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ECOLOGICAL REHABILITATION OF A SEAWATER CONTAMINATED PEATLAND :
the case of Pokesudie Bog, New Brunswick.

Thèse présentée
à la Faculté des études supérieures de l'Université Laval
dans le cadre du programme de maîtrise en Biologie Végétale
pour l'obtention du grade de maîtrise

DÉPARTEMENT DE PHYTOLOGIE
FACULTÉ DES SCIENCES DE L'AGRICULTURE ET DE L'ALIMENTATION
UNIVERSITÉ LAVAL
QUÉBEC

2008

Résumé

Les tourbières exploitées et occasionnellement inondées par de l'eau de mer présentent une ensemble de facteurs qui compliquent leur restauration / réhabilitation, incluant la toxicité du sel, le soulèvement gélival, les inondations par les eaux pluviales et peut être le facteur le plus difficile à gérer, le manque de graines adaptées. Cette étude a eu pour objectif de tester différentes techniques de réhabilitation sur une tourbière exploitée et inondée par l'eau de mer, située sur l'Île de Pokesudie, Nouveau-Brunswick. Lors d'une tempête en janvier 2001, une partie de la zone d'exploitation de cette tourbière a été inondée par de l'eau de mer. En dépit des efforts de mitigation, la tourbe est restée trop salée pour pouvoir être utilisée en horticulture, des recherches ont alors été menées pour trouver des techniques de réhabilitation. Ces techniques de restauration visent à stabiliser le substrat par développement d'un couvert végétal important. Pour cela des espèces typiques des marais salés ont été utilisées. Deux techniques d'introduction ont été testées : le transfert par carottes de densités différentes et le transfert de foin. L'utilisation de fertilisant a également été testé. Le recouvrement végétal le plus important a été obtenu en utilisant le transfert de foin récolté dans des zones dominées par *Juncus bufonius* et dans des communautés végétales des marais salés dominés par *Spartina pectinata*. L'utilisation de fertilisant n'a pas accéléré le développement du recouvrement végétal. Cette étude pourrait être intéressante pour d'autres projets de réhabilitation de tourbières côtieres.

Mots clés: Tourbière, réhabilitation, contamination saline, transfert par carottes, transfert de foin.

Abstract

Harvested peatlands affected by salt contamination present an ensemble of complicating factors concerning their revegetation / rehabilitation, including salt toxicity, frost heaving, flood water control and perhaps most importantly lack of a viable seed bank. This study involves the identification of methods that may be used in the rehabilitation of a coastal post-harvested peatland on Pokesudie Island, New Brunswick. During a storm in January 2001 a large volume of seawater was washed onto the peatland. Despite mitigation efforts the peat resource has remained too saline for horticultural use and rehabilitation methods are being sought. These involve the use of various salt marsh species to establish a vegetal cover of the peat surface to first help stabilize the substrate. Various re-introduction techniques such as plug transfer at various densities and the use of hay transfer were tested. The use of fertilizer was also examined. Highest revegetation rates were achieved using hay transfers taken from swards of *Juncus bufonius* and salt marsh vegetation dominated by *Spartina pectinata*. Fertilizer use did not significantly increase plant establishment. This research may be applicable to other coastal peatland rehabilitation projects.

Keywords: Peatland, rehabilitation, salt contamination, plug transfer, hay transfer

Acknowledgements

I would like to thank my family for all of the support and encouragement they have given me. I would also like to thank everyone in the Peatland Ecology Research Group for their advice and help in the field, but most importantly for their openness, hospitality and friendship. I would especially like to acknowledge the help given to me during my field work by Luc Miousse, Stephanie Boudreau, Fabrice Pellot, Lydia Querrec, Miranda Lewis, Marilou Montemayor, and last but definitely not least Natacha Mosnier. Thanks also to Sungro Horticulture Ltd, New Brunswick for the use of their laboratory facilities. Thanks also to all of my dear friends I met in Quebec and everyone in Les Patriotes de Québec, Club de Football Gaélique who helped me feel so much at home. One last but most important thanks to Pierre-Loup Boudreault for being the soundest Paddy-quebecois I've ever met. Go raibh míle maith agat a charra.

