an Orion ion selective electrode. Analysis of variance calculations and other statistics were done using Super ANOVA by Abacus, for the Macintosh.

Water level experiment

Evaluating the effect of water level on the growth and biomass allocation of eight species of emergent macrophytes was conducted in the 24 round fiberglass tanks (5' diameter, 3' high). Each tank was divided into four compartments by plywood partitions and filled with soil. Eight plant species, *Scirpus californicus, S. acutus, S. robustus, Typha domingensis, Phragmites australis, Ludwigia peploides, Polygonum hydropiperoides* and *Sagittaria latifolia* were planted in the late summer of 1992. They were initially kept at the same water level until established, after which, four different flooding regimes, +30, +10, 0, and -20 cm, each in three replicates, were initiated by the end of June 1993. Plants in 40 cm x 40 cm grid placed in each compartment were measured biweekly and the allometric correlations established previously (see next paragraph) were used for assessing the biomass changes. In September, all the aboveground biomass was collected from the grid, separated into leaves, stems, adventitious roots (where applicable) and litter. These plant parts were dried and weighed. In one tank from each replicate, the belowground biomass was collected from the following layers: 0 to -5cm, -5 to -10cm, -10 to -15 cm, -15 to -25cm, -25 to -35 cm and -35 to -50cm (the bottom). Belowground harvest turned out to be much more time consuming than expected and teams of people were working on it almost non-stop for 12 weeks.

Allometric Relationships

To better quantify standing biomass, obvious features such as stem length or plant height were measured on individual harvested plants and related to the dry weight of each plant respectively. Field recorded measurements of plant height and density can then give estimates of standing biomass over larger areas. We used simple stem length to determine biomass for *Phragmites australis, Scirpus acutus, S. californicus* and *S. robustus*. The biomass of Typha spp. was best correlated with a "leaf length index." This index was calculated as the average length of the four tallest leaves of *Typha* multiplied by the total number of leaves. Biomass of leaves of *Sagittaria latifolia* was determined by measuring the leaf length (C) and width (D) and correlating the index CxD with weight. CxD index showed very close correlastion with the leaf area mesured by the LICOR-LI3000A leaf area meter. The biomass of petioles estimated from the regression of petiole length on its weight was added to leaf biomass. Due to the creeping nature of *Ludwigia peploides* and *Polygonum* sp. allometric correlations were not very accurate.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Greenhouse experiment

Figure 2 demonstrates the effects of water level on biomass for *Hydrocotyle verticillata* and *Ludwigia peploides*. Note the difference in scale on the y axis. *Ludwigia peploides* produces about twice the biomass of *Hydrocotyle verticillata* in greenhouse conditions. The two deeper water levels, (O and +10 cm) supported significantly higher ($P<0.05$; Scheffe F-test) amounts of *H. verticillata* biomass than the lower water levels (-10cm and -5 cm) levels (P 0.05, Scheffe F-test). Due to logistical problems while harvesting, data for Nasturtium aquaticum are incomplete. Preliminary indications seemed to point out similar results with deeper water promoting higher biomass.

The three species differ in their response to nitrate-nitrogen (Fig. 3). Both *Hydrocotyle verticillata* and *Nasturtium aquaticum* show a decrease in biomass production at NO3-N levels greater than 70 ppm. Ludwigia peploides is capable of peak biomass production even at the highest treatment level of 140 ppm. Ludwigia peploides demonstrates the ability to grow well at any tested water level and increase in NO3-N does not inhibit its growth.

Field survey

Table 1 presents examples of the biomass and tissue nitrogen ranges for several types of wetland macrophytes from natural habitats. The time course of decomposition for of some of these species is shown in Fig. 4.

The survey of heavy metals in water from several runoff retention basins sampled in January, February and March, 1992, following rain events did, not reveal any increased metal concentrations. Except for Zn, no detectable levels of heavy metals were found in water samples. Of the plant samples from polluted sites, *Nasturtium aquaticum* was found to contain the highest levels of Zn (154.9 ppm). Surprisingly, *Sagittaria latifolia* from Cosumnes Preserve, our control site, also contained high levels of Zn. If we divide all the plant species tested into two groups based on their growth form, i.e., erect emergent macrophytes and creeping emergent macrophytes, the group of creeping macrophytes, represented by species such as *Nasturtium aquaticum*, have significantly higher levels of Cu and Zn in their tissues than does the group of erect emergents (Fig. 5). Heavy metal concentrations in sediments were not as high as we expected; samples from Octo Inn Basin showed the highest levels of plant available Zn, Pb and Cu among the "polluted" sites. Sediments from the Cosumnes Preserve had the overall highest metals concentrations (Table 2). However, the levels of lead were generally quite low at all sites. The heavy metal content in plant biomass (Table 3) was not correlated with the concentrations of individual elements in sediments. While the Cosumnes Preserve sediments had the highest concentrations of metals, the highest metal concentrations in plants were found at Rancho Solano.

Heavy metals - experiment

Growth

There was no statistical difference detected in the above ground growth of any treated plants and the controls. This was evaluated using percent increase in biomass (Table 4). Growth of belowground biomass was not examined in this experiment.

Metals

Scirpus acutus

Figure 6 shows the average metal accumulation, in parts per million (ppm), for the four metals as divided into three of the plant parts: roots, adventitious roots and shoots. Rhizomes, although tested, were shown not to accumulate metals to any high degree and were therefore not included. The analysis of variance (ANOVA) showed that the differences between the treatment levels were significant. Scheffe's test grouped the means of the 10 ppm treatments separately than the 1.0 ppm and the control in most cases. In general, the metals were remaining in the adventitious roots and roots and were not being translocated to the shoots to any large degree. This was shown by ANOVA using the 10 ppm treatment and the plant part as a factor. Cd, Pb and Zn were all significant in their plant part partitioning, but Cu is not. There appeared to be an anomaly with the Pb results, since the controls were higher than the 1.0 ppm treatment.

Scirpus californicus

Figure 7 shows the average metal accumulation, in ppm, for the four metals as divided into three plant parts: roots, adventitious roots and shoots. The same trend as found in *Scirpus acutus* was also found here. In general, the ANOVA showed significance for treatment levels. The metals were found in the adventitious roots in significantly higher quantities than in the roots and shoots. Again the Pb data showed anomalies, with controls being higher than treatments for shoots and roots. In the case of the shoots, the treatment ANOVA was not significant for the Pb treatments and the p-value was 0.2 at the alpha level of 0.05.

Typha domingensis

Figure 8 shows the average metal accumulation, in ppm, for the four metals as divided into three plant parts: roots, adventitious roots and shoots. The same trend as found in *Scirpus acutus* was also found here. In general, the ANOVA showed significance for treatment levels. The metals were found in the adventitious roots in significantly higher quantities than in the roots and shoots. Pb data were anomalous.

Ludwigia peploides

Figure 9 shows the average metal accumulation, in ppm, for the four metals as divided into two of the plant parts: roots and leaves. The ANOVA showed significance between treatment levels and significance for plants parts, with the exception of Zn. There were no significant differences in the partitioning of zinc between the roots and the leaves. The overall average values for metal uptake for leaves and roots were above those for all of the other five species tested.

Sagittaria latifolia

Figure 10 shows the average metal accumulation, in ppm, for the four metals as divided into two of the plant parts: roots and leaves. The ANOVA showed significant differences between treatment levels but no significance between plant parts. Notice, however, that the soft tissued leaves of this plant had higher values than those of the taller, thick rhizomatous plants. The Pb anomaly also appeared in the roots of this plant.

Using copper as an example, the differences between the biomass allocation into various plant parts and the respective accumulation of the metal into those parts is depicted in Fig. 11.

A ranking of the species in descending order of the amount of metals incorporated into plant tissue in a hypothetical square meter of a monoculture of each species is shown in Table 5. This is based on assigning the species that would incorporate the least a value of one. Ludwigia peploides is by far the superior species for incorporation of metals into biomass given the same area. Some assumptions are robust growth and no turnover.

Allometric relationships

Figures 12 and 13 are examples of the allometric relationships between a linear measured variable (length and width) and biomass (dry weight) or leaf area. Figure 12 a shows the relationship between leaf area (as measured by a leaf area meter) of *Sagittaria latifolia* and dry weight. The leaf area correlates well with an index, CxD, obtained by multiplying leaf length by leaf width (Fig. 12 b). It was more efficient and non-destructive to measure the length and width of the leaves. A direct correlation could then be generated between the index and the biomass (Fig. 12 c). Fig. 13 a and 13 b are the shoot length and dry width relationships for *Scirpus acutus* and *Typha* spp respectively.

