POTENTIAL COAL MINE WASTEWATER TREATMENT OPTIONS-II: EMERGENT AQUATIC PLANTS

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ABSTRACT

This report concerns itself with the literature describing ecology and physiology of emergent aquatic plants, as well as a small scale field experiment using cattails (Typha latifolia). The study of emergent plants is the second phase of a program investigating the feasibility of options for treating coal mine wastewater to remove nitrogen. An earlier report has been completed which reviews the potential treatment of these waters using aquatic plants and spray irrigation. The earlier report also presents the results of a laboratory experiment where duckweed (Lemna and Spirodela), a floating aquatic plant, was used to treat coal mine waste water. Results of the study showed high potential for the removal of nitrogen from these wastewaters.

The literature review identifies the important species, and includes a description of emergent aquatic plant life history, growth, mineral nutrition and responses to environmental stress. The information that was collected indicates that the growth form of many emergent species lends itself readily to their use in managed wetland systems. Species are available which can tolerate a broad range of environmental conditions, including elevated concentrations of toxic chemicals such as heavy metals and biocides not expected in conjunction with coal mine waste waters. The use of a wetland as a reliable sink for the removal of minerals entails management of the system by such means as controlling water depth and retention time, and possibly harvesting the plants. Only certain elements,

such as N, P, Mn, Na, Zn, are removable via harvesting. The harvested biomass has potential uses as fodder, mulch, and fiber for paper and crafts, but must be appropriately disposed of if it is excessively contaminated.

Nitrogen is removed through plant uptake and denitrification, and phosphorus through plant uptake and physical-chemical precipitation. Most other elements, including toxics are bound in the root zone; and remain there as long as soil physical-chemical conditions (e.g. pH, conductivity and oxygen concentrations) remain within specific ranges.

The experiment using cattails establishes that this species can be readily transplanted and that static-water channels planted with Typha are capable of reducing nitrate concentrations by 99.8 percent, from 12 mg N/l to 0.028 mg N/l, within a one week period. The majority of the nitrate, 96.8%, can be removed within one day. Soluble phosphorus concentrations in channels planted with cattails were over 60% lower than in channels without cattails.

It is evident from the results of this study that emergent plants have a demonstrated potential for use in water quality improvement. The further development of aquatic plant applications would benefit from pilot scale field research concentrating on system hydraulics, optimization of harvesting regimes, wastewater-specific species combinations, utilization or disposal of the harvested vegetation, and economic evaluations.

RESUMÉ

Ce rapport passe en revue la littérature sur l'écologie et la physiologie des plantes aquatiques émergentes; il traite également d'une expérience à petite échelle sur le terrain, utilisant des quenouilles (Typha latifolia). L'étude des plantes émergentes est la seconde phase d'un programme évaluant la faisibilité de méthodes d'enlèvement de l'azote des effluents de mines de charbon. Un rapport antérieur examine les possibilités de traitement de ces effluents par les plantes aquatiques et l'irrigation par giclage. Le rapport précédent présente également les résultats d'une expérience de laboratoire dans laquelle deux variétés de plantes flottantes (Lemna et Spirodela), étaient utilisées pour le traitement d'un effluent de mine de charbon.

La revue bibliographique identifie les espèces importantes et comprend une description du cycle vital des plantes émergentes, de leur croissance, leurs besoins en éléments nutritifs minéraux et leur réponse à un stress environnemental. L'information rassemblée indique que le type de croissance de plusieurs espèces de plantes émergentes se prête facilement à leur utilisation dans un système marécageux aménagé. Il existe des espèces tolérantes à un vaste ensemble de conditions environnementales, incluant des concentrations élevées de substances toxiques, tels que les métaux lourds et des biocides dont la présence n'est pas anticipée dans les effluents de mines de charbon. L'utilisation fiable de marécages pour l'enlèvement de minéraux implique la gestion du système

par des moyens tels que le contrôle de la profondeur de l'eau et du temps de rétention, et possiblement la récolte des plantes. Seulement certains éléments tels que N, P, Mn, Na, Zn peuvent être enlevés lors de la récolte. La biomasse récoltée a un potentiel d'utilisation comme nourriture pour le bétail, comme stabilisateur de sol ou comme fibre pour la fabrication du papier; on doit cependant en disposer de façon apropriée si sa contamination est excessive.

L'azote est enlevée par le biais de son absorption dans la tige et les feuilles de la plante et par la denitrification; le phosphore l'est par absorption et précipitation physique-chimique. La plupart des autres éléments, incluant les substances toxiques, sont liés dans la zone des racines; ils y demeurent tant que les propriétés physico-chimiques du sol (i.e. pH, conductivité et contenu en oxygène) restent à l'intérieur de limites spécifiques.

L'expérience avec les quenouilles démontre que cette espèce peut être facilement transplantée et que des canaux d'eau stagnante plantés de <u>Typha</u> sont capable d'une réduction de 99.8 pourcent des concentrations de nitrate, soit de 12 mg N/L à 0.28 mg N/L, et ce en une semaine. Les concentrations de phosphore soluble dans les canaux plantés de quenouilles étaient plus de 60 pourcent inférieures à celles des canaux sans quenouilles.

Il est évident à partir des résultants de cette étude que les plantes émergentes ont démontré un potentiel pour l'amélioration de la qualité de l'eau. Le développement plus poussé de l'utilisation des plantes aquatiques bénéficierait de recherches à l'échelle pilote portant sur les systèmes hydrauliques, sur l'optimisation des cycles de récolte, sur des combinaisons d'espèces spécifiques à certains types d'eau usée, sur le recyclage ou la disposition des plants récoltées et sur l'aspect économique.

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1.0 INTRODUCTION

1.1 Background

Natural and constructed wetlands are recognized to be effective components of water treatment systems. The ability of many aquatic plants or macrophytes to accelerate the removal of dissolved and suspended substances from a variety of wastewaters has been shown (Tourbier and Pierson 1976; Environmental Protection Agency 1979). The dense vegetative growth form, and the plants' minimum requirement for care and attention, make the concept attractive as a low-cost option for water pollution control.

This report has been prepared as the second phase of a research program investigating the use of aquatic plants for wastewater treatment in the coal mining industry. The earlier study investigated the general feasibility of using aquatic plants to remove nitrogen and specifically with an experimental trial using duckweed (Norecol 1986). A literature review pertaining to emergent aquatic plants and an experimental study using cattails are presented in the present report. The scope is limited primarily to the larger rooted emergent macrophyte species that have been identified as being useful in water treatment. The report complements previous laboratory research (Norecol 1986) on the use of floating macrophyte species (the duckweeds, Lemnaceae), and is intended as a contribution to the broadening Canadian knowledge base on the potential utilization of aquatic vegetation in wastewater treatment and resource recovery. This initial work confirmed the potential for the use of aquatic plants to treat coal mine wastewaters to remove nutrients. However, it was evident that more detailed information was required on the physiology and ecology of certain plants, mineral and nutrient storage locations and other requirements.

1.2 Objectives

The objectives of the work were to:

- examine in detail the published information available on the physiology and ecology of emergent aquatic plants, within the context of their utilization in coal mine wastewater treatment;
- conduct a laboratory scale field experiment using cattail (Typha latifolia) to remove nitrate from a synthetic coal mine wastewater;
- evaluate the information gathered in the review of emergent plant physiology and ecology along with the cattail experimental results and relate this information to the use of emergent plants to treat coal mine waste water; and
- determine the feasibility of treating coal mine waste water including additional research needs based on the first two phases of the study, which might best contribute to development of aquatic plant or wetland systems as a low-cost option for water treatment at operating coal mines.

2.0 ECOLOGY OF EMERGENT MACROPHYTES IN RELATION TO THEIR USE IN WATER TREATMENT: A LITERATURE REVIEW.

2.1 Introduction

The literature review is subdivided into four main sections: a general description of emergent macrophytes, growth and mineral nutrition, responses to environmental stress, and a discussion of implications for coal mine wastewater treatment. For the reader's convenience, a species glossary is also provided in Appendix 1. The reader is referred to the appropriate section of the previous review (Norecol 1986) for specific examples of emergent macrophyte use in wastewater treatment.

An attempt has been made here to emphasize aspects of the ecology and physiology of emergent species which are of demonstrated or potential importance in the design, management and/or treatment effectiveness of a wetland system.

2.2 Description of Emergent Macrophytes

2.2.1 Overview

Emergent macrophytes grow in nearly monospecific stands in areas where the water table is at or above ground level. Plant size can vary between species from 0.3 to >2.5 m above ground level. New populations begin from seed, whereas existing stands grow and are maintained primarily through vegetative reproduction. Thus, most plants within a stand will be genetically identical clones. Genetic differentiation is more likely to be found between populations from different geographic locations. Some species, such as the cattails and rushes, are aggressive colonizers of newly created flooded habitats.

The plants are perennial, though the above-ground biomass may die back after the growing season. The rhizome or rootstock provides the nutrient reserves used for initiating vegetative growth in the spring. Flowering, which does not necessarily occur in every plant within a population, takes place during the summer. Seeds are dispersed by wind, water and wildlife.

2.2.2 External anatomy

The terminology used in describing aquatic plants is often confusing, due to the diversity of plant forms and of scientific backgrounds of the investigators. This section provides a generalized description of the morphology and life history of emergent macrophytes, defining terms as they are used in this review. The information in this section originates from the publications of Weldon et al. (1973), Morton (1974), Bayly and O'Neill (1972), and Dickerman and Wetzel (1985).

The main emergent macrophyte species which have been identified for potential use in water treatment are listed in Table 2-1. All of the identified species share above- and below-ground morphological features. The above-ground parts are generally long, slender and

TABLE 2-1

EMERGENT AQUATIC PLANTS
OF POTENTIAL USE IN WATER TREATMENT

COMMON NAME	SCIENTIFIC NAME
Cattail	_Typha_ _sp_.
Giant reed	_Phragmites_ _sp_.
Bulrush	_Scirpus_ _sp_. _Schoenoplectus_ _sp_.
Rush	_Juncus_ _sp_.
Sedge	_Carex_ _sp_. _Cyperus_ _sp_.

unbranched, and emerge above the water level for most (if not all) of their length. In many species, such as the bulrushes, rushes and sedges, there is no clear distinction between "stem" and "leaf". However, cattails show distinct leaves and no real stem, while the giant reed has a true stem with leaves. Generally speaking, the stems or stem-like plant parts that are circular in cross section are known as "culms". Flowers and fruiting bodies are borne either on specialized "spikes", as in the cattails, or as branches (e.g. rushes and sedges) or elongations of a culm (e.g. bulrushes). The meristem (zone from which leaf or culm cell production takes place) can be either apical (at the tip of the stem, as in Phragmites), to basal (at the base of the plant, as in cattails, bulrushes and sedges).The location of the meristem on the shoot is important in relation to multiple harvests.

The below-ground portions of the plants consist of the larger rootstock or rhizome and the smaller roots. The rhizome functions primarily as a storage organ, while the roots are involved in both nutrient uptake and anchoring. Vegetative reproduction occurs from buds on the rhizome, each daughter plant being a clone or "ramet" of the parent plant. The horizontally oriented rhizomes grow laterally at rates which vary with species. The ramets may be produced in clusters or "stools" (e.g. Juncus, Pharagmites) or in more evenly spaced single shoots (e.g. Typha). Rhizomes are not necessarily always found in emergent species, as for example in the native B.C. wool grass, Scirpus cyperinus (Taylor 1983).

2.2.3 Life history

Most species are perennial, maintaining a viable below-ground biomass during the winter. Flowering takes place in summer, and pollination is effected by wind and insects. The plants are generally dioecious (having male and female flowers on the same plant), but asexual budding is the predominant mode of reproduction. The seeds are either buoyant or sinking, and are dispersed by wind, water movement and wildlife.

The onset of flowering has been sparsely studied in aquatic vegetation (Sculthorpe 1967, Hutchinson 1975). The primary factors causing flowering are thought to include photoperiod, temperature and nutrition. Warm temperatures and long days are thought to favour the photosynthetic rates which will allow for the maturation of reproductive organs.

While the foregoing provides an overview of the generalized plant form, detailed descriptions of the life history of cattail and giant reed are summarized below.

Typha (cattail) is described by Dickerman and Wetzel (1985) as a rhizomatous perennial that forms dense, nearly monospecific stands. Though seedlings are important in the initial phase of site colonization, the maintenance of a mature stand is achieved by vigorous vegetative growth. The shoots arise from the apices of lateral rhizomes, and generally die back at the end of the growing season. The shoot is composed of up to 16 leaves (the number differing between species), and can exceed 2.5 m in height (Morton 1974). The flower is in the form of an apical spike. Carbohydrate reserves in the rhizome support the rapid development of leaves in the early spring. Hence, maximum leaf area is available when conditions are most favourable for high photoshythetic rates.

A description of the life history of cattails has been provided by Yeo (1964, in Hutchinson 1975). He presented a schematic plan of the rhizome development showing that up to 10 lateral rhizomes may develop from a single node in the parent rhizome.

Phragmites communis has been described as a system of relatively deep, long-lived rhizomes from which stiff annual shoots arise (Hurlimann, 1951 in Bayly and O'Neill 1972). Shoot heights of up to 4 m have been reported (Bjork 1967, in Hutchinson 1975). Each year the rhizome advances a short distance before turning upwards; another bud is formed where a shoot will arise. Branching sometimes occurs behind the horizontally growing apex producing additional annual bud sites. The main aerial shoot from the terminal bud dies back in the fall and a number of lateral buds are formed as a stool at its base. New buds form in the stool each spring over about six generations, after which the stool no longer produces shoot forming buds. Each shoot consists of a stiff stem with an apical meristem and distinct leaves. Flowers develop from the stem apex, in the form of a plume-like pinacle. Seeds of P. australis have been found to germinate only in unflooded soils (Spence 1964, in Hutchinson 1975).

The aforementioned two species are examples of macrophytes exhibiting basal and apical growth, and separate and attached fruiting bodies. Most other emergent plants of interest for water treatment can be categorized accordingly.

2.3 Growth and Mineral Nutrition

2.3.1 Plant growth

The variation in plant size between species is reflected in the number of plants and in the biomass that can be measured on an areal basis. The smaller species therefore, such as some rushes and sedges, show a higher density of stems per unit area and a lower dry matter mass than the larger species such as the giant reed, bulrushes and cattails.

The amount of biomass produced in any stand depends on the soil and water fertility, the impact of browsing animals, plant genetics, and the stability of the environment. Changing water depths, for example, may in some instances alter the interspecific dominance relationships, suppressing production of one species while favouring that of another. In general, shoot biomass increases rapidly during the first half of the growing season, and then decreases or ceases all together, with subsequent growth being directed to seed production and storage in the rhizome. The below-ground biomass can represent less than 10% to more than 70% of the total biomass within a stand. Dry matter productivities can range from <1 to 6 kg dry matter/m^2/yr. Conversely, loss of dead biomass through physical and microbiological decay can exhibit a similar range of values. An equation for predicting shoot biomass as a function of shoot height and leaf number is available for *Typha latifolia* (Dickerman and Wetzel 1985).

Shoot production in *Typha latifolia* has been studied by Boyd and Hess (1970) at over 20 different sites in the southeastern United States. Biomass ranged between 428 - 2252 g/m^2, and was highly correlated with soil and tissue phosphorus (P) content. Water depth (5 to 76 cm) had no effect on the standing crop. While nutrients in the soil and water correlated with the standing crop, other factors such as browsing and genetics, were also considered to be important. The use of total dissolved phosphorus (TDP) as a measure of available P was recommended. Regression equations were derived for defining nutrient mass (g/m^2) as a function of standing crop, and tissue mineral content as a function of tissue N content.

Growth (shoot biomass) of cattails in a South Carolina reservoir was found to increase rapidly until mid June and then level off (Sharitz et al. 1984). *Typha latifolia* growth in south-central Michigan was found to take place in three annual pulses of ramet (clone) emergence (Dickerman and Wetzel 1985). The first shoot cohort emerged in early spring, followed by a second in mid summer and a third in late summer to early autumn. At the end of the growing season the first cohort died completely, while the second and third exhibited about 80% and <25% mortality, and there was no wintertime mortality of immature shoots. Mean shoot densities of the successive cohorts, respectively, were 22, 2.1 to 12.6 and 10.4 to 24.1 new shoots/m^2. Overall average shoot densities ranging from 11.2 to 43.9 stems/m^2 were recorded. It was determined that shoot density does not regulate ramet (clone) populations in mature cattail stands. A non linear regression equation (r=0.92, n=1455) describing shoot biomass as a function of shoot green height (i.e. height of tallest live leaf) and leaf number was derived:

$$Y = 0.00014 \, X^{1.79} \, Z^{1.13}$$

where Y is the shoot biomass in grams ash-free dry weight, X is the green leaf height, and Z is the number of leaves.

Yeo (1964, in Hutchinson 1975) studied the development of a single <u>Typha latifolia</u> seedling over a one year period. As with the work of Dickerman and Wetzel (1985), three ramet cohorts were reported: 26 emergent shoots having a height >46 cm, 29 shoots of <46 cm, and 37 non-emergent shoots. (Details on timing and environmental conditions were not available.)

Barko and Smart (1978) studied the growth and biomass distribution of <u>Scirpus validus</u> and <u>Cyperus esculentus</u> on sand, silty clay and clay under laboratory conditions. Growth of both species was greatest on silty clay, followed by clay and sand. Shoot density ranged from 231 to 947 stems/m^2 for <u>Scirpus</u> and from 191 to 2983 stems/m^2 for <u>Cyperus</u>. Finer textured soils were correlated with increased plant growth. The ratio of below- to above-ground biomass was inversely related to plant growth. Nitrogen (N) was considered to be more limiting than P, as P was readily adsorbed in all three test soils; (no distinction was made between available and non-available P).

Productivities of seven marsh plant species were measured by Hopkinson et al. (1978) in coastal Louisiana. The species included *Juncus roemerianus*, *Phragmites communis*, *Sagitaria falcata*, *Spartina alterniflora*, *Spartina cynosuroides*, *Spartina patens*, and *Distichlis spicata*. In five of the species, peak biomass (standing crop) was recorded in summer, the range for all species being 648 to 1376 g/m^2 (live biomass). The ratio of annual mean live to dead biomass ranged from 0.21 (*Phragmites communis*) to 0.91 (*Juncus roemerianus*). Plant gross productivities ranged from 1501 to 6043 $g/m^2/yr$ while disappearance rates (i.e. biomass loss through fragmentation and microbial decomposition) ranged from 1572 to 5138 $g/m^2/yr$. Of interest in the context of water treatment was the observation by these authors that *Phragmites communis* and *Spartina cynosuroides* had the lowest loss rates of dead material (and by inference the lowest nutrient recycling rate).

Photosynthesis and respiration in *Scirpus acutus* have been studied in situ in Michigan by Filbin and Hough (1982). The maximum carbon (C) fixation rate of 0.59 mg C/g·h was measured in June, and decreased thereafter. No correlation was found between net productivity and temperature or light. The authors note that the evolution of carbon dioxide (CO_2) from aerobic respiration in the rhizosphere may increase the release of CO_2 via the leaves. The fate of light in a stand of <u>Phragmites communis</u> was investigated by Ondok (1973) in Czechoslovakia. Between 87.4 and 94.3% of the direct and indirect radiation falling on the mature stand was absorbed, and 5.1 - 10.6% was reflected.

2.3.2 Mineral nutrition and tissue composition

<u>Mineral nutrition</u>

The availability of minerals for uptake depends on such factors as soil and water pH, conductivity, organic matter content and the relative concentrations of the various elements in the soil and water. Metals may be taken up more readily under oligotrophic than under eutrophic conditions. Temperature can have an overriding effect on mineral uptake relative to other factors; the uptake rate increasing with increasing temperatures (within a species' tolerance range).

Emergent vegetation can concentrate various elements in the below- or above-ground tissues. Though there are differences between species, certain metals are translocated no further than the root-zone (e.g. Cu, Ni, Pb, Cd), while others (e.g. Zn, Na, Mn) are accumulated in the shoot. The reduced mobility of certain elements beyond the root zone may be related to chelation in the root cell walls and to the root endodermis acting as a barrier. The increased mobility of others may be associated with the pumping effect of transpiration through the leaf stomata. Relative accessibility of elements to the xylem or phloem of the tissue also may affect the mobility of certain elements. Those elements which exist in nature as oxyanions (e.g. As, Mo, Se) are readily translocated to the shoots. As with P, other elements such as Cu, Ni and Co in the water or soil, are not 100% available to the plants. The optimum N:P ratio in wastewater to be treated by emergent vegetation systems is between 10:1 and 15:1 in order to maximize the removal of both N and P from the water.

Taylor and Crowder (1983) have summarized the mineral nutrition of Typha latifolia as follows:

> "Generally spring growth is characterized by mobilization of carbon reserves and mineral nutrients from the soil-sediment. At this time, accumulation of mineral nutrients by aerial tissues exceed that required to sustain the current growth. As the aerial tissue becomes self-supporting, mobilization from the rhizome gives way to translocation of carbon compounds and mineral nutrients from leaf tissue to the developing reproductive shoot and once again back to the rhizomes (or dormant overwintering buds) for winter storage."

Emergent plants obtain nutrients from the soil and water in which they grow. The plants can grow vigorously in hydroponic culture as well, as reported for Typha orientalis (Cary and Weerts 1984) and Phragmites communis (Wolverton 1982). Phragmites communis exhibits water roots that do not grow in the soil and which respond differently to certain environmental conditions than do soil roots (Merezhko et al. 1979).

The availability of minerals to the roots is dependent on such factors as soil pH, conductivity, organic matter content, and the relative concentrations of the various elements in the soil and interstitial water.

In a study comparing the mineral nutrition of Phragmites communis growing in oligotrophic and eutrophic environments in Denmark, Schierup and Larsen (1981) found that metals were taken up more readily under oligotrophic conditions despite lower ambient mineral concentrations at the latter site. Below-ground tissue concentrated Cu, Pb and Cd, while Zn was largely concentrated in the upper leaves and stem. The translocation of Zn to the upper plant was thought to be associated with the plant hormone IAA (indole acetic acid), of which this metal is an important component. The reduced translocation of Cu, Pb and Cd beyond the root zone may be related to a combination of chelation in the root cell walls, and to the action of the root endodermis as a barrier.

Temperature was found to be more important than soil N and P content in determining the growth and mineral uptake by Typha latifolia (Adriano et al. 1980). In a laboratory study, an increase from 19^{o} to $25^{o}C$ yielded 1.7 times more biomass, while an increase from 18^{o} to $32^{o}C$ resulted in a 2.2 times increase in shoot biomass. The authors cite research indicating that growth reduction at higher temperatures may be due to depletion of carbohydrate reserves. Thermal sensitivities of specific isoenzymes of malate dehydrogenase have been shown to determine the thermal tolerance differences between two species of Typha (Liu et al. 1978).

The optimum concentrations of macronutrients of Typha orientalis grown in greenhouse hydroponic culture in Australia were 70 mg N/L and 20 mg P/L at 25 - 28°C (Cary and Weerts 1984). Citing from other research, the authors observed that T. latifolia grew better at 32° than at 25°C. Walrath and Natter (1976) suggested that the optimum N:P ratio in a wastewater to be treated in macrophyte systems should be 10:1 - 15:1 in order to maximize the uptake of both N and P. Lower ratios would result in decreased P removal while higher ratios would lead to reduced N removal.

Tissue mineral content

Tissue mineral content is usually positively correlated with ambient concentration in either water or soil. Below-ground tissues generally have higher concentrations of most elements than do the shoots. The various reports, however, do not reveal a consistent pattern either within or between species.

Generally, (though not always) the concentrations of macronutrients (N, P, K) in the above-ground tissues are highest early in the growing season and decrease thereafter due to a dilution effect as the nutrient reserves are distributed throughout the increasing biomass. Marked decreases may occur in association with fruiting, the fruiting organs exhibiting high nutrient concentrations (though a low biomass) relative to other plant parts. Minerals such as Ca, Na, Mg and Mn tend to increase in the shoots over the growing season. Root-rhizome N and P content decreases during flowering. Rhizomes may store 40 to 70% of the peak above-ground stock of macronutrients.

Interaction effects between soil elements can affect plant uptake of a particular element (e.g. high Zn may inhibit Cd uptake). Live tissue P, K, Ca and Mg may be affected by soil potassium content, and tissue N, Cu, Fe and Mn may be affected by soil Ca content. Dead tissue mineral content is affected more by leaching (particularly K), wind-borne deposition and microbial decomposition.

Equations for predicting tissue mineral content and mineral stocks per unit area on the basis of tissue N content and standing crop are available for _Typha latifolia_ growing at northern latitudes (Boyd and Hess 1970).

Soil mineral content appears to be the primary determinant of live tissue mineral content (McNaughton et al. 1974, Auclair 1979, Babcock et al. 1983). Dead tissue mineral content is affected more by timing and cause of death, and by physical and microbiological decay, than by soil mineral content. As mentioned above, temperature can also have an important effect in certain species (Liu et al., 1978). In hydroponic culture, tissue N and P content is related to the concentration of these nutrients in the growing medium (Cary and Weerts 1984). Regression equations for predicting tissue mineral content on the basis of tissue N content have been derived by (Boyd and Hess 1970) for Typha latifolia in the southeastern United States.

Auclair (1979), in a field study on Typha angustifolia, Scirpus fluviatilis, Equisetum fluviatile, Eleocharis palustris and Scirpus validus, found that soil nutrient content was 4 to 5 times more important than community structure in determining tissue nutrient content. Soil K had the highest correlation with tissue, P, K, Ca and Mg, while soil Ca had the highest correlation with tissue N, Cu, Fe, and Mn.

Cattails growing in a coal ash settling basin in South Carolina (Guthrie and Cherry 1979) were found to concentrate the most K, Ca, Ba, Mn, Cl, Se, and Br, in comparison with duckweed, bald cypress, Pontederia and the algae Oscillatoria and Hydrodyction. Arsenic was concentrated least by cattail and most by duckweed. Synergistic toxic effects of Cu - Zn and Cu - Hg were suggested as possibly inhibiting the establishment of other species.

Typha domingensis was categorized as an Mn accumulator by Hocking (1981). The leaves accumulated 73% of the total plant Mn. Over a range of Mn concentrations from 0.10 to 10 mM in the laboratory rooting medium, Mn was found to reduce growth at only the most concentrated level. At this level (10 mM Mn), the mineral was accumulated in the roots at a faster rate than in the rhizomes or leaves. The concentration of Ca, P and Mg in the leaves, roots and rhizomes decreased with increasing ambient Mn. During senescence, leaf N, P and K content decreased by 65 - 84%, while Na, Mn, and Ca levels increased. The decreases were attributed to translocation to the roots; (leaching was not a factor as no rain had fallen during the field experiment). The accumulation of xylem-mobile Na, Cl and Mn in leaf tissue was likely due to the pumping effect of transpiration. The author suggested that the greatest removal of phloem-mobile minerals such as N, P, K and Mg might be achieved by harvesting the shoots just as they reach full size. Within the context of feeding the leaves to animals, concern was expressed at the potentially toxic Mn levels in the shoots (as the recommended dietary intake for stock, of 1 mg/g dry weight, could easily be exceeded; mixing with a low-Mn feed ingredient such as barley or wheat was suggested).

Leaf mineral content in Typha latifolia decreases as the crop matures (Sharitz et al. 1984), and a marked decrease is observed before fruiting (Boyd and Hess, 1970).

Shoot N, P and K content in cattails declined rapidly during the first two months of growth (March and April in South Carolina) and then gradually during the remainder of the growing season (Sharitz et al. 1984). The sharp decline in shoot nutrient content was attributed to dilution throughout an increasing biomass and possibly a decline in absorption rate. Root N and P content showed a major decrease during pre-reproductive and flowering stages. Losses of tissue K were attributed to leaching. Calcium increased in shoots and rhizomes over the growing season, while Mg increased in the shoots and remained constant in the roots.

Decreases in tissue mineral content from May to August were recorded by Mudroch and Capobianco (1979) in both submerged and emergent species in the Moira River (Lake Ontario), an area historically associated with mining and smelting. Dilution was indicated as the probable cause of the decreases. Submerged species concentrated trace elements (Fe, Au, Cu, As, Ag, and Ni) to a greater extent than emergent species. Only above ground tissues were sampled. Copper, Ni and Co in the sediment were determined to be 71.3%, 56.3% and 81.6% labile (i.e. available to the plants).

Correlations between metal content in the soil and in <u>Typha latifolia</u> growing in wetlands in the Sudbury, Ontario, region were studied by Taylor and Crowder (1983). Plant tissues analysed included root, rhizome, shoot (base, mid and tip), flower (male and female) and pollen. Three classes of sediment-plant interaction were identified. First, no correlation was found in the case of N, Mg, and Ca. Second, a significant correlation was found between Cu and Ni content in the soil and in the below-ground plant organs (roots and rhizomes). Third, a significant correlation was found between Fe and Mn content in the soil and in virtually all plant tissues. No correlation was found between soil pH, Eh (conductivity) and plant metal uptake (contrary to the findings of other studies). With the exception of Mn and Ni in the shoot tips, the highest metal concentrations were consistently found in the plant roots. The authors infer that site-specific interaction effects may be stronger than isolated environmental factors in determining the magnitude of mineral uptake. Shoot tips, fruiting bodies and flowers showed generally higher metals content than other above-ground plant parts. Transpiratory pumping of mobile elements was advanced as a possible explanation for the higher metals content in the older shoot parts. Washing of shoot tips prior to chemical analysis removed significant amounts of Ni and Fe. These authors also cite research indicating that T. latifolia roots continue to absorb P from above-ground tissues past senescence into early winter. Rhizomes may store from 40 - 70% of the peak above-ground stock of macronutrients.

In Phalaris arundinaceae, an emergent species that grows in Scottish lochs (Ho 1979), the tissue mineral content increased during the growing season, peaking in late summer and then decreasing with the onset of senescence. The content of C, P, Na and Fe in shoots peaked in July - August, while N, K, Ca and Mg peaked in August.

The uptake of trace elements (As, Cd, Cr, Cu, Fe, Mn, Ni, Se, and Zn) by Typha latifolia was compared in coal ash-impacted and non-impacted marshes in South Carolina by Babcock et al. (1983). In this particular study, rhizome samples were peeled prior to analysis in order to eliminate the error due to external adsorption. Tissue mineral content was higher in samples from the impacted areas. It was found that those elements which exist in nature as oxyanions (As, Mo, Se), as well as, Cu, were translocated to the shoots, while most other elements were concentrated in the rhizomes.

Cadmium content was lower in plants from impacted areas, possibly due to an interaction effect with high soil Zn at the contaminated site, such that high Zn inhibited Cd uptake. The authors conclude that the relative concentrations of chemically similar elements may be quite important in terms of their effects on plant mineral uptake.

Root secretions

Inorganic molecules such as P and Mg, as well as organic compounds are secreted into the aquatic and soil environment by emergent plants. Organic carbon and cAMP (cyclic adenosine monophosphate) secretions are potentially important as sources of nutrients and as community growth regulators, respectively. Up to 30 - 40% of the carbon production can be released back into the environment as DOC (dissolved organic carbon).

Francko and Wetzel (1984) studied the release of organic compounds from the root-rhizome of Scirpus subterminalis, with particular emphasis on cAMP (a regulatory effector molecule involved in maintenance of homeostasis, including hormonal responses, membrane permeability changes and the regulation of C, N and P metabolism). Marked diurnal fluctuations were found in the cell content of cAMP and in cAMP release rates. Peak release took place at about 1800 hrs in Scirpus and about 2400 hrs in the submerged species Najas flexilis. Organic carbon was also secreted by Scirpus, with similar timing to cAMP but not at similar rates, indicating that the secretions of the two classes of compounds were not necessarily related. Comparison of washed and unwashed specimens of Scirpus revealed that, in intact plants, the epiphytic flora was associated with a daytime decrease in cAMP release rates and with high plant tissue cAMP content at night. It was concluded that the uptake of cAMP by the microflora was associated with its photosynthetic activity. This study provided evidence for the important role played by extracellular secretions and by the epiphyton in emergent macrophyte communities.

Mickle and Wetzel (1978a, 1978b, 1979) conducted extensive work on the interaction of angiosperm-epiphyte complexes in the exchange of nutrients. The authors found that while DOC generally increased over time in laboratory units containing Scirpus subterminalis or Myriophyllum spicatum (a wholly submerged species), the increase was limited to organic compounds having a molecular weight >1000. The source of DOC was considered to be senescence and autolysis (to the extent that 30 to 40% of the production could be released via the latter process). The export of DOC was not evident when the plants (and associated epiphyton) were metabolically most active.

Release of Mg and P from Phragmites communis roots to the soil is suggested by data from Ontario (Bayly and O'Neill 1972). Export of oxygen from the roots of Typha into the adjacent soil also appears to occur (Sale and Wetzel 1983).

2.3.3 Decomposition processes

The decomposition of aquatic plants results from physical fragmentation, biodegradation and leaching mechanisms, which recycle minerals and compounds to the environment. Submerged litter decomposes at a faster rate than emergent litter. The rate at which species decompose, both above and below water, varies. Rapid decomposition is often associated with submergence and high tissue N content. Potassium and sodium tend to leach rapidly from plant litter. In unmanaged (i.e. unharvested) stands of certain species (e.g. <u>Typha</u>, <u>Pharagmites</u>, <u>Scirpus</u>), the disappearance of standing biomass may proceed at a relatively slow rate of less than 14 to 20% per year. Estimates are available for nutrient releases (or accumulations) from decomposing plant litter of <u>Scirpus</u> and <u>Typha</u>.

The decomposition of <u>Typha glauca</u> and <u>Scirpus fluviatilis</u> has been studied under field conditions in Iowa (Davis and van der Valk 1978), using free-standing plants and litter placed in submerged and suspended net bags. <u>Typha</u> was found to decompose more rapidly than <u>Scirpus</u>. After 525 days, only 14% and 20% of the original wild (i.e. not in bags) standing biomass of <u>Scirpus</u> and <u>Typha</u>, respectively, had been lost due to weathering and decomposition processes. A similarly low fraction of the original nutrients was lost during the experimental period. Litter in the submerged bags decomposed faster than in the suspended bags. Nutrient releases (or accumulation) from decomposing plant litter were estimated, as shown below in Table 2-2. The increases in litter nutrient content, with the

TABLE 2-2

ESTIMATED ANNUAL RELEASE OF MINERALS
FROM DECOMPOSING EMERGENT MACROPHYTES
(Davis and van der Valk 1978)

NUTRIENT	Scirpus (kg/ha/yr)	Typha (kg/ha/yr)
N	10	71
P	9 (8)*	10
K	-	123
Na	11	94
Ca	(55)	-
Mg	(5)	41
Fe	(>11)	(20)
Al	(>13)	(21)

* Values in () are accumulations.
\- Not given.

exception of Ca, were attributed to contamination of submerged litter by silt. Calcium accumulation was found in the suspended litter, and was attributed to deposition from spray.

Rapid decomposition has been associated with high leaf N content, while lower disappearance rates have been noted in species that do not fall over on dying, such as Phragmites communis (Hopkinson et al. 1978). Increases in substrate (soil and water) Mg content during a summertime investigation of a Phragmites communis marsh in Ontario were attributed to decay of organic matter and possibly export from the live plants (Bayly and O'Neill 1972). Potassium and Na have been recorded to leach rapidly from decomposing tissue of Scirpus subterminalis (Mickle and Wetzel 1978a).