Dedicated to my grandmother Kathleen Walsh, who believed in me right to the very end.

Remerciements

Je veux remercier ma famille pour tout le soutien et les encouragements qu'ils m'ont donné pendant mes études. Je souhaite aussi remercier toute l'équipe du Groupe de Recherche en Écologie des Tourbières pour leurs conseils et leurs aides sur le terrain, mais plus important pour leur accueil et camaraderie. Je souhaite dire un grand merci pour leur aide sur le terrain à Luc Miousse, Stéphanie Boudreau, Fabrice Pellot, Lydia Querrec, Miranda Lewis, Marilou Montemayor ainsi qu'à Natacha Mosnier pour son aide précieuse lors de l'installation des expériences. Merci aussi à Sungro Horticulture Lté, Nouveau-Brunswick pour l'utilisation de leur laboratoire. Merci à tous mes amis à Québec et tout le monde dans les Patriotes de Québec, Club de Football Gaélique qui m'ont fait me sentir chez moi toute suite. Un dernier mais vraiment important merci à Pierre-Loup Boudreault, le plus génial Paddy-québécois que j'ai jamais rencontré. Go raibh míle maith agat a charra.

Dédié à ma grand-mère Kathleen Walsh, qui a eu confiance en moi jusqu'à la fin.

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1. Introduction

The revegetation of bare peat substrates following disturbances such as fire or peat harvesting has been well studied in recent years (Price et al, 2003; Rochefort et al, 2003). However, post-harvest peatlands affected by salt water contamination pose further challenges to an already difficult task. Most studies concerning salts in peat accumulating systems are focused on salt marshes. References to salt in ombrotrophic peatlands are usually limited to descriptive chemistry and do not go into much detail concerning how it reacts in the peat and the effects it has on the vegetation. Salts, such as NaCl, are typically present in peatlands in extremely low concentrations. Consequently, peatland plants do not require or possess mechanisms to deal with elevated salt concentrations. Harvested coastal peatlands in New Brunswick that have been affected by salt contamination due to sea water inundation during winter storms present an ensemble of complicating factors concerning their revegetation / rehabilitation, including salt toxicity, frost heaving, desiccation, flood water control and perhaps most importantly lack of a viable seed bank.

1.1. Management of peatlands in New Brunswick

Peatlands account for 2% of the land mass of New Brunswick (Department of Natural Resources, Government of New Brunswick, 2008a). Today, New Brunswick is Canada's largest producer of horticultural grade peat (Department of Natural Resources, Government of New Brunswick, 2008b). These peatlands are mainly located in the East and North East of the province

(Figure 1) and are often found in close proximity to the coast. Of the peatlands considered to contain peat of commercial quality, 70% occur on Crown Lands. Part of the pre-requisite for the granting of an extraction licence on these lands is the submission of a clearly outlined restoration plan and the submission of a monetary guarantee. This is refunded after the conditions imposed by a representative from the Department of Natural Resources regarding the rehabilitation of the peatland have been met.

The principal method used to extract the peat resource in Canada is the vacuum method. Firstly, a perimeter ditch is dug to drain the peatland. The vegetation is then removed from the surface. Further parallel drainage canals leading into the main perimeter ditch are dug at 30 m intervals to ensure adequate drainage that will allow heavy machinery to pass over the peat without sinking. Once dry enough to support the machinery, the surface of the peat is milled to loosen it and allow it to dry. This is then collected using large vacuums and stored in piles before being transported to the production factory for processing into the final grades of commercial peat.