Water levels

The mesocosm experiment studying the effect of four different water levels on the growth and biomass allocation of tall erect emergents (*Scirpus californicus, S. acutus, Typha domingensis, Phragmites australis*) and short emergents (*Polygonum* sp., *Scirpus robustus, Sagittaria latifolia* and *Ludwigia peploides*) showed that with the exception of *Typha domingensis, Sagittaria latifolia* and *Scirpus robustus*, all other species allocated more biomass into belowground organs in the low water level treatment than in the high water treatment (Fig. 14). Results of this experiment in combination with the observations from the field are crucial for proper species selection for various treatment purposes.

Conclusions

Our overall conclusions and, consequently, recommendations from various experiments and observation conducted in this project are as follows:

(1) Selection of plant species for respective water treatment projects has to be based on a thorough knowledge of plant life history strategies.

(2) Tall emergent macrophytes (*Scirpus* spp., *Typha* spp.) grow well in a range of water depth and nutrient concentrations and usually are highly productive. Once established, they can survive occasional desiccation or deep water flooding. They differ in their phenology. All the Californian members of this group, with the exception of *Scirpus californicus,* senesce in the fall under regular circumstances and survive winter as belowground rhizomes. On the onset of senescence, substantial amounts of nutrients are translocated to rhizomes. Senescence in *Typha* spp. seems to be delayed by increased nutrient levels (Post, unpublished data).

(3) Short, soft stem and/or creeping macrophytes (*Polygonum, Ludwigia, Nasturtium*) generally display highly plastic response to different water levels, some of them growing better in drier soils (*Polygonum*), some thriving in flooded conditions (*Ludwigia*). Their biomass production is lower than in tall emergents but it has a significantly faster turnover. After sensecence and death, these plants decompose very rapidly. Since they do not posses any robust belowground structures, the nutrient translocations are not very important in this group and most nutrients are released back to the water column during decomposition. Some species in this group can tolerate very high nutrient levels without adverse growth effects.

(4) Creeping macrophytes have the potential for heavy metal uptake from the water column. The uptake efficiency can be matched by tall emergents producing large quantities of adventitious roots in deeper waters. Removal of the metals from the ecosystem can then be accomplished by routine harvesting.

(5) Recommendations: A simple system for treating heavy metals from urban runoff using wetland plants should include species with vigorous growth of adventitious roots in the water column, such as *Scirpus acutus* and *Typha domingensis.* A creeping macrophyte, *Ludwigia peploides,* would be a suitable co-dominant of such a system as it also produces large quantities of roots in the water column. At the first signs of senescence, the aboveground biomass should be harvested to remove metals.

Results obtained in the course of this project are directly relevant to any agencies of consulting firms responsible for wetland design. The municipalities of Fairfield and Davis and The Nature Conservancy at the Cosumnes Preserve cooperated on some phases of this project.

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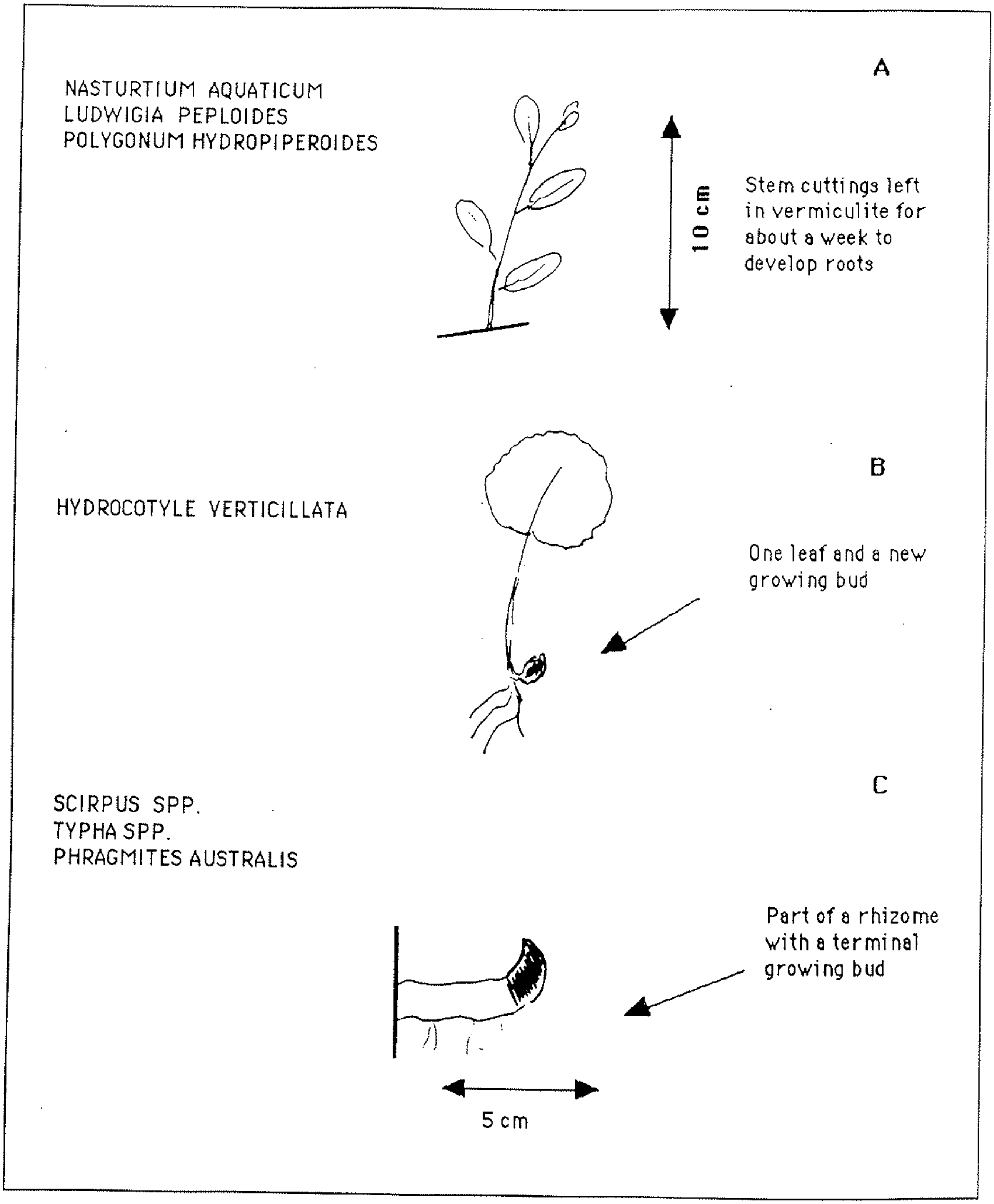


NASTURTIUM AQUATICUM
LUDWIGIA PEPLOIDES
POLYGONUM HYDROPIPEROIDES

Stem cuttings left in vermiculite for about a week to develop roots

HYDROCOTYLE VERTICILLATA

One leaf and a new growing bud

SCIRPUS SPP.
TYPHA SPP.
PHRAGMITES AUSTRALIS

Part of a rhizome with a terminal growing bud

Fig. 1
Methods of plant material propagation for species used in this project.