2.4 Responses to Environmental Stress

2.4.1 Water depth

Changes in water depth can affect community structure in wetlands. Periodic drought may contribute to the maintenance of species diversity in natural wetlands. Certain species of emergent vegetation respond to increasing water depth by allocating more resources and energy to the leaves while decreasing resource allocation to asexual or vegetative reproduction.

Typha latifolia and T. angustifolia in Michigan were both found to allocate nutrients and energy differently in response to increasing water depth (Grace and Wetzel 1982). Plants in deeper water had taller leaves, increased resource allocation to the leaves, decreased allocation to sexual reproduction, and decreased allocation to vegetative reproduction.

Fulton et al. (1983) studied species dominance patterns of rooted vegetation in strip mine impoundments containing Typha galuca, Sparganium eurycarpum, Scirpus fluviatilis and Scirpus validus. Periodic drought was thought to maintain species diversity by allowing a subdominant or temporarily absent (except in seed form) species such as S. validus to re-establish a living population.

2.4.2 Salinity

Tolerance to high ambient salinity varies within and between species, with the reed Phragmites australis and the sedge Cyperus involucratus showing high tolerances, and Typha exhibiting slight to moderate salt tolerance. A common physiological response to salt stress is increased water content in the plant tissues. Nitrate accumulation in leaf tissues is often associated with high ambient NaCl concentrations, a phenomenon also observed in terrestrial plants.

Typha domingensis in Australia was determined to be slightly salt-tolerant (Hocking 1981). In plants exposed to a salinity range of 0.5 - 100 mM NaCl in the laboratory, growth was not significantly reduced until salt concentrations exceeded 50 mM. At 100 mM NaCl, most roots died "within a few days", and the shoots were stunted and showed necrotic, curled tips. Sodium was more toxic than chloride. Rhizomes had the lowest, and leaves the highest levels of Na and Cl. Sodium can retard plant growth through its effects on osmotic adjustment, ion uptake, enzyme activity and hormonal balance. Citing other research, the author advises using a more salt tolerant species such as *Phragmites australis* if the wastewater to be treated exhibits elevated salinity levels.

The effects of sodium and potassium chlorides on *Cyperus involucratus* were subsequently investigated by Hocking (1985). The upper concentration limits for vigorous growth were 75 mM NaCl and 100 mM KCl. As with *Typha*, Na was the most damaging ion, followed by Cl and K; NaCl was more detrimental to growth than KCl. Shoot:root ratio of Na and K decreased from 6:1 and 4:1, respectively, at the lowest concentrations to approximately 2:1 (both elements) at the higher (>100 mM) concentrations. The shoots contained 60% or more of the total plant content of Na, Cl, K, Ca, Mg, N and P. Extrapolating from the laboratory results, it was estimated that, in a wastewater containing 25 - 50 mM NaCl or KCl, a harvest of *C. involucratus* could remove 44.6 g Cl and 78.4 g Na per m^2.

Salt stress has been associated with accumulation of nitrogen in the roots and rhizomes of *Typha domingensis* (Hocking 1981) and in all organs except the roots in *Cyperus involucratus* (Hocking 1985). In the latter study, elevated shoot (leaf and bud) nitrate content was also recorded under NaCl- but not KCl-stressed conditions, as had been found with other plants. The inference was made that high Na levels diminish nitrate reductase activity, though not affecting root uptake of nitrate.

Differences in salinity tolerance response between two populations of <u>Typha domingensis</u> have been reported in Australia by von Oertzen and Finlayson (1984). Using seedlings, the authors found an increase in tissue water content (succulence) in the less salt-tolerant ecotype. Community structure in intertidal marsh plant communities is affected profoundly by interstitial water salinity in the soil (Ewing 1983). Ecological studies such as the latter are useful in selecting species for potential application in water treatment.

2.4.3 Temperature

Plant responses to thermal stress, as in water cooling ponds, appear to be related to two main factors. At sub-lethal temperatures there may be an increase in plant production, and possibly a decrease in the rhizome nutrient reserves. At higher temperatures, plants typically exhibit reduced size and eventual elimination, due possibly to the exhaustion of rhizome carbohydrate reserves for growth the following spring. (No reports were found linking wintertime low temperatures to adverse effects on emergent macrophytes.)

"The most common responses observed in natural populations are the enhancement of production by sublethal temperature elevations and the drastic reduction in growth rate and eventual elimination of species by larger increases in temperature" (Grace 1977, in Adriano et al. 1980).

Mention has been made previously to the effects of water temperature on growth of cattails. *Typha latifolia* has been found to tolerate temperatures of 34 to 40°C in a nuclear powerplant water cooling pond in South Carolina (Sharitz et al. 1984, Liu et al. 1978). The plants exhibited shorter leaves when grown under thermal stress, compared to plants growing at temperatures below about 30°C. *Typha domingensis* was present in the same pond, but was not found in sites warmer than 30 to 34°C. Liu et al. (1978) had previously shown that the differential thermal tolerance of the two species was associated with greater heat stability of three isoenzymes of malate dehydrogenase in *T. latifolia* than in *T. domingensis*. Overwinter marsh temperatures >8°C in Wisconsin were found to reduce carbohydrate reserves in *T. latifolia*, inhibiting growth in the subsequent spring (Bedford, pers. comm., in Adriano et al. 1980).

In a study comparing the effects of temperature on seed germination in *Typha* in North America, McNaughton (1960, in Hutchinson 1975) found that the seeds from the more southern localities (i.e. warmer climates) were able to germinate at lower temperatures than those from cooler latitudes. (No quantitative temperature details were provided in Hutchinson's review.)

Spartina alterniflora, *Spartina patens*, *Distichlis spicata* and *Juncus roemerianus* were reported to exhibit winter growth in southeastern Louisiana (Hopkinson et al. 1978).

Freezing temperatures did not cause death of immature cattail shoots overwintering in south-central Michigan (Dickerman and Wetzel 1985). The effect of a power-line right-of-way construction through a frozen *Typha latifolia* marsh was investigated in Massachusetts by Thibodeau and Nickerson (1984). No differences were found in indices of species number, diversity, evenness and richness before and after construction, indicating that heavy machinery was not harmful to the root zone when the ground was frozen. (This observation has implications with respect to mechanized harvesting in cold climates.)

2.4.4 Toxic chemicals

Information is available on the effects of many heavy metals and some synthetic organic chemicals on the growth and metabolism of emergent macrophytes. Much of the information on heavy metal uptake is discussed in section 3.2.2.

Cattails have been identified as a genus endowed with a special resistance to metal contaminated soils in the north-eastern United States (McNaughton et al. 1974). The latter authors were unable to identify genotypic differences in *Typha latifolia* populations growing on Zn, Pb and Cd contaminated and uncontaminated soils. Both populations showed similar growth inhibition when grown on the contaminated soils (which contained 385, 37 and 16 times the content of Zn (13 ppm), Cd (2 ppm), and Pb (27 ppm), respectively, in the uncontaminated soil). Plants growing on the contaminated soils showed a significant inhibition of shoot production, a "marginally significant" inhibition of shoot production, and a "marginally significant" inhibition of root biomass yield. The study concluded the metals tolerance is probably not due to physical exclusion alone, but may involve a physiological response mechanism including cell wall precipitation. (No quantitative evidence was provided for the latter assertion.)

Dickman et al. (1983) studied the variations in aquatic vegetation of the Welland River (Ontario) as affected by discharges from the Cyanamid of Canada Ltd. chemical manufacturing plant. The exact nature of the discharge was not specified, though the report does provide suitable references. The impact zone of about 0.3 km downstream from the discharge point was completely devoid of macrophytes. The primary recovery zone of about 0.7 km below the impact zone contained sparse stands of Typha only. The secondary and tertiary recovery zones showed the re-establishment of dense Typha together with Sagittaria, followed by the re-appearance of submerged species and filamentous algae. Cattails again stand out as species that have a generalized tolerance to conditions that are toxic to many other plants.

The response of Phragmites communis roots to DDT and hexachlorane was investigated in the Soviet Union by Merezhko et al. (1979). Low ambient concentrations (25 and 50 ug/L) were associated with inhibited growth of adventitious roots in water and soil, with a reduction in the total active absorbing surface (TAS), and with an increase in anion and cation exchange capacity.

Increasing concentrations up to 2000 ug/L resulted in a decrease and an increase, respectively, in the TAS of roots in soil or water. Soil root area decreased by 2.5 and 1.7 times (DDT and hexachlorane, respectively), while water root area increased by 2.6 and 1.9 times. Anion exchange capacity became higher in soil roots while cation exchange capacity increased in the water roots. The results provided evidence for reconstruction of the internal mechanisms regulating mineral absorption, such that an optimum level of ion exchange capacity was maintained.

The effect of DDT and Hexachlorane on carbon assimilation in <u>Phragmites</u> <u>communis</u> was investigated by Shokod'ko (1979) in the Soviet Union. Five concentrations of the pesticides, up to 1000 ug/L were tested using the ^{14}C radio-isotope. A curve of percent photoassimilation as affected by the different pesticide concentrations showed two types of toxic effect. The first effect took place at the lowest concentrations (50 ug/L DDT and 25 ug/L Hexachlorane) and caused rapid drop in carbon assimilation efficiency of 25% and 35% respectively for the two chemicals. The second effect was a more gradual decrease in photoassimilation efficiency, of a further 10% for DDT and 17% for Hexachlorane at the maximum treatment levels. The first decrease was considered to be the specific toxic effect, possibly a suppression of cyclic phosphorylation, while the second was considered to be a more "general" toxic effect involving decreased photosynthetic efficiency. As the concentration of pesticide increased, the amount and transport rate of C to the root zone also increased. The results provided evidence for preferential allocation of C to the root (as opposed to the leaf) zone as a defensive reaction to severe toxicity.

2.4.5 Harvesting

Tolerance to cutting differs between species, with the softstem and hardstem bulrushes (Scirpus acutus and validus, respectively) exhibiting the best response. Regrowth of leaf and root-rhizome biomass is greater in plants cut above the water level than in those cut below water. Cutting appears to reduce the overall leaf biomass production, although higher mineral content (e.g. P) in young leaves may result in higher overall mineral removal from cropped systems.

Spangler et al. (1976) investigated the role of harvesting as a means of P removal in natural wetlands dominated by Typha or Scirpus. Each successive harvest yielded a smaller quantity of new biomass. Also, the subsequent growth rates were smaller and the percentage of shoots exhibiting regrowth decreased with the number of cuttings. The authors cite other research showing similar results for Typha and Phragmites in Czechoslovakia. Despite the lower biomass yields in comparison with plots subjected to a single end-of-season harvest, the higher P content in the younger regrowth tissue yielded a greater overall yield of P via multiple harvests. However, it was noted that species respond differently to harvesting. For example, Scirpus acutus and Scirpus validus were better adapted to cropping than were Typha, Scirpus fluviatilis, and Sparganium eurycarpum. Uncited studies in natural marshes were also reported to have found that harvesting at very low water levels may adversely affect the plants. The effect of cutting frequency on the removal of other minerals was not reported.

Sale and Wetzel (1983) studied the interaction of water depth and cutting in Typha latifolia and T. angustifolia. They studied plants that had been cut above the water level and those which had the cut end submerged. Oxygen could diffuse very readily to the rhizome (which was in an anoxic soil) as long as a small amount of leaf or cut stem remained above the water. More root biomass was produced in plants cut above water than below water level. The authors suggested that three below water cuts during the growing season would be sufficient to eradicate a cattail stand. Using oxygen electrodes, it was determined that oxygen in the rhizomal tissue air spaces was depleted in 8 hours if the cut end was submerged. In an attempt to determine whether the rhizomes-roots in Typha were physiologically adapted to anoxia, the authors sought evidence of non-toxic respiratory metabolites. Only ethanol, which is toxic, and methane, which was attributed to bacterial colonization of dead tissue, was found, leading to the conclusion that the plant is not adapted to having anoxic roots. The uncut control treatments showed the highest overall leaf production. No data were provided on tissue mineral content.

2.5 Implications for Use in Water Treatment

2.5.1 Habitat and life history

There is no doubt that the life form and natural history of emergent aquatic macrophytes lends itself readily to their utilization in water treatment systems. The pre-adaptation to forming monodominant stands, the apparent resistance to pests, the tendency toward vegetative reproduction and genetic uniformity, and the perennial nature of the plants are all desirable characteristics in a wastewater treatment context. (Genetic uniformity may, however, cause sub-optimal performance in cases where the best available genotype has not been recognized.)

2.5.2 Productivity

The available information on productivity indicates that stands of emergent vegetation will best perform the function of removing minerals from the water during the warmer season of the year, and that prevention of flowering (i.e. preferential maintenance of vegetative growth) as well as removal of accumulated biomass would be advantageous. Optimization of mineral removal efficiency would appear to entail selecting species (singly or mixed) that will provide the most mineral removal through harvesting.

2.5.3 Mineral uptake

Certain minerals will be more easily removed from a wetland treatment system than others, depending on where in the plant the particular elements are accumulated. Those elements which are accumulated on or in the root-rhizome may be re-released into the environment if changing physical-chemical conditions (e.g. anoxia, low pH) make them more labile. Using the wetland as a reliable mineral sink will therefore entail managing the system in such a manner as to maintain the unharvested minerals in a non-labile form. Under certain conditions (e.g. N-poor wastewaters) it would appear that macronutrient limitation may affect the potential benefit of constructed wetland systems. Treatment of low nutrient wastewaters was not discussed in the literature.

2.5.4 Tissue mineral content

The information available on tissue mineral content implies that the timing of harvesting may be important in terms of maximizing the removal of specific elements. Thus, the best timing for removing N may not necessarily correspond with that for P or other minerals. Nevertheless, because of the low fraction of the total mineral mass that can be captured in harvestable form, cropping would appear to be a measure which, more than having a short-term benefit, would extend the useful life of the wetland system by reducing the rate at which the system becomes saturated with elements such as P and metals.

2.5.5 Secretions into the environment

The implications of plant secretions in a water treatment context are not yet well understood. It does appear that, since the attached microbiota benefit from the secretions, and since these microbiota may have a role to play in the treatment function, the export of organic substances from the macrophytes into the environment is probably beneficial. This is a subject area which requires considerable fundamental and applied research.

2.5.6 Decomposition processes

The information on decomposition appears to corroborate the argument that preventing (or at least diminishing the rate of) accumulation of biomass minerals within a wetland system, by means of harvesting the standing crop, should be included as an operational factor.

2.5.7 Responses to varying water depth

The information available implies that, in a well established stand, temporary water depth increases would not be detrimental, and might in fact be beneficial in terms of generating more harvestable biomass.

In a water treatment context, increased species diversity resulting from water depth management might be an asset in cases where there is limited control over hydraulic loading. Short-duration flooding or drying would be tolerated without ill effect.

2.5.8 Responses to salt stress

Salt stress leads to accumulation of nitrogen in the plant tissues, though there is no consistent pattern between species in terms of the organs (shoots, roots, rhizomes) in which the N accumulation takes place. Researchers infer that high Na levels somehow interfere with the activity of the nitrate reductase enzyme in the phosynthetic tissues. It remains to be demonstrated whether such an effect might be beneficially applied for increasing the removal of nitrogen from a waste water.

2.5.9 Effect of temperature

It appears that the use of emergent macrophytes in water treatment would be limited to temperatures between about 4° and $35^{\circ}C$, with the exact limits depending on the species. Wintertime reduction in the biologically - mediated mineral cycling mechanisms in a wetland undoubtedly occurs. However, physical-chemical reactions in the soil, as well as the activity of psychrophilic bacteria (adapted to cold), do continue to exert an effect on nutrient cycling during the winter.

2.5.10 Effect of toxic chemicals

There is a need for more research on the environmental toxicology of emergent macrophytes. The indications from the sparse information available are that some species exhibit considerable tolerance to chemical toxicity. Cattail (Typha) and giant reed (Phragmites) are identified as being naturally tolerant to toxicity from heavy metals such as Zn, Pb and Cd, and synthetic organic chemicals such as DDT and Hexachlorane, respectively. The tolerance mechanisms are thought to consist of a combination of physical exclusion and a physiological response.

Potential problems due to phytotoxicity of a given wastewater may be encountered, particularly where chemical industry effluents are involved.

2.5.11 Effect of harvesting

Plant cutting appears to have significant implications with respect to the management of emergent vegetation for water treatment. Undesirable vegetation may be controlled by cutting below water level, while desirable vegetation must be cropped above water level. The manipulation of water level in a constructed wetland system must be carefully coordinated with harvesting schedule in order to maintain optimum conditions for treatment.

3.0 EXPERIMENTAL CULTURE OF CATTAIL (Typha latifolia) FOR NITRATE REMOVAL FROM SIMULATED COAL MINE WASTEWATER

3.1 Introduction

3.1.1 Background

The research reported here was developed to investigate the means of reducing the elevated nitrogen concentrations in drainage water from surface coal mines. The use of explosives, consisting of a combination of ammonium nitrate and diesel oil, is known to be the cause of elevated nitrate (NO_3), and to a lesser extent, ammonia (NH_4) concentrations in open pit mine discharge water (Pommen 1983).

The cattails, Typha sp., are a ubiquitous, tall, reedlike macrophyte, found in freshwater and estuarine shore environments. The genus has been identified, together with other rooted emergents, such as the bulrushes and reeds, as having particularly favourable characteristics for use in water treatment. These include tolerance to varying water depths, aggressive colonization of new habitats, growth in dense monospecific stands, rapid growth rate, and potential for economic utilization (Lakshman 1984, Morton 1974).

3.1.2 Objectives

The specific study objectives are to:

- assess the transplantability of cattails from natural stands to constructed impoundments;
- compare the growth rates of transplanted and natural cattails;
- measure the distribution of nitrogen (N) and phosphorus (P) in the cattail tissues (above and below-ground parts) during the growing season;
- compare the removal of N and P from a synthetic wastewater, in the presence and absence of cattails.

3.2 Materials and Methods

3.2.1 Natural cattail populations

Two wild populations of the broadleaf cattail (*Typha latifolia*) were selected for study. Both populations occurred in the vicinity of the University of British Columbia (U.B.C) campus.

Population A (also referred to in the text as Musqueam) was a larger (ca. 0.5 ha), long-established, dense stand located in a wetland receiving runoff from a golf course. Population B (also referred to as Marine Drive) was a smaller, more sparse, recently-established stand colonizing sandy soil along a roadway runoff swale. The two wild stands were monitored for comparison with the experimental populations, and served as sources of rootstock for the latter.

3.2.2 Experimental units

Experimental channels were constructed in the research field of the U.B.C. Plant Science Department, adjacent to the University's meteorological station. These studies took place between April and October 1986.

The experiment was designed to compare three conditions or treatments: cattails from population A, cattails from population B, and no cattails. Each experimental unit consisted of a rectangular channel, 0.6 m wide by 2.4 m long by 0.6 m deep, constructed of plywood and lined with clear polyethylene plastic sheeting. The bottom was covered with approximately 20 cm of soil. Water entered each channel via rain or was added to maintain a water depth of between approximately 5 and 10 cm; there was no outlet. Each treatment was replicated in two contiguous channels (See Figure 3-1).

3.2.3 Transplant procedures

Propagules consisting of newly emerging shoots and a 15-20 cm length of attached rhizome (Figure 3-2) were collected from the wild sites in the mid April, 1986. Each propagule was transplanted with an amount of original soil approximately 15 cm deep by 20 cm in diameter. All shoots were placed in the channels at a similar level above the channel bottom, and back-filled with top soil from the experimental site. Total time elapsed between excavation and re-planting did not exceed three hours. Approximately 40 shoots were initially planted in each channel, though subsequent thinning reduced the number to 36.

Figure 3-1 Experimental channels planted with _Typha latifolia_.

Figure 3-2 Detail of an emerging Typha ramet, the rhyzome and roots.

A mixture of soil from both wild sites was prepared and added to the soil in the unplanted channels, in order to innoculate the control channels with a similar microbiota to the planted channels.

3.2.4 Sampling and monitoring

Plant growth

Ten plants from each wild site were selected at random and labelled with plastic tags. Ten plants within each experimental channel were similarly tagged. Monitoring of plant growth was initiated on May 8 and continued through October 1, 1986. Growth measurements, including leaf number and the height of the longest leaf, were taken weekly during most of the growing season. The wild populations were measured on a biweekly basis. The number of plants within the channels was counted on three occasions after initial thinning. Observations were also made on the general appearance of the plants, onset of flowering, pests, and other features.

Tissue N and P content

Samples of plant root/rhizome, leaf (and flower, when present) were taken on four occasions during the study. Generally, 10 whole plants were collected at random from the wild sites, while 2-6 untagged plants were selected from the channels. Below-ground parts were thoroughly rinsed with running tap water, and above-ground parts were lightly rinsed to remove adhering soil. Tissue samples were made from 8-10 cm length of rhizome and attached roots, a 20 cm length of leaves taken from the mid-section of the green foliage, and whole fruiting bodies, when present (Figure 3-3). Moisture content was determined after drying to constant weight at 70^{o} C, and mineral content was determined on subsamples of the dried material.

Water quality

Water sampling was initiated in mid June and continued through October 1, 1986.

Water quality in the experimental channels was monitored weekly. (No water samples were taken from the wild sites, as there was no continuous standing water at either site.) Each water sample consisted of a composite from three, equally spaced, locations within each channel. Determinations were made of ammonia (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), total phosphorous (TP), total dissolved phosphorous (TDP) and ortho-phosphate (ortho-P). Filtration for TDP was performed in the field. The samples were refrigerated and delivered to the Environmental Protection Service (EPS) laboratory for analysis. Water pH and temperature were also measured.

Soil nutrient content

Soil was sampled on four occasions during the study. All samples consisted of composites taken from three locations within each field or experimental site. Determinations of total Kjeldahl nitrogen (TKN) and TP for the first sample (April 17, 1986) were made at the

Figure 3-3 Inflorescence of Typha sp.. Male flower is above female flower on same spike; seed-bearing fruiting body from previous season is also visible.

Bio-Resource Engineering laboratory at U.B.C. All subsequent soil analyses were carried out at the EPS laboratory in West Vancouver.

Nitrate enrichment

The experimental design called for weekly enrichment of the water to a 12 mg/L concentration of NO_3-N and, if necessary, to 0.030 mg/L of TP (phosphorous addition was not required). Therefore, each channel was "spiked" weekly with a solution of potassium nitrate ($KNO_3 \cdot 7H_2O$). The amount of KNO_3 to be added to each channel was calculated from the concentration data at the end of the previous weekly period. Thus, a weekly cycle would entail, for example:

- day 1 - collect water and measure NO_3 (and other parameters)
- day 2 - enrich with KNO_3 to nominal 12 mg/L NO_3-N
- day 8 - collect water and measure NO_3

Spiking was generally carried out one or two days after the last nitrate determination. On one occasion, nitrate concentrations were tracked over several days within a one-week period (August 22-27). Measurements were made of nitrite, nitrate, ammonia and total nitrogen, in samples taken 1, 25, 74, and 115 hours after spiking.

Evaporative water loss

Water level in the experimental channels was measured weekly. Changes in water level during rainless periods were used as estimates of evaporation and evapotranspiration.

3.3 Results and Discussion

3.3.1 Transplanting

All propagules but one survived transplanting. The latter plant was damaged by a shovel cut at the junction between the shoot and the rhizome. At the time of transplanting, there had been concern whether or not uprooting of the propagules would be detrimental once dormancy had been broken. The results indicate that propagule dormancy is not necessary for successful transplanting.

It is likely that some, if not all, of the propagules selected for transplanting actually belonged to shoot cohorts that have emerged during the previous growing season. Dickerman (1985) and Wetzel reported that, in Michigan, shoot emergence took place in the three pulses or cohorts during the growing season; between 78% and 92% of the final cohort overwintered and resumed growth in the following spring.

Labour requirements were crudely estimated to be approximately one minute per propagule for excavation and planting. Transportation times were not measured due to the small scale of the experiment.

3.3.2 Plant growth and development

Plant height

Plant growth was rapid during the first 7-10 weeks (mid April to mid July), and negligible thereafter. Populations of *Typha latifolia* in South Carolina attained maximum plant height and leaf number in mid June (Sharitz et al. 1984). Figures 3-4 and 3-5, respectively, illustrate the generalized growth pattern and compare the two populations. Growth rates were estimated from the slopes of linear regression equations derived for the data over the interval of maximum increase in plant height (Table 3-1). The highest growth rate, 1.47 cm/d, was measured in the Musqueam clones (population B) growing at the experimental site, and in the Marine Drive clones, (population A) growing in the wild. The wild stand B, showed a slightly lower growth rate of 1.42 cm/d. Population A in the experimental channnels exhibited the lowest growth rate, 0.89 cm/d.

The condition of the rhizomes may have been a factor affecting the plant growth rate. The rhizomes in population A were, at the time of collection, about 10 mm thick, the outer cortex appeared wrinkled, and the interior tissue gray in colour and separated from the cortex. The rhizomes from population B, on the contrary, were much thicker (20-30 mm) and showed a smooth "turgid" cortex over a light-coloured interior. The difference between the two sites may well be related to differences in the soil fertility (see section 3.4) and water availability. The low lying

FIGURE 3-4

Growth pattern of _Typha latifolia_ populations at wild and cultured sites

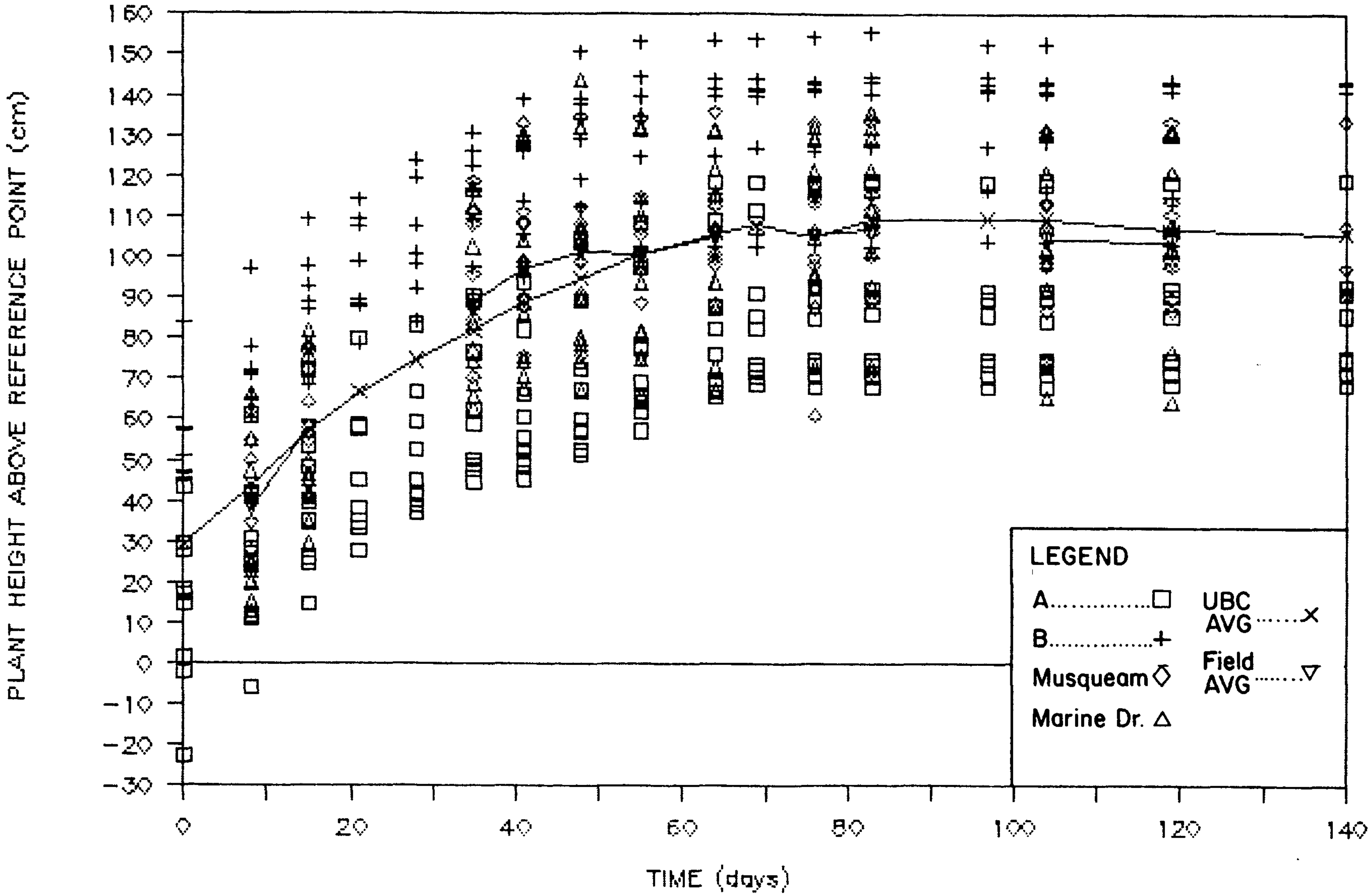


FIGURE 3-5

Height of cultured and wild <u>Typha latifolia</u> over time, June to October, 1986

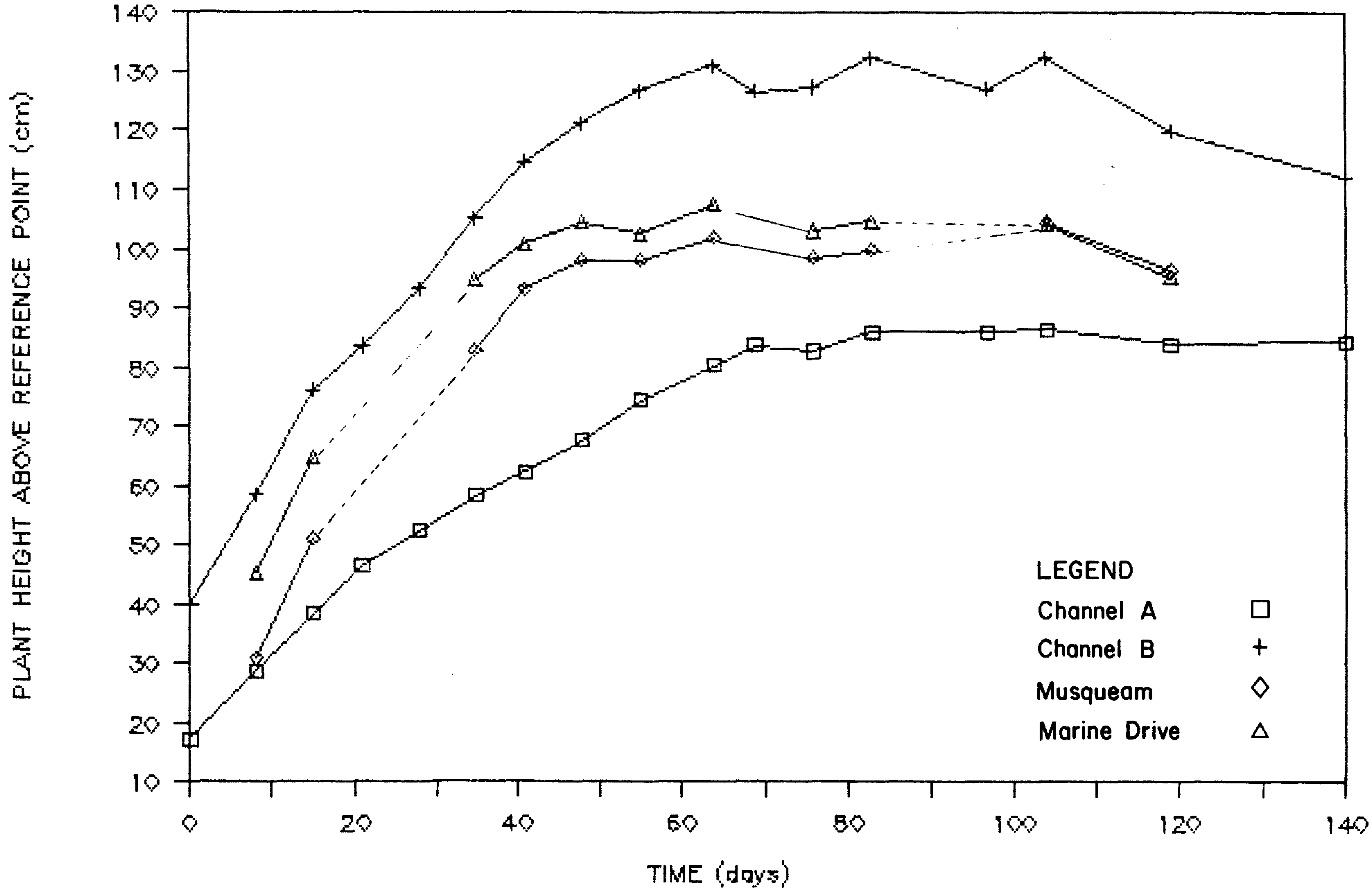


TABLE 3-1

GROWTH RATES OF CATTAILS, *Typha latifolia*, AT WILD AND EXPERIMENTAL SITES, JUNE TO OCTOBER, 1986

	MEAN	STANDARD DEVIATION	RANGE	SAMPLE NUMBER
WILD SITES:				
Marine Drive	1.47	0.41	0.83 - 2.23	(n=10)
Musqueam	1.42	0.32	0.93 - 1.96	(n=10)
EXPERIMENTAL:				
Channel A	0.89	0.14	0.69 - 1.21	(n=20)
Channel B	1.47	0.31	0.99 - 2.03	(n=20)

UNITS: cm/day

Musqueam site was not as prone to drought as the relatively "upland" roadside location of the Marine Drive site. Evidently, transplanting had no effect on the growth rate of the "healthier" Musqueam population, but was associated with decreased growth rate in the initially "weaker" Marine Drive population.

Leaf number

Plant leaf number followed a pattern similar to that of plant height, increasing from an initial 2-4 to about 10-11 leaves per plant by the end of July, (Figure 3-6). Mortality of older leaves increased throughout the growing season, such that the maximum number of living leaves peaked at 7-8 leaves in late June (Figure 3-7), decreasing thereafter to 3 or 4 leaves per plant by the end of the experiment. The decline in the wild plants was due in part to mortality of the meristem as a result of damage by insect larvae.