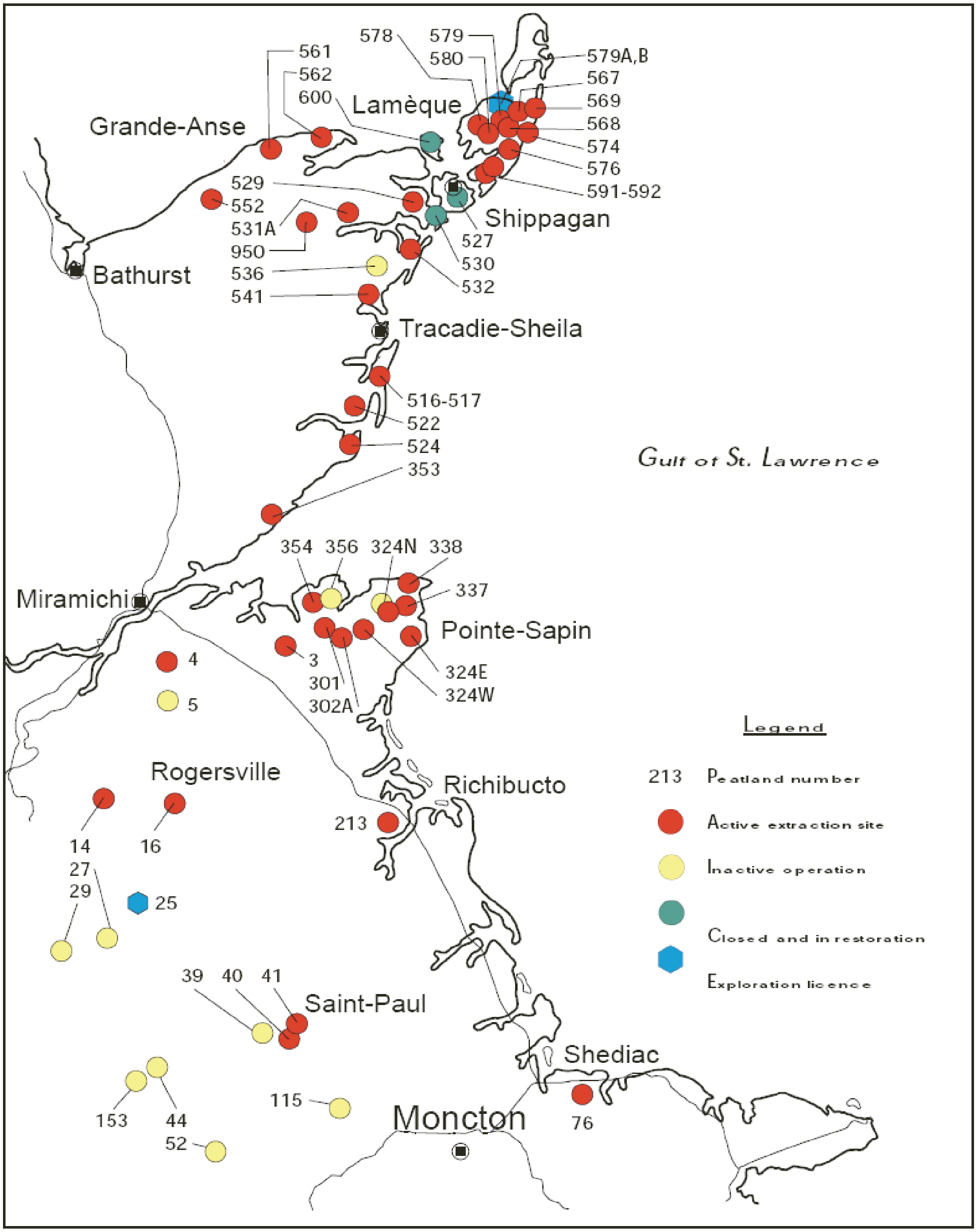

Figure 1: Locations and status of the peat extraction industry in New Brunswick in 2008 (Dept of Natural Resources, Govt. of New Brunswick, 2008c).

1.2. Peatland Rehabilitation

Peatlands harvested using the vacuum method are recognised as being harder to rehabilitate than the former block cut method for extracting peat (Robert et al, 1999; Lavoie et al. 2003). The opening of extensive bare peat areas to allow the vacuum machines to operate leaves a substrate devoid of a viable seed bank (Salonen, 1987; Salonen et al, 1992). Exploited peatlands also undergo changes at a physical and chemical level. These changes occur due to the lowering of the water table and increased decomposition rates which accompany aeration (Wells and Williams, 1996).