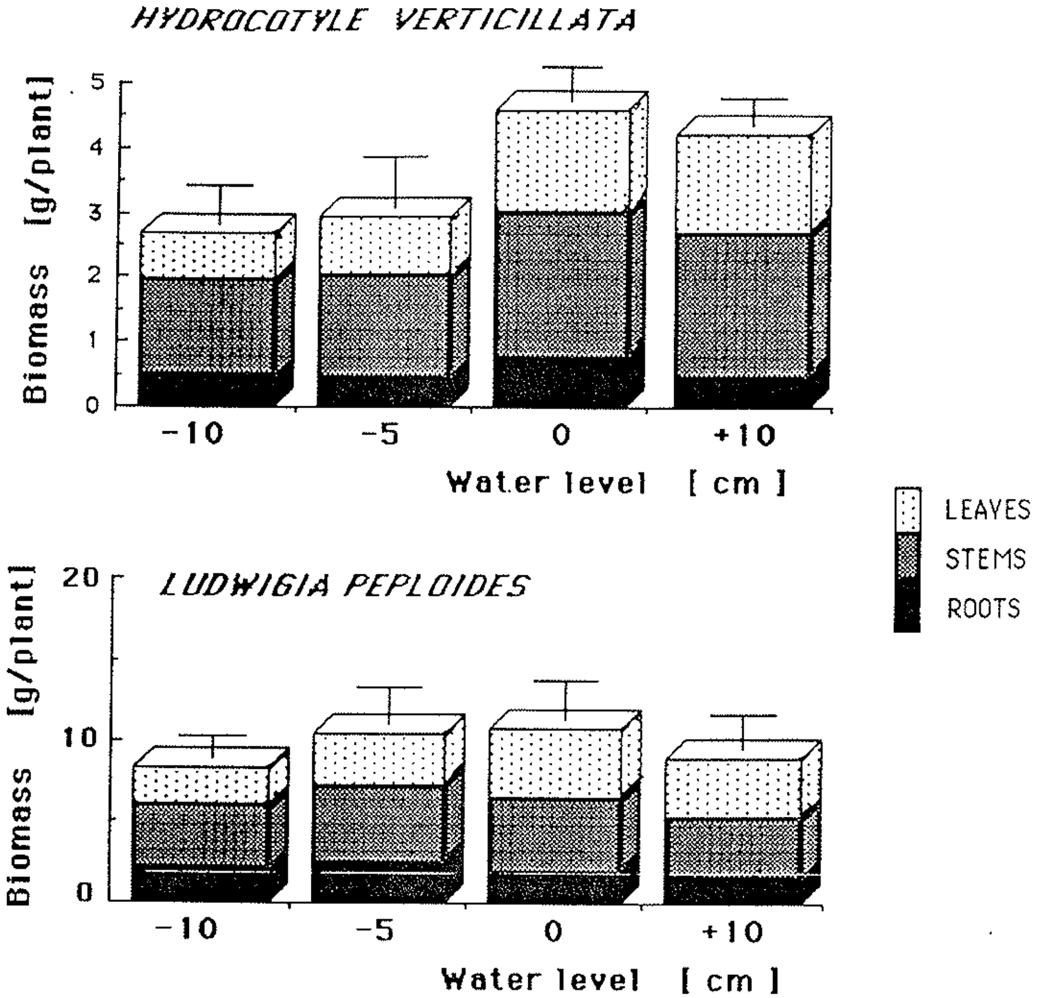


Fig. 2

Biomass (g dry wight per plant) allocation of *Hydrocotyle verticillata* and *Ludwigia peploides* grown at different water depth in a greenhouse experiment. Error bars indicate the standard deviation. Experiment duration four weeks.

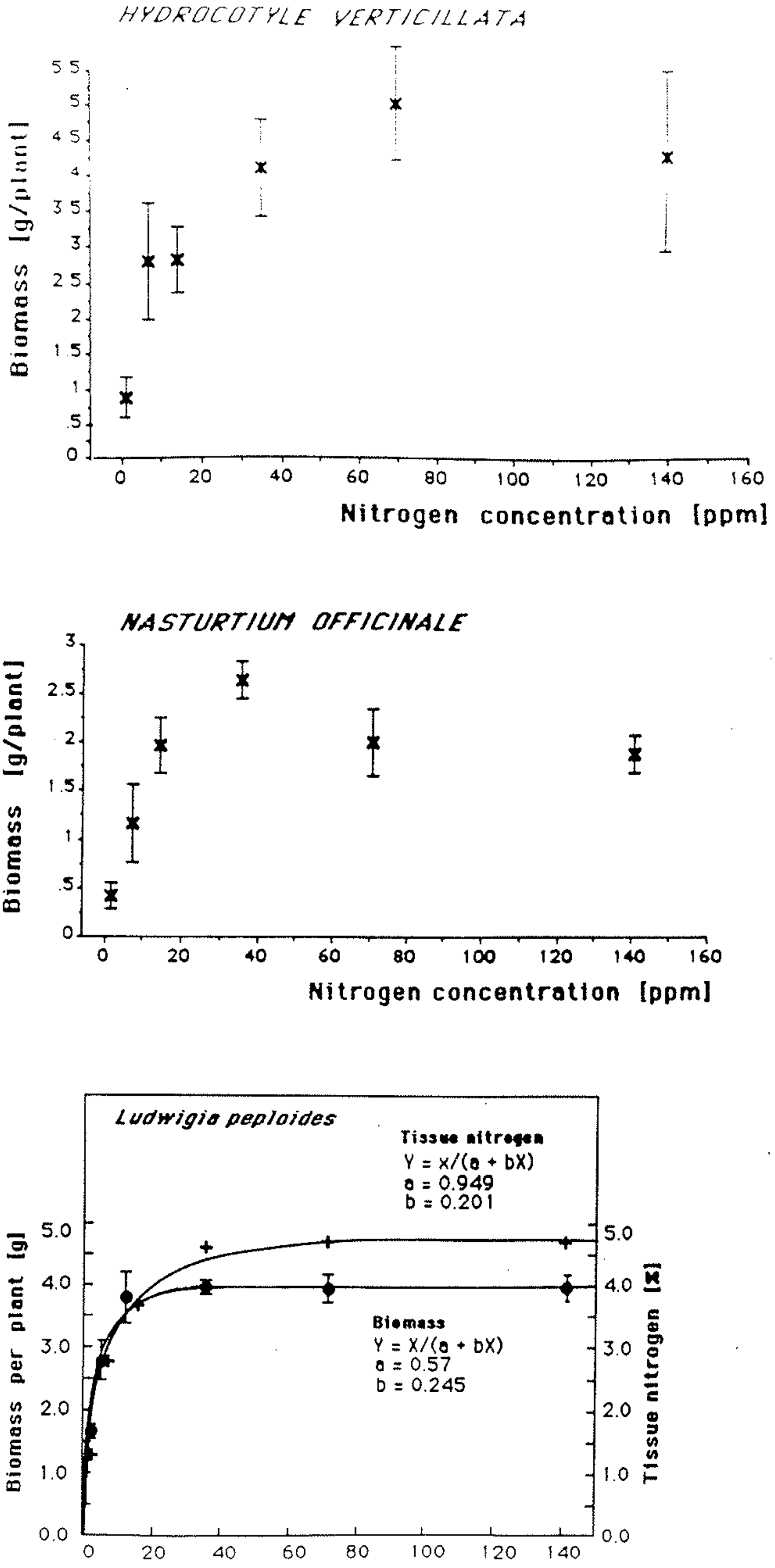


Fig. 3 Final biomass (g dry wight per plant) as a function of increasing nitrogen (NO3-N) in nutrient solution. Experiment duration 25 days.

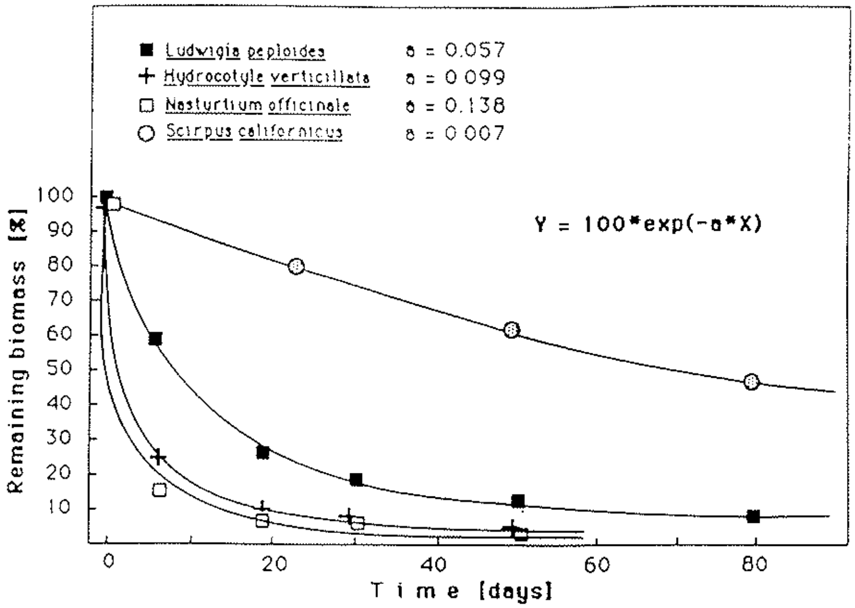


Fig. 4 Percentage of biomass remaining in litter-bags in the course of decomposition of *Ludwigia peploides, Nasturtium aquaticum, Hydrocotyle verticillata* and *Scirpus californicus*.