More leaves were present on the average in plants from the experimental than the wild sites. This difference may be attributable in part to an increased likelihood of older leaves being omitted from the count on any particular occasion, especially since the latter tended to break away or decompose. Nevertheless, at least two environmental factors may have contributed to the consistent difference between wild and experimental sites. First, the additional nitrate available to the experimental populations might have stimulated plant growth (though the design of the experiment did not allow direct comparison of height between sites). This hypothesis is not, however, supported strongly by the

FIGURE 3-6

Average number of live and dead leaves in cultured cattails, _Typha latifolia_, May to September, 1986

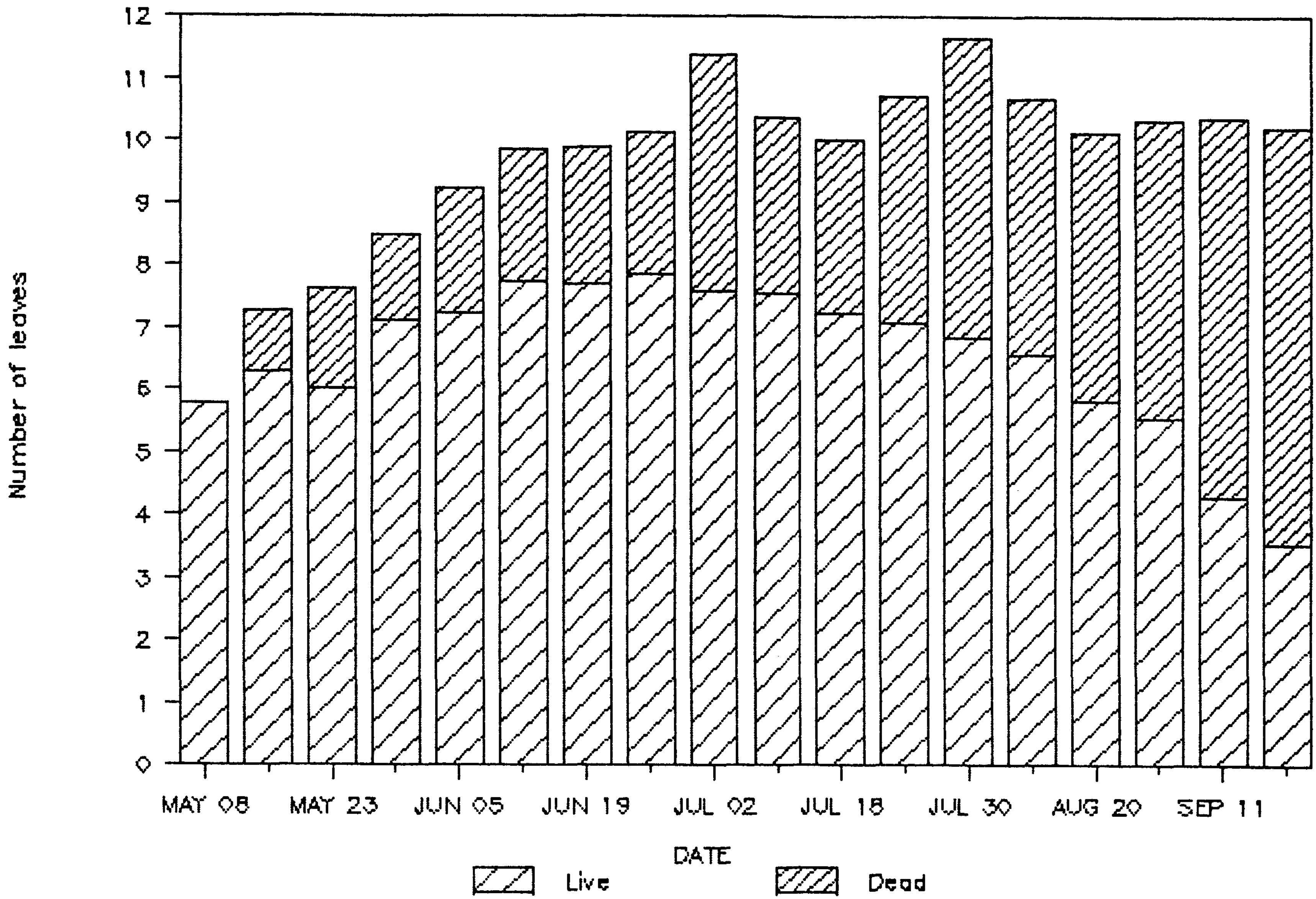
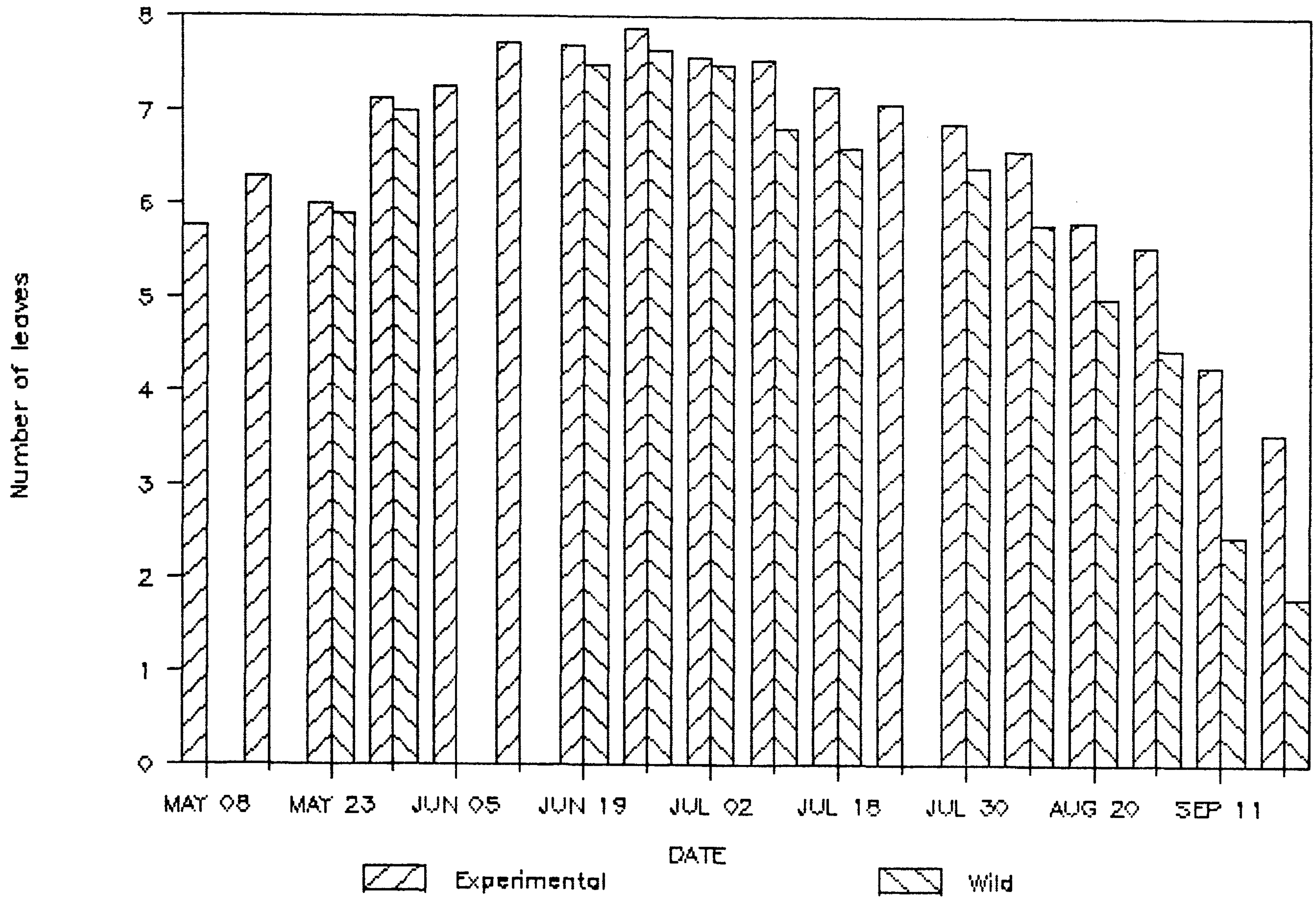


FIGURE 3-7

Average number of live leaves in cattails, *Typha latifolia*, growing at wild and experimental sites, May to September, 1986



growth rate data because the growth rate of population A was much slower under cultured that wild conditions (Table 3-1). However, a slightly higher growth rate was measured for population B under cultured conditions than in the wild.

The influence of insect pests was considered to be of greater importance to the continuing production of new leaves at the wild sites (more frequently in population B). Larvae of an unidentified, 15-25 mm long, boring insect were associated with all plants exhibiting mortality of the youngest leaves. Dissection of several affected plants revealed that the meristematic region at the base of the shoot had been damaged by the burrowing larvae. Similar damage of up to 40% of shoots in small stands of Typha sp. by larvae of the noctuid moth Bellura obliqua has been described in Minnesota (Penko and Pratt 1986). Caterpillars have also been mentioned in the literature as minor pests on cattail stands in South Carolina (Sharitz el al. 1984).

The data indicate that, at the time of peak live leaf number (late June), the proportion of dead leaves is less than 25 percent of the total leaf number. Together with the increasing chance of insect damage as the season progresses, these observations suggest that harvesting for nutrient removal should first be carried out before the average number of live leaves begins to decline in the population.

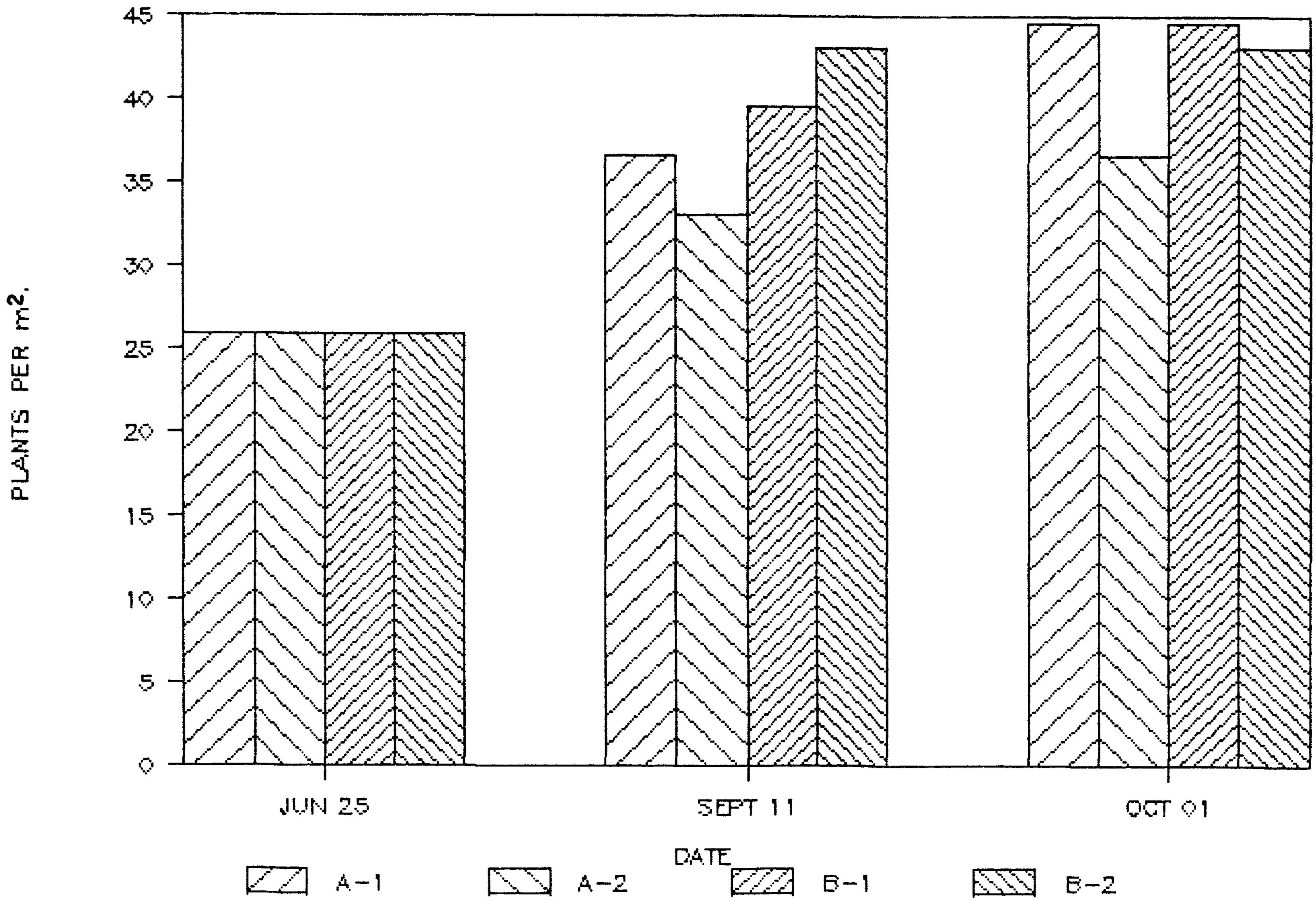
Vegetative reproduction

All experimental channels were thinned back to 36 plants each, or 26 plants/m^2, as of June 25 (Figure 3-8). By September 11, the average density had increased to 34 and 42 plants/m^2, respectively in populations A and B. The densities at the end of the experiment showed a further increase to 40 and 44 plants/m^2, representing a 154% and 169% increase, respectively, over the whole period. While the variability between replicate channels was about the same at the time of the September 11 count, by the October 1 count it was evident that the rate of ramet production in channel A-2 was considerably lower than in the other channels. The reason for this difference is unknown.

While the initial planting densities were probably higher than would usually be implemented on a full scale constructed wetland, the present results indicate that a considerable increase in plant number can take place within one growing season. The data also imply that the relatively high planting density did not inhibit vegetative reproduction. Maximum seasonal densities of 43.2 to 43.9 plants per m^2 have been reported in Michigan, while up to 108 shoots/m^2 have been recorded in Czechoslovakia (Dickerman and Wetzel 1985). In South Carolina, Sharitz et al. (1984) have reported mean densities of 28.7 shoots/m^2.

FIGURE 3-8

Changes in plant areal densities over time in experimental channels planted with cattails, _Typha latifolia_, June to October, 1986



Flowering

Flowering was observed to begin in early June at both wild sites and one of the experimental channels. Two out of 72 transplants from population A developed the characteristic flowering spike. The fruiting bodies from the cultured plants were smaller than those from either of the wild sites (approximately 5 cm versus >8 cm, respectively).

3.3.3 Cattail mineral content

Tissue nitrogen

The nitrogen content of the plants was measured on four occasions: June 26, August 6, August 27 (except wild populations), and October 1. Similarities were found between all populations, in that leaf N content was consistently greater than root-rhizome N content, and that leaf N content peaked during August (Figures 3-9 through 3-12). The initial (i.e. June 25) leaf N content ranged from 0.55% dry matter in the cultured B population to 0.81% in the wild plants of the same population. Nitrogen concentrations peaked on August 6 at 1.10% at the Musqueam site, 0.85% at the Marine Drive, and 0.75% in channel A. The summer maximum for the leaves in channel B, 0.75% N, was measured on August 27. By October 1, leaf N content had decreased to a range of 0.43% to 0.59% (Marine Drive and channel A, respectively). Tissue N contents ranging from 2.3% to 2.8% of dry matter have been reported from *Typha latifolia* grown in a greenhouse experiment in South Carolina (Adriano et al. 1980), and from 0.75 to 2.25%

FIGURE 3-9

Typha latifolia tissue nitrogen content - wild population (Marine Drive)

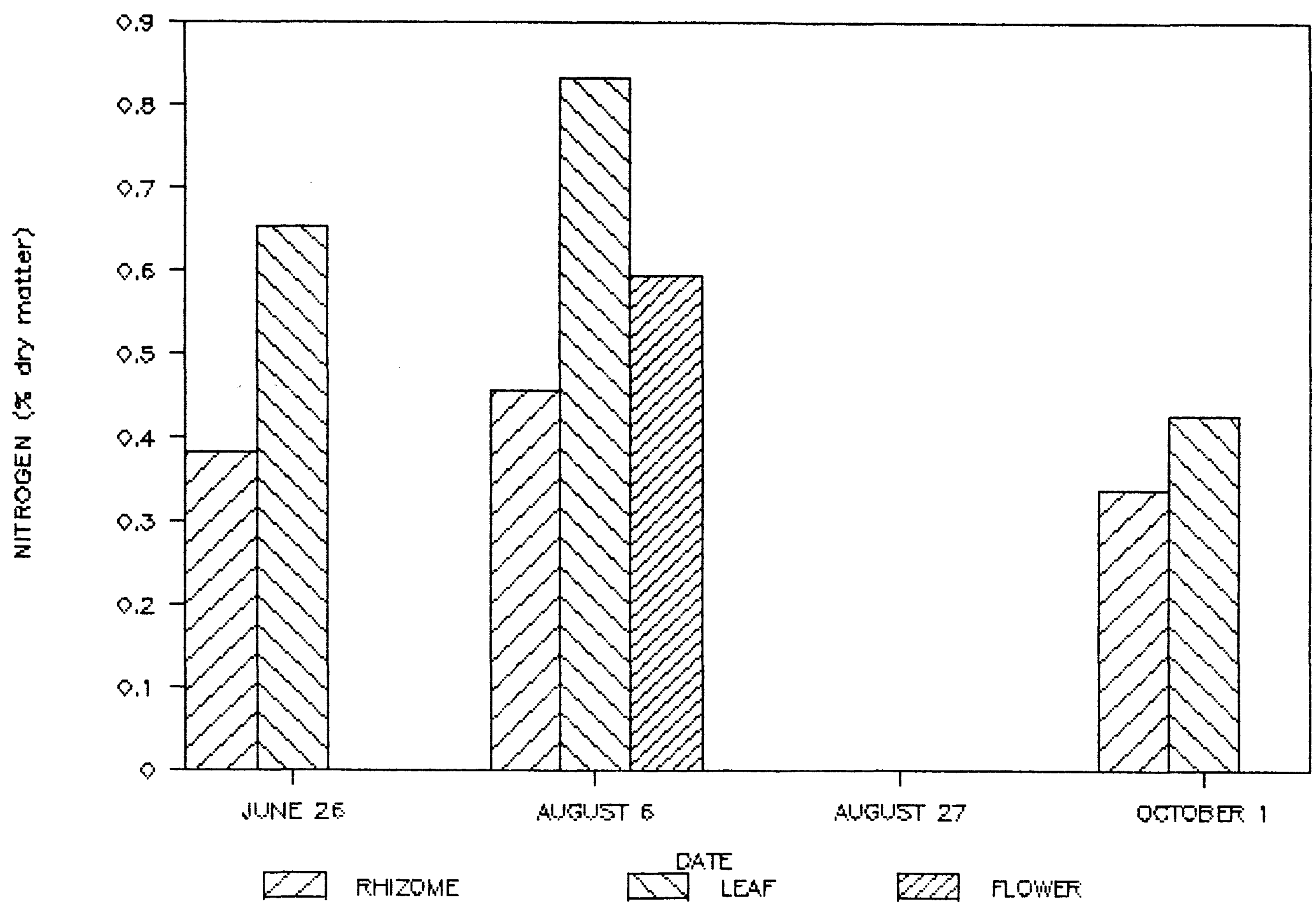


FIGURE 3-10

Typha latifolia tissue nitrogen content - Experimental Channel A

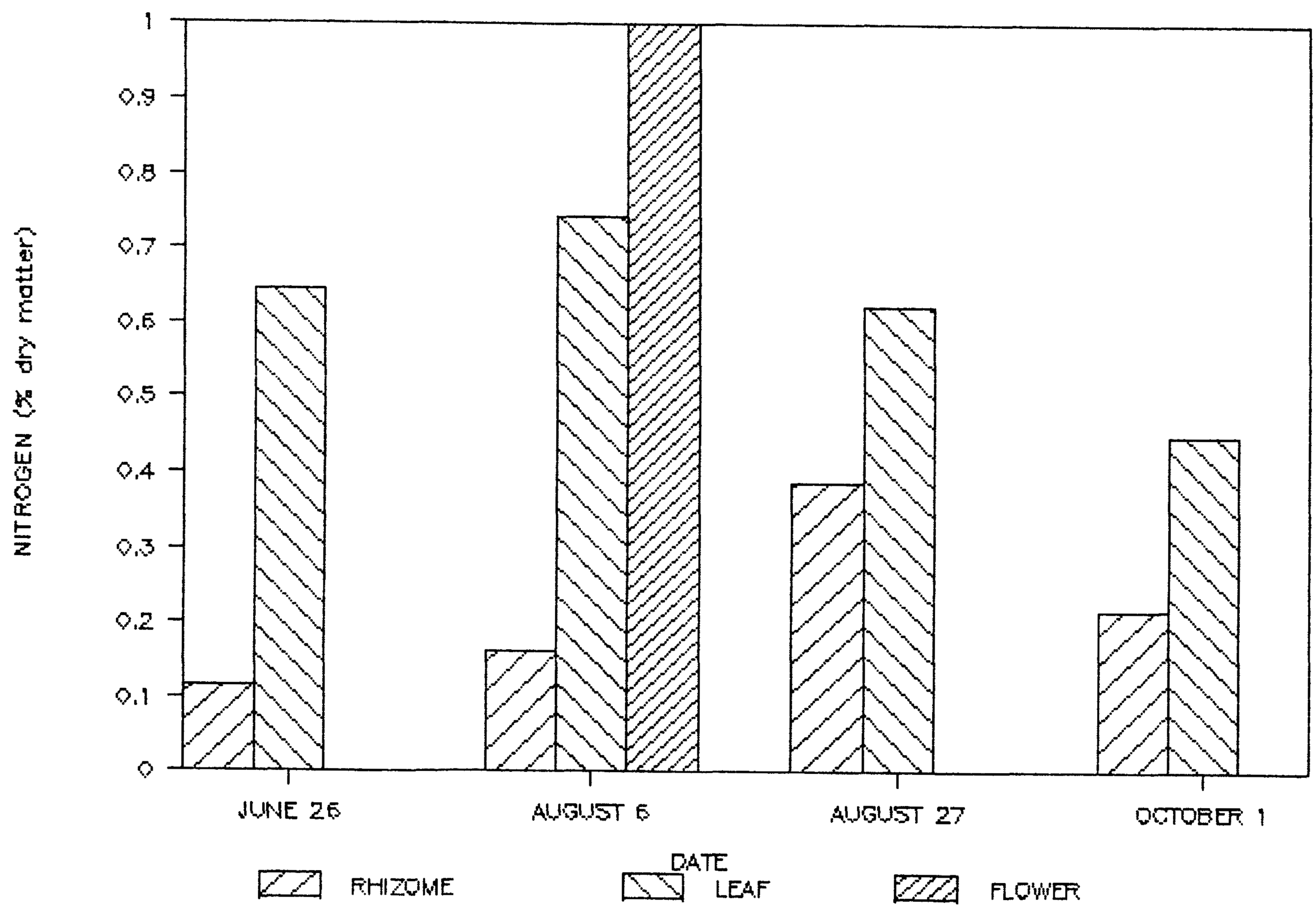


FIGURE 3-11

Typha latifolia tissue nitrogen content - wild population (Musqueam)

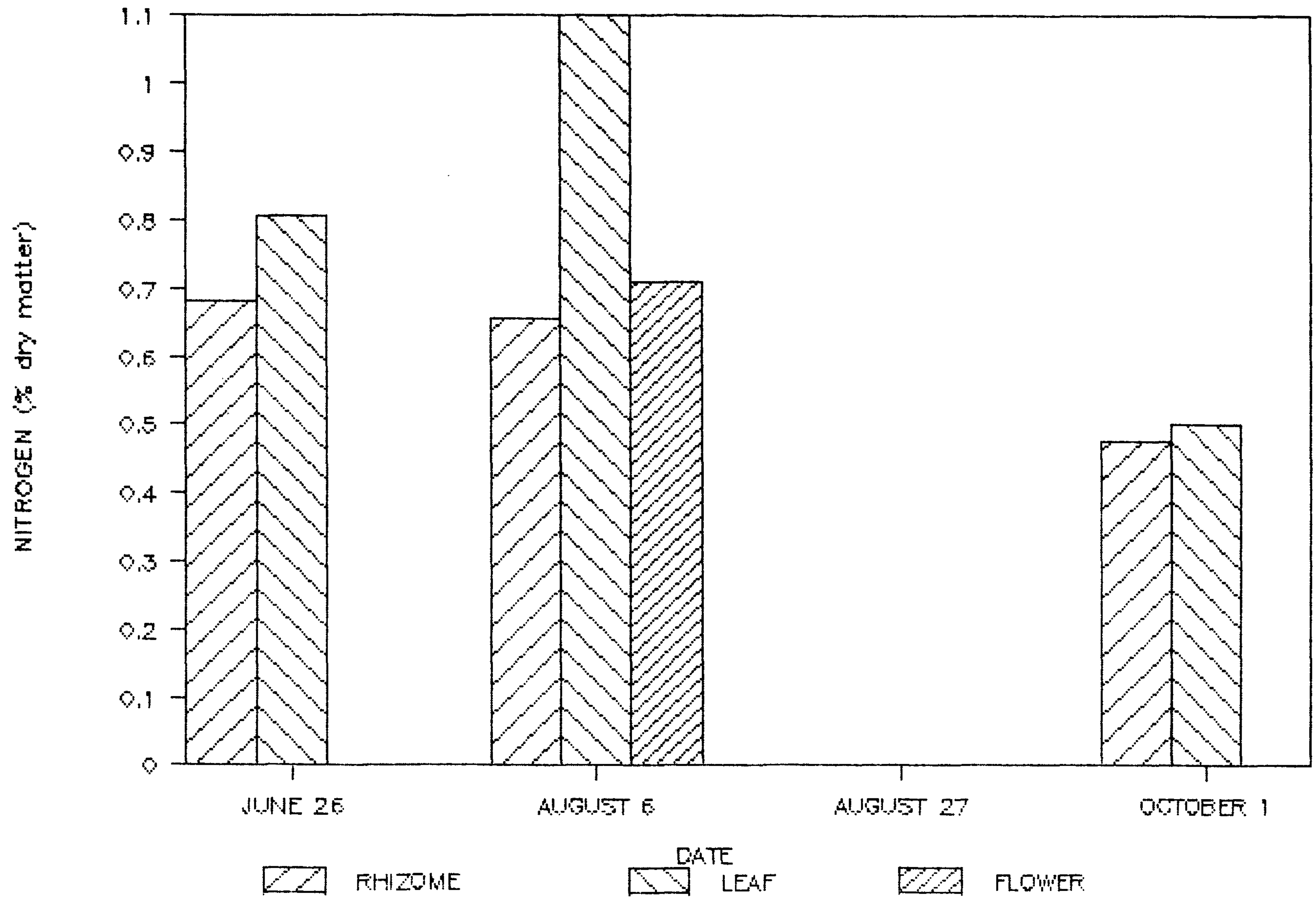
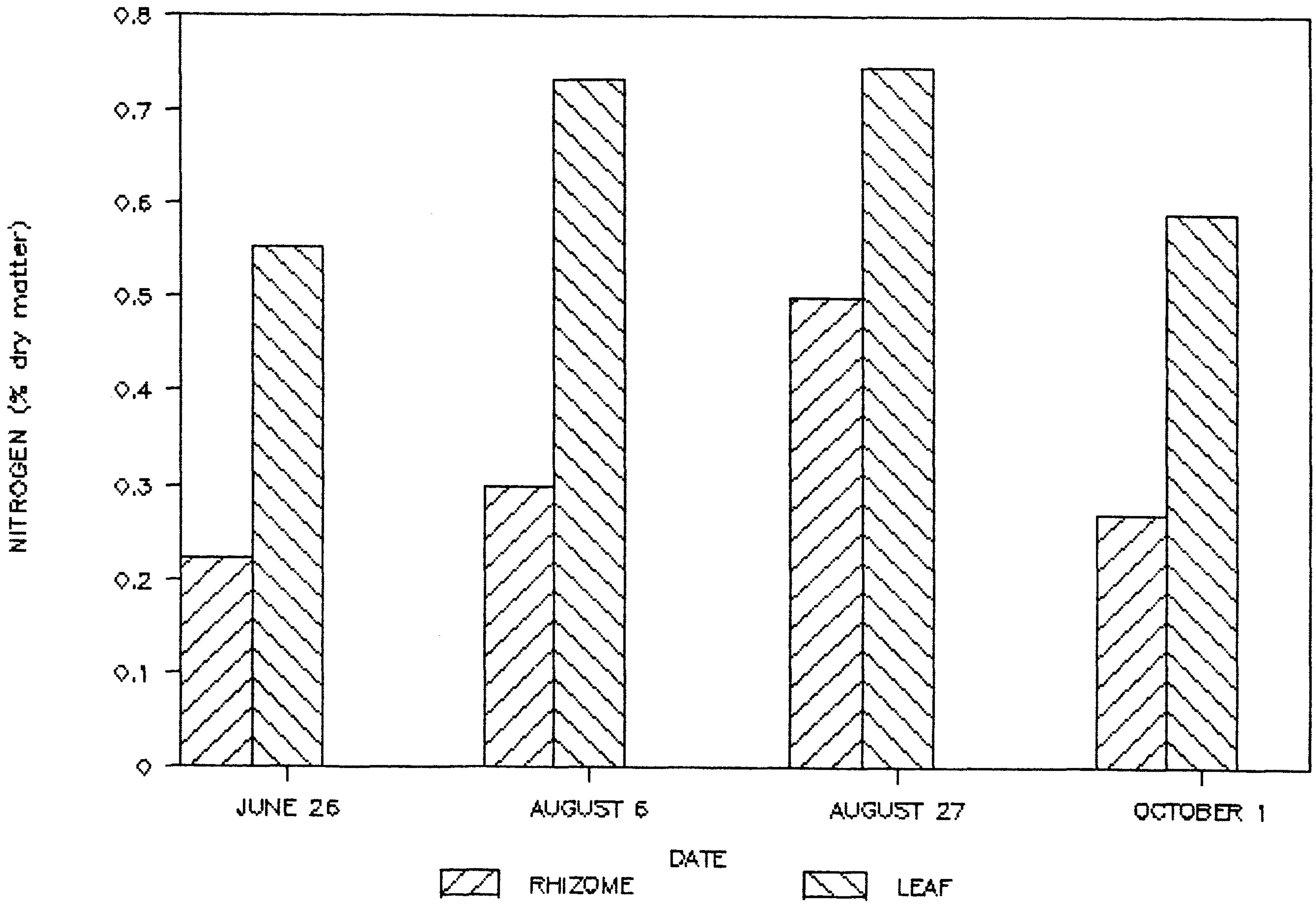


FIGURE 3-12

Typha latifolia tissue nitrogen content - experimental Channel B



in wild stands in the southeastern United States (Boyd and Hess 1970). Cary and Weerts (1984) measured tissue N concentrations of 0.98-1.62% dry matter in potted _Typha orientalis_ supplied with 2-20 mg N/L.

Root-rhizome N content exhibited different patterns of change between the two wild populations. The Musqueam population contained about 0.68% N (dry matter basis) on June 25, appearing to decline thereafter, to a value of 0.48% N by October 1 (Figure 3-9). The Marine Drive population contained 0.38% N in the below-ground tissue on June 25 and 0.46% on August 6, declining to 0.34% by October 1 (Figure 3-10). The cultured population exhibited an increase in rhizome N from 0.12 and 0.22% (populations A and B, respectively) on June 25 to a maximum value of 0.39 and 0.50% on August 27, declining thereafter to 0.22 and 0.27% on October 1 (Figures 3-11 and 3-12).

Fruiting body N content was measured on the August 6 sampling. The highest N content was found in fruits from channel A (1.00% dry matter), followed by 0.71% from the wild Musqueam population and 0.60% in the wild Marine Drive plants. Plants in channel B did not flower. Only in the cultured plants did the fruit N contents exceed that in the leaves; this observation, however, is based on one sample only.