Drainage is very efficient in vacuum mined peatlands, altering the bogs hydrology drastically from its original status. The lowering of the water table exposes organic matter that had previously been in an anaerobic environment to an aerobic one, thereby increasing levels of decomposition (Mitsch and Gosselink, 2000; Greenwood, 1961; Price et al, 1998). In post harvest peatlands it is common to see a dry crust that forms on the peat surface. This crust prevents newly introduced plants from gaining access to water that is usually supplied by capillary action in natural peatlands (Price, 1996; 1997).

Previous studies have shown that harvested peatlands differ greatly in terms of their chemical status to those of natural unharvested peatlands (Wind-Mulder et al. 1996). Extraction of the peat exposes layers of the peat formed during earlier successional stages in the peatland's development. These layers have different physiochemical properties than were found in overlying layers, marked especially between the fen/ombrotrophic peatland transitional layers where pH changes from typically alkaline to acidic (Wind-Mulder et al. 1996)

Another problem faced in rehabilitation programs such as that of the Pokesudie Island peatland is frost heaving. Frost heaving occurs in the autumn and spring when temperatures in the peat frequently descend below and rise above zero. Water near the peat surface forms ice columns which push the overlying peat upwards. Once the temperature rises above zero, these ice columns melt and the peat is left displaced or even overturned. These freeze and thaw cycles leave behind an uneven microtopography which is thought to hinder plant and moss establishment (Groeneveld, 2002). Frost heaving has also been known to break the roots of newly established plants.

Despite the difficulties encountered in the rehabilitation of harvested peatlands, much success has been achieved by the Peatland Ecology Restoration Group (PERG) with the development of a cost effective, paludifying restoration approach (Ferland and Rochefort, 1997). This approach focuses on the active reintroduction of typical peatland plants, particularly the *Sphagnum* mosses, onto the restoration site. Live diaspores of *Sphagnum* mosses are harvested from a donor area and then spread onto the restoration site. This is then covered with a layer of straw. The straw acts as an insulating layer which keeps temperatures within a narrower range and improves the water retention potential of the peat (Price et al, 1998). Because of the plant re-establishment rates, reduction in evaporative rates and reduction of frost heaving damage resulting from this method, a similar approach was tested for Pokesudie.

1.3. Sea water contaminated coastal peatlands

Saltwater affected coastal peatlands in New Brunswick present us with the all of the problems for restoration plans that were mentioned before plus that of salt toxicity. Mitigation efforts to limit the movement of or remove the salt from peatland by mechanical means have proved unsuccessful and the peat has remained too salty for use in the horticultural industry (Mouneimne and Price, 2007). The peatland have therefore been abandoned.

The salt concentration of the residual peat at Pokesudie peatland is two to three orders of magnitude greater than levels in natural peatlands. In oceanic areas, Na input into peatlands often occurs through precipitation, with highest precipitation input rates occurring during foggy periods (Damman, 1986). Glaser (1992) noted a decrease in Na concentrations in water from maritime peatlands to others located further inland in North America. Damman (1986) estimated the Na concentration in bog water of a natural, oceanic, ombrotrophic peatlands in western Newfoundland to be approximately 3.85 ppm. However, the levels at which Na is added by through precipitation in oceanic regions are still low enough that they do not cause any problems for typical peatland vegetation and result only in minor changes of community structures. Some of the Na is even taken up by plants and used for various metabolic functions. In Canadian continental peatlands far removed from the coast, Wind-Mulder et al (1996) estimated Na concentrations in peat to range between 0.11ppm and 0.4ppm. The Pokesudie site has Na water concentrations ranging between 590-3300 ppm in the flood water affected areas (personal observation).