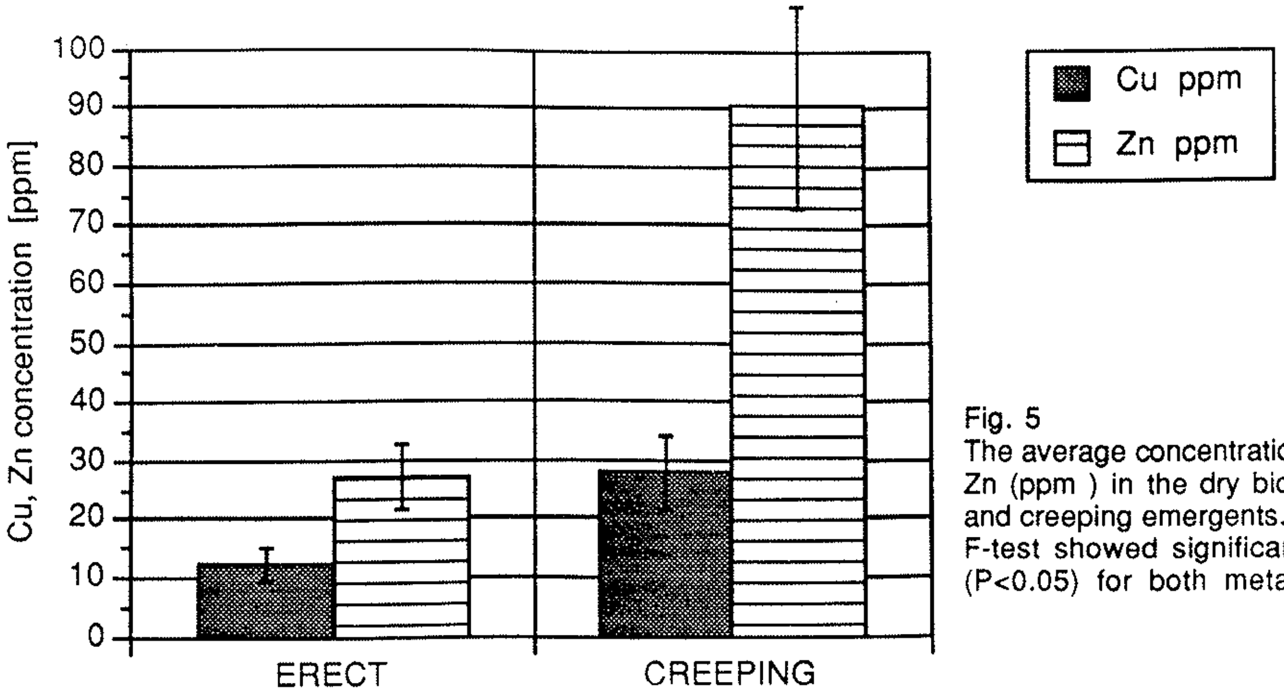


Fig. 5
The average concentrations of Cu and Zn (ppm) in the dry biomass of erect and creeping emergents. The Sheffe F-test showed significant difference ($P<0.05$) for both metals.

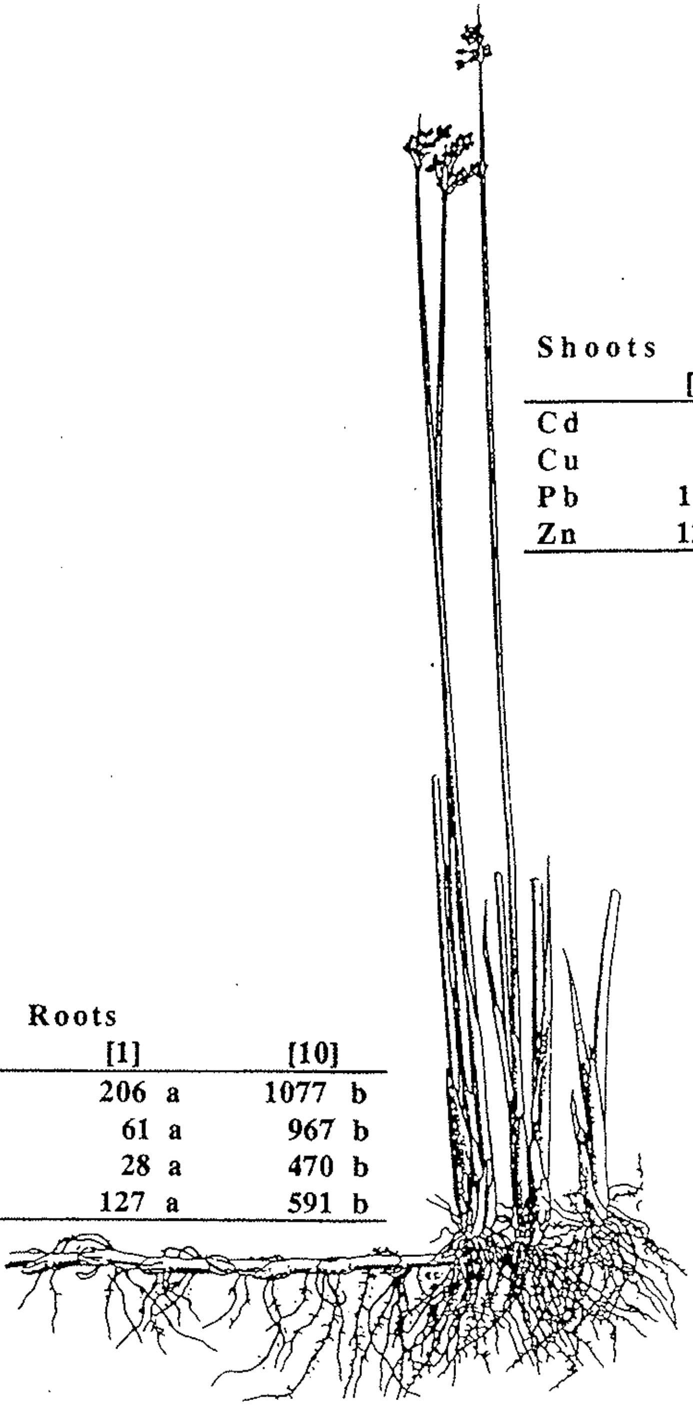


Figure 6- Average metal accumulation for various parts of *Scirpus acutus.* Small letter designates Scheffe's test of significance grouping. ANOVA was significant between treatment levels within a metal. Metal accumulation in adventitious roots was significant for Cd, Pb, and Zn, when compared to other plant parts.

Shoots

	[0]	[1]	[10]
Cd	2 a	5 ab	9 b
Cu	5 a	7 a	22 b
Pb	18 ab	4 a	24 b
Zn	12 a	23 a	48 b

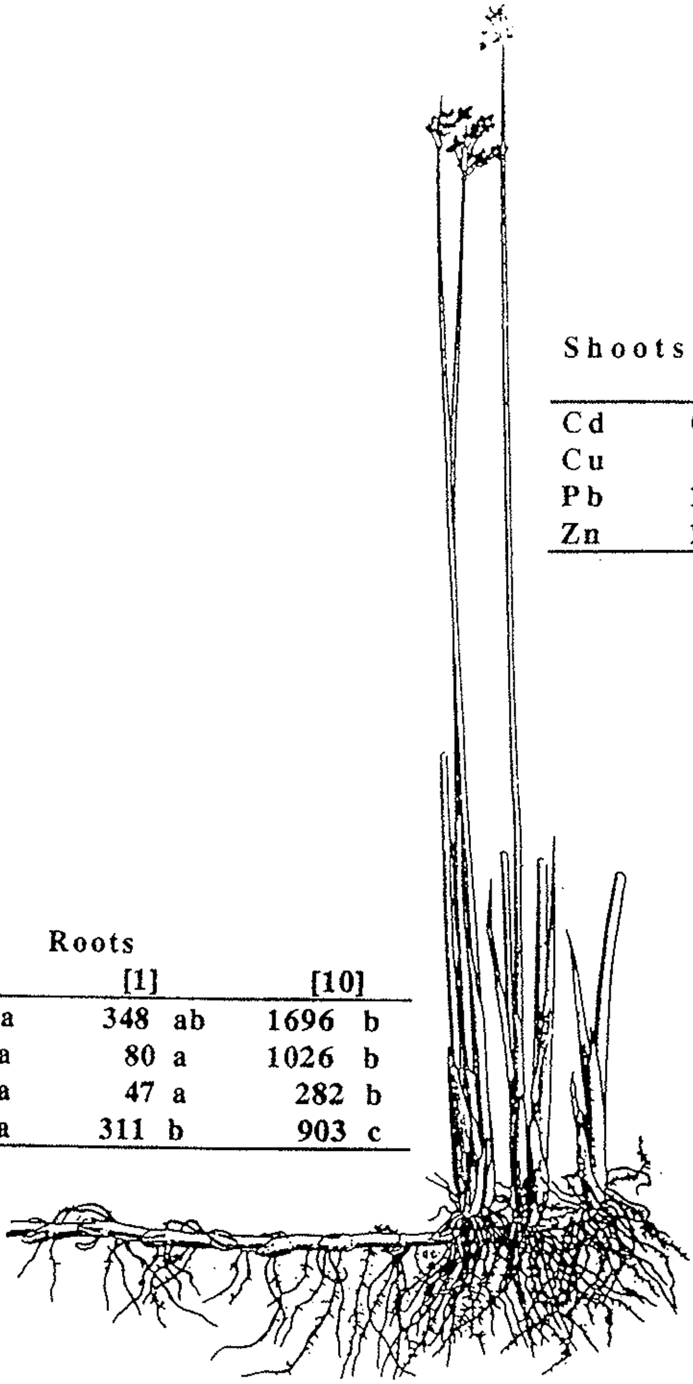
Adventitious Roots

	[0]	[1]	[10]
Cd	3 a	206 a	1077 b
Cu	18 a	61 a	967 b
Pb	30 a	28 a	470 b
Zn	37 a	127 a	591 b

Roots

	[0]	[1]	[10]
Cd	3 a	111 a	691 b
Cu	19 a	46 ab	429 b
Pb	23 a	12 a	97 b
Zn	30 a	104 a	272 b

Figure 7- Average metal accumulation for various parts of *Scirpus californicus*. Small letter designates Scheffe's test of significance grouping. ANOVA was significant between treatment levels within a metal. Metal accumulation in adventitious roots was significant for all metals when compared to other plant parts.