Tissue phosphorous

Tissue P content is summarized graphically in Figures 3-13 to 3-16. Leaf P content on the first sampling occasion ranged from 0.18% (Marine Drive) to 0.26%

FIGURE 3-13

<u>Typha latifolia</u> tissue phosphorus content - wild population (Marine Drive)

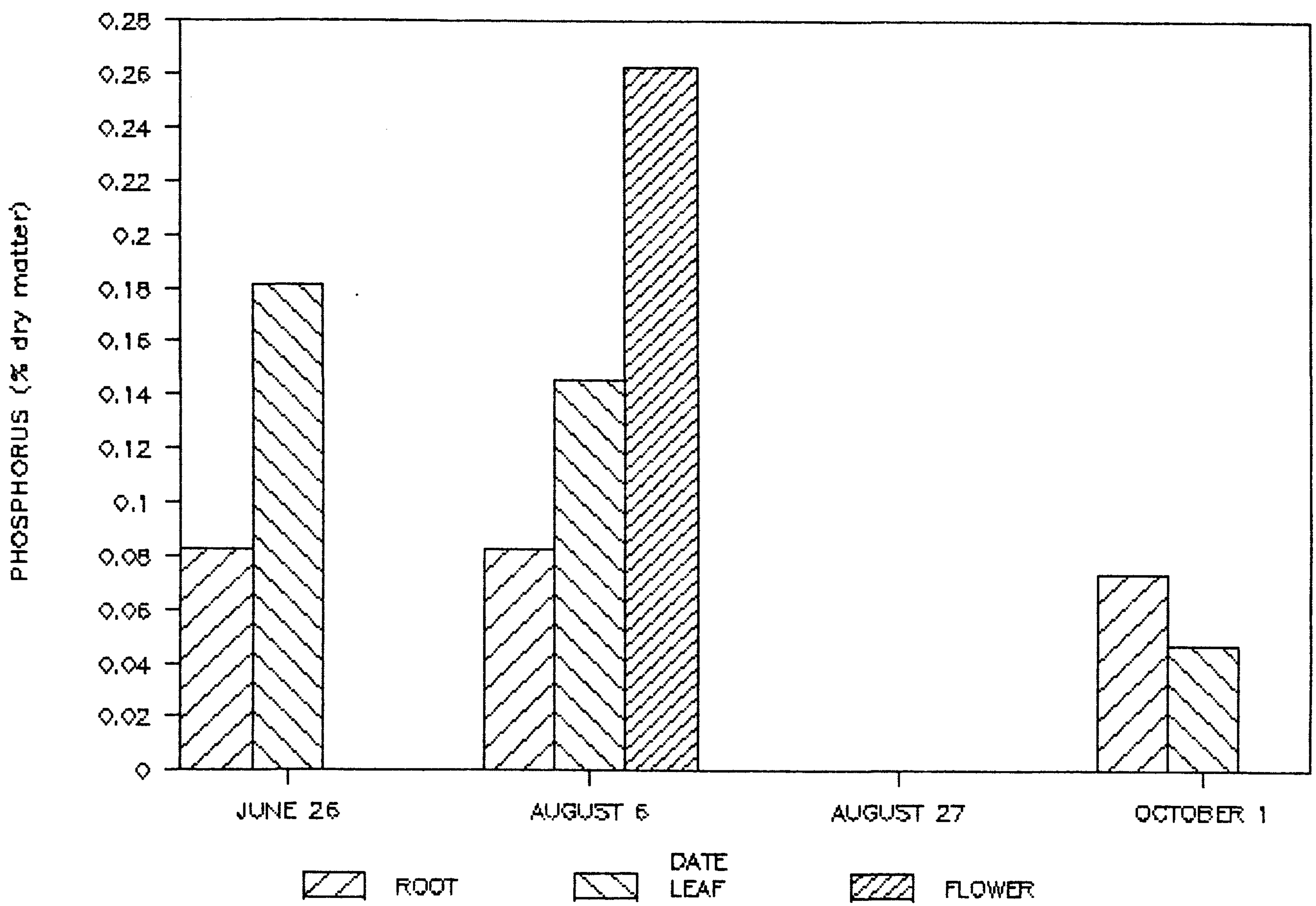


FIGURE 3-14

Typha latifolia tissue phosphorus content - wild population (Musqueam)

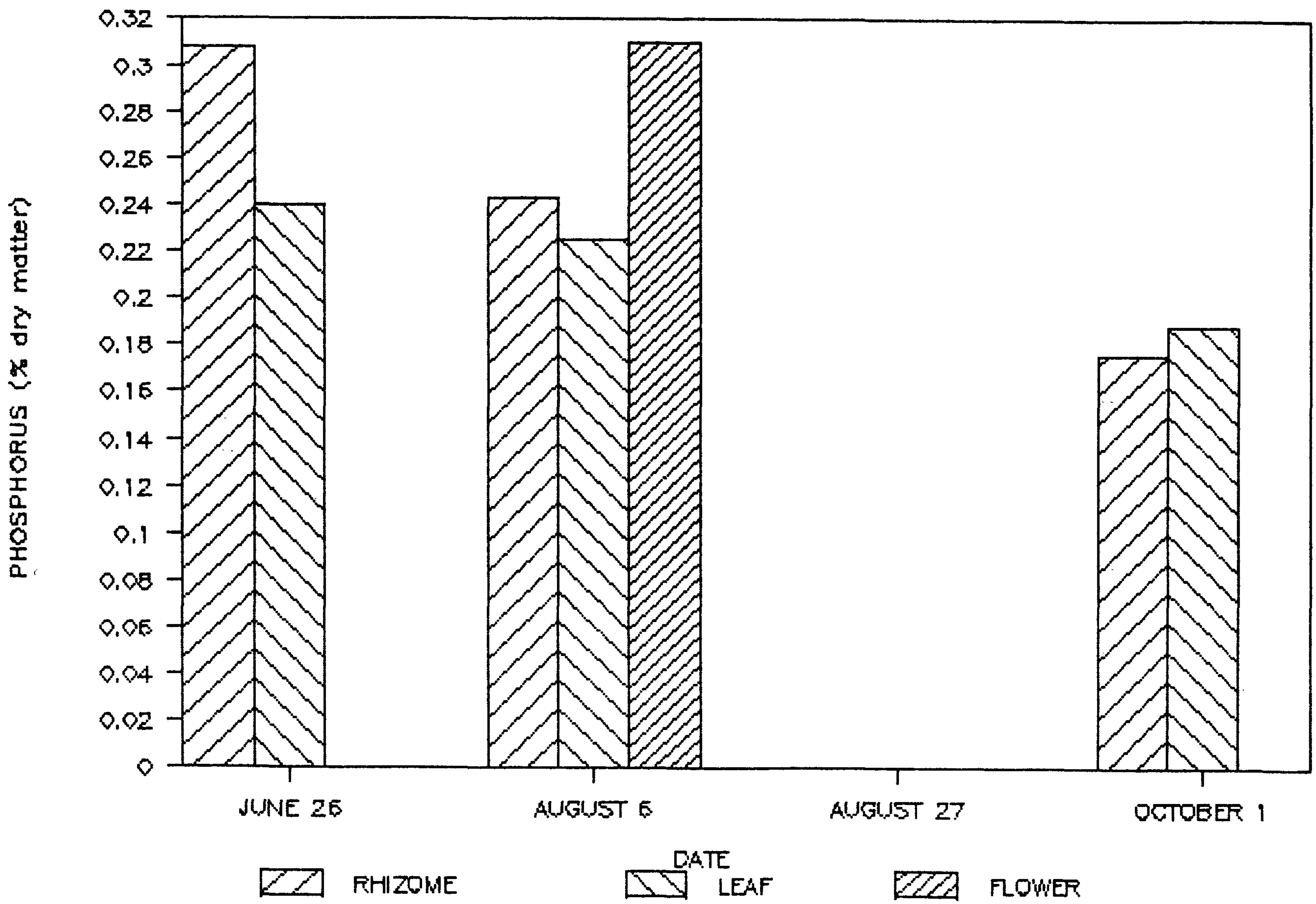


FIGURE 3-15

Typha latifolia tissue phosphorus content - experimental Channel A

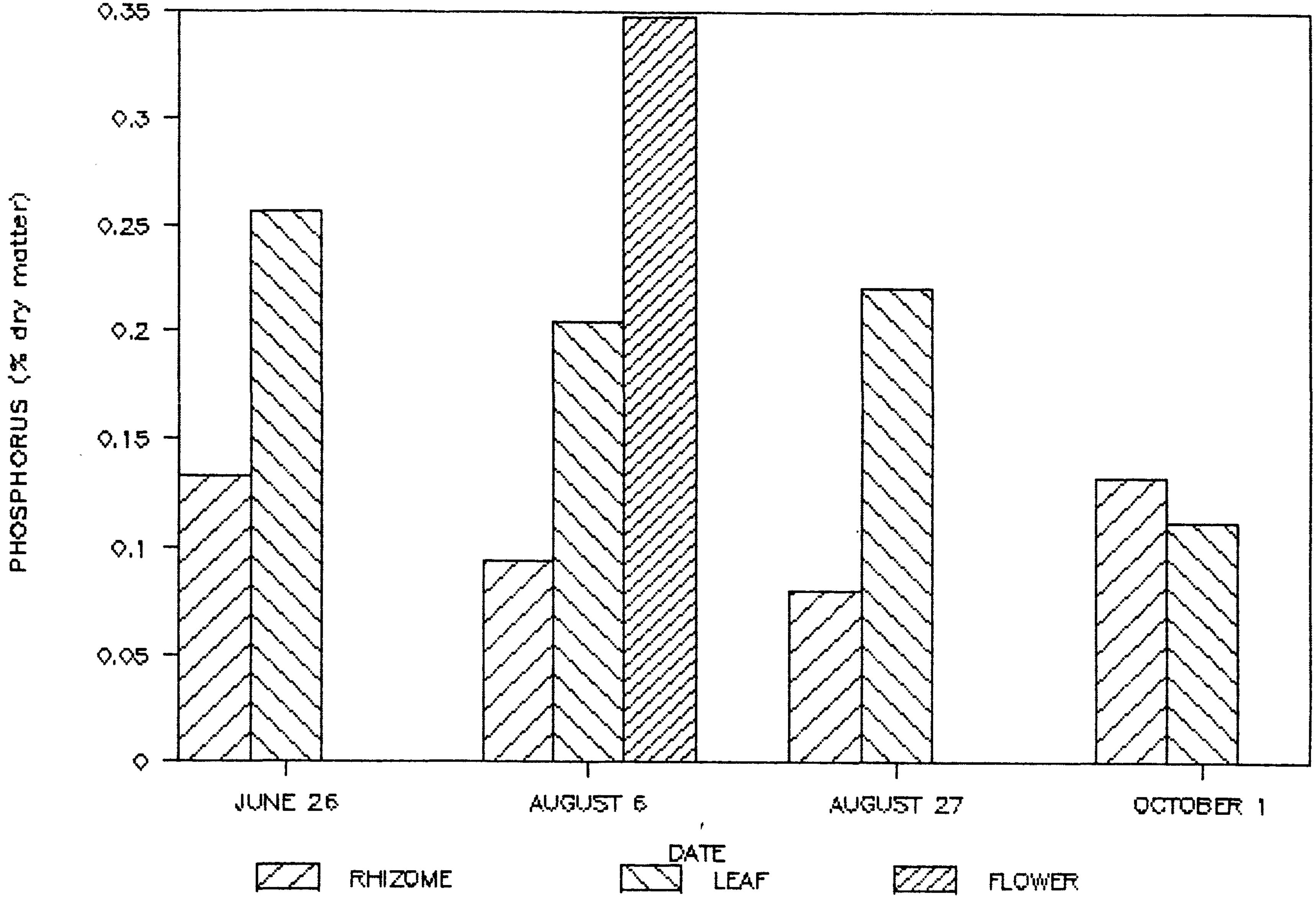
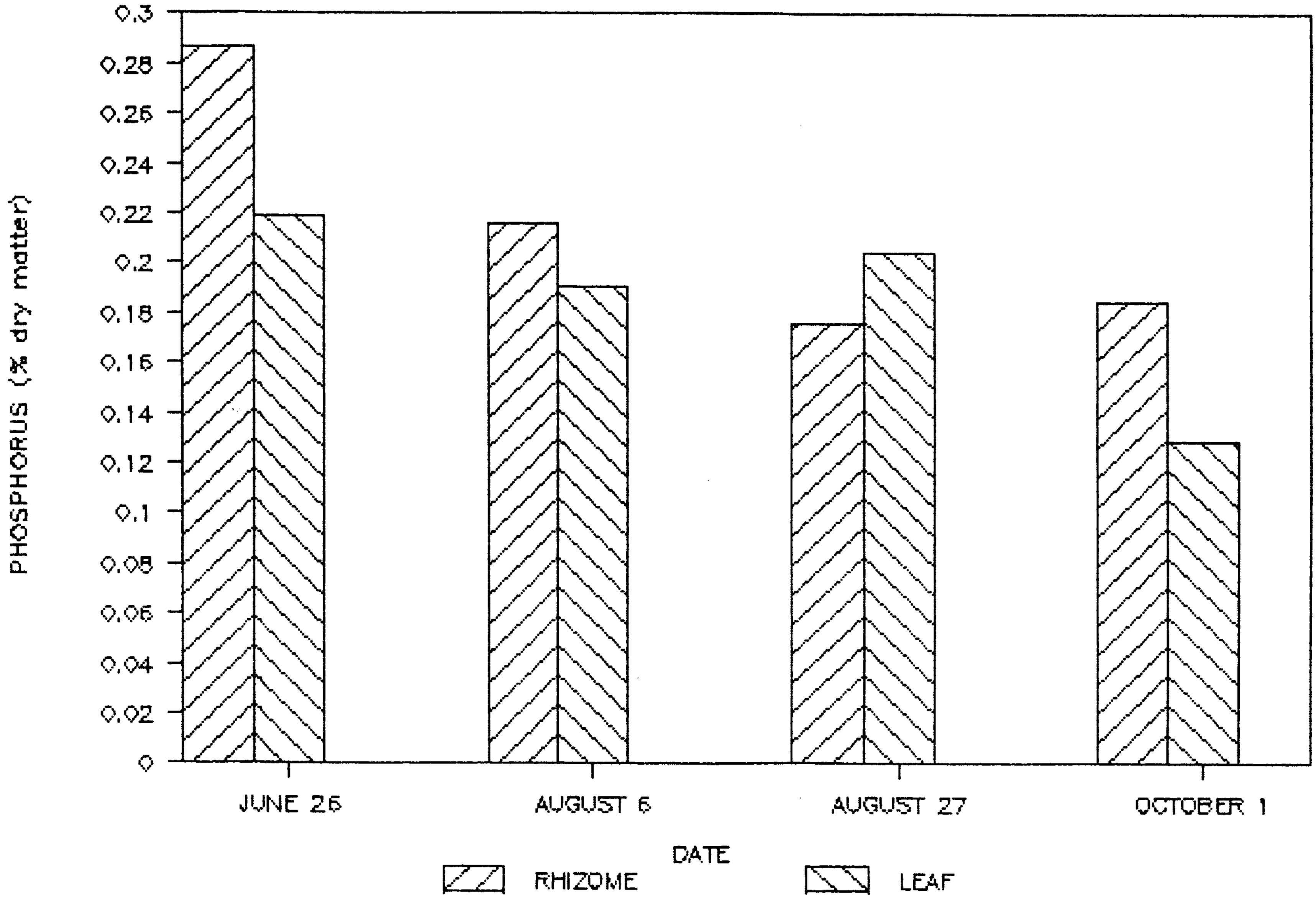


FIGURE 3-16

Typha latifolia tissue phosphorus content - experimental Channel B



(channel A), on a dry matter basis. In the wild populations there was a subsequent decline in leaf P content to 0.05 and 0.014% (Marine Drive and Musqueam, respectively). In the cultured populations, leaf P content declined by August 6, subsequently increasing to 0.20% and 0.22% by August 27, and decreasing to 0.11 and 0.13% by the end of the season (populations A and B, respectively). Tissue (leaf) P contents ranging from 0.19% to 0.26% dry matter have been measured in *Typha latifolia* grown in the greenhouse in South Carolina (Adriano et al. 1980), and from 0.05 to 0.40 % in wild populations in the southeastern United States (Boyd and Hess 1970).

Rhizome-root P content was initially much higher in the wild and cultured plants of population B (0.27 and 0.31%) than in population A (0.08 and 0.13%). The wild populations exhibited a trend of decreasing root P content over time, with final values of 0.06 and 0.18% on October 1 for the Marine Drive and Musqueam plants, respectively. The cultured populations exhibited a similar decreasing trend over the first three sampling occasions, to a low of 0.08 and 0.18% respectively, in channels A and B, but showed a subsequent increase in rhizome P content, to 0.13 and 0.19% respectively, by the end of the season. Cary and Weerts (1984) measured whole tissue P contents of 0.318 to 0.350% in potted *Typha orientalis* supplied with 1-10 mg P/L.

Fruiting body P contents were 0.26% (dry matter) in the Marine Drive population, 0.31% in the Musqueam population and 0.35% in channel A.

Tissue P content over time exhibited a similar relative distribution between plant parts. In population A, leaf P content was higher than root P content on all but the final sampling occasion. In population B, rhizome P content was consistently higher than leaf P throughout the season.

Fruiting body P content was always greater than in the other plant tissues measured. Interestingly, Boyd (1970a in Taylor and Crowder 1983) has demonstrated that the net uptake of N and P in Typha latifolia during flowering was not sufficient to account for the quantities of these elements found in the fruits. The decline of tissue mineral content during the growing season has been described by Boyd (1970b, in Boyd and Hess 1970), with marked decreases being observed before flowering. Similarly, Bayly and O'Neill (1972) found that Phragmites communis shoot P content decreased over the growing season.

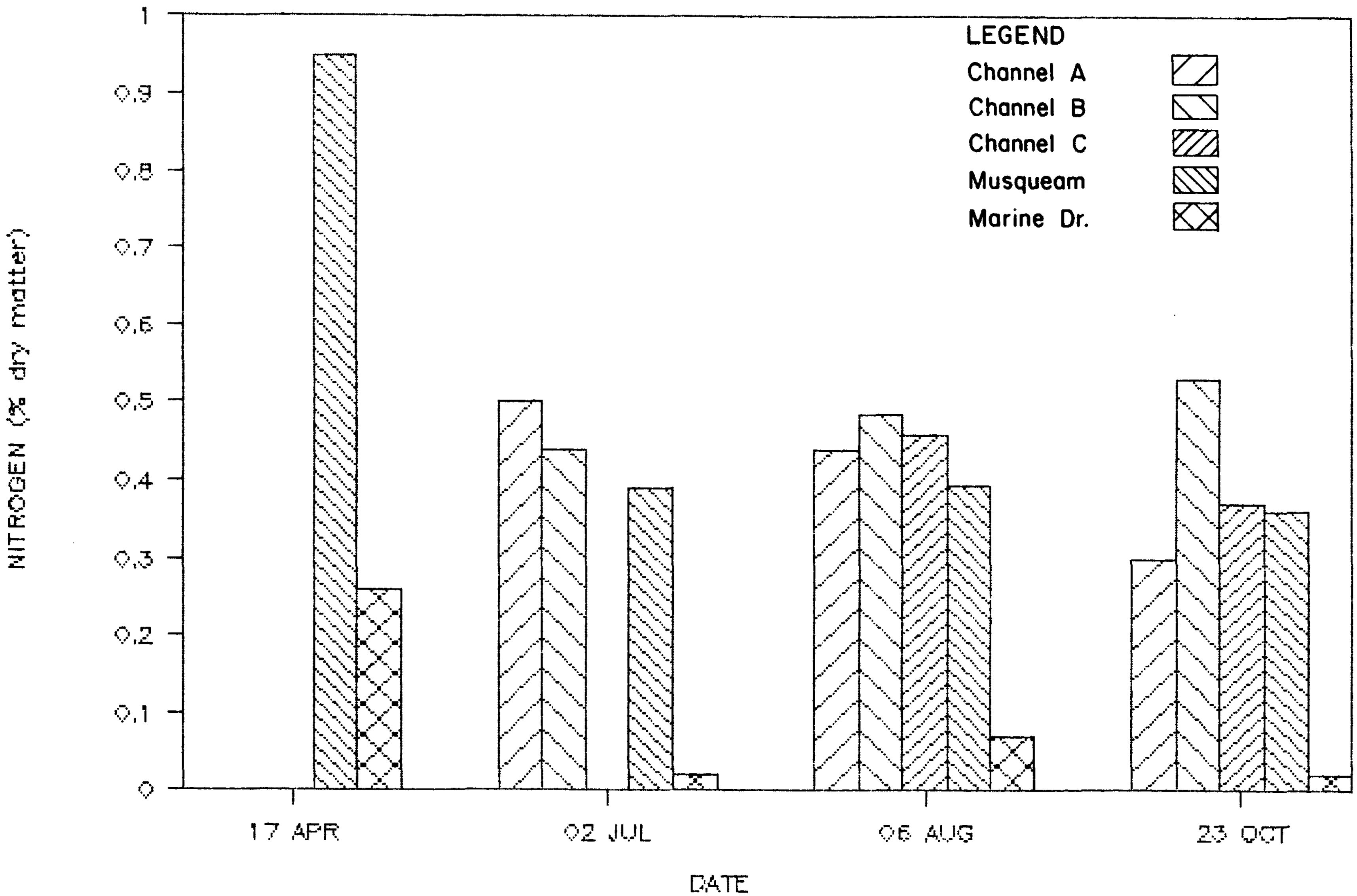
3.3.4 Soil nutrient content

Soil nitrogen

Figure 3-17 summarizes the changes in the soil N content over the experimental period. As can be seen, the Musqueam site at the time of transplanting had a high N content of approximately 0.95% of dry matter, compared to 0.27% at the Marine Drive site. Channel A soil exhibited a trend of decreasing N content over the growing season, from approximately 0.50% in late June to 0.30% on October 1. Channel B soil N content increased over time, from 0.44% in late June to 0.53%

FIGURE 3-17

Soil nitrogen content in the planted and unplanted experimental channels and at the wild Typha latifolia stands, April to October, 1986



by October 1. Soil N content in channel C was only measured on August 6 and October 1, showing an increase from 0.40% to 0.57%.

Soil phosphorous

Figure 3-18 summarizes the changes in soil P content at the wild experimental sites. The Musqueam wetland had a higher P content than any of the other soils, and oscillated around 0.40% of dry matter throughout the experimental period. The lowest P content was measured in the Marine Drive soils, and were approximately 0.05% throughout the growing season. Channel A exhibited a decrease in soil P from approximately 0.26% in late June to 0.16% by October 1. Channel B showed an opposite trend, increasing from about 0.21% in late June to 0.29% by October 1. Channel C soil exhibited little change in the P content from 0.25% to 0.26% between August 6 and October 1.

It is likely that the soils did not go anaerobic in the planted channels. Composition of sediment gas in an experimental Typha angustifolia stand in Michigan was found to contain 1.4% oxygen, while gas in the air spaces of the rhizomes contained 18.9% oxygen (Sale and Wetzel, 1983).

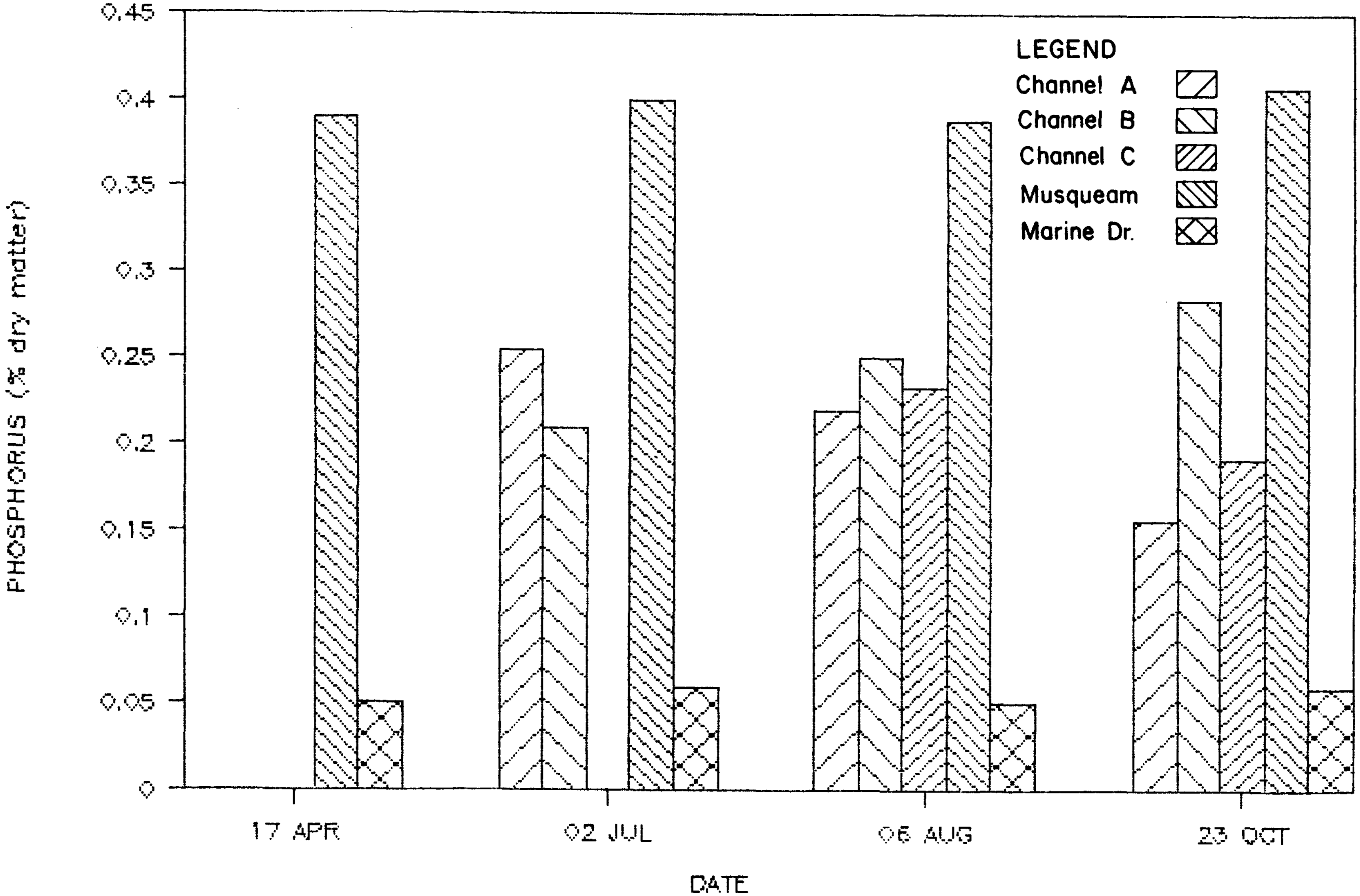
3.3.5 Water quality

Water loss

The rate of water loss through evaporation and transpiration was higher in the planted than in the

FIGURE 3-18

Soil phosphorus content in the planted and unplanted experimental channels and at the wild Typha latifolia stands, April to October, 1986

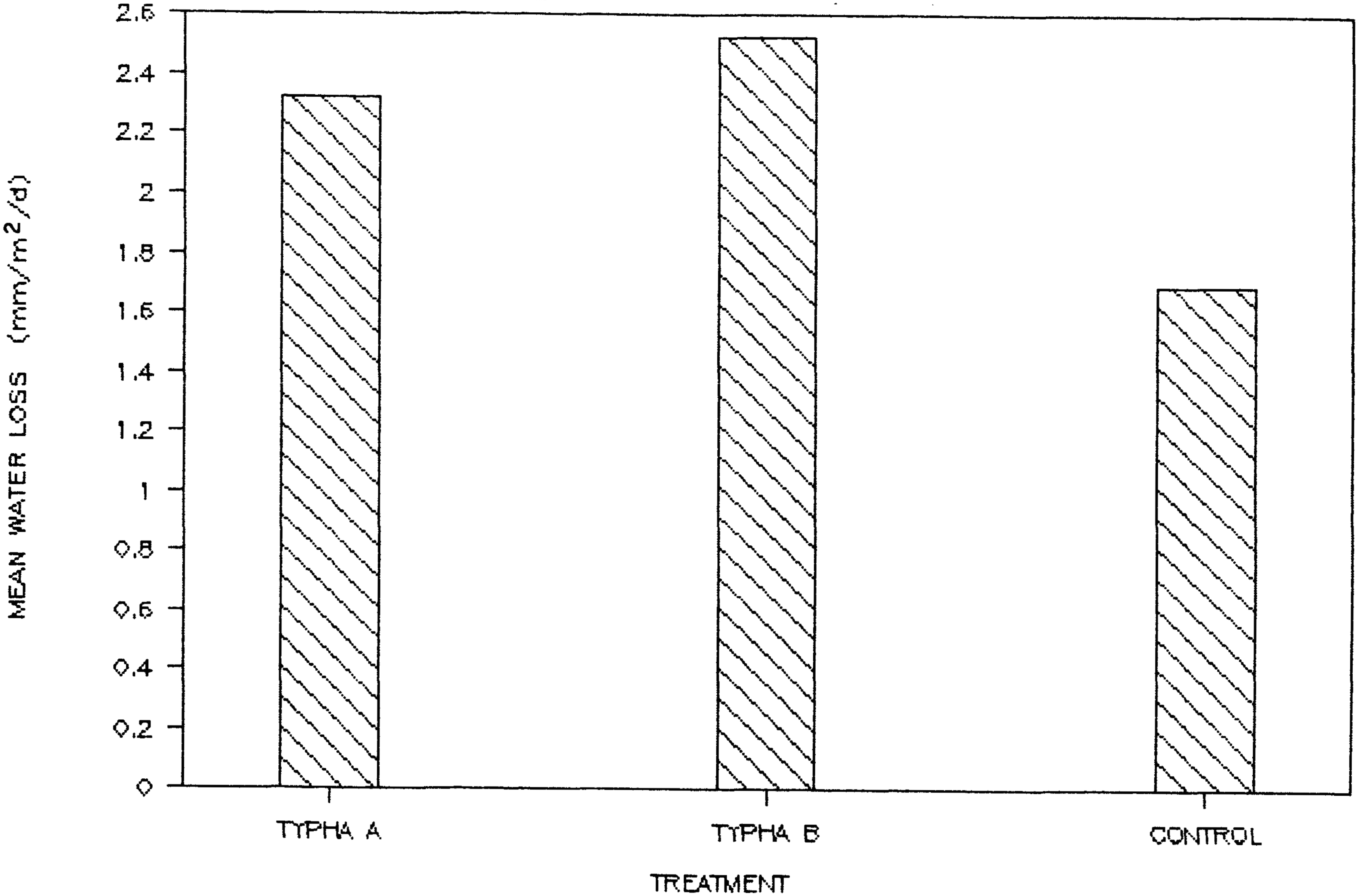


unplanted channels, by 35 to 47%, respectively, for channels A and B. Water loss rates were calculated for the period between July 30 and August 27, 1986 (Figure 3-19). During this period there was no measurable precipitation. The unplanted control channels lost, on average, 1.7 $mm/m^2/d$, while the corresponding values for channels A and B, respectively containing "weaker" and "healthier" populations, were 2.3 and 2.5 $mm/m^2/d$. (1 $mm/m^2/d$ is equivalent to 1 $L/m^2/d$.) Water temperatures ranged from a minimum of 11^oC to a maximum of 33^oC, with a median range of approximately 18-24^oC.

It is evident from the results that cattails increase the rate of water loss relative to open water. Similar results have been reported in other studies. Lakshman (1983) reported water loss rates of 1.3 - 7.8 $L/m^2/d$, over a three year period, in lagoons and ditches planted with cattails. Evaporation losses from experimental channels planted with Phragmites communis in Mississippi were 11.3 $L/m^2/d$, compared to 6.3 $L/m^2/d$ from unplanted channels (Wolverton 1982). The importance of a higher water loss rate would appear, within the context of water treatment, to depend on the value placed on the treated water at a particular location. In some instances, where it is desirable, for example, to maintain a certain minimum flow in the receiving water, the additional water loss through cattail stands may be prohibitive. On the other hand, if the main objective of treatment is to minimize the loading of dissolved substances into a receiving water, then the water loss increment via the cattail stand would be beneficial.

FIGURE 3-19

Average rates of water loss through evapotranspiration from experimental channels planted with cattails, *Typha latifolia* and from an unplanted control



The data also point out that, given the different rates of water loss under planted and unplanted conditions, the concentrations of dissolved minerals would be higher in a planted than in an unplanted system. Therefore, if the concentrations of a particular element are higher in an unplanted system after a given period of time, despite the lower water volume loss, the indication is that the solute removal mechanism in the planted system functions at a higher rate than in the absence of plants. Such appears to be the case in this study.

pH

Conditions in the planted channels evidently maintained a lower pH than in the unplanted channels. Water pH in the experimental channnels was measured on four occasions between August 13 and September 24 (Table 3-2). In the planted channels, the pH ranged from 5.0 to 5.9 (averaging 5.4), while in the control channels, the pH ranged from 5.8 to 6.4 (averaging 6.1). This may be the result of a greater amount of decaying organic matter in the planted channels and, possibly, to the addition of more low pH water to vegetated than unplanted channels.

Decreases in water and soil pH, respectively from 7.5 and 8.1 in May to 6.8 and 6.9 in late August, were measured on Ontario by Byly and O'Neill (1972). Higher pH levels, of 7.0-9.4, were recorded in Florida in channels planted with a combination of cattails and the submergent species elodea (Elodea densa) (Reddy 1983).

TABLE 3-2

RECORD OF WATER pH IN THE PRESENCE AND ABSENCE OF CATTAILS, *Typha latifolia*, IN EXPERIMENTAL CHANNELS

CHANNEL*	DATE (1986)				SEASONAL AVERAGE
	AUG 13	AUG 27	SEP 05	SEP 24	
A-1	5.1	5.5	5.9	5.2	
A-2	5.5	5.1	5.8	5.2	5.4 (planted)
B-1	5.2	5.0	5.6	5.4	
B-2	5.1	5.4	5.6	5.2	5.3 (planted)
C-1	5.9	6.2	6.0	5.8	
C-2	6.2	6.4	6.3	5.9	6.1 (unplanted)

* See text for an explanation of treatments.

Nitrogen monitoring

Table 3-3 summarizes the concentrations of the various N species based on weekly measurements in the experimental channels. All concentrations are reported as nitrogen. It should be noted that the concentrations measured represent the water quality at the end of the weekly nitrate spiking cycle, averaged over the whole monitoring period. The channels containing cattails were associated with lower mean concentrations of all nitrogen species. Relatively high variabilities, however, (see Table 3-3) were due to the changes in concentration over time, as shown in Figure 3-17 to 3-20.

Ammonia concentrations averaged 0.031 mg N/L in channel A, 0.017 mg N/L in channel B, and 1.10 mg N/L in channel C. The higher values obtained in the control during August (with a maximum of 3.6 mg N/L on August 27) would appear to be due to decomposition of organic matter (Figure 3-20) without plant uptake. Despite the greater quantities of organic matter in the planted channels, the maximum recorded ammonia concentration was 0.221 mg N/L, compared to 4.200 mg N/L in the controls.

Nitrite concentrations averaged 0.006 mg N/L in channel A, 0.005 mg N/L in channel B, and 0.084 mg N/L in channel C. Nitrate concentrations averaged 0.045 mg N/L in channel A, 0.011 mg N/L in channel B, and 0.639 mg N/L in the controls. Nitrification was very much in evidence in the unplanted, though not in the planted treatments. This is evidenced in a marked

TABLE 3-3

NITROGEN CONCENTRATIONS IN THE PRESENCE AND ABSENCE OF CATTAILS, *Typha latifolia*, IN EXPERIMENTAL CHANNELS*

AMMONIA CONCENTRATIONS (mg/L)

	A	B	C
mean	0.030	0.017	1.303
S.D.	0.030	0.011	1.311
min.	0.009	0.005	0.070
max.	0.126	0.038	3.535
n	13	13	13

NITRITE CONCENTRATIONS (mg/L)

	A	B	C
mean	0.006	0.005	0.084
S.D.	0.001	0.000	0.089
min.	0.005	0.005	0.016
max.	0.010	0.006	0.343
n	13	13	13

NITRATE CONCENTRATIONS (mg/L)

	A	B	C
mean	0.045	0.010	0.639
S.D.	0.072	0.021	0.576
min.	0.001	0.000	0.096
max.	0.266	0.083	2.192
n	13	13	13

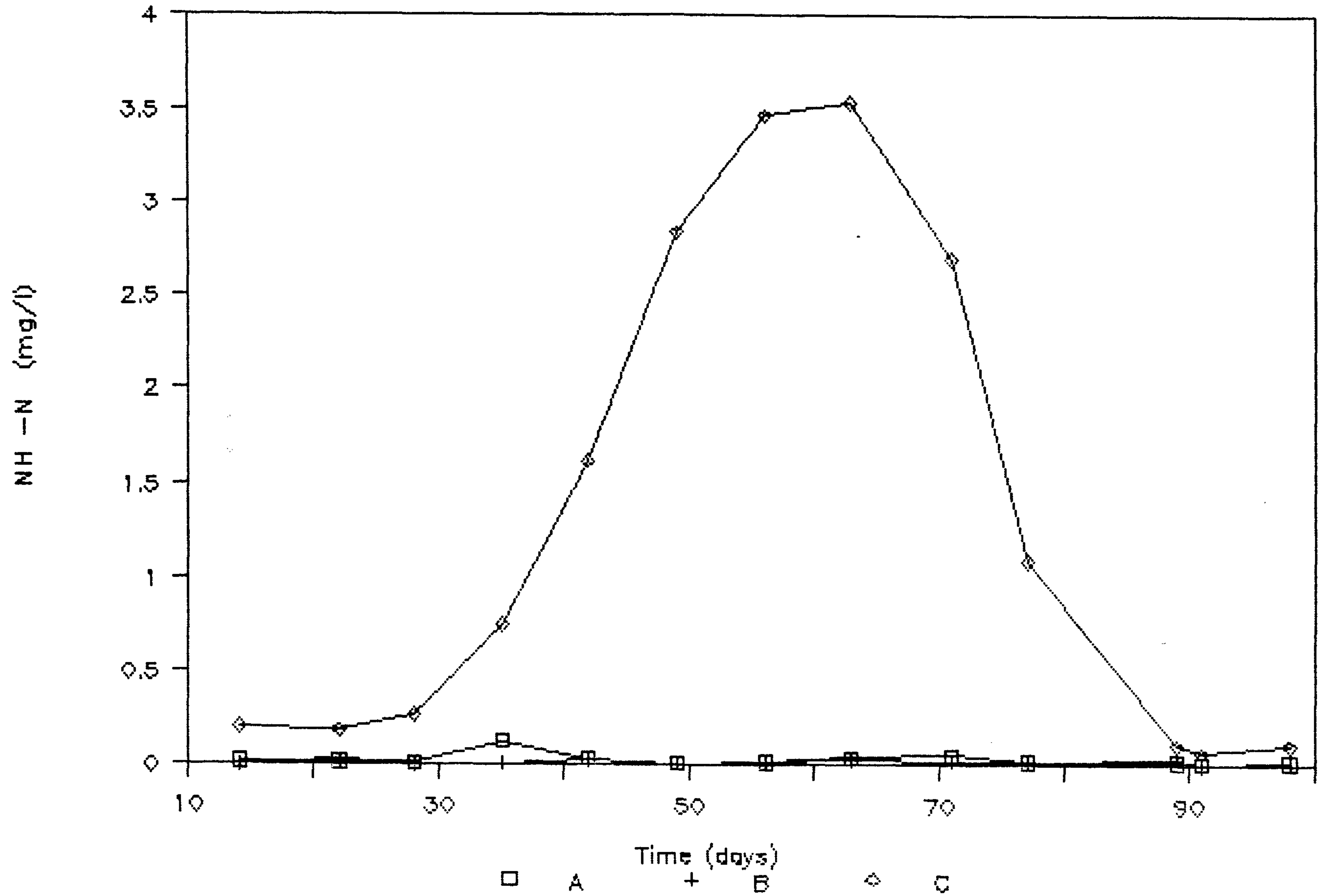
TOTAL-N CONCENTRATIONS (mg/L)

	A	B	C
mean	3.433	4.638	7.129
S.D.	2.085	2.649	3.427
min.	0.000	0.000	0.000
max.	8.800	10.200	11.500
n	13	13	13

* A and B are planted with cattails; C is unplanted control.