Typically, Na is found at its highest concentrations in the surface layers of unharvested peatlands, decreasing with depth (Wind-Mulder et al. 1996). Mouneimne and Price (2007) showed an overall downward hydrological gradient whereby solutes were transported along with the water, resulting in higher concentrations at depths below 50cm. The long term effect of this was predicted to be an eventual leaching of the salts from the peatland, although a time frame for this could not be estimated from this study. With restoration of the harvested and flooded area in mind, the concentration of salts in the rooting zone is more important. Due to seasonal dilution in spring and autumn precipitation as well as the evaporative concentration (Bertness et al, 1992, Mitsch and Gosselink, 2000) resulting from drier periods in the summer during which salt concentrations can increase twenty fold between 0 – 22cm depth (Mouneimne and Price, 2007), the salt concentrations in this layer are of vital importance. Salt concentrations in this layer during the summer were reported by Mouneimne and Price (2007) to be above the tolerance levels of native bog species (Wilcox, 1984; Wilcox, 1986a; Wilcox and Andrus 1987).

An added problem in planning the restoration of Pokesudie site is seasonal flooding following the spring snowmelt and heavy autumn rainfalls (personal observation). Rewetting of the site is a vital part of any peatland restoration program; however, too much flooding can prove problematic also. Since the drainage canals of the peatland at Pokesudie are no longer functional, in spring and autumn the salt water affected area becomes inundated with water and large lakes are formed. When winds are high it has been noted that there has been strong wave action in these lakes (personal observation). These waves erode the peat from the edges of the lakes and mix the peat up in the water. When the floodwater eventually retreats there is evidence of peat redeposition (Mouneimne and Price, 2007, personal observation). This substrate instability may cause problems for plant establishment due to uprooting, burial and/or exposure.

The problem of spring and autumn flooding at Pokesudie abandoned peatland is separated by a summer time drought, particularly in areas of higher elevation nearest to the access road and higher grounds away from the sea edge. Precipitation rates fall toward the mid and late summer while temperatures rise. This creates conditions ideal for evaporation and the floodwater disappears quickly. The peat dries rapidly and a hard crust develops on the peat surface. Within a matter of weeks, areas of the peatland change from very wet to crusty dry or dusty where fine peat was redeposited (personal observation).

Salt affects plants by causing an osmotic pressure gradient from the plant cells to the exterior environment. The internal ionic concentration within cells is usually lower than that of the surrounding saline water. This causes a loss of water from the cytoplasm and a passive diffusion of Na^+ into the cell. Apart from cell structural damage due to water loss, Na^+ can also reach toxic concentrations in plant tissues. Na^+ is thought to interfere with or even halt many metabolic reactions (Mitsch and Gosselink, 2000).

Mosses, particularly the *Sphagnum* mosses, are severely affected by salt contamination. Wilcox (1984) observed an absence of living *Sphagnum* in an area of a peatland in Indiana affected by runoff resulting from a nearby road de-icing stockpile. Wilcox showed how the main cause of mortality of *Sphagnum recurvum*, a coastal species, was salt encrustation of the leaves due to evapotranspiration, resulting in a physical breakdown of the plant structure and desiccation of the plant tissue. Low levels of NaCl concentration were also shown to inhibit growth. In fact, drastic changes at all levels were noted by Wilcox in the community structures of these areas, as endemic species such as *Larix laricina* (Du Roi, K. Koch), *Vaccinium corymbosum* L. and *Gaylussacia baccata* (Wangenh, K. Koch) were replaced by invading species such as *Typha spp*. Strangely, initial trials using plug transplants of *Typha latifolia* L. in the lesser affected area at Pokesudie resulted in no surviving plants in the following growing season. Thus, other types of plants were sought.

As mentioned previously, the lack of a viable seed bank either due to spatial isolation or adaptability is likely to be one of the most challenging factors to overcome. Many rehabilitation projects in Europe have resolved this challenge by using a technique known as a hay transfer technique (Pywel et al, 1995). Seed containing hay is harvested from areas containing the target species required and then spread on to the receiving area. This technique has proven to be successful in many studies (Kiehl and Wagner, 2006; Rasran et al, 2006) with high similarities between the established species and those contained within the hay as seeds. The species that will grow from a hay transfer will depend strongly on the harvest time as not all seeds mature at the same time of the year. An added bonus to using a hay transfer technique will be the shade offered by the plant material. This will help ameliorate the hydrological conditions and reduce the temperature ranges of the peat. However, this technique is usually used to restore ecosystems that resemble the donor site. Saline peatlands are not normally found in nature; therefore hay from a salt marsh will be used. Another technique often employed in salt marsh restorations uses plug transplants. Soil cores containing the below and above ground biomass of the target plants are harvested from a donor area and then transplanted to the target area. This is a labour intensive method, however it has been observed to work well in salt marsh restorations.