Shoots

	[0]	[1]	[10]
Cd	0.2 a	3 a	13 b
Cu	7 a	9 a	28 b
Pb	17 a	7 a	13 a
Zn	16 a	42 b	43 b

p=.2004

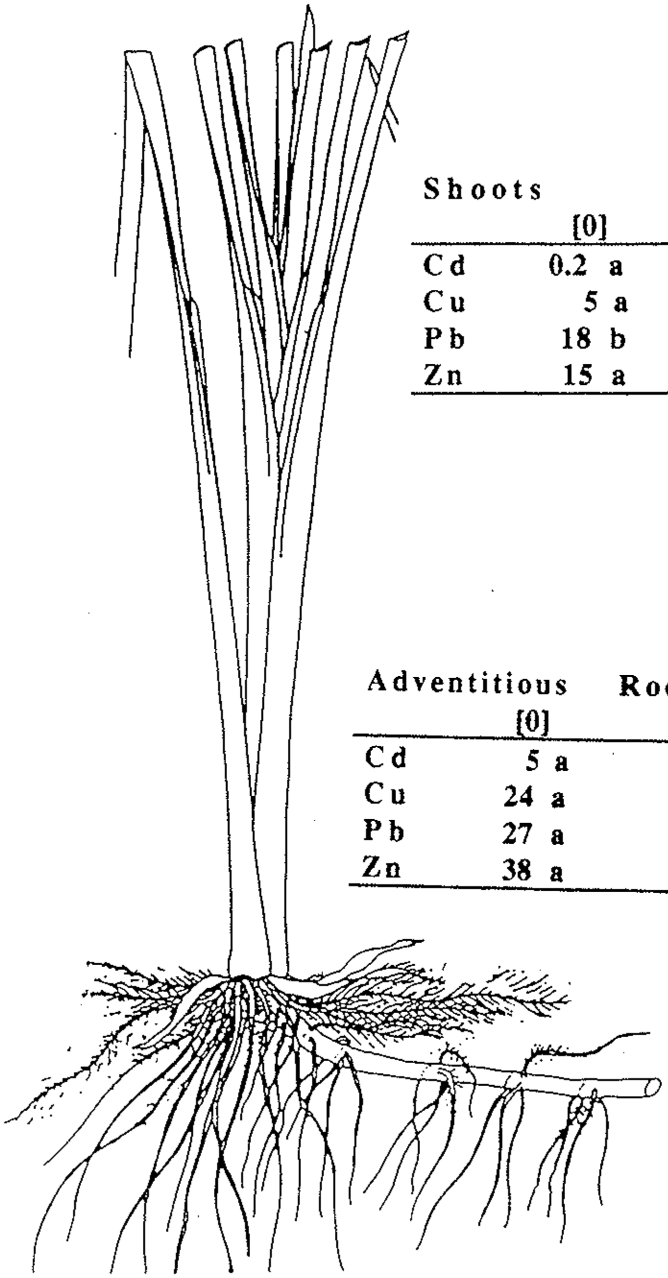
Adventitious Roots

	[0]	[1]	[10]
Cd	2 a	348 ab	1696 b
Cu	23 a	80 a	1026 b
Pb	34 a	47 a	282 b
Zn	25 a	311 b	903 c

Roots

	[0]	[1]	[10]
Cd	3 a	201 a	428 b
Cu	21 a	75 b	214 c
Pb	24 a	22 a	86 a
Zn	20 a	145 ab	250 b

Figure 8- Average metal accumulation for various parts of *Typha domingensis* . Small letter designates Scheffe's test of significance grouping. ANOVA was significant between treatment levels within a metal. Metal accumulation in adventitious roots was significant for all metals when compared to other plant parts.



Shoots

	[0]	[1]	[10]
Cd	0.2 a	3 b	8 c
Cu	5 a	13 ab	21 b
Pb	18 b	4 a	15 ab
Zn	15 a	39 ab	75 b

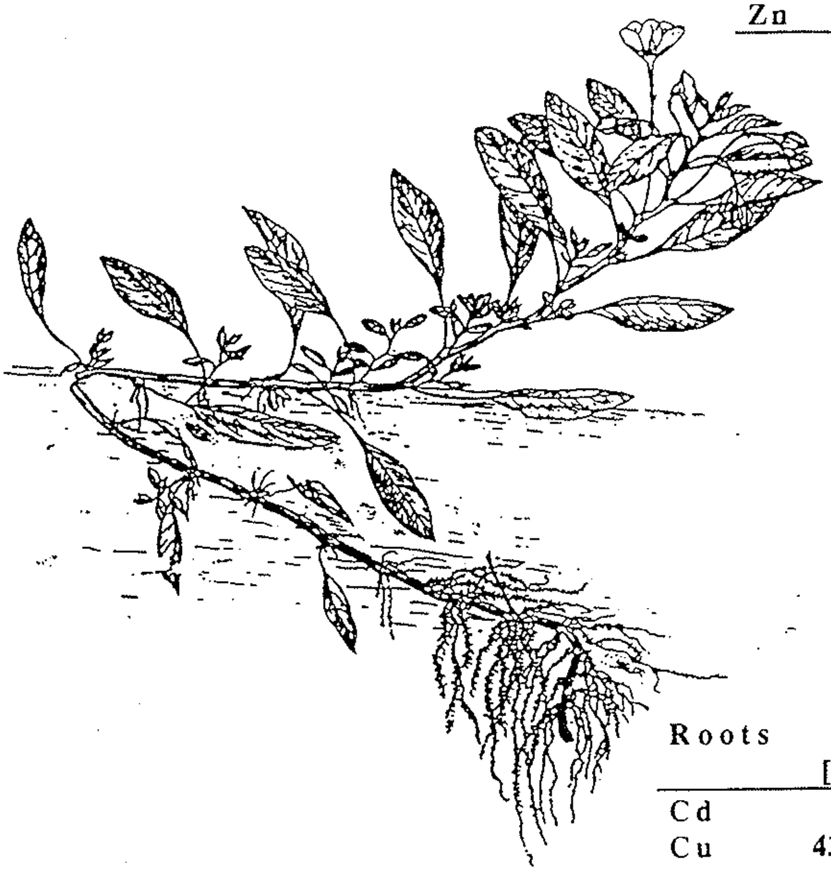
Adventitious Roots

	[0]	[1]	[10]
Cd	5 a	550 a	3150 b
Cu	24 a	126 b	1030 c
Pb	27 a	49 a	732 b
Zn	38 a	196 a	565 b

Roots

	[0]	[1]	[10]
Cd	3 a	148 ab	372 b
Cu	19 a	73 b	195 c
Pb	25 a	53 a	209 b
Zn	35 a	103 a	203 b

Figure 9- Average metal accumulation for various parts of *Ludwigia Peploides* . Small letter designates Scheffe's test of significance grouping. ANOVA was significant between treatment levels within a metal. Metal accumulation in roots was significant for Cd, Cu and Pb when compared to leaves.