FIGURE 3-20

Comparison of ammonia concentration in experimental channels planted with cattails, *Typha latifolia*, and in an unplanted channel, June to October, 1986



increase in nitrite and nitrate concentrations in the control channels (Figures 3-21 and 3-22) between mid August and mid September, coinciding with a sharp decrease in ammonia concentration (Figure 3-20).

The low concentrations of ammonia and nitrite/nitrate in the planted channels as compared to the control (channel C) appear to indicate that N cycling (i.e. oxidation and/or absorption) was taking place at a faster rate in the planted channels than in the controls.

The decrease in inorganic N (ammonia plus nitrate plus nitrite) in the unplanted channels during the latter half of September was probably due to the growth of volunteer grasses and, possibly, to denitrification. The accumulation of nitrate during August, however, would suggest that denitrification of added nitrate was not taking place in the control channels.

Given that the nominal nitrate concentration in the channels at the beginning of each one-week spiking cycle was 12 mg N/L, mean nitrate removal efficiencies were calculated based on the weekly changes in concentrations (Table 3-3). The corresponding efficiencies were 99.6% in treatment A, 99.9% in the treatment B, and 94.7% in the control. (See detailed nitrate study below.)

The concentrations of total N are summarized in Table 3-3. Channel A averaged 3.72 mg/L, channel B averaged 5.03 mg/L, and channel C averaged 7.28 mg/L. There was considerable variation in total N over time in all

FIGURE 3-21

Comparison of nitrite concentrations in experimental channels planted with cattails, Typha latifolia and in an unplanted channel, June to October, 1986

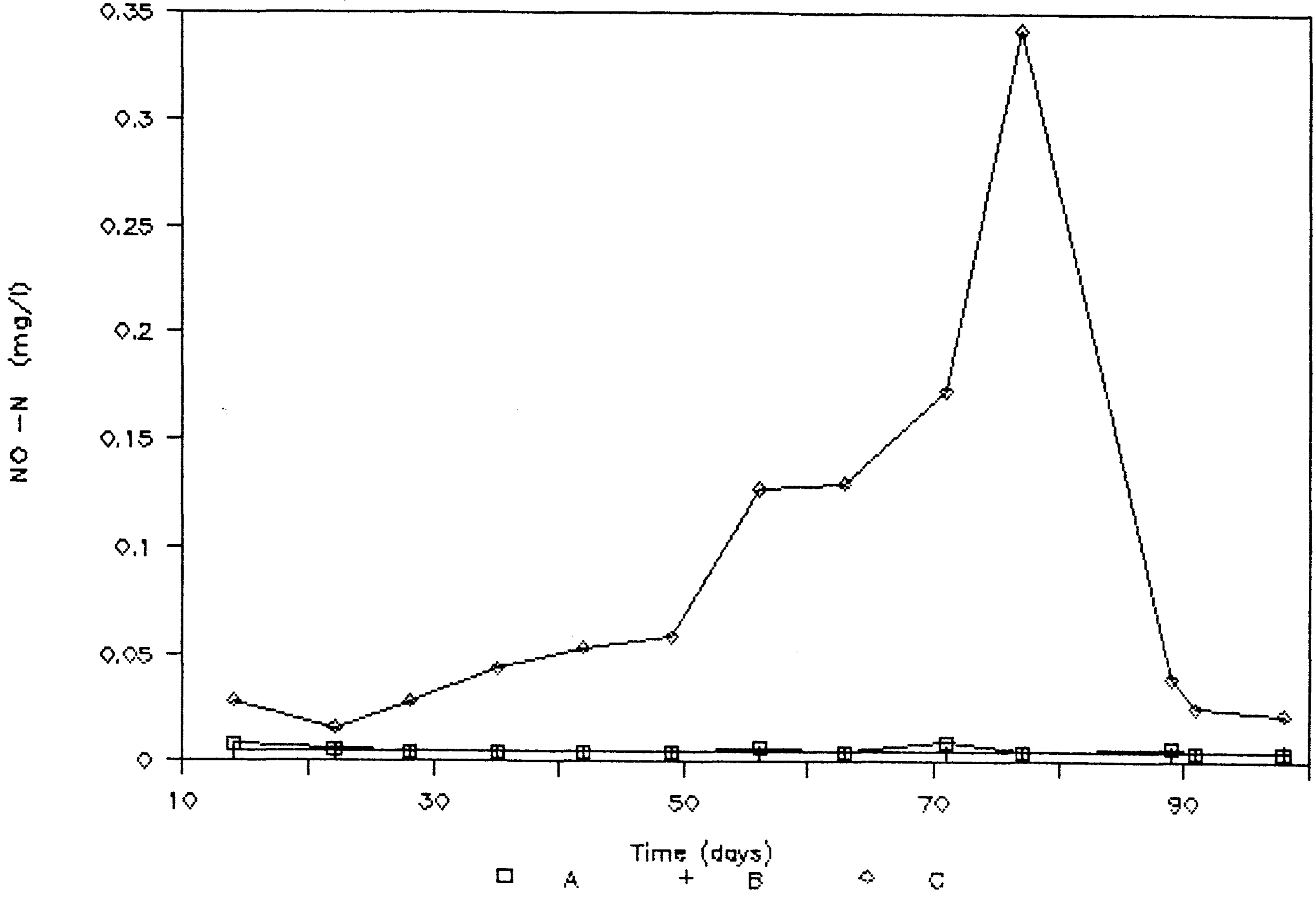
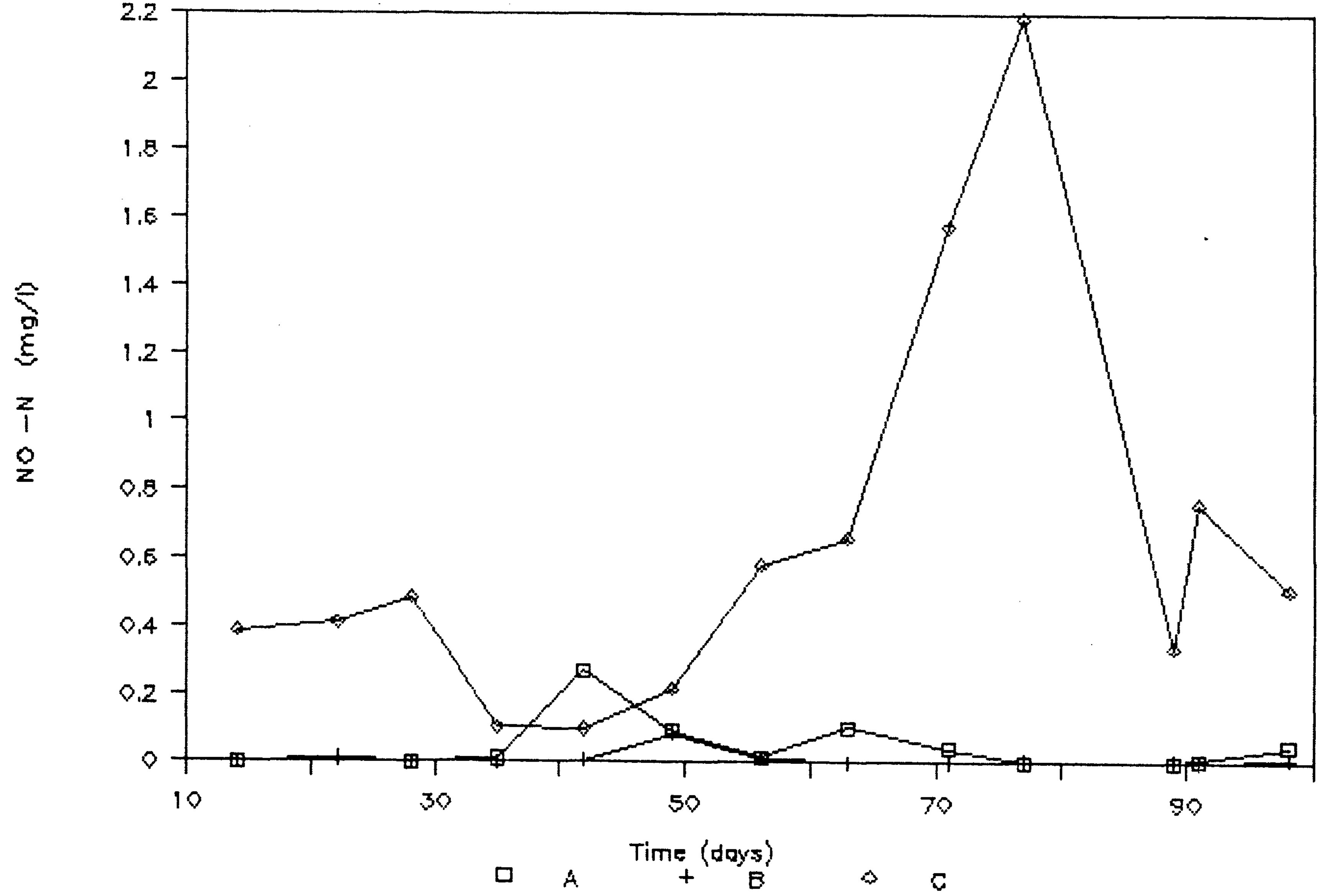


FIGURE 3-22

Comparison of nitrate concentrations in experimental channels planted with cattails, Typha latifolia, and in an unplanted channel, June to October, 1986



three treatments (Figure 3-23). In the planted channels this was almost entirely due to organic N. The inorganic component of the total N (i.e. ammonia, nitrite and nitrate) comprised, on average, 1.3%, 0.7% and 27.8% of the nitrogen in channels A, B, and C, respectively. It is evident therefore that >98% and >70% of the total N under planted and unplanted conditions, respectively, existed as organic N.

Detailed nitrate study

The high nitrate removal efficiencies noted in the planted channels early in the study led to the design of a sub-experiment during which the sampling frequency was increased. Table 3-4 summarizes the changes in nitrogen species concentrations over a 115 hour period after nitrate spiking. Figure 3-24 illustrates the trends in nitrate concentration during this period. As can be seen from the figure, low nitrate concentrations, representing 89.5-99.9% nitrogen removal, were obtained within 25 hours (one day) in the planted channels. The control treatment was able to achieve a similar efficiency within 74 hours (three days). Thus, the nitrate removal rate was three times faster in the presence of cattails than in their absence. These results suggest that the optimum hydraulic retention time for nitrate removal need not necessarily be longer than one day.

Phosphorus

Mean phosphorus concentrations in the planted channels were consistently lower than in the unplanted

FIGURE 3-23

Comparison of total nitrogen concentrations in experimental channels planted with cattails, Typha latifolia, and in an unplanted channel, June to October, 1986

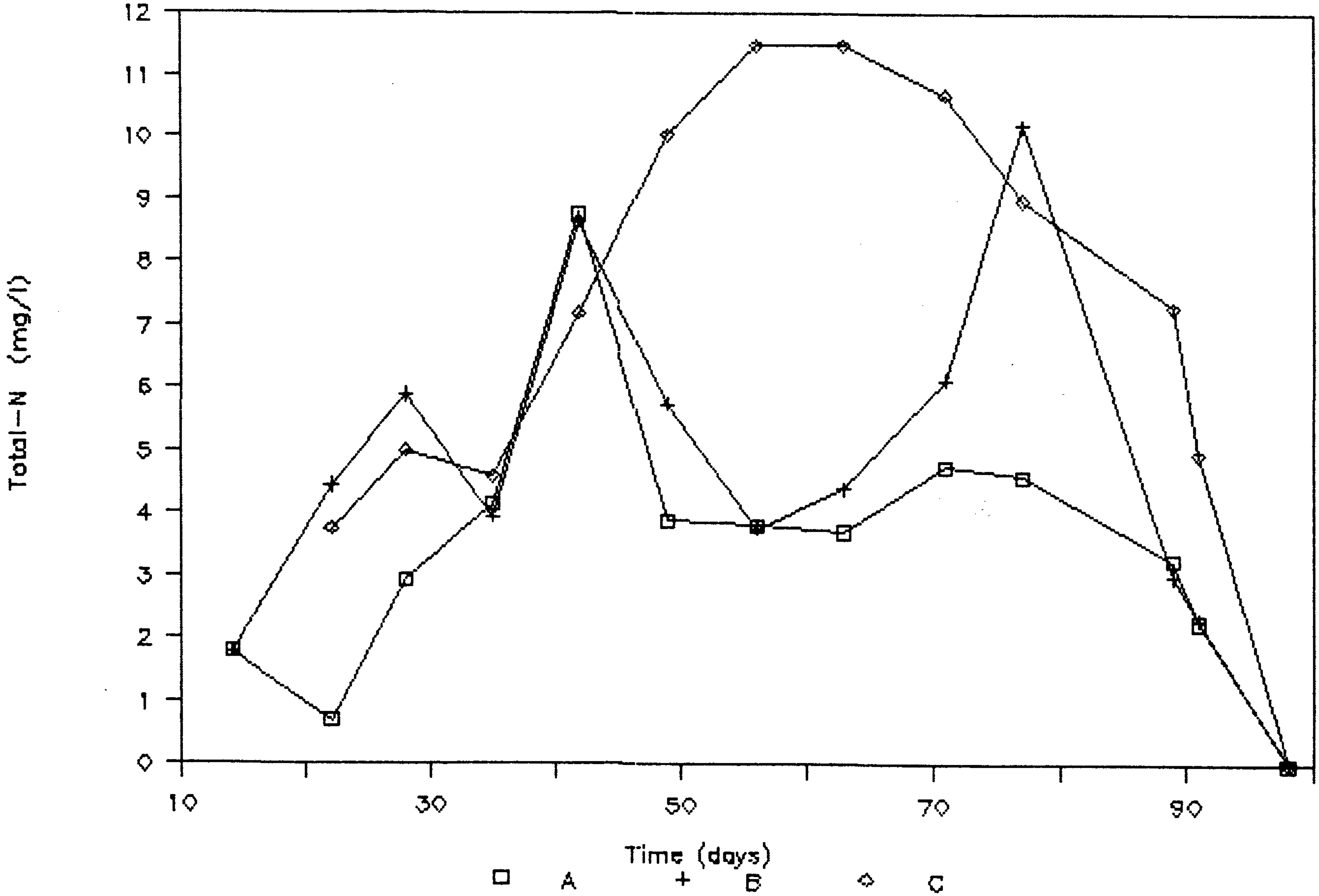


TABLE 3-4

NITROGEN CONCENTRATIONS RECORDED IN THE EXPERIMENTAL CHANNELS DURING THE DETAILED NITRATE STUDY (SEE TEXT)

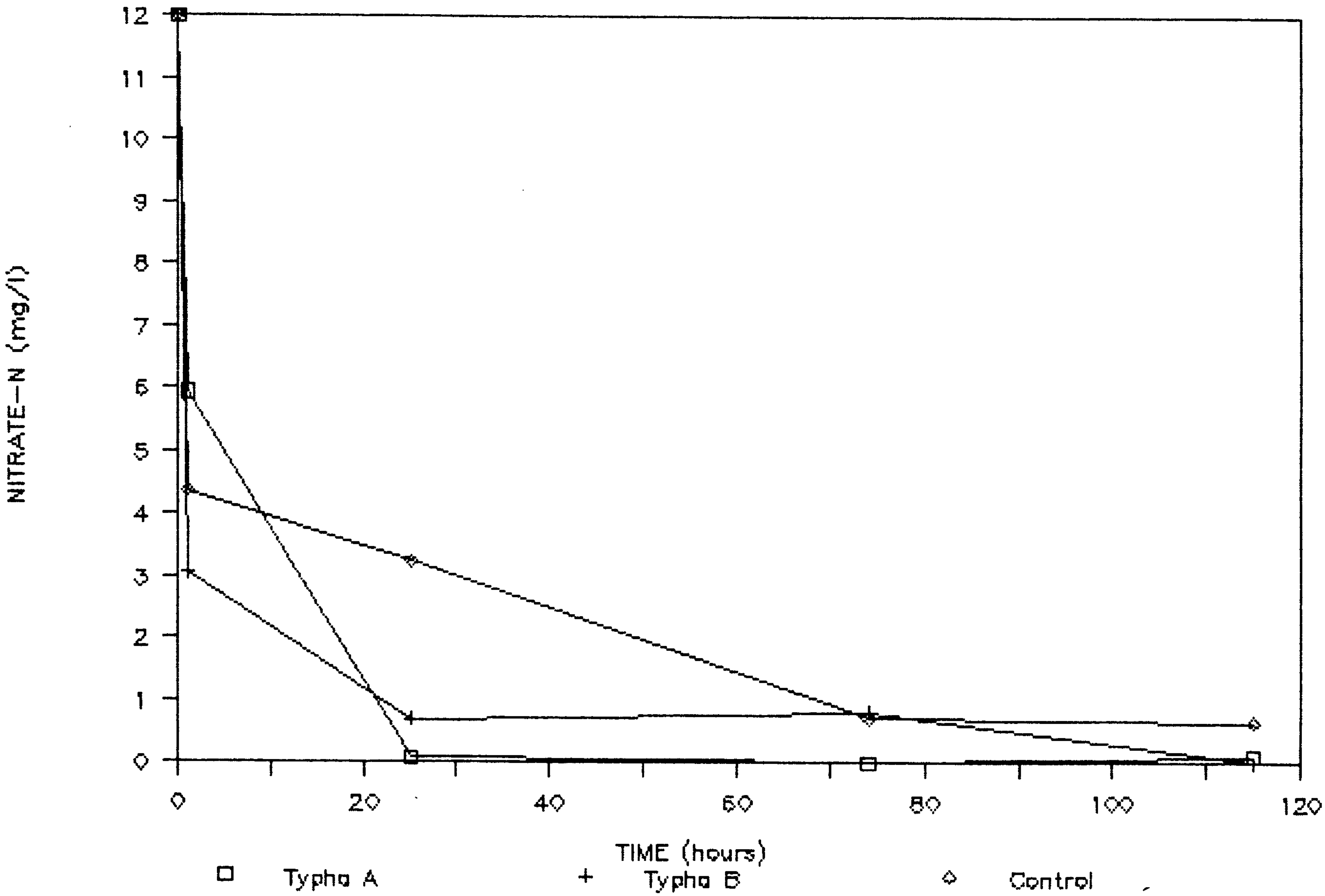
DATE	TIME (hours)	CHANNEL A	CHANNEL B	CHANNEL C
		AMMONIA CONCENTRATION (mg/L)		
22 AUG 86	0	-	-	-
22 AUG 86	1	0.063	0.051	2.680
23 AUG 86	25	0.142	0.095	3.025
25 AUG 86	74	0.071	1.768	1.124
27 AUG 86	115	0.040	0.031	3.535
		NITRITE CONCENTRATION (mg/l)		
22 AUG 86	0	-	-	-
22 AUG 86	1	0.043	0.010	0.075
23 AUG 86	25	0.011	0.007	0.113
25 AUG 86	74	0.005	0.063	0.072
27 AUG 86	115	0.005	0.005	0.130
		NITRATE CONCENTRATION (mg/L)		
22 AUG 86	0	12.000*	12.000*	12.000*
22 AUG 86	1	5.943	3.065	4.380
23 AUG 86	25	0.081	0.695	3.263
25 AUG 86	74	0.008	0.815	0.711
27 AUG 86	115	0.102	0.000	0.659
		TOTAL-N CONCENTRATION (mg/L)		
22 AUG 86	0	-	-	-
22 AUG 86	1	10.500	10.750	13.500
23 AUG 86	25	1.200	2.100	11.000
25 AUG 86	74	1.175	6.350	4.950
27 AUG 86	115	3.700	4.400	11.500

'-' not determined

'*' estimate, based on addition of KNO_3, as described in Section 3.2.4 under Nitrate Enrichment.

FIGURE 3-24

Change in nitrate concentrations in the planted and unplanted channels during the detailed nitrate study (see text)



controls. The least difference between planted and unplanted treatments was found for total P, and the largest difference for ortho-phosphate P (Table 3-5). Treatment A usually exhibited lower P concentrations than treatment B.

The mean ortho-P concentrations over the experimental period were 0.033 mg P/L, 0.189 mg P/L and 0.852 mg P/L in channels A, B, and C, respectively. Minimum ortho-P values of 0.002 to 0.051 mg P/L in the planted channels, and 0.360 to 0.640 mg P/L in the control channels were recorded. Maximum ortho-P levels in the planted channels ranged from 0.034 to 0.430 mg P/L and, in the unplanted channels, from 1.200 to 1.700 mg P/L. The variability in ortho-P was greater in the control than in the planted channels. The former exhibited an increase over time, while the latter showed either little change or a general decrease (Figure 3-25).

The mean total dissolved P (TDP) levels were 0.589 mg P/L, 0.490 mg P/L and 1.396 mg P/L, respectively, in channels A, B, and C. Minimum value ranges were 0.200 to 0.300 mg P/L (planted) and 0.360 to 0.640 mg P/L (control) while maximum value ranges were 0.649 to 1.530 mg P/L (planted) and 1.860 to 2.190 mg P/L (control). Variations in the TDP over time (Figure 3-26) followed a pattern similar to ortho-P. The higher mean TDP than ortho-P values indicate that the larger fraction of the TDP was made up of non-ortho-phosphate (i.e. organic) P.

Mean Total-P concentrations in the three treatments were 0.655 mg P/L, 1.224 mg P/L, and 1.432 mg P/L in

TABLE 3-5

PHOSPHORUS CONCENTRATIONS IN THE PRESENCE AND ABSENCE OF CATTAILS, *Typha latifolia*, IN EXPERIMENTAL CHANNELS**

ORTHO-P* CONCENTRATIONS (mg/L)

	A	B	C
mean	0.033	0.189	0.853
S.D.	0.052	0.116	0.334
min.	0.002	0.035	0.303
max.	0.199	0.390	1.450
n	13	13	13

* ortho phosphate phosphorus

TDP* CONCENTRATIONS (mg/L)

	A	B	C
mean	0.589	0.489	1.396
S.D.	0.234	0.144	0.510
min.	0.205	0.310	0.510
max.	0.965	0.740	2.025
n	13	13	13

* total dissolved phosphorus

TOTAL-P CONCENTRATIONS (mg/L)

	A	B	C
mean	0.655	1.214	1.431
S.D.	0.292	0.747	0.559
min.	0.290	0.345	0.445
max.	1.350	2.665	2.200
n	13	11*	13

* contaminated samples excluded from the calculations.

** A and B are planted with cattails; C is unplanted control

FIGURE 3-25

Comparison of ortho-phosphate concentrations in experimental channels planted with cattails, Typha latifolia, and in an unplanted channel, June to October, 1986

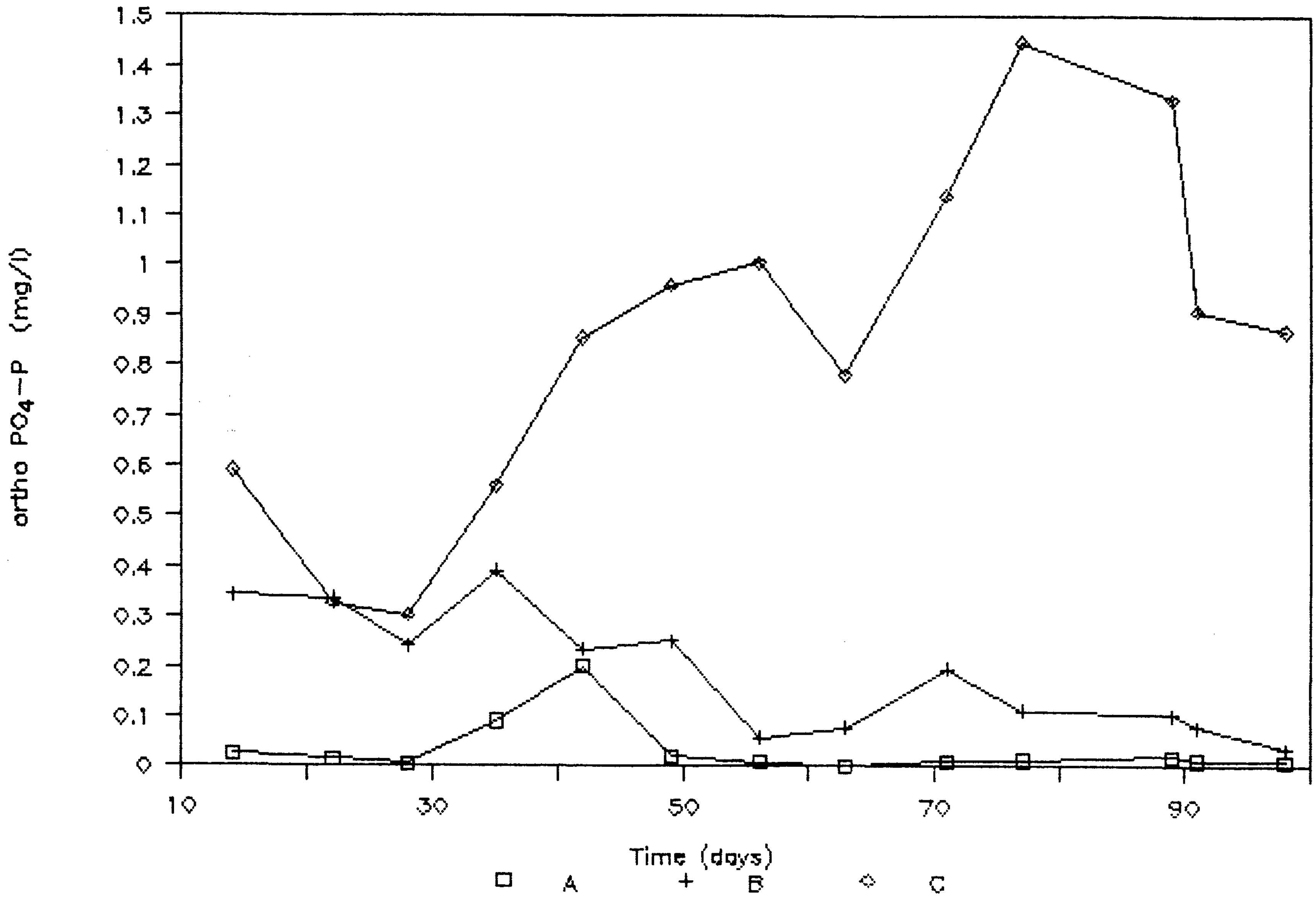
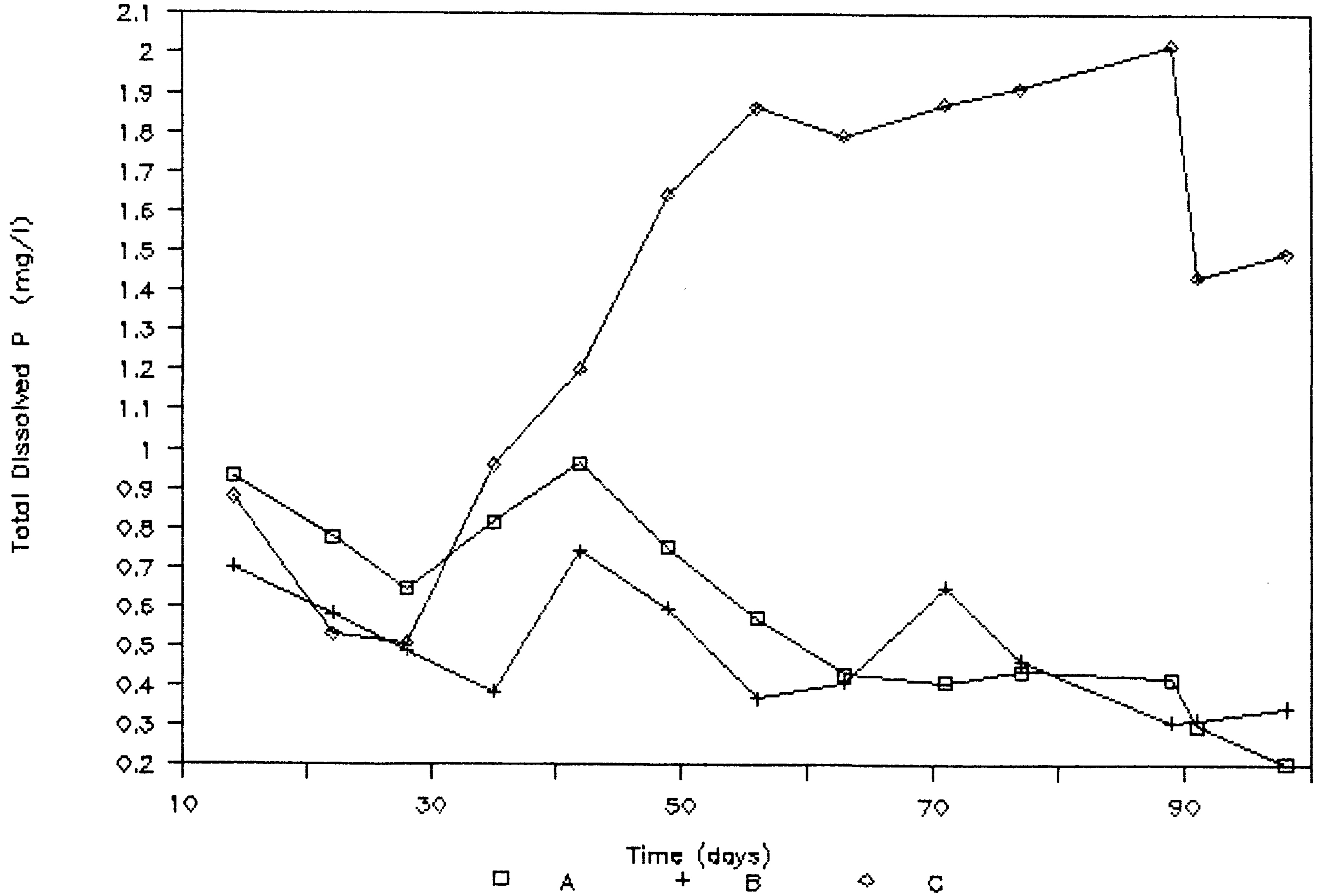


FIGURE 3-26

Comparison of total dissolved phosphorus concentrations in experimental channels planted with cattails, <u>Typha latifolia</u>, and in an unplanted channel, June to October, 1986

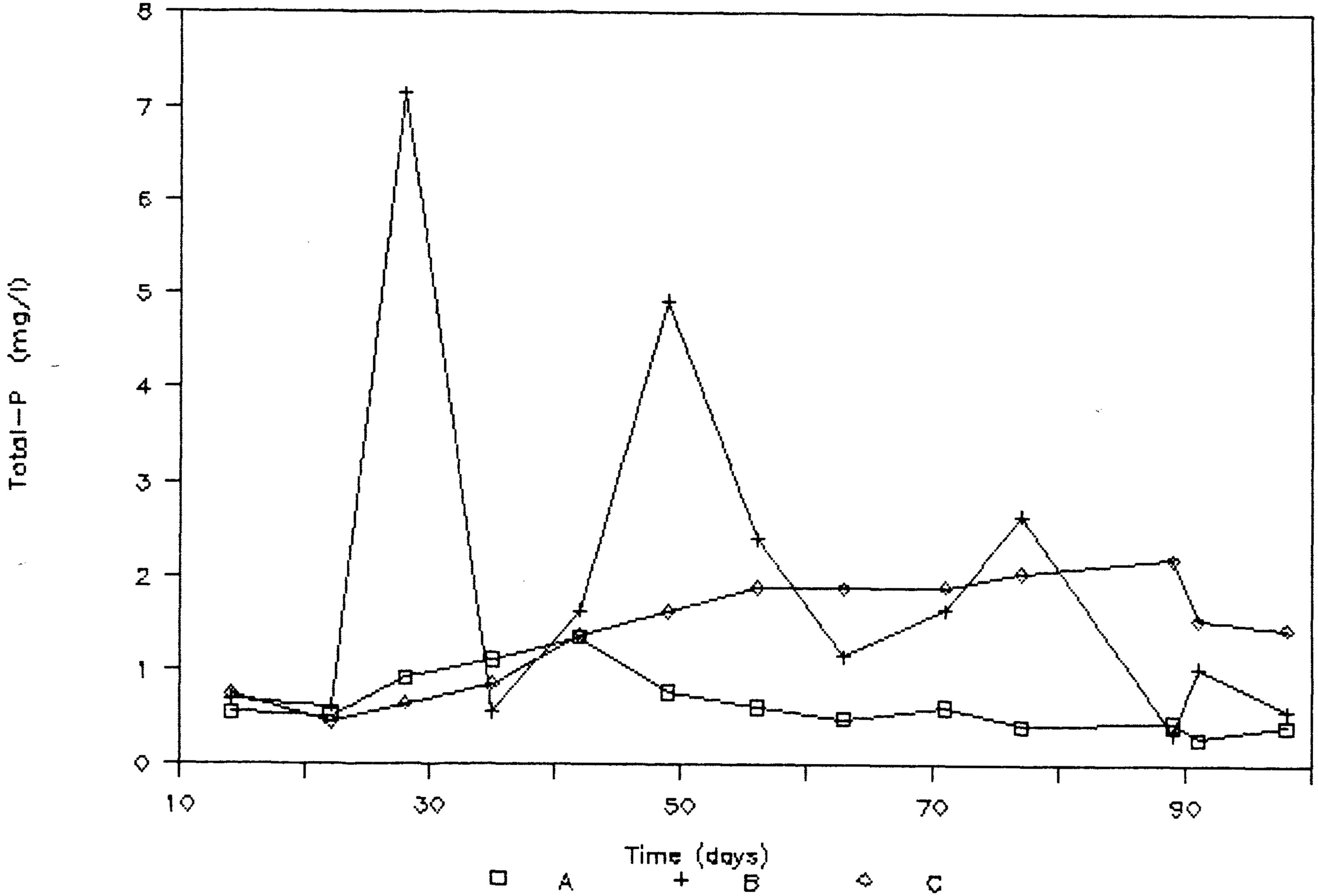


channels A, B and C, respectively. Minimum TP concentration ranges were 0.230 to 0.340 mg P/L in the planted, and 0.310 to 0.580 mg P/L in the unplanted channels, while maximum ranges were 1.330 to 3.800 mg P/L and 2.000 to 2.400 mg P/L, respectively.