1.4. Similarities and differences between saline peatland and salt marsh rehabilitations

The plants to be used in the rehabilitation of saline peatlands will have to be tolerant of many diverse conditions. They will have to be able to contend with;

- Low pH
- Poor nutrient status
- Flooding and anoxia
- Drought
- Wave erosion
- Wind erosion
- Salinity
- Bare / exposed areas

As mentioned previously, peat mosses will not be suitable for the rehabilitation of saline floodwater affected peatlands. Damaged salt marshes are ecosystems where these conditions do exist. Plants found growing in salt marshes have evolved to be tolerant of these conditions. A salt marsh, as defined by Beeftink and quoted by Mitsch and Gosselink (2000) is a “natural or semi-natural halophytic grassland and dwarf brushwood on the alluvial sediments bordering saline water bodies whose water level fluctuates either tidally or non-tidally”. The fluctuation in water levels, along with the salinity, causes conditions that only certain plants are capable of tolerating. This results in a highly organised species zonation across the salt marsh, mixing pastures of grassland communities with sparsely vegetated salt and mud flats. The dominant plants, often grasses such as *Spartina spp.* and *Juncus spp.* have various mechanisms that allow them to tolerate elevated salinity levels, inundation and drought. Species of these genera are the species most often used in salt marsh restorations.

1.5. The use of fertilizer

To succeed in reintroducing vascular plants originating from a salt marsh to Pokesudie abandoned peatland, it is highly likely that fertilization will be needed. Despite peatlands and salt marshes both being wetlands, differences exits between the types of fertilization carried out during restoration work based on the availability of certain elements, particularly N and P.

In well drained soils, oxygen is used to fuel the decomposition of organic matter by micro-organisms. As previously explained, oxygen is limiting in both salt marshes and peatlands; therefore, other compounds are used to fuel these processes. The use of terminal electron acceptors other than O_2 by anaerobically respiring micro-organisms to decompose organic matter has important implications for the chemical and physical status of wetland soils. Micro-organisms oxidise organic matter by chemically reducing nitrate (NO_3^-) to nitrite (NO_2^-), ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), and sulphate (SO_4^{2-}) to sulphide (S^{2-}). This has important consequences for the availability of N and P in inundated soils leading to an accumulation of the reduced forms of ferrous iron and sulphide, and the release of nitrogen from the soils by volatilisation and thereby an increase in the redox potential (Mitsch and Gosselink, 2000;

Otte, 2003). This must be taken into consideration when deciding on the type of fertilizer to be used in any restoration work to be carried out in wetlands.

Coastal waters are generally accepted to be poor in nitrogen (Mitsch and Gosselink 2000), and nitrogen is often the most limiting nutrient under natural conditions in coastal ecosystems such as salt marshes (Boyer and Zedler, 1998; Vitousek and Howarth, 1991; Ngai and Jefferies, 2004; Kaplan et al, 1979). Kaplan et al (1979) found that denitrification rates exceeded nitrogen fixation in a New England salt marsh, supporting theories that salt marshes are N limited. Furthermore, Teal et al (1979) found that N-fixation by bacteria was not enough to support plant growth in a salt marsh used in that particular study. However, in the same study N addition through freshwater sources was found to be over three times that of N fixation, enough to support plant growth. Depending on the source of water input, N often forms the sole or major component in fertilizers used in salt marsh restorations. In post-harvest peatlands however, the only water input is often through precipitation, and not likely to contain high levels of nitrogen. Wind-Mulder et al (1996) found increased nitrate and ammonium levels in post harvest peatlands compared to natural peatlands and found N levels in post harvest peatlands not to be limiting for peatland plants; however, the level of N which is limiting for salt marsh plants is likely to be very different. As N forms the major component of fertilizer regimes in salt marsh restorations, it also made up a significant part of the fertilizer used in this study. N exists in several forms which are commercially available in agricultural fertilizers. However, the choice of the form of N to be used depends upon the soil in need of fertilization.