Leaves

	[0]	[1]	[10]
Cd	0.2 a	9 a	269 b
Cu	14 a	34 a	717 b
Pb	19 a	27 a	248 b
Zn	27 a	113 b	255 c

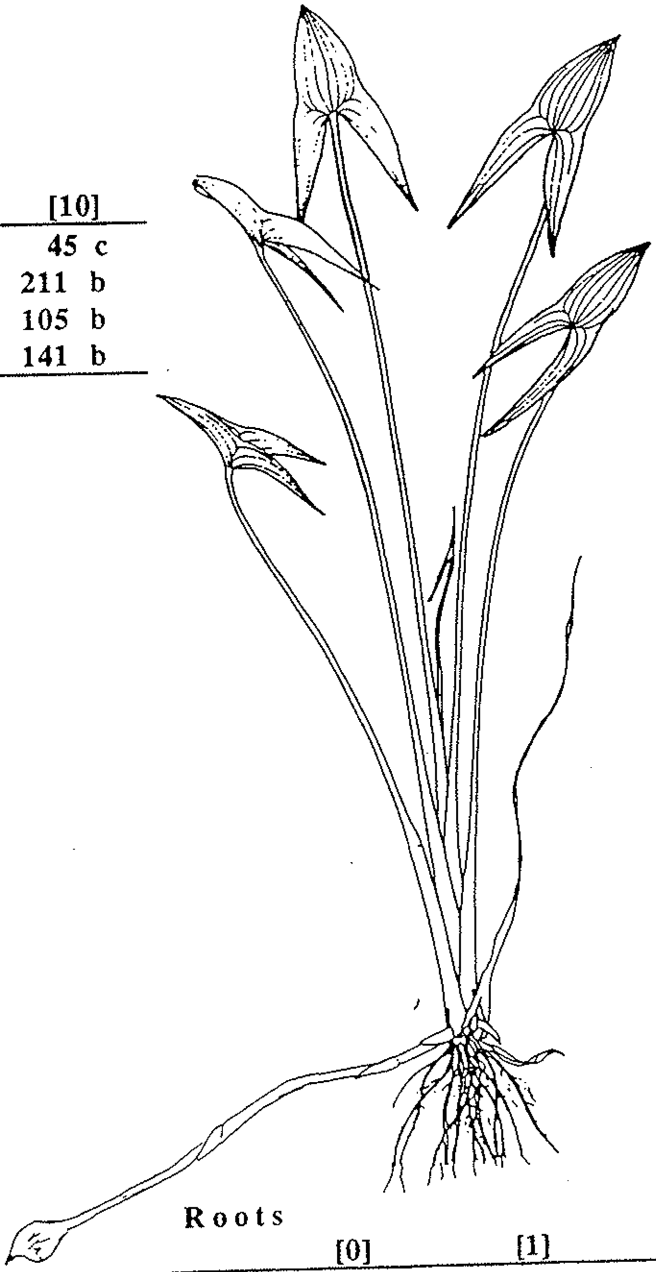
Roots

	[0]	[1]	[10]
Cd	3 a	79 a	2875 b
Cu	43 a	124 a	2945 b
Pb	38 a	92 a	1150 b
Zn	33 a	176 ab	761 b

Figure 10 - Average metal accumulation for various parts of *Sagittaria latifolia* . Small letter designates Scheffe's test of significance grouping. ANOVA was significant between treatment levels within a metal. There were no significant differences in metal accumulations between plant parts.

Leaves

	[0]	[1]	[10]
Cd	0.5 a	11 b	45 c
Cu	13 a	20 a	211 b
Pb	18 a	23 a	105 b
Zn	24 a	71 ab	141 b



Roots

	[0]	[1]	[10]
Cd	1 a	71 a	266 b
Cu	58 a	82 a	543 b
Pb	35 a	24 a	163 a
Zn	41 a	87 b	187 c

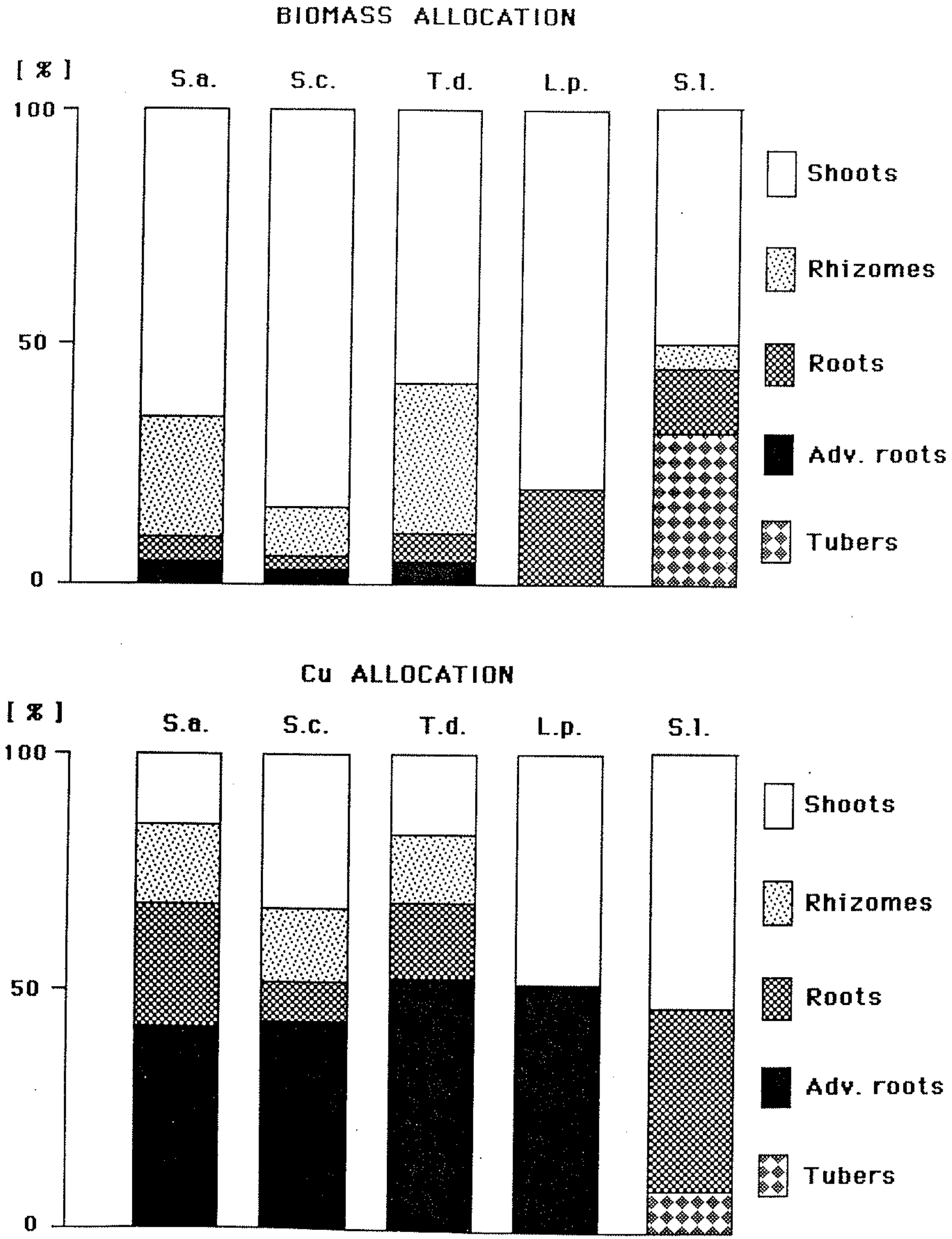
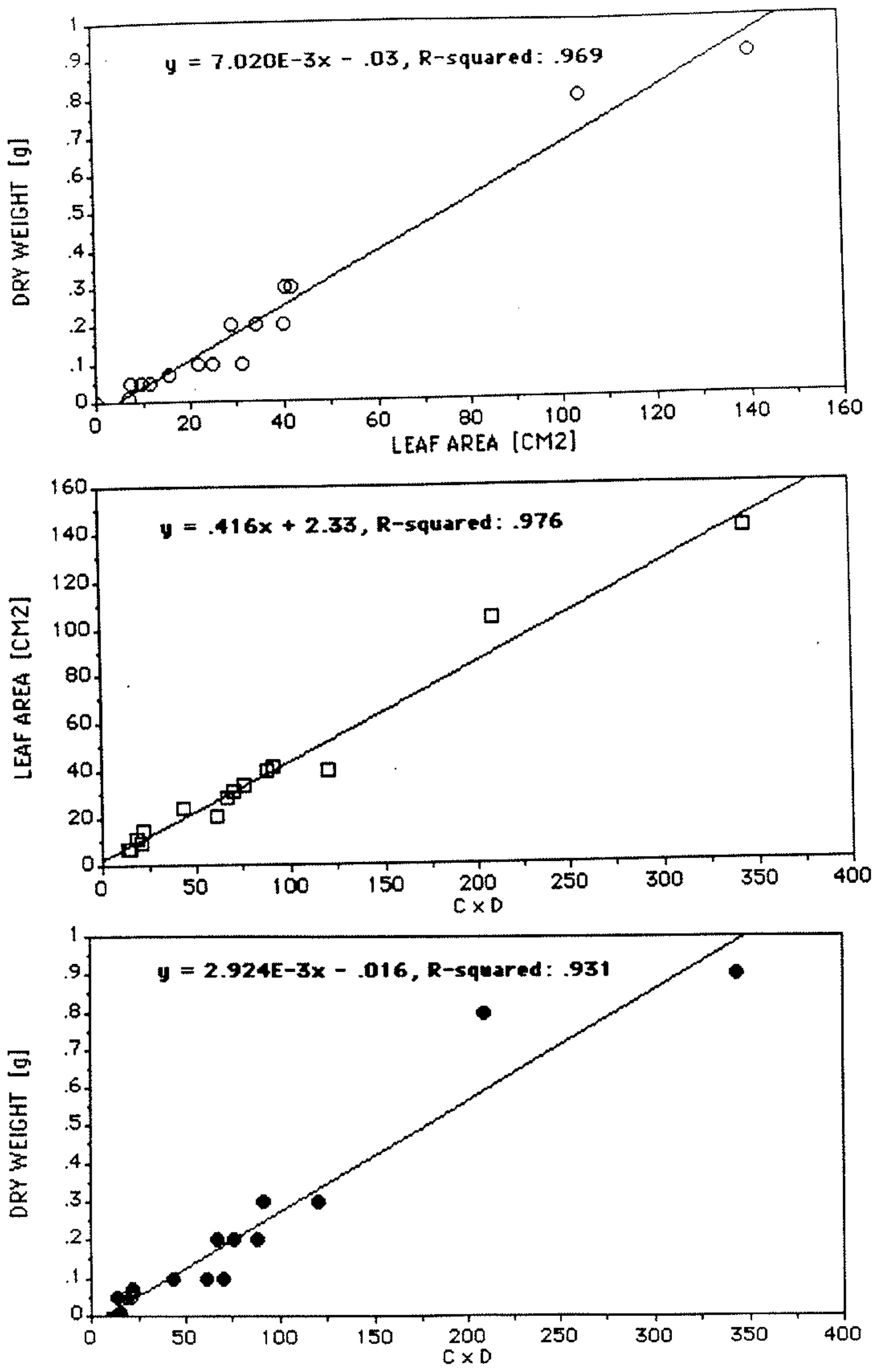