Figure 3-27 illustrates the changes in TP over time. The peaks in the curve for treatment B on days 28 and 49 are due to contamination. The concentrations in treatment A exhibited a rising trend during the first four weeks of monitoring, declining thereafter to levels below 0.3 mg P/L. The control showed a gradual increase in TP until the final two weeks of the experiment. The concentration differences were greater between the two cattail treatments (and less between treatment B and the control) for TP than for ortho-P and TDP. The reasons for this are not clear, but may reflect the greater contribution of particulate P in the channels B and C, as the water in the latter channels appeared to contain more algae than that in channel A.

FIGURE 3-27

Comparison of total phosphorus concentrations in experimental channels planted with cattails, _Typha latifolia_, and in an unplanted channel, June to October, 1986



4.0 CONCLUSIONS

It is clear from the literature review that considerable information is already available on the relationships between many species of emergent aquatic plants and their environments. Common to many of the reports on natural wetlands is the observation that the interaction of factors (whether physical, chemical or biological) at the particular site, presented the greatest unknowns in terms of the effects on the plants. The implication here is that site specificity limits the usefulness of comparing field results from different locations, and by extrapolation, that research might best be designed on a case specific basis.

The experimental study has provided information regarding the water treatment capabilities of cattail, Typha latifolia, in experimental, constructed wetlands. The following conclusions are drawn from the study:

- Cattail propagules, consisting of an emerging shoot attached to a 20 cm length of rhizome, can be successfully transplanted in the early spring; dormancy does not appear to be necessary for successful transplanting. Flowering can take place within the same season as transplanting.

- Growth rates of transplanted cattails were dependent on the condition of the source stand;

transplants from a weak stand (i.e. poor rhizome condition) grew more slowly than plants from healthy stock. Plant growth rates averaging 0.89 $\pm$ 0.14 cm/d to 1.47 $\pm$ 0.31 cm/d were recorded between April and July. After July, growth of the original transplants was negligible, although growth of new ramets continued throughout the experiment. Plant densities in the experimental channels between June 25 and October 1 increased from 26 to 44 plants per square metre.

- Cattail tissue nutrient content varied over the growing season. Maximum leaf nitrogen contents of 0.75 to 1.10% (dry matter) were recorded during August, and maximum leaf phosphorus content of 0.18 to 0.26% were found in late June (N and P not measured before June 26). Rhizome N content generally peaked in August, at 0.23 to 0.69%, except in the wild population at a nutrient-rich site, which exhibited a decline throughout the June 26 to October 1 monitoring period. Rhizome P contents, ranging over 0.13 to 0.31% in the wild stands and 0.10 to 0.28% in the cultured populations, generally decreased through the season. In the cultured populations, there was an increase in rhizome P during September. Fruiting body N and P content ranges were 0.60 to 1.1% and 0.26 to 0.34%, respectively. Fruit N content was higher than that found in leaves or rhizomes only in cultured plants, whereas fruit P content was consistently higher than in other tissues.

- Lower dissolved nitrogen concentrations and stable, low phosphorus concentrations, were associated with channels containing cattails, in comparison with unplanted channels. Nitrate concentrations in channels containing cattails were reduced within one day from 12 mg N/L to an average of 0.388 mg N/L, and within 8 days to an average of 0.028 mg N/L. In unplanted channels the mean nitrate concentration after three days was 3.3 mg N/L, and after 8 days was 0.639 mg N/L. The corresponding nitrate concentration reduction efficiencies were 96.8% and 99.8% (1 and 8 days) in the cattail channels, compared to 72.5% and 94.7% (3 and 8 days) in the controls.

- Concentrations of total dissolved phosphorus in experimental cattail wetlands can be lower than 1 mg P/L. Soluble phosphorus concentrations in the presence of cattails were over 60% lower than in the unplanted channels, averaging 0.539 mg P/L compared to 1.396 mg P/L, respectively.

The study confirms that channels planted with cattails can improve the quality of a simulated mine wastewater. The further development of this technology would benefit from concentrated research in the areas of hydraulics (retention times, depths, drying), plant harvesting frequency and timing, optimization of micronutrient availability, and wastewater specific species selection. Also, investigation of reuse options for the cropped biomass is necessary. Because of the success of the laboratory and small-scale field trials, a transition to pilot scale research is warranted. It is necessary to test the concept under field, operating conditions so that the feasibility of using aquatic plants to treat nitrogen-rich coal mine wastewaters can be determined.

5.0 ACKNOWLEDGMENTS

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APPENDIX 1

Glossary of Emergent Plant Species

APPENDIX 1

GLOSSARY OF EMERGENT PLANT SPECIES

The names presented below are based on the following sources: Fasset 1957, Muenscher 1972, Weldon et al. 1973, and Morton 1974.

SCIENTIFIC NAME	COMMON NAMES(S)
Cyperus esculentus	Galingale, sedge
Cyperus involucratus	Galingale
Distichlis spicata	Salt grass
Eleocharis palustris	Spikerush
Equisetum fluviatile	Pipes, horsetail
Juncus effusus	Soft rush
Juncus roemerianus	Rush
Phalaris arundinaceae	Reed canary grass
Phragmites communis	Reed grass, giant reed
Phragmites australis	Reed
Sagittaria falcata	Arrowhead, duck potato
Scirpus* acutus	Hardstem bulrush, clubrush
Scirpus fluviatilis	River bulrush
Scirpus subterminalis	Water clubrush
Scirpus validus	Softstem, or great bulrush
Sparganium eurycarpum	Bur reed
Spartina alterniflora	Cord Grass
Spartina cynosuroides	Cord Grass
Spartina patens	Cord Grass
Typha angustifolia	Narrowleaf cattail
Typha domingensis	Southern cattail
Typha glauca	Blueflag cattail
Typha latifolia	Common, or broadleaf cattail
Typha orientalis	Asian cattail

* This genus is sometimes named Schoenoplectus, particularly in the European literature.

APPENDIX 2

Cattail Height Measurements

APPENDIX 2(a)

TYPHA HEIGHT MEASUREMENTS *

CHANNEL A-1

DATE	DAY No.	REPLICATE PLANT NUMBER									
		1	2	3	4	5	6	7	8	9	10
MAY 15	0	29.8	18.5	14.8	17.0	29.0	43.0	-2.2	1.3	28.1	-22.5
MAY 23	8	42.1	28.5	24.7	30.5	42.3	60.9	11.1	11.4	41.1	-5.8
MAY 30	15	53.5	35.2	35.0	39.8	50.2	72.4	25.8	24.9	48.2	14.8
JUN 05	21	58.5	38.4	38.3	45.1	55.3	79.8	34.9	33.1	57.8	27.9
JUN 12	28	59.4	44.9	41.4	52.5	64.1	83.2	42.2	37.2	66.7	39.0
JUN 19	35	62.6	50.2	48.9	58.8	65.5	90.4	47.5	44.3	76.4	44.4
JUN 25	41	66.2	52.7	50.2	60.5	68.2	93.8	55.4	45.2	82.1	48.8
JUL 02	48	72.3	60.1	56.8	67.2	78.6	104.5	57.5	51.1	89.2	52.3
JUL 09	55	78.3	69.2	65.7	77.3	81.6	108.6	64.1	57.2	97.0	61.8
JUL 18	64	87.9	76.2	69.1	82.2	84.5	118.3	66.7	65.6	109.3	68.9
JUL 23	69	90.9	82.4	72.4	85.6	89.6	118.4	68.6	70.5	111.6	73.9
JUL 30	76	92.1	84.8	73.9	89.1	92.4	117.0	68.0	70.5	118.3	74.6
AUG 06	83	92.5	86.2	74.8	90.2	93.6	118.6	68.3	70.4	119.0	73.9
AUG 20	97	91.5	85.8	75.1	90.0	92.2	118.1	68.1	70.7	118.5	73.9
AUG 27	104	91.8	84.4	74.6	90.1	92.5	117.8	68.2	71.5	119.1	74.0
SEP 11	119	92.4	85.5	74.6	90.3	93.2	118.5	68.5	71.1	118.6	75.1
OCT 01	140	92.7	85.8	75.3	91.2	93.7	119.1	68.9	71.0	119.0	75.1

'*' - cm above a fixed reference point **(approx. 40cm above ground level for all channels)**

TYPHA HEIGHT MEASUREMENTS *

CHANNEL A-2

DATE	DAY No.	REPLICATE PLANT NUMBER									
		11	12	13	14	15	16	17	18	19	20
MAY 15	0	34.4	18.1	40.6	3.5	10.2	26.7	4.9	9.8	19.9	31.0
MAY 23	8	45.5	27.4	56.5	13.8	14.6	39.5	12.9	18.5	30.6	41.6
MAY 30	15	60.5	38.6	68.2	21.9	22.5	49.6	18.4	26.0	25.4	48.3
JUN 05	21	72.0	44.6	85.5	27.8	27.3	60.3	23.9	34.5	43.4	53.1
JUN 12	28	75.6	52.0	80.5	35.2	31.0	65.2	37.3	40.5	49.7	60.1
JUN 19	35	74.8	55.3	88.8	45.4	38.8	75.1	40.4	44.3	53.1	68.2
JUN 25	41	75.9	57.1	97.2	50.2	40.7	77.6	49.8	49.1	62.5	71.2
JUL 02	48	79.8	59.1	102.7	53.4	43.4	84.6	53.4	55.1	66.1	78.0
JUL 09	55	85.6	67.1	110.6	58.9	46.5	92.9	57.4	57.2	71.7	85.1
JUL 18	64	92.7	78.5	111.1	68.6	46.5	94.1	54.7	62.3	82.2	92.8
JUL 23	69	99.4	80.6	112.0	68.6	46.7	95.4	63.3	62.6	83.7	104.5
JUL 30	76	102.1	81.2	112.1	69.0	-	101.2	64.0	65.9	82.8	100.9
AUG 06	83	102.9	81.6	112.1	73.4	46.6	102.8	64.6	66.9	86.7	102.0
AUG 20	97	101.9	81.8	112.8	75.7	47.2	102.2	63.7	66.9	87.4	102.1
AUG 27	104	102.5	82.6	112.2	75.8	48.2	103.4	64.8	68.8	87.4	102.6
SEP 11	119	102.7	82.6	112.0	75.7	-	102.8	64.2	67.0	87.1	102.2
OCT 01	140	102.2	83.0	112.4	76.6	-	103.3	64.7	67.5	87.1	102.6

'-' - not available

APPENDIX 2(b)

TYPHA HEIGHT MEASUREMENTS *

CHANNEL B-1

DATE	DAY No.	REPLICATE PLANT NUMBER									
		21	22	23	24	25	26	27	28	29	30
MAY 15	0	51.0	16.0	45.4	57.2	65.5	43.1	41.0	18.0	34.5	29.0
MAY 23	8	71.1	40.5	71.3	77.8	83.8	59.0	61.7	31.0	50.4	44.6
MAY 30	15	87.3	70.2	92.7	97.8	101.2	73.0	82.0	51.0	68.0	56.9
JUN 05	21	99.0	87.7	107.8	109.2	113.4	79.4	95.2	59.2	80.1	67.4
JUN 12	28	107.8	100.6	123.9	119.4	128.2	90.3	108.9	68.9	91.6	75.3
JUN 19	35	117.0	116.2	130.8	122.5	137.7	96.4	124.9	77.2	95.7	81.3
JUN 25	41	126.8	129.8	139.0	127.5	151.4	114.8	135.1	85.3	104.5	89.7
JUL 02	48	129.1	139.2	150.8	137.9	161.6	118.2	150.3	87.5	108.2	94.8
JUL 09	55	135.0	139.9	153.3	139.7	174.1	121.5	156.6	92.2	115.3	103.8
JUL 18	64	141.6	141.8	153.7	139.9	183.5	126.1	159.4	94.3	119.3	115.9
JUL 23	69	141.7	141.2	153.8	139.7	183.2	126.8	158.7	96.6	120.3	116.5
JUL 30	76	142.8	142.0	154.6	141.3	198.2	126.9	160.2		120.3	116.8
AUG 06	83	143.5	144.6	155.8	140.7	185.9	129.5	160.3	97.1	122.2	116.3
AUG 20	97	142.7	142.0	152.6	140.8	188.1	127.3	150.6	97.2	121.0	116.0
AUG 27	104	143.4	143.0	152.9	140.6	184.5	126.5	159.1	97.2	120.5	117.4
SEP 11	119	143.6	142.8	-	141.1	185.0	127.7	159.3	-	120.8	116.7
OCT 01	140	143.8	142.9	-	141.0	188.5	-	160.8	-	121.4	116.8

'-' - not available

TYPHA HEIGHT MEASUREMENTS *

CHANNEL B-2

DATE	DAY No.	REPLICATE PLANT NUMBER									
		31	32	33	34	35	36	37	38	39	40
MAY 15	0	28.3	32.5	43.8	61.8	64.0	43.5	43.1	54.5	30.4	56.3
MAY 23	8	47.2	47.0	57.5	84.1	88.2	56.1	58.2	72.0	46.1	71.4
MAY 30	15	62.6	65.4	72.2	97.2	101.1	65.7	72.4	90.3	67.3	93.3
JUN 05	21	73.6	68.6	88.7	109.3	123.6	65.0	84.1	101.2	80.8	104.6
JUN 12	28	89.3	78.5	88.5	114.1	133.2	64.5	90.6	110.6	91.6	123.8
JUN 19	35	98.3	84.0	92.1	119.5	144.5	72.0	96.8	119.7	100.2	138.0
JUN 25	41	109.1	87.8	97.4	126.0	153.9	79.9	106.9	134.3	108.6	152.8
JUL 02	48	113.8	95.1	105.6	126.0	159.2	94.9	110.4	136.5	115.8	160.4
JUL 09	55	119.1	102.4	112.3	134.5	165.3	102.3	119.2	137.6	115.9	164.9
JUL 18	64	124.7	102.3	113.6	144.5	165.2	110.0	131.5	138.9	115.6	167.3
JUL 23	69	125.1	102.6	115.6	143.9	165.5	110.9	133.2	138.5	117.8	167.7
JUL 30	76	126.9	102.4	105.7	144.1	165.5	111.1	131.7	137.9	118.2	167.2
AUG 06	83	126.3	103.1	115.1	143.2	166.2	110.5	131.8	137.8	118.5	167.2
AUG 20	97	127.1	102.5	115.3	143.7	165.6	111.3	133.3	138.7	117.1	166.9
AUG 27	104	127.1	104.0	116.3	144.5	167.2	111.6	132.9	140.3	119.1	168.8
SEP 11	119	128.6	104.1	116.4	141.0	167.0	111.7	133.5	139.4	118.2	169.0
OCT 01	140	107.8	103.0	114.7	143.7	165.8	110.9	132.7	138.6	118.6	167.5

APPENDIX 2(c)

PLANT HEIGHT MEASUREMENTS

MUSQUEAM NATURAL WETLAND

DATE	DAY No.	REPLICATE PLANT NUMBER									
		41	42	43	44	45	46	47	48	49	50
MAY 15	0	-	-	-	-	-	-	-	-	-	-
23	8	40.0	34.6	61.1	28.0	40.5	49.2	62.2	43.8	54.8	41.0
30	15	54.7	56.5	76.6	49.1	64.1	73.4	77.6	74.7	72.2	58.0
JUN 05	21	-	-	-	-	-	-	-	-	-	-
JUN 12	28	-	-	-	-	-	-	-	-	-	-
JUN 19	35	84.6	87.6	118.5	70.4	95.6	104.7	111.1	107.9	88.3	89.6
JUN 25	41	89.2	90.0	133.1	75.6	108.7	105.2	111.0	108.1	87.9	98.6
JUL 02	48	90.7	103.2	134.6	76.0	112.4	109.1	112.3	108.1	98.9	98.5
JUL 09	55	99.5	105.7	134.3	75.6	101.4	108.9	114.8	107.5	88.8	98.1
JUL 18	64	99.7	106.2	135.9	100.9	112.7	108.3	114.6	107.2	88.5	98.2
JUL 23	69	-	-	-	-	-	-	-	-	-	-
JUL 30	76	99.8	105.6	133.2	61.0	113.2	107.9	114.5	106.5	87.6	98.1
AUG 06	83	100.3	106.1	133.9	71.7	111.9	108.2	115.5	108.2	89.1	100.1
AUG 20	97	-	-	-	-	-	-	-	-	-	-
AUG 27	104	98.5	107.0	131.4	74.5	113.0	107.4	113.7	105.7	86.9	97.8
SEP 11	119	99.4	106.4	133.5	-	114.0	87.1	110.5	90.0	86.8	97.8
OCT 01	140	91.1	107.7	133.6	-	-	86.6	-	-	-	97.4

'-' - not available

PLANT HEIGHT MEASUREMENTS

MARINE DRIVE NATURAL WETLAND

DATE	DAY No.	REPLICATE PLANT NUMBER									
		51	52	53	54	55	56	57	58	59	60
MAY 15	0	-	-	-	-	-	-	-	-	-	-
23	8	55.3	66.3	47.3	25.0	20.2	13.0	24.2	22.7	15.5	20.0
30	15	78.5	82.0	69.8	29.8	40.9	41.6	46.4	45.1	34.4	42.2
JUN 05	21	-	-	-	-	-	-	-	-	-	-
JUN 12	28	-	-	-	-	-	-	-	-	-	-
JUN 19	35	116.9	102.6	112.0	65.4	65.5	68.9	83.6	77.1	62.4	74.5
JUN 25	41	130.2	104.0	129.5	75.4	70.8	74.4	97.5	99.3	67.2	85.9
JUL 02	48	132.1	106.3	143.7	89.7	80.2	74.6	103.8	107.0	66.7	78.8
JUL 09	55	131.4	97.0	132.1	93.6	82.0	74.7	110.1	114.7	66.0	81.3
JUL 18	64	131.6	106.8	131.1	93.7	87.2	73.1	121.4	115.3	67.3	93.8
JUL 23	69	-	-	-	-	-	-	-	-	-	-
JUL 30	76	132.0	117.5	129.2	92.9	96.1	73.1	129.7	121.1	31.9	95.1
AUG 06	83	135.6	111.7	132.0	93.2	101.5	72.8	129.6	121.1	32.1	101.7
AUG 20	97	-	-	-	-	-	-	-	-	-	-
AUG 27	104	131.2	98.9	130.9	92.2	101.9	73.0	130.6	121.0	65.7	102.2
SEP 11	119	131.6	107.7	130.7	76.9	101.7	64.2	130.2	120.8	-	102.0
OCT 01	140	-	-	-	-	-	-	-	-	-	-

'-' - not available

APPENDIX 3

Cattail Nitrogen and Phosphorus Content

APPENDIX 3(a)

TYPHA NITROGEN CONTENT (ug/g dry weight)

DATE	JOB	SAMPLE	TISSUE	MEAN	S.D.	C.V.*	MIN	MAX	"n"
26 JUNE	860831	MUSQUEAM	ROOTS	6815	2506	36.8	2822	9571	10
			SHOOTS	8069	2568	31.8	1080	10375	10
		SWMDRIVE	ROOTS	3831	2485	64.9	138	10520	10
			SHOOTS	6551	1529	23.3	4047	9254	10
		CHAN.A	ROOTS	1175	1098	93.5	405	3070	4
			SHOOTS	6437	1289	20.0	4810	8185	4
		CHAN.B	ROOTS	2226	1527	68.6	650	4450	4
			SHOOTS	5533	320	5.8	5202	6008	4
20 AUG	861059	MUSQUEAM	ROOTS	6575	882	13.4	4200	9100	4
			SHOOTS	11000	707	6.4	10000	12000	4
			FLOWERS	7100	700	9.9	6400	7800	2
		SWMDRIVE	ROOTS	4575	2330	50.9	1000	7100	4
			SHOOTS	8350	3050	36.5	3600	12000	4
			FLOWERS	5950	2650	44.5	3300	8600	2
		CHAN.A	ROOTS	1600	308	19.3	1100	1900	4
			SHOOTS	7450	2358	31.7	3600	10000	4
			FLOWERS	10000	0	0.0	10000	10000	1
		CHAN.B	ROOTS	3000	1420	47.3	1100	5100	10
			SHOOTS	7325	1450	19.8	5300	9400	4
22 SEP	861232	CHAN.A	ROOTS	3883	1635	42.1	2000	12000	6
			SHOOTS	6233	1706	27.4	3200	8300	6
		CHAN.B	ROOTS	5017	1689	33.7	3000	8300	6
			SHOOTS	7450	1695	22.7	5600	11000	6
23 OCT	861307	MUSQUEAM	ROOTS	4767	2373	49.8	2200	8700	6
			SHOOTS	5000	935	18.7	3200	6300	6
		SWMDRIVE	ROOTS	3385	1818	53.7	540	5400	4
			SHOOTS	4275	460	10.8	3700	4900	4
		CHAN.A	ROOTS	2167	512	23.6	1500	3000	6
			SHOOTS	4500	638	14.2	3500	5200	6
		CHAN.B	ROOTS	2717	1187	43.7	1100	4800	6
			SHOOTS	5883	855	14.5	4900	7600	6

* - C.V. = coefficient of variability (%)
(standard deviation, S.D., as % of mean)

APPENDIX 3(b)

TYPHA PHOSPHORUS CONTENT (ug/g dry weight)

DATE	JOB	SAMPLE	TISSUE	MEAN	S.D.	C.V.*	MIN	MAX	"n"
26 JUNE	860831	MUSQUEAM	ROOTS	3080	621	20.2	2380	4410	10
			SHOOTS	2395	221	9.2	1980	2690	10
		SWMDRIVE	ROOTS	828	187	22.5	530	1250	10
			SHOOTS	1814	348	19.2	1250	2400	10
		CHAN.A	ROOTS	1333	623	46.8	740	2290	4
			SHOOTS	2565	285	11.1	2180	2980	4
		CHAN.B	ROOTS	2865	329	11.5	2390	3320	4
			SHOOTS	2195	135	6.1	2010	2380	4
06 AUG	861059	MUSQUEAM	ROOTS	2433	166	6.8	2260	2700	4
			SHOOTS	2255	119	5.3	2070	2400	4
			FLOWERS	3105	165	5.3	2940	3270	2
		SWMDRIVE	ROOTS	826	557	67.4	35	1550	4
			SHOOTS	1463	602	41.1	712	2180	4
			FLOWERS	2630	270	10.3	2360	2900	2
		CHAN.A	ROOTS	943	389	41.3	540	1450	4
			SHOOTS	2055	287	14.0	1700	2480	4
			FLOWERS	3480	0	0.0	3480	3480	1
		CHAN.B	ROOTS	2160	490	22.7	1410	2680	4
			SHOOTS	1910	183	9.6	1730	2200	4
27 AUG	861232	CHAN.A	ROOTS	805	213	26.5	423	1060	6
			SHOOTS	2212	224	10.1	1800	2500	6
		CHAN.B	ROOTS	1763	221	12.5	1540	2180	6
			SHOOTS	2045	165	8.1	1800	2350	6
01 OCT	861307	MUSQUEAM	ROOTS	2722	1057	38.8	1270	4170	5
			SHOOTS	1419	802	56.5	763	3170	6
		SWMDRIVE	ROOTS	738	47	6.4	659	774	4
			SHOOTS	469	204	43.6	283	805	4
		CHAN.A	ROOTS	1332	295	22.1	810	1830	6
			SHOOTS	1125	258	22.9	662	1480	6
		CHAN.B	ROOTS	1852	212	11.5	1390	2020	6
			SHOOTS	1292	148	11.5	1050	1490	6

*' - C.V. = coefficient of variability (%)
(standard deviation, S.D., as % of mean)

APPENDIX 4

Soil Nitrogen and Phosphorus Content

APPENDIX 4

SOIL NITROGEN AND PHOSPHORUS CONTENT
DURING CATTAIL CULTURE EXPERIMENT

LOCATION	NUTRIENT	CONCENTRATION (% dry matter)			
		17 APR	02 JUL	06 AUG	01 OCT
CHANNEL A	N:	-	0.50	0.44	0.30
(planted)	P:	-	0.26	0.22	0.16
CHANNEL B	N:	-	0.44	0.49	0.53
(planted)	P:	-	0.21	0.25	0.29
CHANNEL C	N:	-	-	0.46	0.37
(control)	P:	-	-	0.23	0.19
MUSQUEAM	N:	0.95*	0.39	0.39	0.36
(wild)	P:	0.39*	0.40	0.39	0.41
MARINE DR	N:	0.26*	0.02	0.07	0.02
(wild)	P:	0.05*	0.06	0.05	0.06

* N and P values marked with an asterisk represent TKN and total P, respectively.
(This data from UBC, all other data from EPS lab.)
Note: soil at the experimental site prior to channel excavation (17 Apr.) contained 0.35% TKN and 0.07% P.

APPENDIX 5

Water Loss

APPENDIX 5

WATER LOSS IN THE EXPERIMENTAL CHANNELS (EVAPORATION/TRANSPIRATION)

CHANGE IN WATER LEVEL units: cm

DATE	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
		CHANNEL (planted)				(unplanted)	
MAY 15	0	3.0	3.2	2.4	2.4	-	-
MAY 23	8	0.6	0.1	-1.6	-1.6	-	-
MAY 30	15	0.9	0.1	-1.6	-1.6	-2.3	-4.7
JUN 05	21	4.7	3.9	1.9	1.9	-	-
JUN 12	28	7.4	7.1	4.9	4.9	-	-
JUN 19	35	7.9	7.1	5.7	5.7	1.9	0.1
JUN 25	41	8.4	8.4	6.7	6.7	2.2	0.2
JUL 02	48	-0.2	0.0	0.3	0.3	-0.6	-0.9
JUL 09	55	3.2	2.8	3.4	3.4	1.3	1.6
JUL 18	64	0.3	0.5	0.9	0.9	-0.4	-0.4
JUL 23	69	2.1	1.8	2.1	2.1	0.6	0.5
JUL 30	76	2.4	2.6	3.7	3.7	1.9	2.2
AUG 06	83	2.3	2.5	3.6	3.6	1.7	2.3
AUG 13	90	1.4	1.9	2.5	2.5	1.1	1.7
AUG 20	97	1.4	2.3	2.5	2.5	1.7	1.8
AUG 27	104	2.2	2.8	3.6	3.6	1.8	2.1
SEP 03	111	1.4	1.4	2.6	2.6	0.8	1.0
SEP 11	119	1.9	1.2	3.0	3.0	0.8	1.0
SEP 24	132	-1.5	-1.2	-0.5	-0.5	-2.9	-3.5
OCT 01	140	-2.1	-1.7	-0.9	-0.9	-4.0	-4.1

WATER LOSS RATE units: mm/m^3/d

DATE	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
		(planted)				(unplanted)	
MAY 15	0	-	-	-	-	-	-
MAY 23	8	0.5	0.1	-1.0	-1.4	-	-
MAY 30	15	0.9	0.1	-1.6	-1.6	-2.3	-4.8
JUN 05	21	5.7	4.7	2.5	2.3	-	-
JUN 12	28	7.6	7.2	5.2	5.0	-	-
JUN 19	35	8.1	7.2	5.7	5.9	1.9	0.1
JUN 25	41	10.0	10.0	7.9	8.0	2.7	0.3
JUL 02	48	-0.2	0.0	-0.7	0.3	-0.6	-0.9
JUL 09	55	3.3	2.9	2.0	3.5	1.3	1.6
JUL 18	64	0.2	0.4	-0.6	0.7	-0.3	-0.3
JUL 23	69	3.0	2.6	1.3	3.0	0.9	0.7
JUL 30	76	2.5	2.7	2.2	3.8	1.9	2.3
AUG 06	83	2.4	2.6	2.4	3.7	1.7	2.4
AUG 13	90	1.4	1.9	1.5	2.6	1.1	1.7
AUG 20	97	1.4	2.4	1.8	2.6	1.7	1.8
AUG 27	104	2.3	2.9	1.8	3.7	1.8	2.2
SEP 03	111	1.4	1.4	1.0	2.7	0.8	1.0
SEP 11	119	1.7	1.0	1.5	2.7	0.7	0.9
SEP 24	132	-0.9	-0.7	-1.8	-0.3	-1.6	-1.9
OCT 01	140	-1.9	-1.5	-3.6	-0.8	-3.6	-3.7

'-' not applicable or no measurement taken

APPENDIX 6

Water Nitrogen Concentration

APPENDIX 6(a)

CATTAIL WATER AMMONIA CONCENTRATION Units:mgN/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	0.028	0.007	0.005	0.005	0.118	0.288
17 JULY	860863	22	0.028	0.006	0.009	0.045	0.268	0.103
23 JULY	860945	28	0.023	0.005	0.006	0.005	0.450	0.085
30 JULY	860901	35	0.031	0.221	0.011	0.013	1.330	0.172
06 AUG	860974	42	0.037	0.031	0.016	0.044	1.940	1.290
13 AUG	860991	49	0.013	0.005	0.008	0.009	2.510	3.170
20 AUG	861057	56	0.025	0.012	0.019	0.011	3.010	3.920
27 AUG	861098	63	0.053	0.026	0.04	0.022	2.87	4.2
04 SEP	861117	71	0.090	0.022	0.023	0.021	2.200	3.200
10 SEP	861138	77	0.025	0.012	0.015	0.014	0.850	1.330
22 SEP	861233	89	0.020	0.014	0.055	0.021	0.092	0.120
24 SEP	861242	91	0.012	0.007	0.005	0.005	0.077	0.063
01 OCT	861167	98	0.032	0.005	0.009	0.005	0.100	0.111
		MEAN	0.032	0.029	0.017	0.017	1.217	1.389
		S.D.	0.020	0.056	0.014	0.013	1.101	1.565
		MIN.	0.012	0.005	0.005	0.005	0.077	0.063
		MAX.	0.090	0.221	0.055	0.045	3.010	4.200
		n	13	13	13	13	13	13

CATTAIL WATER NITRITE CONCENTRATION Units:mgN/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	0.0110	0.0050	0.0050	0.0050	0.0180	0.0390
17 JULY	860863	22	0.0070	0.0050	0.0050	0.0050	0.0100	0.0210
23 JULY	860945	28	0.0050	0.0050	0.0050	0.0050	0.0340	0.0230
30 JULY	860901	35	0.0050	0.0050	0.0050	0.0050	0.0750	0.0120
06 AUG	860974	42	0.0050	0.0050	0.0050	0.0050	0.0930	0.0240
13 AUG	860991	49	0.0050	0.0050	0.0050	0.0050	0.0680	0.0430
20 AUG	861057	56	0.0080	0.0050	0.0050	0.0050	0.1330	0.1220
27 AUG	861098	63	0.0050	0.0050	0.0050	0.0050	0.1400	0.1200
04 SEP	861117	71	0.0140	0.0050	0.0050	0.0050	0.1700	0.1760
10 SEP	861138	77	0.0050	0.0050	0.0050	0.0050	0.1510	0.5350
22 SEP	861233	89	0.0070	0.0060	0.0050	0.0050	0.0290	0.0490
24 SEP	861242	91	0.0050	0.0050	0.0050	0.0050	0.0220	0.0290
01 OCT	861167	98	0.0050	0.0050	0.0060	0.0050	0.0190	0.0260
		MEAN	0.0067	0.0051	0.0051	0.0050	0.0732	0.0942
		S.D.	0.0027	0.0003	0.0003	0.0000	0.0552	0.1360
		MIN.	0.0050	0.0050	0.0050	0.0050	0.0100	0.0120
		MAX.	0.0140	0.0060	0.0060	0.0050	0.1700	0.5350
		n	13	13	13	13	13	13

APPENDIX 6(b)

CATTAIL WATER NITRATE CONCENTRATION Units:mgN/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	0.002	0.004	0.002	0.003	0.468	0.305
17 JULY	860863	22	-0.002	0	0	0.020	0.530	0.293
23 JULY	860945	28	0.002	0.002	0	0	0.808	0.169
30 JULY	860901	35	0.019	0.002	0	0	0.205	0.001
06 AUG	860974	42	0.481	0.051	0.008	0.001	0.185	0.007
13 AUG	860991	49	0.101	0.081	0.079	0.087	0.269	0.156
20 AUG	861057	56	0.007	0.023	0.011	0.012	0.479	0.682
27 AUG	861098	63	0.203	0	0	0	0.537	0.780
04 SEP	861117	71	0.077	0.006	0	0	1.130	2.024
10 SEP	861138	77	0	0.001	0.004	0.003	1.549	2.835
22 SEP	861233	89	0.001	0.004	0.007	0.003	0.477	0.198
24 SEP	861242	91	0.013	0.001	0	0	0.358	1.161
01 OCT	861167	98	0.090	0.009	0.016	0.010	0.225	0.794
		MEAN	0.076	0.014	0.010	0.011	0.555	0.723
		S.D.	0.130	0.024	0.021	0.023	0.381	0.816
		MIN.	0	0	0	0	0.185	0.001
		MAX.	0.481	0.081	0.079	0.087	1.549	2.835
		n	13	13	13	13	13	13

CATTAIL WATER TOTAL-NITROGEN CONCENTRATION Units:mgN/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	2.20	1.40	1.50	2.10	3.70	(<1)
17 JULY	860863	22	0.59	0.78	4.70	4.20	3.70	3.80
23 JULY	860945	28	4.70	1.20	6.80	5.00	5.50	4.50
30 JULY	860901	35	2.10	6.20	4.50	3.40	3.60	5.60
06 AUG	860974	42	6.60	11.00	9.90	7.40	4.40	10.00
13 AUG	860991	49	4.10	3.70	8.30	3.20	9.10	11.00
20 AUG	861057	56	4.90	2.70	4.10	3.40	10.00	13.00
27 AUG	861098	63	4.80	2.60	3.30	5.50	10.00	13.00
04 SEP	861117	71	5.90	3.60	7.50	4.80	9.40	12.00
10 SEP	861138	77	6.00	3.20	8.40	12.00	8.00	10.00
22 SEP	861233	89	4.20	2.30	2.60	3.40	6.50	8.10
24 SEP	861242	91	2.80	1.70	2.10	2.50	4.50	5.40
01 OCT	861167	98						
		MEAN	4.07	3.37	5.31	4.74	6.53	8.03
		S.D.	1.74	2.69	2.67	2.59	2.51	3.97
		MIN.	0.59	0.78	1.50	2.10	3.60	(<1)
		MAX.	6.60	11.00	9.90	12.00	10.00	13.00
		n	12	12	12	12	12	12

APPENDIX 7

Water Phosphorus Concentration

APPENDIX 7(a)

CATTAIL WATER ORTHO-PHOSPHORUS CONCENTRATION Units:mgP/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	0.034	0.015	0.260	0.430	0.871	0.310
17 JULY	860863	22	0.005	0.025	0.290	0.380	0.515	0.140
23 JULY	860945	28	0.006	0.004	0.154	0.330	0.460	0.145
30 JULY	860901	35	0.020	0.160	0.390	0.390	0.720	0.400
06 AUG	860974	42	0.018	0.380	0.320	0.147	1.030	0.680
13 AUG	860991	49	0.024	0.016	0.170	0.330	1.230	0.690
20 AUG	861057	56	0.010	0.005	0.051	0.063	1.300	0.710
27 AUG	861098	63	0.002	0.002	0.106	0.047	0.800	0.760
04 SEP	861117	71	0.018	0.003	0.194	0.197	1.700	0.580
10 SEP	861138	77	0.016	0.007	0.146	0.078	1.700	1.200
22 SEP	861233	89	0.027	0.015	0.153	0.055	1.570	1.100
24 SEP	861242	91	0.014	0.010	0.118	0.038	1.080	0.740
01 OCT	861167	98	0.007	0.015	0.051	0.019	0.990	0.750
		MEAN	0.015	0.051	0.185	0.193	1.074	0.631
		S.D.	0.009	0.103	0.099	0.150	0.397	0.308
		MIN.	0.002	0.002	0.051	0.019	0.460	0.140
		MAX.	0.034	0.380	0.390	0.430	1.700	1.200
		n	13	13	13	13	13	13

CATTAIL WATER TOTAL DISSOLVED PHOSPHORUS CONCENTRATION Units:mgP/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	1.530	0.330	0.598	0.805	1.090	0.669
17 JULY	860863	22	1.110	0.450	0.605	0.563	0.640	0.420
23 JULY	860945	28	0.970	0.320	0.400	0.580	0.660	0.360
30 JULY	860901	35	0.780	0.850	0.350	0.420	1.070	0.850
06 AUG	860974	42	0.670	1.260	0.600	0.880	1.470	0.940
13 AUG	860991	49	0.760	0.740	0.510	0.680	1.920	1.370
20 AUG	861057	56	0.760	0.380	0.320	0.420	2.140	1.590
27 AUG	861098	63	0.611	0.250	0.350	0.470	2.000	1.590
04 SEP	861117	71	0.601	0.220	0.649	0.654	2.140	1.610
10 SEP	861138	77	0.616	0.260	0.430	0.497	2.130	1.700
22 SEP	861233	89	0.545	0.290	0.360	0.260	2.190	1.860
24 SEP	861242	91	0.340	0.260	0.300	0.330	1.300	1.580
01 OCT	861167	98	0.210	0.200	0.400	0.290	1.700	1.300
		MEAN	0.731	0.447	0.452	0.527	1.573	1.218
		S.D.	0.322	0.302	0.119	0.184	0.550	0.490
		MIN.	0.210	0.200	0.300	0.260	0.640	0.360
		MAX.	1.530	1.260	0.649	0.880	2.190	1.860
		n	13	13	13	13	13	13

APPENDIX 7(b)

CATTAIL WATER TOTAL-PHOSPHORUS CONCENTRATION Units:mgP/L

DATE	JOB No.	DAY No.	A-1	A-2	B-1	B-2	C-1	C-2
09 JULY	860830	14	0.790	0.310	0.490	0.912	0.930	0.555
17 JULY	860863	22	0.650	0.380	0.695	0.539	0.580	0.310
23 JULY	860945	28	1.160	0.670	*13.000	1.290	0.870	0.420
30 JULY	860901	35	1.170	1.050	0.720	0.400	0.980	0.730
06 AUG	860974	42	1.370	1.330	1.950	1.340	1.500	1.240
13 AUG	860991	49	0.850	0.690	*6.060	3.800	1.890	1.370
20 AUG	861057	56	0.830	0.390	2.520	2.290	2.180	1.600
27 AUG	861098	63	0.740	0.240	0.300	2.000	2.200	1.570
04 SEP	861117	71	0.950	0.270	1.900	1.400	2.200	1.590
10 SEP	861138	77	0.626	0.230	2.980	2.350	2.300	1.800
22 SEP	861233	89	0.589	0.320	0.400	0.290	2.400	2.000
24 SEP	861242	91	0.340	0.240	1.600	0.480	1.700	1.400
01 OCT	861167	98	0.587	0.260	0.300	0.860	1.600	1.300
		MEAN	0.819	0.491	1.066	1.381	1.641	1.222
		S.D.	0.273	0.336	0.962	0.968	0.600	0.523
		MIN.	0.340	0.230	0.300	0.290	0.580	0.310
		MAX.	1.370	1.330	2.980	3.800	2.400	2.000
		n	13	13	11	13	13	13

'*' Contaminated samples, not included in statistical calculations.