When using low biuret urea some guidelines have been suggested by Overdahl et al (1991) that are pertinent to both salt marsh and peatland rehabilitations. Nitrogen from urea can be quickly lost to the atmosphere if left resting on the soil surface during warm weather, therefore incorporation into the soil by tilling or placement in the soils profile is suggested. Urea can also be incorporated into the soil with irrigation water in agricultural croplands. When urea fertilizer comes in contact with moisture in soils it is hydrolyzed by the enzyme urease and converted to ammonia (NH_3) and carbon dioxide in the following reaction

$$CO(NH_2)_2 + H_2O + \text{urease} \rightarrow 2NH_3 + CO_2$$

As NH_3 is gaseous above -33°C much of the nitrogen that is put in place may be lost to the atmosphere unless rapidly incorporated into the soil or taken up by plants. The rate at which this reaction proceeds depends on soil pH and temperature and the example of Overdahl et al (1991) is given below in tables 1 and 2. Given that peatlands are generally wet and that temperatures on bare peat surfaces can reach high levels (Price et al, 1998) urea based fertilizers are likely to be unsuitable for peatland restorations. Instead, ammonium based fertilizers are recommended.

In salt marsh restorations, N is usually added in the form of ammonium sulphate ($(NH_4)2SO_4$) (Gibson et al, 1994), ammonium nitrate (NH_4NO_3) and/or urea ($CO(NH_2)_2$) (Parsons and Zedler, 1997). Some researchers suggest the use of ammonium based fertilizers as opposed to nitrate based fertilizers, but this is usually based on one reference dating back to 1967 from Tyler. This study revealed species specific reactions depending on the form of N used in the fertilizer.

Table 1: Percent of surface added urea volatilised at different temperatures (Adapted from Overdahl et al, 1991).

	Temperature			
Day	7.2°C	15.6°C	23.9°C	32.2°C
0	0	0	0	0
2	0	0	1	2
4	2	2	4	5
6	5	6	7	10
8	5	7	12	19
10	6	10	14	20

Table 2: Percent of surface added urea volatilised at different pHs (Adapted from Overdahl et al, 1991).

	pH					
Day	5	5.5	6	6.5	7	7.5
0	0	0	0	0	0	0
2	0	0	0	0	1	5
4	1	2	5	10	18	20
6	4	5	7	11	23	30
8	8	9	12	18	30	33
10	8	10	13	22	40	44

Peatlands are widely recognised as being phosphorus limited (Sottocornola et al. 2007; Wind-Mulder et al, 1996). Although one of the most commonly limiting elements in many ecosystems, both terrestrial and wetland, P is not thought to be limiting in salt marshes (Mitsch and Gosselink, 2000). Due to the periodic flooding with seawater, which is rich in P, salt marshes continually receive a renewal of P. Salt marsh plants have evolved in areas where P limitation is not problematic, however if we are to introduce them to a P limited system then P should also form a major part of the fertilization.

One major difference between the P and N cycles of wetlands is that the P cycle is sedimentary (Richardson, 1985) and the N cycle has an out flowing gaseous stage. The ability to retain P by either constructed or natural wetlands is regarded as a good indicator of its ecosystem state. P is retained in wetlands by the removal of dissolved inorganic P from water inputs by biotic uptake, sorption on to clay particles, geochemical adsorption or the accumulation of organic P in peat (Richardson, 1985). Incorporation into vegetal biomass however is only a short term sink for P, as once the plants die P is quickly released to the peat substrate; however Kao et al (2003) showed that high variation of this rate exists between species. The main forms in which P are found in wetlands are listed in Table 1. When soils become flooded, ferric iron (Fe_3^+) is reduced to ferrous iron (Fe_2^+). When this occurs, P that is bound in a specific ferric phosphate, known as reductant-soluble phosphorous, is released and made available to plants. The hydrolysis of ferric and aluminum phosphates and the release through anion exchange of organic and hydrous oxide bound P is also thought to be a major source of P in wetlands (Mitsch and Gosselink, 2000).