Fig. 11

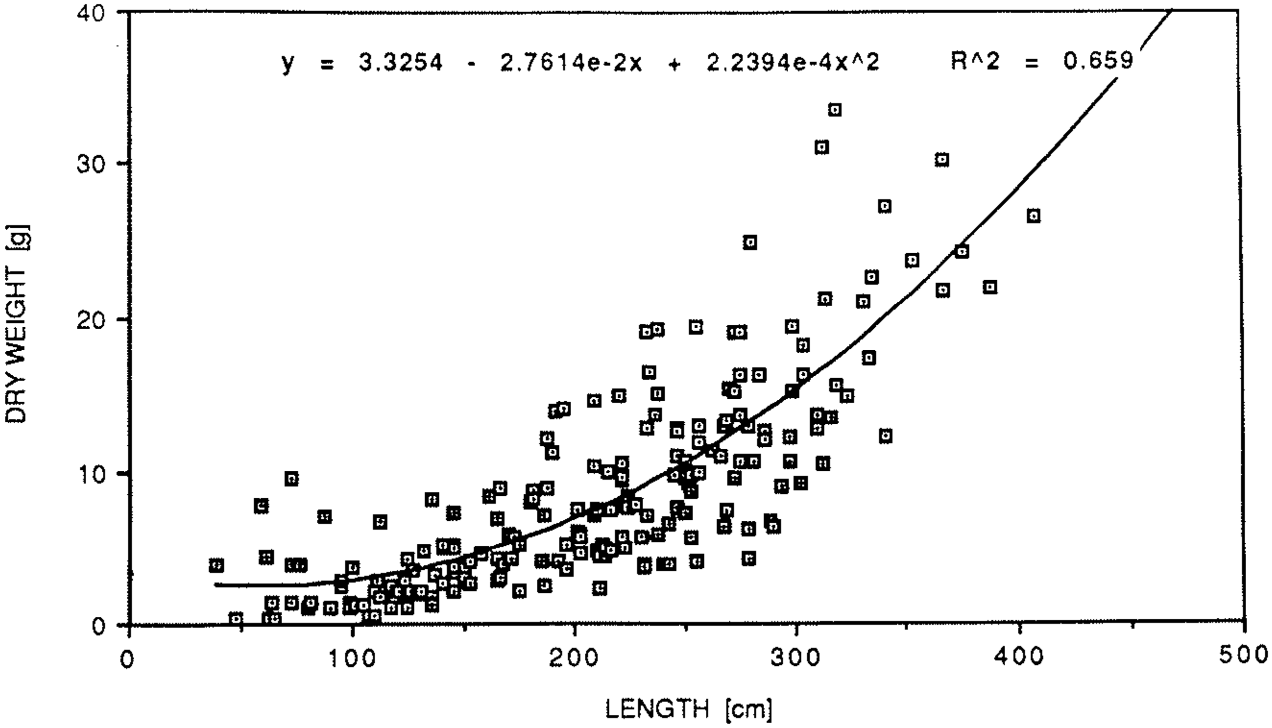
Top - The relative biomass allocation into various plant parts of the species used in the heavy metal experiment: S.a. - *Scirpus acutus*, S.c. - *Scirpus californicus*, T.d. - *Typha domingensis*, L.p. - *Ludwigia peploides*, S.l.- *Sagittaria latifolia.*

Bottom - The relative accumulation of copper into various plant parts. Heavy metal experiment, 10ppm treatment.



SAGITTARIA LATIFOLIA - CORRELATIONS

Figure 12. (a) Correlation between leaf area, as measured by leaf area meter, and dry weight. (b) Relationship between leaf area and an index calculated from leaf length (C) multiplied by leaf width (D). (c) Correlation between the CxD index and dry weight. *Sagittaria latifolia.*



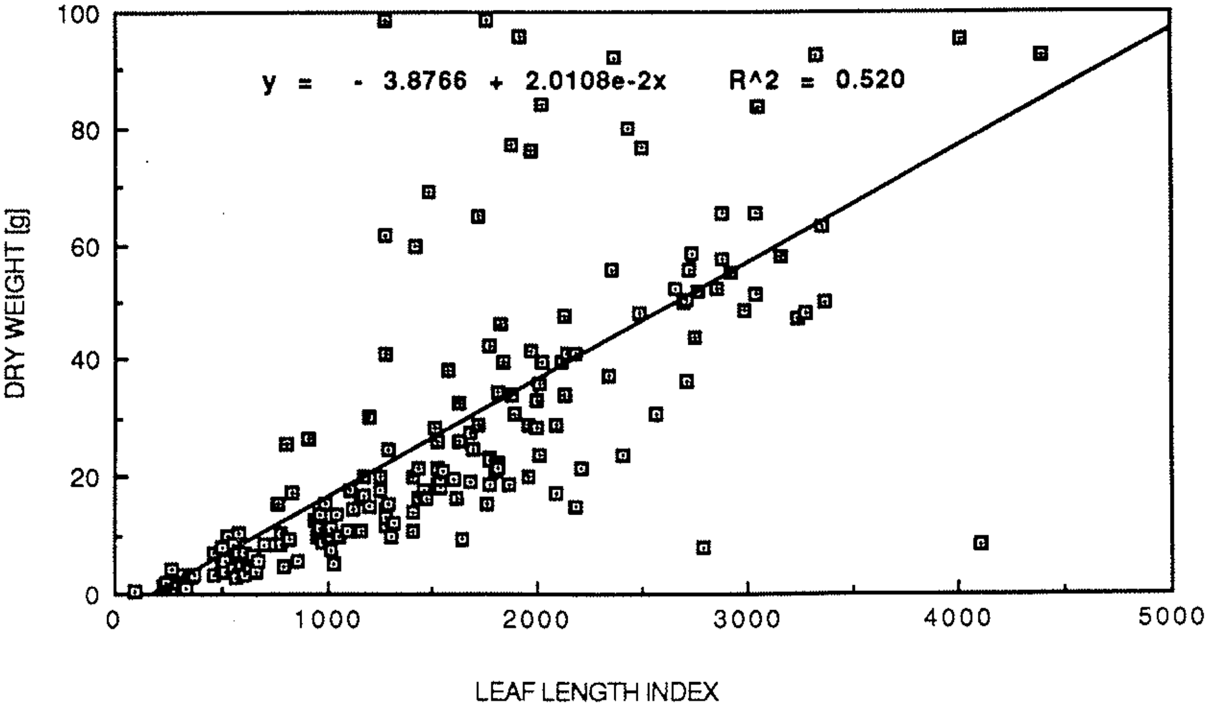


Figure 13
(a) Relationship between shoot length and corresponding biomass (g dry weight). *Scirpus acutus.*
(b) Correlation between leaf biomass (g dry weight) and leaf length index calculated as a mean length of the four longest leaves multiplied by the number of leaves. *Typha latifolia.*