APPENDIX 8

AQUATIC PLANT SPECIES OF POTENTIAL USE IN TREATING COAL MINE WASTEWATERS

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1.0 INTRODUCTION

This booklet provides basic information on aquatic plants or macrophytes that are potentially useful for treating coal mine drainage. The information is presented in two sections. The first section gives an overview of how wastewaters are treated in environments that contain aquatic plants. The second section provides a listing of species, their common and scientific names, a brief description of the plant form, habitat and range, as well as comments on preferred transplanting methods and, where available, other observations related to their use for water treatment.

The species presented here have been selected from scientific and technical reports dealing with aquatic macrophytes and wetland treatment of a variety of wastewaters. Most of the plants listed have been recognized to contribute to the removal of suspended materials and of dissolved substances from wastewater. The list is preliminary, however, and will hopefully be revised and expanded as more information becomes available.

2.0 OVERVIEW OF WETLAND TREATMENT PROCESSES

The basic objective of a macrophyte treatment system is to remove pollutants, such as nutrients, from a water source prior to discharge to a receiving environment. Macrophyte systems remove nutrients from water through a variety of biological, chemical and physical mechanisms which are related to the general ecosystem of the wetland.

Biological removal of nutrients is accomplished by direct uptake of nitrogen and phosphorus by plants, and by micro-organisms growing on the surface of plants, in the water and in the soil. Plant assimilation of nutrients takes place through both the roots and other submerged plant surfaces. Nutrients are also removed by chemical mechanisms that are largely a by-product of microbiological activity, and by settling of suspended particles.

Nitrogen is removed through direct uptake by plants, and through chemical changes brought about by bacteria living in the sediment. After a series of transformations, most of the nitrogen leaves the wetland as gas, and returns to the atmosphere.

Phosphorus removal occurs through uptake by the plants, through chemical conditions which transform the mineral to a form which makes it unavailable (insoluble) as a nutrient, and through settling of suspended particles containing phosphorus. Due to these processes, a major portion of the phosphorus ends up in the bottom soils. Provided there is sufficient oxygen, the phosphorus will remain in the soil in an insoluble state and will not be released into the water. Rooted emergent plant species planted in artificial wetlands are selected because they have the ability to pump oxygen to the root zone and adjacent soil.

Harvesting is a means of removing nitrogen and phosphorus and other minerals that have accumulated in the plants. Cutting also stimulates growth of most species, producing more vegetation than under uncropped conditions. Harvesting also means there is less material to decompose during the winter months, and therefore fewer nutrients tend to be recycled within the wetland.

3.0 List of Selected Plant Species

3.1 Cattails

Species:

broadleaf cattail (*Typha latifolia*)
narrowleaf cattail (*Typha angustifolia*)

Description:

Cattails are a large marsh plant commonly found in waters generally less than 30 cm deep, including recently constructed impoundments. The species is readily identified by the furry appearance (like a cat's tail) of the brown to tan seed head that is borne at the tip of a long spike. The leaves are long and narrow, light green to blue-green, flattened and spongy to the touch, up to 2.5 m long and less than 2 cm wide for most of their length. The plants have a creeping rootstock or rhizome from which new shoots arise.

Habitat:

Cattails are found in still water along the shores of lakes and ponds, as well as in the upper intertidal zone of estuaries. The species often occur in extensive stands having more than 30 plants per square meter.

Range:

T. latifolia: throughout Canada
T. angustifolia: Ontario to Nova Scotia

Comments:

Cattails are early colonizers of newly established wetlands, as the light seeds are readily transported by wind. The plants are also easily transplanted in Spring using 20 cm lengths of rhizome (preferably with emerging shoot) planted 10 cm deep in soil. Recommended spacing is about 0.5 to 1 m between transplants. A dense stand can develop during the growing season following planting.

3.2 Bulrushes

Species:

Soft-stemmed bulbrush; Tule	Scirpus lacustris
American bulbrush	Scirpus americanus
Seacoast bulbrush	Scirpus maritimus
(and others)	

Description:

An erect marsh plant commonly found in waters less than 1.5 m deep. The species are readily identified by the light to dark green colour and shape of the plant. The leaves are narrow and may be longer or shorter than the stem, or reduced to scales at the base of the stem. The stem or "culm" which may be circular (S. lacustris) to triangular (S. americanus and S. maritimus) in cross section, is usually green, up to about 2 cm thick and up to 3 m long depending on the species. The flower generally occurs at the tip of the culm, and is light green to light brown in colour. Culms arise singly from a creeping rootstock which may also have tubers (e.g. S. fluviatilis).

Habitat:

Bulbrushes are found on moist soil, in fresh to brackish water, along the outer (i.e. deeper) edge of shore vegetation, or in separate stands away from shore. The species can occur in extensive dense stands which can contain in excess of 200 culms (stems) per square meter.

Range:

S. lacustris:	throughout Canada
S. americanus:	throughout southern Canada
S. maritimus:	common along the Atlantic and Pacific coasts, also found inland

Comments:

Bulrushes transplant easily by means of rhizome cuttings and, or, tubers, planted 5 - 10 cm deep in the soil. Recommended spacing is 0.5 m between transplants. A dense stand can develop during the growing season following transplanting. Since bulbrush seeds are relatively large, new stands can also be started from seeds planted in wet but unflooded soil. Certain smaller species, such as S. sylvaticus and S. caespitosus can grow at higher elevations.

3.3 Reeds

Species:

Common or giant reed (*Phragmites communis*)

Reedgrass

Description:

A tall marsh reed found in dense stands. The species is readily identified by the prominent plume-like flower that is borne at the tip of the stem. The plant has a true cane-like stem supporting grass-like leaves. The stem can be up to 4 m long and the long flattened leaves range from 1 to 5 cm wide. The stems occur in dense clusters or "stools" that arise from the rootstock which may be either on top of or below ground level.

Habitat:

Reeds can grow both in and out of water, at depths ranging from over 2 m deep to 1 m above the water table.

Range:

Throughout southern Canada.

Comments:

Reeds can be transplanted by means of rhizome cuttings. Since plant propagation through budding is slower than in cattails and bulbrushes, two growing seasons must be allowed to establish a mature stand. Recommended plant spacing is 0.5 m between transplants.

3.4 Rushes

Species:

Common rush (*Juncus effusus*)
Bayonet rush (*Juncus militaris*)

Description:

A smaller plant, less than 1 m high, that grows in dense clusters rather than extensive stands. The common rush is readily identified by its yellow-brown to dark-brown flower that characteristically arises from the side of the culm, up to 20 cm below the tip. The green culms are round in cross-section, usually less than 5 mm thick. Creeping rhizomes may or may not be present.

Habitat:

Rushes are typically found in wet or periodically flooded soils where water depth seldom exceeds 5 cm.

Range:

J. effusus: throughout southern Canada
J. militaris: Ontario to Nova Scotia

Comments:

Rushes can be propagated from seed or from rootstock cuttings. Recommended spacing is less than 0.4 m between transplants or sprouts. This species would appear to be well adapted to seepage areas where water flow occurs mostly through rather than over the soil.

3.5 Duckweed

Species:

common duckweed (Lemna minor)
giant duckweed (Spirodela polyrhiza)

Description:

Duckweed is a small (2 - 5 mm diameter) free-floating plant that, in sheltered areas, grows in mats on the water surface. Although microscopic flowers do occur, the main form of reproduction is through budding. The common duckweed is smaller than the giant duckweed, and is readily identified by its single root (0.1 cm to more than 10 cm long) compared to the multiple root of the latter species. Where the two species co-exist, Lemna is usually dominant.

Habitat:

Duckweed is commonly found in still, freshwater environments, sheltered from wind or current. Typical habitats include drainage ditches, slow-flowing brooks and small lakes or ponds. The plants are often found growing among other emergent species such as cattails, bulbrushes and reeds.

Range:

Throughout Canada

Comments:

Duckweeds are among the fastest growing plants in the world, and consequently have the potential to extract considerable quantities of nutrients (nitrogen and phosphorus), as well as other substances, from the water. The species is easily transplanted between sites and is commonly introduced to new impoundments by waterfowl. An effective duckweed mat will only become established in a coal mine settling pond if the water surface is sheltered from wind.

APPENDIX 9

Tissue and Soils Metals Content during the Cattail Experiment

The following table summarizes the metals content of cattail tissue and soil, from samples collected at the wild sites and experimental channels during the growing season of 1986. The sites are characterized as follows:

Marine Drive - wild cattail population, sandy soil;

Musqueam Wetland - wild cattail population, organic soil;

Channel A - cattails transplanted from Marine Drive; mixed soil;

Channel B - cattails transplanted from Musqueam Wetland; mixed soil;

Channel C - no cattails; mixed soil.

TABLE 1 Metal concentrations in leaves of *Typha latifolia* from Southwest Marine Drive, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					06 August					01 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	5674.0	1205.0	3850.0	7460.0	10	6652.5	2241.6	4450.0	9760.0	4	15125.0	2789.7	12400.0	19000.0	4
nitrogen	N	6550.6	1612.1	4047.0	9254.0	10	8350.0	3521.8	3600.0	12000.0	4	4275.0	531.5	3700.0	4900.0	4
manganese	Mn	1314.0	63.3	1150.0	1380.0	10	1387.3	493.7	759.0	1920.0	4	792.8	523.3	236.0	1500.0	4
phosphorus	P	1814.0	366.6	1250.0	2400.0	10	1463.0	694.9	712.0	2180.0	4	468.8	235.9	283.0	805.0	4
magnesium	Mg	1253.0	159.9	1040.0	1470.0	10	1287.5	196.2	1080.0	1520.0	4	3782.5	1484.8	2090.0	5710.0	4
sodium	Na	823.2	280.7	441.0	1400.0	10	1965.8	1659.3	432.0	3720.0	4	878.0	409.8	352.0	1280.0	4
iron	Fe	122.1	29.1	91.3	192.0	10	165.1	135.7	44.9	344.0	4	107.1	31.8	73.6	142.0	4
silicon	Si	30.8	4.0	25.0	37.0	10	28.5	13.7	13.0	41.0	4	36.8	16.1	26.0	60.0	4
aluminium	Al	24.8	5.3	17.0	33.0	10	44.0	46.0	7.0	103.0	4	36.8	12.1	25.0	53.0	4
strontium	Sr	41.2	9.7	27.5	55.7	10	56.4	27.6	35.5	95.4	4	114.7	20.1	94.9	141.0	4
molybdenum	Mo	2.8	0.9	1.6	4.8	10	3.4	2.3	1.1	6.3	4	2.9	1.7	1.5	5.3	4
barium	Ba	13.1	3.5	8.1	18.1	10	21.4	15.3	8.5	42.0	4	32.6	9.6	21.1	43.1	4
zinc	Zn	22.0	3.1	17.9	27.1	10	29.8	3.9	24.1	32.9	4	27.3	4.0	24.3	32.7	4
titanium	Ti	0.4	0.2	0.2	0.8	10	0.6	0.5	0.2	1.3	4	1.1	0.3	0.7	1.3	4
lead	Pb	3.1	1.2	2.0	5.0	10	3.0	2.0	L 2.0	6.0	4	9.8	5.3	4.0	16.0	4
nickel	Ni	3.8	0.6	3.0	5.0	10	4.3	2.6	2.0	7.0	4	3.5	0.6	3.0	4.0	4
copper	Cu	4.2	1.1	2.8	5.6	10	3.4	0.7	2.6	4.3	4	3.0	0.6	2.3	3.6	4
tin	Sn	0.8	0.0	L 0.8	L 0.8	10	1.2	0.6	L 0.8	2.0	4	0.8	0.0	L 0.8	L 0.8	4
cobalt	Co	1.5	0.3	1.1	1.9	10	0.4	0.0	L 0.4	L 0.4	4	0.6	0.2	0.4	0.8	4
arsenic	As	4.0	0.0	L 4.0	L 4.0	10	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	L 4.0	4
beryllium	Be	0.1	0.0	L 0.08	L 0.08	10	0.1	0.0	L 0.08	L 0.08	4	0.1	0.0	L 0.08	L 0.08	4
cadmium	Cd	0.2	0.0	L 0.2	L 0.2	10	0.2	0.0	L 0.2	L 0.2	4	0.2	0.1	L 0.2	0.3	4
antimony	Sb	4.0	0.0	L 4.0	L 4.0	10	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	L 4.0	4
vanadium	V	0.4	0.0	L 0.4	L 0.4	10	1.0	0.5	L 0.4	1.7	4	0.4	0.0	L 0.4	L 0.4	4

TABLE 2 Metal concentrations in roots of Typha latifolia from Southwest Marine Drive, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight).

Date:		26 June					6 August					1 October				
element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	3931.0	1233.0	2780.0	7070.0	10	3880.0	2592.0	302.0	7560.0	5	3155.0	1232.0	1770.0	4730.0	4
nitrogen	N	3831.0	2619.0	138.0	10520.0	10	5220.0	2740.0	1000.0	7800.0	5	3385.0	2099.0	540.0	5400.0	4
manganese	Mn	518.0	133.0	341.0	734.0	10	222.0	155.0	21.3	376.0	5	104.0	54.0	57.2	156.0	4
phosphorus	P	828.0	197.0	530.0	1250.0	10	1201.0	1006.0	35.0	2700.0	5	738.0	54.0	659.0	774.0	4
magnesium	Mg	2153.0	813.0	1240.0	3880.0	10	936.0	973.0	140.0	2330.0	5	14585.0	177.0	1320.0	1700.0	4
sodium	Na	5829.0	2600.0	3050.0	10600.0	10	2263.0	1548.0	286.0	4200.0	5	1905.0	787.0	1280.0	3020.0	4
iron	Fe	10653.0	3491.0	6820.0	17300.0	10	6617.0	5539.0	397.0	13500.0	5	871.0	360.0	444.0	1320.0	4
silicon	Si	1484.0	891.0	371.0	3280.0	10	1504.0	1530.0	53.0	3730.0	5	78.0	20.0	55.0	99.0	4
aluminium	Al	2376.0	1213.0	800.0	4480.0	10	1991.0	1849.0	68.0	4630.0	5	249.0	81.0	163.0	340.0	4
strontium	Sr	34.7	7.1	28.2	52.6	10	33.8	17.4	2.9	44.7	5	23.9	8.2	15.2	34.8	4
molybdenum	Mo	4.0	0.0	L 4.0	L 4.0	10	3.2	2.2	L 0.4	6.0	5	0.4	0.0	L 0.4	L 0.4	4
barium	Ba	24.2	24.2	15.6	35.1	10	27.6	18.83	1.7	47.10	5	11.3	4.3	8.4	17.6	4
zinc	Zn	64.1	23.8	27.0	104.0	10	46.1	28.8	2.7	83.0	5	25.4	7.8	16.7	32.5	4
titanium	Ti	97.1	52.9	30.0	177.0	10	101.4	98.2	4.1	234.0	5	9.6	6.7	2.7	15.9	4
lead	Pb	40.0	24.0	L 20.0	100.0	10	28.4	26.0	L 2.0	70.0	5	4.0	2.0	L 2.0	6.0	4
nickel	Ni	231.0	200.0	60.0	710.0	10	39.0	43.0	L 2.0	110.0	5	8.1	1.0	3.0	6.0	4
copper	Cu	19.6	5.6	12.0	30.0	10	10.5	6.6	0.6	18.0	5	4.0	2.3	6.1	11.4	4
tin	Sn	8.0	0.0	L 8.0	L 8.0	10	8.1	6.0	L 2.0	18.0	5	0.8	0.0	L 0.08	L 0.8	4
cobalt	Co	49.9	21.0	21.0	88.0	10	2.6	2.0	L 0.4	L 4.0	5	4.1	1.0	2.4	5.9	4
arsenic	As	40.0	0.0	L 40.0	L 40.0	10	37.0	29.0	L 4.0	70.0	5	4.0	0.0	L 4.0	L 4.0	4
beryllium	Be	0.8	0.0	L 0.8	L 0.8	10	0.5	0.4	L 0.08	L 0.8	5	0.08	0.0	L 0.08	L 0.08	4
cadmium	Cd	2.2	0.0	L 2.0	3.0	10	1.3	0.9	L 0.2	L 2.0	5	0.4	0.0	L 0.2	0.5	4
antimony	Sb	40.0	0.0	L 40.0	L 40.0	10	26.0	19.0	L 4.0	L 40.0	5	4.0	0.0	L 4.0	L 4.0	4
vanadium	V	22.0	10.0	11.0	41.0	10	14.5	12.0	0.6	29.0	5	2.2	0.7	1.4	2.8	4

TABLE 3 Metal concentrations in soil with Typha latifolia, Southwest Marine Drive, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		06 August					01 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	4836.7	755.9	3970.0	5360.0	3	4233.3	51.3	4190.0	4290.0	3
nitrogen	N	690.0	491.0	220.0	1200.0	3	1266.7	57.7	1200.0	1300.0	3
manganese	Mn	263.0	68.8	189.0	325.0	3	202.3	19.4	180.0	215.0	3
phosphorus	P	512.7	72.2	447.0	590.0	3	461.3	18.5	443.0	480.0	3
magnesium	Mg	2826.7	470.8	2290.0	3170.0	3	2436.7	110.2	2310.0	2510.0	3
sodium	Na	310.0	52.9	250.0	350.0	3	243.3	11.5	230.0	250.0	3
iron	Fe	19433.3	1026.3	18300.0	20300.0	3	17133.3	642.9	16400.0	17600.0	3
silicon	Si	656.7	66.6	600.0	730.0	3	696.7	37.9	670.0	740.0	3
aluminium	Al	15566.7	1184.6	14200.0	16300.0	3	16766.7	321.5	16400.0	17000.0	3
strontium	Sr	44.2	5.7	37.7	47.5	3	40.5	1.5	39.2	42.1	3
molybdenum	Mo	0.8	0.0	L 0.8	L 0.8	3	0.8	0.0	L 0.8	L 0.8	3
barium	Ba	63.6	5.0	57.9	66.8	3	73.4	1.5	71.7	74.7	3
zinc	Zn	27.2	0.9	26.3	28.1	3	28.7	1.0	28.0	29.8	3
titanium	Ti	1153.3	63.5	1080.0	1190.0	3	1176.7	15.3	1160.0	1190.0	3
lead	Pb	9.7	6.4	6.0	17.0	3	13.3	1.5	12.0	15.0	3
nickel	Ni	10.5	0.7	10.0	11.0	2	13.7	2.1	12.0	16.0	3
copper	Cu	11.2	2.1	8.9	13.1	3	10.2	0.6	9.5	10.6	3
tin	Sn	7.3	2.1	5.0	9.0	3	8.3	3.8	4.0	11.0	3
cobalt	Co	7.6	1.6	6.0	9.1	3	5.1	0.5	4.7	5.7	3
arsenic	As	8.0	0.0	L 8.0	L 8.0	3	8.0	0.0	L 8.0	L 8.0	3
beryllium	Be	0.3	0.1	0.2	0.3	3	0.2	0.1	0.2	0.3	3
cadmium	Cd	0.3	0.0	0.3	0.3	3	0.3	0.0	0.3	0.3	3
vanadium	V	59.9	2.8	56.9	62.3	3	56.7	1.5	55.1	58.1	3

TABLE 4 Metal concentrations in flowers of Typha latifolia, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Site:		Southwest Marine Drive					Musqueam Wetland					Channel A, U.B.C.				
Date:		06 August					06 August					06 August				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	4065.0	261.6	3880.0	4250.0	2	5370.0	297.0	5160.0	5580.0	2	6050.0	0.0	6050.0	6050.0	1
nitrogen	N	6000.0	3748.0	3300.0	8600.0	2	7100.0	990.0	6400.0	7800.0	2	10000.0	0.0	10000.0	10000.0	1
manganese	Mn	481.5	84.1	422.0	541.0	2	82.2	6.6	77.5	86.8	2	1380.0	0.0	1380.0	1380.0	1
phosphorus	P	2630.0	381.8	2360.0	2900.0	2	3105.0	233.3	2940.0	3270.0	2	3480.0	0.0	3480.0	3480.0	1
magnesium	Mg	1920.0	183.8	1790.0	2050.0	2	1530.0	113.1	1450.0	1610.0	2	2130.0	0.0	2130.0	2130.0	1
sodium	Na	416.5	33.2	393.0	440.0	2	394.5	7.8	389.0	400.0	2	310.0	0.0	310.0	310.0	1
iron	Fe	70.6	18.1	57.8	83.4	2	50.0	5.7	45.9	54.0	2	123.0	0.0	123.0	123.0	1
silicon	Si	19.5	2.1	18.0	21.0	2	13.5	4.9	10.0	17.0	2	50.0	0.0	50.0	50.0	1
aluminium	Al	16.0	2.8	14.0	18.0	2	17.5	3.5	15.0	20.0	2	30.0	0.0	30.0	30.0	1
strontium	Sr	23.7	6.0	19.4	27.9	2	18.1	1.6	16.9	19.2	2	25.1	0.0	25.1	25.1	1
molybdenum	Mo	3.0	0.2	2.8	3.1	2	1.3	0.2	1.1	1.4	2	10.0	0.0	10.0	10.0	1
barium	Ba	4.0	1.4	3.0	5.0	2	0.8	0.1	0.8	0.9	2	6.0	0.0	6.0	6.0	1
zinc	Zn	34.3	3.7	31.6	36.9	2	31.8	3.0	29.7	33.9	2	45.5	0.0	45.5	45.5	1
titanium	Ti	0.2	0.0	L 0.2	L 0.2	2	0.3	0.1	L 0.2	0.3	2	12.5	0.0	12.5	12.5	1
lead	Pb	2.0	0.0	L 2.0	L 2.0	2	2.5	0.7	L 2.0	3.0	2	8.0	0.0	L 8.0	L 8.0	1
nickel	Ni	5.5	0.7	5.0	6.0	2	3.0	0.0	L 3.0	L 3.0	2	8.0	0.0	8.0	8.0	1
copper	Cu	7.7	1.3	6.7	8.6	2	3.4	0.1	3.3	3.5	2	4.0	0.0	4.0	4.0	1
tin	Sn	0.8	0.0	L 0.8	L 0.8	2	1.4	0.8	L 0.8	2.0	2	4.0	0.0	L 4.0	L 4.0	1
cobalt	Co	0.4	0.0	L 0.4	L 0.4	2	0.5	0.1	L 0.4	0.6	2	2.0	0.0	L 2.0	L 2.0	1
arsenic	As	4.0	0.0	L 4.0	L 4.0	2	5.0	1.4	L 4.0	6.0	2	20.0	0.0	L 20.0	L 20.0	1
beryllium	Be	0.1	0.0	L 0.08	L 0.08	2	0.1	0.0	L 0.08	0.1	2	0.4	0.0	L 0.4	L 0.4	1
cadmium	Cd	0.2	0.0	L 0.2	L 0.2	2	0.3	0.1	L 0.2	0.3	2	0.8	0.0	L 0.8	L 0.8	1
antimony	Sb	4.0	0.0	L 4.0	L 4.0	2	5.0	1.4	L 4.0	6.0	2	20.0	0.0	L 20.0	L 20.0	1
vanadium	V	0.5	0.1	L 0.4	0.6	2	0.5	0.1	L 0.4	0.6	2	2.0	0.0	L 2.0	L 2.0	1

TABLE 5 Metals concentrations in leaves of *Typha latifolia* from Musqueam Wetland, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					06 August					01 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	8594.0	837.0	7020.0	9650.0	10	14275.0	2140.7	11200.0	16100.0	4	15346.7	5357.3	5180.0	20100.0	6
nitrogen	N	8845.4	1209.2	7159.0	10375.0	9	11000.0	816.5	10000.0	12000.0	4	5000.0	1023.7	3200.0	6300.0	6
manganese	Mn	492.8	208.9	299.0	895.0	10	398.3	105.4	285.0	535.0	4	163.6	74.2	47.5	264.0	6
phosphorus	P	2395.0	233.2	1980.0	2690.0	10	2255.0	137.2	2070.0	2400.0	4	1418.5	878.6	763.0	3170.0	6
magnesium	Mg	1294.0	167.9	1050.0	1570.0	10	1367.5	37.7	1330.0	1420.0	4	566.2	176.7	341.0	766.0	5
sodium	Na	350.3	86.5	262.0	485.0	10	787.3	77.7	679.0	856.0	4	416.2	302.5	217.0	951.0	5
iron	Fe	80.5	19.6	55.3	119.0	10	86.6	23.7	52.7	107.0	4	391.3	205.6	88.7	585.0	5
silicon	Si	45.2	9.3	27.0	59.0	10	30.8	10.2	18.0	40.0	4	83.5	27.7	38.0	121.0	6
aluminium	Al	29.1	8.5	17.0	47.0	10	28.3	6.9	20.0	37.0	4	147.3	70.1	42.0	231.0	6
strontium	Sr	27.3	2.5	22.3	32.0	10	49.4	7.8	40.8	58.6	4	55.1	14.6	28.3	69.9	6
molybdenum	Mo	8.3	3.9	3.4	14.1	10	8.5	0.2	8.3	8.8	4	2.0	1.2	0.4	3.3	6
barium	Ba	1.8	0.6	0.7	2.7	10	3.0	0.4	2.7	3.5	4	3.8	1.4	1.9	5.8	6
zinc	Zn	20.1	4.6	15.4	31.8	10	27.8	3.5	23.0	30.9	4	32.2	6.3	21.8	41.1	6
titanium	Ti	1.0	0.4	0.4	1.9	10	0.2	0.0	L 0.2	L 0.2	4	3.8	2.6	1.0	7.4	6
lead	Pb	2.0	0.0	L 2.0	L 2.0	10	2.0	0.0	L 2.0	L 2.0	4	4.8	1.6	3.0	7.0	6
nickel	Ni	4.4	1.5	3.0	6.0	9	2.8	1.5	2.0	5.0	4	6.0	2.2	3.0	9.0	6
copper	Cu	3.2	0.5	2.3	3.8	9	3.0	0.4	2.4	3.4	4	4.5	1.6	2.8	7.3	6
tin	Sn	0.8	0.0	L 0.8	L 0.8	9	0.8	0.0	L 0.8	L 0.8	4	0.8	0.0	L 0.8	L 0.8	6
cobalt	Co	0.4	0.0	L 0.4	0.6	9	0.4	0.0	L 0.4	L 0.4	4	2.0	1.6	0.4	5.1	6
arsenic	As	4.0	0.0	L 4.0	L 4.0	9	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	4.0	6
beryllium	Be	0.1	0.0	L 0.08	L 0.08	9	0.1	0.0	L 0.08	L 0.08	4	0.1	0.0	L 0.8	L 0.08	6
cadmium	Cd	0.2	0.0	L 0.2	L 0.2	9	0.2	0.0	L 0.2	L 0.2	4	0.2	0.0	L 0.2	L 0.2	6
antimony	Sb	4.0	0.0	L 4.0	L 4.0	9	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	L 4.0	6
vanadium	V	0.4	0.0	L 0.4	L 0.4	9	0.9	0.1	0.8	0.9	4	0.8	0.6	0.4	2.0	6

TABLE 6 Metals concentrations in roots of Typha latifolia from Musqueam Wetland, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					6 August					01 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	6531.0	1073.1	4920.0	7980.0	10	4742.5	1947.8	3330.0	7560.0	4	10105.0	6399.8	5000.0	21500.0	6
nitrogen	N	6815.0	2641.3	2822.0	9571.0	10	6575.0	2266.0	4200.0	9100.0	4	4766.7	2599.7	2200.0	8700.0	6
manganese	Mn	147.8	34.2	84.9	191.0	10	61.0	23.5	42.9	94.5	4	159.8	115.1	74.1	369.0	6
phosphorus	P	3080.0	654.5	2380.0	4410.0	10	2432.5	191.4	2260.0	2700.0	4	4918.3	5482.7	1270.0	15900.0	6
magnesium	Mg	2266.0	736.0	1530.0	3560.0	10	1680.0	452.3	1280.0	2330.0	4	1655.8	616.1	455.0	2190.0	6
sodium	Na	4978.0	1264.1	3550.0	7400.0	10	2985.0	1426.3	1700.0	5000.0	4	5059.0	2823.1	604.0	8420.0	6
iron	Fe	7901.0	2832.9	5050.0	12900.0	10	2301.0	1717.0	554.0	4420.0	4	10565.7	15393.1	244.0	41400.0	6
silicon	Si	3827.0	2402.2	1180.0	7890.0	10	613.3	899.2	52.0	1940.0	4	15309.8	35369.7	84.0	87480.0	6
aluminium	Al	3602.0	2718.0	800.0	7910.0	10	840.0	1107.9	214.0	2500.0	4	1242.2	1823.7	104.0	4860.0	6
strontium	Sr	39.0	9.0	28.0	53.3	10	28.8	10.7	22.0	44.7	4	66.0	50.7	27.3	163.0	6
molybdenum	Mo	4.0	0.0	L 4.0	L 4.0	10	3.9	3.1	1.2	7.0	4	2.8	1.9	L 0.4	4.0	6
barium	Ba	23.3	12.3	11.8	41.8	10	8.2	8.0	2.6	20.0	4	39.3	63.5	2.9	166.0	6
zinc	Zn	94.3	18.5	69.0	119.0	10	55.0	18.7	44.0	83.0	4	82.6	37.9	28.3	131.0	6
titanium	Ti	166.1	122.0	30.0	364.0	10	43.1	69.1	L 0.2	145.0	4	64.5	102.1	L 0.2	266.0	6
lead	Pb	25.0	8.5	L 20	40.0	10	13.5	13.9	2.0	30.0	4	14.2	10.8	3.0	30.0	6
nickel	Ni	400.0	681.4	30.0	2260.0	10	15.3	7.6	4.0	20.0	4	12.0	8.8	4.0	20.0	6
copper	Cu	25.1	10.8	14.0	45.0	10	12.0	4.1	9.0	18.0	4	21.7	17.1	3.0	52.0	6
tin	Sn	8.0	0.0	L 8.0	L 8.0	10	4.4	4.1	L 0.8	L 8.0	4	4.4	3.9	L 0.8	L 8.0	6
cobalt	Co	22.9	6.7	16.0	37.0	10	2.2	2.1	0.4	4.0	4	23.4	28.5	0.7	80.0	6
arsenic	As	40.0	0.0	L 40	L 40	10	29.5	25.1	7.0	60.0	4	22.0	19.7	L 4.0	40.0	6
beryllium	Be	0.8	0.0	L 0.8	L 0.8	10	0.4	0.4	L 0.08	L 0.8	4	0.4	0.4	L 0.08	L 0.8	6
cadmium	Cd	3.6	1.0	L 2.0	5.0	10	1.4	0.7	0.6	2.0	4	5.2	5.4	L 0.2	15.0	6
antimony	Sb	40.0	0.0	L 40	L 40	10	22.3	20.5	L 4.0	40.0	4	22.0	19.7	L 4.0	40.0	6
vanadium	V	18.8	11.0	7.0	36.0	10	6.7	5.3	2.0	14.0	4	7.2	7.5	0.4	21.0	6