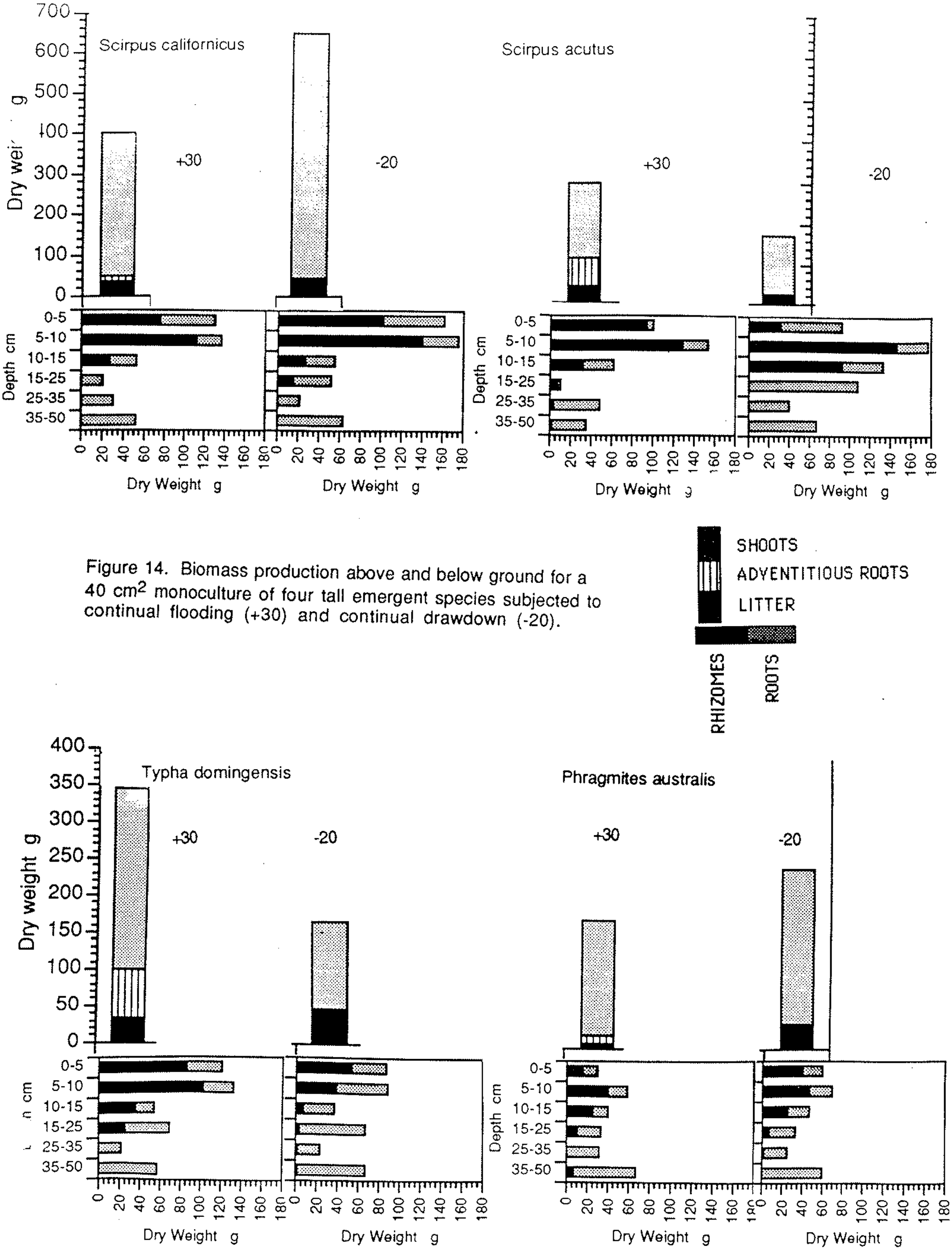


Figure 14. Biomass production above and below ground for a 40 cm^2 monoculture of four tall emergent species subjected to continual flooding (+30) and continual drawdown (-20).

Table 1

Biomass (g dry weight/m2), total plant nitrogen and carbon (%), and C:N ratio of selected species of wetland macrophytes growing in relatively undisturbed wetlands in the Central Valley of California. Plants were collected during the time of the maximum biomass development.

SPECIES		BIOMASS g/m^2	NITROGEN %	NITROGEN g/m^2	CARBON %	C:N
Scirpus californicus	av.	2235.0	1.61	35.98	41.23	26:1
	max.	3015.0	2.48	74.77	45.10	18:1
	min.	1460.0	0.89	12.99	35.40	40:1
Scirpus acutus	av.	1355.0	0.44	5.96	40.20	91:1
	max.	2150.0	0.46	9.89	41.63	90:1
	min.	560.0	0.38	2.13	38.90	100:1
Typha latifolia	av.	1500.0	0.60	9.00	41.00	68:1
	max.		0.90		42.58	47:1
	min.		0.45		39.15	87:1
Hydrocotyle verticillata	av.	544.8	3.57	19.45	36.28	10:1
	max.	671.3	4.56	30.61	38.80	13:1
	min.	300.5	2.59	7.78	28.50	8:1
Nasturtium officinale	av.	540.2	3.57	19.28	37.00	11:1
	max.	618.6	4.40	27.22	37.30	13:1
	min.	297.4	2.74	8.15	36.70	9:1
Oenanthe sarmentosa	av.	430.3	3.58	15.40	37.87	10:1
	max.	466.7	3.60	16.80	39.80	11:1
	min.	303.9	3.55	10.79	36.00	9:1
Potamogeton pectinatus	av.	298.9	2.34	6.99	30.10	13:1
	max.	514.8	3.14	16.16	36.09	15:1
	min.	96.8	1.55	1.50	20.90	11:1

	Zn ppm	Cu ppm	Pb ppm	Mo ppm	Cd ppm
COSUMNES	105	63	92	21	2.5
OCTO BASIN	95	56	61	13	2
RANCHO SOLANO	68	48	49	12	2.2
NORTH POND	96	49	59	17	2.5
WEST POND	82	45	49	13	2.4

Table 2 Concentration of heavy metals Zn, Cu, Pb, Mo, and Cd; ppm) in sediments. Shaded areas show the highest concentration.

LOCATION	Cu ppm	Zn ppm	Pb ppm
COSUMNES	11.2	20.3	0.5
CALHOUN CT.	11.4	19.9	1.3
RANCHO SOLANO	27.2	95.3	0.9
OCTO BASIN	8.2	16.4	1.2

Table 3 The average concentration of Cu, Zn and Pb (ppm) in the biomass of erect emergent macrophytes collected from the Cosumnes River Presaerve, Calhoun Slough, Rancho Solano and Octo Inn Basin. The highest concentration of each element are shaded.

Table 4 - Increase in biomass in response to treatment with metals. There were no statistical differences between the treatments and the controls.

Treatment		Biomass Increase [%]			
	S.a.	S.c.	T.d.	L.p.	S.l.
Cd	173	156	149	461	110
Cu	167	201	185	332	175
Pb	180	180	155	419	143
Zn	182	157	168	290	122
Control	225	190	242	347	120

S.a. - *Scirpus acutus*, S.c. - *Scirpus californicus*, T.d. - *Typha domingensis*
L.p. - *Ludwigia peploides*, S.l. - *Sagittaria latifolia*

Table 5 The amount of metal removed (in parenthesis) by one square meter of a species monoculture as compared to the species removing the lowest amount, indexed to one. S.a. - *Scirpus acutus*, S.c. - *Scirpus californicus*, T.d. - *Typha domingensis*, L.p. - *Ludwigia peploides*, S.l.- *Sagittaria latifolia*.

Cd	L.p. (10)	T.d (6)	S.a. (4)	S.c. (3)	S.l. (1)
Cu	L.p. (5)	S.a. (1)	S.l. (1)	T.d. (1)	S.c. (1)
Pb	L.p. (6)	T.d. (2)	S.a. (2)	S.l. (1)	S.c. (1)
Zn	L.p. (21)	S.a. (17)	S.c. (17)	T.d. (14)	S.l. (1)

PUBLISHED PAPERS

Rejmankova, E. 1992. Ecology of creeping macrophytes with special reference to *Ludwigia peploides*. Aquatic Botany 43: 283-299.

Rejmankova, E. and Rejmanek M. 1992. Size and age dependence of growth in Cyperaceae from contrasting environments. Proceedings of the 13th Annual Conference of Society of Wetland Scientists, WES Vicksburg, Mississippi.

PROFESSIONAL PRESENTATIONS

Rejmankova, E., R. A. Post, M. Hojjati and M. Herzog. 1993. Accumulation of Zn, Pb, Cd and Cu in five species of emergent macrophytes. Paper presented at the Conference on Wetland Biogeochemistry in Baton Rouge, LA, February 1993.

Rejmankova, E., R. A. Post, M. Hojjati and M. Herzog. 1993. Growth effects and accumulation of Zn, Pb, Cd and Cu in five species of emergent macrophytes. Paper presented at the ASLO & SWS Annual Meeting, Edmonton, Alberta, Canada, June 1993.

Vymazal. J., E. Rejmankova, C. B. Craft and C. Richardson. 1993. Morphometric measurements for biomass estimates of aquatic macrophytes. Paper presented at the ASLO & SWS Annual Meeting, Edmonton, Alberta, Canada, June 1993.

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