TABLE 7 Metal concentrations in soil with Typha latifolia, Musqueam Wetland, Vancouver, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		02 July					06 August					01 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	12500.0	565.7	12100.0	12900.0	2	11766.7	305.5	11500.0	12100.0	3	11500.0	173.2	11300.0	11600.0	3
nitrogen	N	3800.0	141.0	3700.0	3900.0	2	3933.0	1097.0	3300.0	5200.0	3	3600.0	100.0	3500.0	3700.0	3
manganese	Mn	309.5	13.4	300.0	319.0	2	249.3	6.4	242.0	254.0	3	232.7	3.2	229.0	235.0	3
phosphorus	P	4400.0	551.5	4010.0	4790.0	2	3890.0	425.8	3420.0	4250.0	3	4086.7	126.6	3990.0	4230.0	3
magnesium	Mg	6340.0	537.4	5960.0	6720.0	2	6470.0	275.1	6200.0	6750.0	3	6486.7	92.9	6410.0	6590.0	3
sodium	Na	545.0	49.5	510.0	580.0	2	536.7	80.2	460.0	620.0	3	613.3	45.1	570.0	660.0	3
iron	Fe	19500.0	1272.8	18600.0	20400.0	2	19966.7	1026.3	19100.0	21100.0	3	19100.0	264.6	18800.0	19300.0	3
silicon	Si	1320.0	99.0	1250.0	1390.0	2	713.3	15.3	700.0	730.0	3	710.0	60.8	640.0	750.0	3
aluminium	Al	20350.0	1909.2	19000.0	21700.0	2	19233.3	1234.2	18200.0	20600.0	3	17900.0	200.0	17700.0	18100.0	3
strontium	Sr	110.5	7.8	105.0	116.0	2	101.6	1.6	99.8	103.0	3	95.1	1.9	93.2	96.9	3
molybdenum	Mo	0.8	0.0	L 0.8	L 0.8	2	0.8	0.0	L 0.8	L 0.8	3	0.8	0.0	L 0.8	L 0.8	3
barium	Ba	103.1	8.3	97.2	109.0	2	90.0	7.7	84.7	98.9	3	83.2	2.5	81.6	86.1	3
zinc	Zn	112.0	8.5	106.0	118.0	2	106.3	11.9	99.3	120.0	3	104.0	1.7	102.0	105.0	3
titanium	Ti	1225.0	106.1	1150.0	1300.0	2	1103.3	30.6	1070.0	1130.0	3	1106.7	11.5	1100.0	1120.0	3
lead	Pb	33.5	0.7	33.0	34.0	2	37.3	12.1	28.0	51.0	3	29.7	3.1	27.0	33.0	3
nickel	Ni	23.0	1.4	22.0	24.0	2	21.0	1.0	20.0	22.0	3	18.7	1.2	18.0	20.0	3
copper	Cu	53.2	8.3	47.3	59.1	2	38.0	6.6	33.6	45.6	3	33.8	1.1	32.9	35.1	3
tin	Sn	5.5	0.7	5.0	6.0	2	7.0	2.0	5.0	9.0	3	10.0	1.0	9.0	11.0	3
cobalt	Co	7.0	0.1	6.9	7.0	2	8.8	2.2	6.4	10.6	3	8.6	0.4	8.1	8.9	3
arsenic	As	8.0	0.0	L 8.0	L 8.0	2	8.0	0.0	L 8.0	L 8.0	3	8.0	0.0	L 8.0	L 8.0	3
beryllium	Be	0.3	0.1	0.2	0.3	2	0.4	0.1	0.4	0.5	3	0.3	0.1	0.2	0.3	3
cadmium	Cd	2.1	0.2	1.9	2.2	2	1.5	0.3	1.2	1.8	3	1.0	0.1	0.9	1.1	3
vanadium	V	59.4	6.4	54.9	63.9	2	60.1	3.4	57.9	64.0	3	56.3	1.1	55.1	57.0	3

TABLE 8 Metal concentrations in leaves of Typha latifolia cultured in Channel A, U.B.C., in simulated coal mine wastewater, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					6 August					27 August					1 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	8447.5	1137.7	7100.0	9750.0	4	9322.5	2520.7	5590.0	10900.0	4	11375.0	1303.7	9850.0	13000.0	6	11783.3	2637.0	9300.0	16100.0	6
nitrogen	N	6436.5	1487.9	4810.0	8185.0	4	7450.0	2723.4	3600.0	10000.0	4	6900.0	1141.9	5500.0	8300.0	6	4500.0	698.6	3500.0	5200.0	6
manganese	Mn	1275.0	130.8	1080.0	1360.0	4	1812.5	496.1	1120.0	2300.0	4	1903.3	48.4	1840.0	1960.0	6	1928.3	40.7	1900.0	2010.0	6
phosphorus	P	2565.0	328.7	2180.0	2980.0	4	2055.0	331.2	1700.0	2480.0	4	2211.7	245.5	1800.0	2500.0	6	1125.0	282.1	662.0	1480.0	6
magnesium	Mg	1437.5	99.8	1330.0	1560.0	4	1592.5	366.8	1310.0	2130.0	4	1346.5	260.7	869.0	1550.0	6	554.0	366.1	183.0	1020.0	6
sodium	Na	703.0	282.1	501.0	1120.0	4	311.5	182.4	169.0	578.0	4	359.2	103.5	240.0	524.0	6	332.8	93.5	176.0	419.0	6
iron	Fe	84.4	31.5	60.6	130.0	4	146.8	37.3	119.0	200.0	4	149.0	33.7	108.0	208.0	6	177.2	57.6	121.0	251.0	5
silicon	Si	41.0	7.6	34.0	49.0	4	41.0	20.7	23.0	70.0	4	47.3	9.8	31.0	61.0	6	62.4	22.9	34.0	91.0	5
aluminium	Al	39.8	2.5	37.0	43.0	4	53.3	29.5	28.0	95.0	4	70.8	23.2	53.0	116.0	6	69.4	11.9	51.0	82.0	5
strontium	Sr	36.9	6.6	29.8	45.3	4	44.6	9.0	31.3	50.2	4	44.5	4.9	37.9	51.2	6	57.6	17.0	41.3	86.2	6
molybdenum	Mo	34.0	8.7	24.8	45.9	4	46.5	20.8	16.4	63.6	4	47.0	10.4	31.8	58.4	6	34.3	10.2	20.3	46.7	6
barium	Ba	12.2	2.1	10.1	14.3	4	14.2	3.5	9.5	17.8	4	14.4	1.7	12.2	17.4	6	18.8	8.2	12.1	34.9	6
zinc	Zn	16.4	3.1	12.6	20.0	4	17.6	3.5	13.3	21.7	4	15.3	3.4	12.2	21.4	6	15.5	4.2	12.5	23.5	6
titanium	Ti	4.0	0.0	L 4.0	L 4.0	4	3.9	3.3	0.2	7.0	4	2.4	1.3	1.6	5.0	6	11.0	5.2	7.1	21.1	6
lead	Pb	2.0	0.0	L 2.0	L 2.0	4	3.0	1.4	2.0	5.0	4	2.8	0.8	2.0	4.0	6	3.8	1.3	2.0	6.0	6
nickel	Ni	8.5	7.0	4.0	19.0	4	2.7	0.6	2.0	3.0	3	2.7	0.8	2.0	4.0	6	4.0	1.3	2.0	6.0	6
copper	Cu	2.5	0.3	2.3	3.0	4	2.3	0.8	1.2	3.1	4	3.3	0.6	2.5	3.9	6	3.2	1.0	2.2	4.8	6
tin	Sn	0.8	0.0	0.8	0.8	4	1.2	0.6	0.8	2.0	4	1.4	0.8	0.8	2.5	6	1.1	0.5	0.8	2.1	6
cobalt	Co	0.5	0.1	0.4	0.5	4	0.4	0.0	L 0.4	L 0.4	4	0.7	0.1	0.6	0.9	6	1.3	1.0	0.8	3.4	6
arsenic	As	4.0	0.0	4.0	4.0	4	4.0	0.0	L 4.0	L 4.0	4	4.8	1.3	L 4.0	7.0	6	4.8	1.0	4.0	6.0	6
beryllium	Be	0.1	0.0	L 0.08	L 0.08	4	0.1	0.0	L 0.08	L 0.08	4	0.1	0.0	L 0.08	L 0.08	6	0.1	0.0	L 0.08	L 0.08	6
cadmium	Cd	0.2	0.0	L 0.2	L 0.2	4	0.2	0.0	L 0.2	L 0.2	4	0.2	0.0	L 0.2	L 0.2	6	0.2	0.0	L 0.2	L 0.2	6
antimony	Sb	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	L 4.0	4	4.0	0.0	L 4.0	L 4.0	6	4.0	0.0	L 4.0	L 4.0	6
vanadium	V	0.4	0.0	L 0.4	L 0.4	4	1.9	0.8	1.0	2.7	4	0.4	0.0	L 0.4	L 0.4	6	0.5	0.3	L 0.4	1.2	6

TABLE 9 Metals concentrations in roots of Typha latifolia cultured in Channel A, U.B.C., in simulated coal mine wastewater, sampled during the summer and early autumn of 1986. (all measurements in ug/g, dry weight).

Date:		26 June					6 August					27 August					1 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	3738.0	1324.0	1900.0	4870.0	4	4143.0	909.0	2920.0	5110.0	4	3215.0	871.0	1920.0	4250.0	6	3315.0	418.0	2670.0	3930.0	6
nitrogen	N	1175.0	1267.0	405.0	3070.0	4	2000.0	2000.0	1000.0	2000.0	4	3200.0	800.0	2000.0	4200.0	6	2167.0	561.0	1500.0	3000.0	6
manganese	Mn	297.0	123.0	172.0	418.0	4	305.0	84.0	207.0	410.0	4	262.0	134.0	134.0	491.0	6	382.0	214.0	215.0	792.0	6
phosphorus	P	1333.0	719.0	740.0	2290.0	4	943.0	449.0	540.0	1450.0	4	805.0	233.0	423.0	1060.0	6	1332.0	323.0	810.0	1830.0	6
magnesium	Mg	1625.0	598.0	1000.0	2350.0	4	1235.0	183.0	1010.0	1420.0	4	1301.0	402.0	709.0	1670.0	6	1277.0	337.0	920.0	1910.0	6
sodium	Na	4600.0	1521.0	3470.0	6760.0	4	3370.0	702.0	2540.0	4240.0	4	2130.0	801.0	1480.0	3610.0	6	3178.0	384.0	2620.0	3520.0	6
iron	Fe	7958.0	4540.0	3170.0	12500.0	4	7825.0	1306.0	6420.0	9140.0	4	6702.0	4168.0	2940.0	14400.0	6	8735.0	2483.0	5620.0	12100.0	6
silicon	Si	955.0	706.0	300.0	1760.0	4	1008.0	255.0	870.0	1390.0	4	2301.0	2922.0	135.0	7640.0	6	1877.0	1554.0	840.0	4900.0	6
aluminium	Al	2263.0	2241.0	320.0	5140.0	4	1323.0	788.0	860.0	2500.0	4	2355.0	1681.0	357.0	4320.0	6	1322.0	1217.0	260.0	3650.0	6
strontium	Sr	22.4	6.7	14.6	29.4	4	29.5	5.2	23.2	35.3	4	20.7	5.7	12.3	28.2	6	35.8	41.1	14.8	119.6	6
molybdenum	Mo	L 4.0	0.0	L 4.0	L 4.0	4	L 4.0	0.0	L 4.0	L 4.0	4	2.2	2.0	L 0.4	4.0	6	L 4.0	0.0	L 4.0	L 4.0	6
barium	Ba	19.5	11.2	8.1	32.5	4	21.8	7.0	17.3	32.3	4	23.1	11.8	8.2	36.9	6	16.6	6.4	10.7	29.0	6
zinc	Zn	39.0	18.0	26.0	64.0	4	27.0	30.0	1.1	60.0	4	34.0	18.0	13.0	61.0	6	21.0	13.0	11.0	45.0	6
titanium	Ti	91.0	82.0	19.0	193.0	4	74.0	25.0	58.0	112.0	4	34.0	18.0	4.0	223.0	6	88.0	82.0	29.0	244.0	6
lead	Pb	30.0	14.0	L 20	50.0	4	33.0	10.0	L 20	40.0	4	65.0	65.0	L 2.0	183.0	6	22.0	4.0	20.0	30.0	6
nickel	Ni	475.0	393.0	130.0	920.0	4	158.0	86.0	70.0	250.0	4	16.0	11.0	3.0	30.0	6	30.0	24.0	20.0	80.0	6
copper	Cu	16.0	13.0	5.0	34.0	4	7.0	3.0	4.0	11.0	4	11.0	6.0	3.0	18.5	6	6.7	4.5	4.0	15.0	6
tin	Sn	L 8.0	0.0	L 8.0	L 8.0	4	11.0	3.0	L 8.0	14.0	4	4.0	4.0	2.1	11.0	6	8.5	1.2	8.0	11.0	6
cobalt	Co	35.0	20.0	14.0	55.0	4	L 4.0	0.0	L 4.0	L 4.0	4	14.6	9.0	6.2	30.0	6	17.0	6.0	9.0	24.0	6
arsenic	As	L 40	0.0	L 40	L 40	4	L 40	0.0	L 40	L 40	4	25.0	20.0	L 4.0	50.0	6	L 40	0.0	L 40	L 40	6
beryllium	Be	L 0.8	0.0	L 0.8	L 0.8	4	L 0.8	0.0	L 0.8	L 0.8	4	0.5	0.4	L 0.08	0.8	6	L 0.8	0.0	L 0.8	L 0.8	6
cadmium	Cd	L 2.0	0.0	L 2.0	L 2.0	4	L 2.8	1.0	L 2.0	3.0	4	1.2	0.9	L 0.2	2.0	6	L 2.0	0.0	L 2.0	L 2.0	6
antimony	Sb	L 40	0.0	L 40	L 40	4	L 40	0.0	L 40	L 40	4	22.0	20.0	L 40	40.0	6	L 40	0.0	L 40	L 40	6
vanadium	V	16.0	14.0	4.0	32.0	4	7.8	3.0	L 4.0	11.0	4	13.5	8.4	2.4	22.0	6	6.5	3.5	4.0	13.0	6

TABLE 10 Metal concentrations in soil in experimental channel A with Typha latifolia, sampled during the summer and early autumn of 1986.
(all measurements in ug/g, dry weight)

Date:		02 July					06 August					01 October				
element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	7860.0	0	7860.0	7860.0	1	6710.0	396.0	6430.0	6990.0	2	6600.0	84.9	6540.0	6660.0	2
nitrogen	N	5000.0	0	5000.0	5000.0	1	4400.0	300.0	4200.0	4600.0	2	3000.0	989.9	2300.0	3700.0	2
manganese	Mn	311.0	0	311.0	311.0	1	309.0	9.9	302.0	316.0	2	321.0	12.7	312.0	330.0	2
Phosphorus	P	2550.0	0	2550.0	2550.0	1	2205.0	176.8	2080.0	2330.0	2	1570.0	480.8	1230.0	1910.0	2
magnesium	Mg	2660.0	0	2660.0	2660.0	1	2555.0	35.4	2530.0	2580.0	2	2785.0	35.4	2760.0	2810.0	2
sodium	Na	270.0	0	270.0	270.0	1	135.0	190.9	0.0	270.0	2	260.0	14.1	250.0	270.0	2
iron	Fe	21200.0	0	21200.0	21200.0	1	0.1	707.1	19600.0	20600.0	2	19900.0	1697.1	18700.0	21100.0	2
silicon	Si	1610.0	0	1610.0	1610.0	1	1165.0	35.4	1140.0	1190.0	2	820.0	56.6	780.0	860.0	2
aluminium	Al	28800.0	0	28800.0	28800.0	1	24900.0	1131.4	24100.0	25700.0	2	19800.0	3959.8	17000.0	22600.0	2
strontium	Sr	56.9	0	56.9	56.9	1	49.8	2.3	48.2	51.4	2	47.7	2.8	45.7	49.7	2
molybdenum	Mo	0.8	0	0.8	0.8	1	0.8	0.0	0.8	0.8	2	0.8	0.0	0.8	0.8	2
barium	Ba	94.7	0	94.7	94.7	1	84.0	3.8	81.3	86.7	2	74.6	13.5	65.0	84.1	2
zinc	Zn	72.7	0	72.7	72.7	1	68.0	3.1	65.8	70.2	2	57.8	18.5	44.7	70.9	2
titanium	Ti	2060.0	0	2060.0	2060.0	1	1630.0	70.7	1580.0	1680.0	2	1470.0	198.0	1330.0	1610.0	2
lead	Pb	27.0	0	27.0	27.0	1	28.5	0.7	28.0	29.0	2	19.0	8.5	13.0	25.0	2
nickel	Ni	9.0	0	9.0	9.0	1	9.5	0.7	9.0	10.0	2	10.5	3.5	8.0	13.0	2
copper	Cu	24.9	0	24.9	24.9	1	21.4	1.3	20.4	22.3	2	18.7	4.7	15.4	22.0	2
tin	Sn	7.0	0	7.0	7.0	1	7.5	2.1	6.0	9.0	2	13.5	2.1	12.0	15.0	2
cobalt	Co	8.2	0	8.2	8.2	1	10.9	3.6	8.3	13.4	2	5.7	2.2	4.1	7.2	2
arsenic	As	8.0	0	8.0	8.0	1	8.0	0.0	8.0	8.0	2	8.0	0.0	8.0	8.0	2
beryllium	Be	0.4	0	0.4	0.4	1	0.6	0.1	0.5	0.6	2	0.4	0.1	0.3	0.5	2
cadmium	Cd	1.3	0	1.3	1.3	1	0.5	0.1	0.4	0.6	2	0.5	0.3	0.3	0.7	2
vanadium	V	75.8	0	75.8	75.8	1	68.0	3.1	65.8	70.2	2	63.4	7.0	58.4	68.3	2

TABLE 11 Metal concentrations in leaves of Typha latifolia cultured in Channel B, U.B.C., in simulated coal mine wastewater, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					6 August					27 August					1 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	6387.5	496.7	5900.0	7010.0	4	7175.0	497.0	6440.0	7510.0	4	8641.7	1364.6	6940.0	10900.0	6	8944.0	2786.4	6080.0	13100.0	5
nitrogen	N	5533.0	369.8	5202.0	6008.0	4	7325.0	1674.0	5300.0	9400.0	4	7325.0	1674.0	5300.0	9400.0	6	5960.0	1026.2	4900.0	7600.0	5
manganese	Mn	393.0	37.6	364.0	443.0	4	538.5	258.7	328.0	916.0	4	926.3	291.0	572.0	1340.0	6	720.2	218.5	401.0	982.0	5
phosphorus	P	2195.0	155.5	2010.0	2380.0	4	1910.0	211.2	1730.0	2200.0	4	2045.0	181.0	1800.0	2350.0	6	1296.0	180.8	1050.0	1490.0	5
magnesium	Mg	1078.3	190.4	944.0	1360.0	4	1250.0	253.9	1020.0	1610.0	4	1303.0	401.0	638.0	1710.0	6	1138.0	85.0	1010.0	1240.0	5
sodium	Na	234.0	76.6	156.0	308.0	4	242.0	66.3	177.0	320.0	4	413.3	182.0	145.0	687.0	6	477.6	212.2	270.0	750.0	5
iron	Fe	58.7	5.1	52.7	63.4	4	101.0	17.3	77.0	118.0	4	108.6	17.2	84.2	130.0	6	136.8	83.8	88.2	286.0	5
silicon	Si	33.8	2.2	31.0	36.0	4	35.3	10.2	27.0	50.0	4	37.2	7.1	28.0	46.0	6	75.6	77.2	36.0	213.0	5
aluminium	Al	32.0	3.4	30.0	37.0	4	45.5	3.7	41.0	50.0	4	63.3	9.8	48.0	75.0	6	87.4	70.8	45.0	213.0	5
strontium	Sr	21.0	2.9	19.0	25.2	4	28.6	2.2	26.7	31.7	4	32.0	5.7	26.2	40.2	6	36.3	14.0	24.5	58.8	5
molybdenum	Mo	8.8	1.5	6.6	9.9	4	14.9	8.5	8.6	27.5	4	19.5	14.5	6.5	48.0	6	8.6	1.5	6.5	10.5	5
barium	Ba	2.5	0.8	1.6	3.6	4	3.7	0.8	3.0	4.9	4	4.2	0.5	3.7	5.0	6	3.6	1.0	2.6	5.0	5
zinc	Zn	17.0	2.0	14.6	19.4	4	21.6	9.9	7.3	30.0	4	18.7	2.7	15.3	22.0	6	23.3	2.9	20.5	26.9	5
titanium	Ti	1.4	0.4	1.2	2.0	4	1.6	2.3	L 0.2	5.0	4	2.6	0.4	2.1	3.2	6	7.4	8.0	1.7	20.5	5
lead	Pb	2.0	0.0	L 2.0	L 2.0	4	2.3	0.5	L 2.0	3.0	4	5.0	7.3	L 2.0	20.0	6	2.8	0.8	L 2.0	4.0	5
nickel	Ni	3.8	2.9	L 2.0	8.0	4	4.8	3.6	L 2.0	10.0	4	4.3	0.5	4.0	5.0	6	4.2	1.6	3.0	7.0	5
copper	Cu	2.0	0.3	1.7	2.4	4	1.8	0.4	1.4	2.3	4	2.8	0.4	2.3	3.4	6	2.8	0.7	2.1	3.5	5
tin	Sn	0.8	0.0	L 0.8	L 0.8	4	0.9	0.1	L 0.8	1.0	4	0.8	0.0	L 0.8	L 0.8	6	0.8	0.0	L 0.8	L 0.8	5
cobalt	Co	0.4	0.0	L 0.4	L 0.4	4	0.4	0.2	L 0.2	0.7	4	0.4	0.0	L 0.4	L 0.4	6	0.7	0.4	L 0.4	1.4	5
arsenic	As	4.0	0.0	L 4.0	L 4.0	4	5.5	1.7	L 4.0	7.0	4	4.8	1.6	L 4.0	8.0	6	4.0	0.0	L 4.0	L 4.0	5
beryllium	Be	0.08	0.0	L 0.08	L 0.08	4	0.08	0.0	L 0.08	0.1	4	0.08	0.0	L 0.08	L 0.08	6	0.1	0.0	L 0.08	L 0.08	5
cadmium	Cd	0.2	0.0	L 0.2	L 0.2	4	0.2	0.1	L 0.2	0.3	4	0.2	0.0	L 0.2	L 0.2	6	0.2	0.0	L 0.2	L 0.2	5
antimony	Sb	4.0	0.0	L 4.0	L 4.0	4	4.8	1.5	L 4.0	7.0	4	4.0	0.0	L 4.0	L 4.0	6	4.0	0.0	L 4.0	L 4.0	5
vanadium	V	0.4	0.0	L 0.4	L 0.4	4	6.5	11.3	L 0.7	23.5	4	0.4	0.0	L 0.4	L 0.4	6	4.5	9.0	L 0.4	20.7	5

TABLE 12 Metal concentrations in roots of Typha latifolia cultured in Channel B, U.B.C., in simulated coal mine wastewater, sampled during the summer and early autumn of 1986. (ug/g, dry weight)

Date:		26 June					6 August					27 August					1 October				
Element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	6930	1492	4880	8190	4	4853	1566	3750	6330	4	4698	1566	3070	7040	6	4550	1338	3120.0	6330.0	6
nitrogen	N	2226	1764	650	4450	4	3000	2000	1000	5000	4	5000	2000	3000	8000	6	2717	1300	1100.0	4800.0	6
manganese	Mn	175	14	161	194	4	125	57	42	165	4	91	22	54	119	6	130	75	34.0	243.0	6
phosphorus	P	2865	380	2390	3230	4	2160	566	1410	2680	4	1797	278	1540	2180	6	1772	264	1390.0	2020.0	6
magnesium	Mg	2463	417	1910	2920	4	1355	403	900	1830	4	1331	338	847	1860	6	1357	35	850.0	1860.0	6
sodium	Na	3483	634	2800	4330	4	1900	781	1120	2970	4	2285	981	1180	3490	6	2452	1145	1320.0	4540.0	6
iron	Fe	7268	1918	4450	8560	4	5023	2764	1810	7490	4	3743	1934	1800	7060	6	3748	1510	2430.0	6650.0	6
silicon	Si	3305	1753	1390	5390	4	1214	1283	107	3060	4	1351	1665	241	3900	6	1463	2263	136.0	5770.0	6
aluminium	Al	4903	1802	2280	6250	4	1404	1396	455	3480	4	1351	1080	352	3240	6	1052	658	367.0	1910.0	6
strontium	Sr	37	10	25	47	4	31	11	20	45	4	30	11	18	45	6	24	7	17.0	35.0	6
molybdenum	Mo	L 4.0	0.0	L 4.0	L 4.0	4	6	5	1	12	4	1.6	2	L 0.4	L 4.0	6	1.6	1.9	L 0.4	L 4.0	6
barium	Ba	25	9	14	35	4	18	11	5.77	27.9	4	11	8	4	24	6	10	4.8	5.5	17.9	6
zinc	Zn	65	14	47	82	4	35	18	18	61	4	33	20	7	65	6	32	17	4.7	54.9	6
titanium	Ti	214	75	110	271	4	96	106	2	249	4	45	71	9	189	6	47	59	0.4	152.0	6
lead	Pb	22.5	5	20	30	4	16	8	5	20	4	8	9	2	20	6	10	9	2.0	20.0	6
nickel	Ni	403	363	120	880	4	20	8	11	30	4	21	34	2	90	6	11	7.0	3.0	20.0	6
copper	Cu	32.5	10.8	17	42	4	7.2	5.3	3.8	15	4	6.1	3.3	2.6	11	6	8.4	4.3	4.5	16.0	6
tin	Sn	L 8.0	0.0	L 8.0	L 8.0	4	8.9	5	2.6	14	4	2.1	2.9	L 0.8	8	6	3.3	3.6	L 0.8	8.0	6
cobalt	Co	31.3	9	18	39	4	3.1	2	0.4	4	4	8.1	4.4	3.6	16	6	11	2	9.0	14.5	6
arsenic	As	L 40	0	L 40	L 40	4	40	24	10	70	4	16	18	L 4.0	L 40	6	16	18	L 4.0	L 40	6
beryllium	Be	L 0.8	0	L 0.8	L 0.8	4	0.6	0.0	L 0.08	L 0.8	4	0.32	0.0	L 0.08	L 0.8	6	0.32	0.0	L 0.08	L 0.8	6
cadmium	Cd	2.8	1	L 2.0	4	4	1.9	0.0	1.6	2	4	1.2	1	L 0.2	3	6	1	1.0	L 0.2	L 2.0	6
antimony	Sb	L 40	0	L 40	L 40	4	31	18	L 4.0	L 40	4	16	19	L 4.0	L 40	6	16	19	L 4.0	L 40	6
vanadium	V	18	7	9	24	4	5	4	2.7	11	4	8.2	7	2	20	6	9.3	13.8	1.3	37.0	6

Note: L = less than

TABLE 13 Metal concentrations in soil in experimental channel B with Typha latifolia, sampled during the summer and early autumn of 1986. (ug/g, dry weight).

Date:		02 July					06 August					01 October				
element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	6790.0	0	6790.0	6790.0	1	7060.0	254.6	6880.0	888.0	2	7675.0	700.0	7180.0	8170.0	2
nitrogen	N	4400.0	0	4400.0	4400.0	1	4900.0	100.0	4800.0	4900.0	2	5300.0	141.4	5200.0	5400.0	2
manganese	Mn	0.8	0	0.8	0.8	1	306.5	13.4	297.0	316.0	2	279.5	3.5	277.0	282.0	2
phosphoru	P	2090.0	0	2090.0	2090.0	1	2510.0	28.3	2490.0	2530.0	2	2850.0	254.6	2670.0	3030.0	2
magnesium	Mg	3090.0	0	3090.0	3090.0	1	2535.0	35.4	2510.0	2560.0	2	3215.0	558.6	2820.0	3610.0	2
sodium	Na	290.0	0	290.0	290.0	1	255.0	7.1	250.0	260.0	2	260.0	28.3	240.0	280.0	2
iron	Fe	20500.0	0	20500.0	20500.0	1	21050.0	636.4	20600.0	21500.0	2	20750.0	70.7	20700.0	20800.0	2
silicon	Si	1460.0	0	1460.0	1460.0	1	1130.0	70.7	1080.0	1180.0	2	1045.0	106.1	970.0	1120.0	2
aluminium	Al	28800.0	0	28800.0	28800.0	1	27650.0	919.2	27000.0	28300.0	2	25200.0	0.0	25200.0	25200.0	2
strontium	Sr	53.7	0	53.7	53.7	1	50.1	1.6	48.9	51.2	2	56.9	8.6	50.8	63.0	2
molybdenu	Mo	0.8	0	0.8	0.8	1	0.8	0.0	0.8	0.8	2	0.8	0.0	0.8	0.8	2
barium	Ba	93.1	0	93.1	93.1	1	88.6	2.3	87.0	90.2	2	89.7	3.7	87.0	92.3	2
zinc	Zn	71.7	0	71.7	71.7	1	70.9	0.9	70.2	71.5	2	90.5	8.6	84.4	96.6	2
titanium	Ti	2290.0	0	2290.0	2290.0	1	1725.0	35.4	1700.0	1750.0	2	1620.0	28.3	1600.0	1640.0	2
lead	Pb	25.0	0	25.0	25.0	1	25.5	0.7	25.0	26.0	2	25.0	1.4	24.0	26.0	2
nickel	Ni	9.0	0	9.0	9.0	1	9.0	1.4	8.0	10.0	2	13.0	1.4	12.0	14.0	2
copper	Cu	24.1	0	24.1	24.1	1	22.7	0.2	22.5	22.8	2	29.3	3.4	26.9	31.7	2
tin	Sn	5.0	0	5.0	5.0	1	10.5	0.7	10.0	11.0	2	11.0	4.2	8.0	14.0	2
cobalt	Co	8.0	0	8.0	8.0	1	7.0	0.4	6.7	7.3	2	6.2	4.0	3.4	9.0	2
arsenic	As	8.0	0	8.0	8.0	1	8.0	0.0	8.0	8.0	2	8.0	0.0	8.0	8.0	2
beryllium	Be	0.5	0	0.5	0.5	1	0.6	0.0	0.6	0.6	2	0.5	0.1	0.4	0.5	2
cadmium	Cd	0.9	0	0.9	0.9	1	0.7	0.1	0.6	0.7	2	1.2	0.4	0.9	1.5	2
vanadium	V	73.7	0	73.7	73.7	1	72.4	1.9	71.0	73.7	2	69	0	69	69	2

TABLE 14 Metal concentrations in soil in experimental channel C (without Typha latifolia), sampled during the summer and early autumn of 1986. (ug/g, dry weight).

Date:		06 August					01 October				
element		mean	S.D.	minimum	maximum	n	mean	S.D.	minimum	maximum	n
calcium	Ca	7070.0	70.7	7020.0	7120.0	2	7290.0	155.6	7180.0	7400.0	2
nitrogen	N	4000.0	707.0	3500.0	4500.0	2	5700.0	282.8	5500.0	5900.0	2
manganese	Mn	252.5	16.3	241.0	264.0	2	299.5	2.1	298.0	301.0	2
phosphorus	P	2515.0	7.1	2510.0	2520.0	2	2565.0	63.6	2520.0	2610.0	2
magnesium	Mg	3025.0	77.8	2970.0	3080.0	2	2550.0	28.3	2530.0	2570.0	2
sodium	Na	270.0	0.0	270.0	270.0	2	240.0	14.1	230.0	250.0	2
iron	Fe	18700.0	848.5	18100.0	19300.0	2	21500.0	282.8	21300.0	21700.0	2
silicon	Si	1080.0	28.3	1060.0	1100.0	2	1195.0	49.5	1160.0	1230.0	2
aluminium	Al	23150.0	2192.0	21600.0	24700.0	2	28050.0	919.2	27400.0	28700.0	2
strontium	Sr	55.8	0.5	55.4	56.1	2	48.0	0.8	47.4	48.6	2
molybdenum	Mo	0.8	0.0	0.8	0.8	2	0.8	0.0	0.8	0.8	2
barium	Ba	77.8	5.7	73.8	81.8	2	91.3	0.5	90.9	91.6	2
zinc	Zn	71.4	3.2	69.1	73.6	2	84.4	2.5	82.6	86.1	2
titanium	Ti	1460.0	127.3	1370.0	1550.0	2	1790.0	28.3	1770.0	1810.0	2
lead	Pb	24.0	0.0	24.0	24.0	2	25.5	0.7	25.0	26.0	2
nickel	Ni	11.0	0.0	11.0	11.0	2	9.0	0.0	9.0	9.0	2
copper	Cu	27.6	6.0	23.3	31.8	2	24.3	0.1	24.2	24.3	2
tin	Sn	11.0	0.0	11.0	11.0	2	11.5	0.7	11.0	12.0	2
cobalt	Co	4.2	1.3	3.3	5.1	2	4.2	0.1	4.1	4.3	2
arsenic	As	8.0	0.0	8.0	8.0	2	8.0	0.0	8.0	8.0	2
beryllium	Be	0.5	0.1	0.4	0.5	2	0.5	0.1	0.4	0.5	2
cadmium	Cd	0.7	0.2	0.5	0.8	2	0.3	0.0	0.3	0.3	2
vanadium	V	63.4	4.2	60.4	66.4	2	72.8	1.4	71.8	73.8	2

APPENDIX 10

Duckweed Metals Content

The following table summarizes the metals content data generated during the course of a laboratory study. Duckweed was grown under artificial illumination in a greenhouse. The plants were grown on water collected from a coal mine settling pond in south eastern B.C. The tissue analyzed consisted of a mixture of *Lemna minor* and *Spirodela polyrhiza*.

A complete description of the duckweed experiment and results is available in:

Norecol Environmental Consultants Ltd. 1986.
Potential Coal Mine Wastewater Treatment Options.
Manuscript Report 87-03, Environmental Protection,
Mining, Mineral and Metallurgical Process Division,
Environmental Canada.

TABLE 15 Metal concentrations in duckweed grown on simulated coal mine waste water in a greenhouse. (ug/g, dry weight).

Date:		April 1986				
Element		mean	S.D.	minimum	maximum	n
calcium	Ca	54175.0	40661.6	13600.0	97400.0	4
nitrogen	N	25.8	17.7	13.0	52.0	4
manganese	Mn	213.7	333.3	32.0	713.0	4
phosphorus	P	5626.0	8661.4	794.0	18600.0	4
magnesium	Mg	6340.0	3458.7	1350.0	8770.0	4
sodium	Na	1237.5	878.9	570.0	2430.0	4
iron	Fe	259.3	225.4	103.0	590.0	4
silicon	Si	138.8	67.6	60.0	200.0	4
aluminium	Al	134.0	64.5	88.0	229.0	4
strontium	Sr	123.1	85.5	33.2	202.0	4
molybdenum	Mo	10.0	13.4	1.6	29.9	4
barium	Ba	486.9	409.8	5.7	882.0	4
zinc	Zn	232.3	158.8	60.2	409.0	4
titanium	Ti	3.8	4.1	L 0.3	9.5	4
lead	Pb	40.0	11.5	27.0	52.0	4
nickel	Ni	6.0	3.6	L 3.0	10.0	4
copper	Cu	32.3	13.4	20.4	50.5	4
tin	Sn	2.1	0.8	L 1.0	3.0	4
cobalt	Co	1.9	0.6	1.4	2.7	4
arsenic	As	6.5	1.7	L 4.0	8.0	4
beryllium	Be	0.1	0.1	L 0.08	0.2	4
cadmium	Cd	0.8	0.6	L 0.3	1.3	4
antimony	Sb	7.0	0.8	L 6.0	8.0	4
vanadium	V	0.7	0.2	L 0.4	0.8	4