In post harvest restorations of peatlands Ferland and Rochefort (1997) recommend the addition of phosphate to aid in vegetation establishment. The bog plant species used in regular post harvest peatland restorations have evolved in an ecosystem where P is generally limiting, and thus even a small addition of P will aid their growth and establishment. Salt marshes are not P limited, however when the rapid re-establishment of vegetation cover is desired, the furnishing of an initial supply of P in the form of $NaH_2PO_4 \cdot 2H_2O$ or $NaH_2PO_4 \cdot H_2O$ which is readily available to plants has been used successfully in several studies in salt marshes (van Wijnen and Bakker, 1999;

Handa and Jefferies, 2000; Ngai and Jefferies, 2004). Ortho-phosphates are readily available to plants, helping them to germinate and get established quicker. Di-ammonium phosphate fertilizers are a readily available commercial type of fertilizer that fulfils the nutrient requirements for the rehabilitation of a saline peatland. N is present in the form of ammonium, and P in the form of orthophosphate.

Table 3: Forms of P in wetland soils (Adapted from Mitsch and Gosselink, 2000)

	Soluble	Insoluble
Inorganic	Orthophosphates ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}). Polyphosphates. Ferric phosphate ($FeHPO_4^+$). Calcium phosphate ($CaH_2PO_4^+$).	Clay-phosphate complexes. Metal hydroxide phosphates. Minerals.
Organic	Dissolved organics (e.g. sugar phosphates, phospholipids, phosphoproteins).	Insoluble organic phosphorus bound in organic matter.

1.6. Objectives

The primary objective of this study is to identify techniques that will optimize vegetation establishment of an abandoned salt affected peatland, thereby stabilizing the peat surface. This would also result in a reduction of evaporative losses, causing a further reduction in NaCl concentration. It is hoped that this will result in an eventual return of native bog species and a reduction of non-native species, as occurred in Wilcox's study of 1986. This work will be valuable to other projects working with coastal peatlands affected by Na input through sea spray or storm incursions. The secondary objectives of this study include examining the suitability of plant introduction techniques and the effects of soil preparations.

Hypothesis 1: With a plug reintroduction method, units with higher initial transplant densities will have higher percentage groundcover than units with lower initial planting densities.

Hypothesis 2: Parcels treated with sand application will have higher percentage vegetal groundcover than those that do not receive sand.

Hypothesis 3: Parcels treated with hay transfer treatments will have higher percentage vegetal groundcover than control plots where no hay is transferred.

Hypothesis 4: Parcels treated with fertilizer will have higher percentage vegetal groundcover than unfertilized parcels.

2. Experimental site

2.1. Site description

The site where the research was carried out is located on Pokesudie Island, New Brunswick, Canada (47°49'N; 64°49'W). All experiments were carried out in low lying (1 – 2 m.a.s.l.) saline floodwater affected and slightly more elevated abandoned areas of the peatland. The site is a former Atlantic coastal raised bog of the Acadian peninsula in New Brunswick province. Average yearly precipitation is 1,059 mm, 314 mm of which falls as snow. Average

January temperature is -11.1°C and average July temperature is 19.3°C (Bathurst NB station, Environment Canada 2008). It is surrounded by the sea on its Northern, Western and Eastern sides. Close to the sea can be found areas of natural salt marsh habitat. A wide band of forest borders the peatland.

On the 21st January 2000 a storm surge occurred, resulting in the incursion of a large volume of sea water and sea ice on to the peatland at the northern end of low lying fields. An access road between the low lying and slightly elevated areas limited incursion of seawater into the former to a small volume. This has resulted in two very different salinity levels, the severely affected low lying field and the lesser affected slightly elevated field (see table 4). Estimates of the storm flood depths at the site at the time were between 0.3 to 0.7 m.

At the time of flooding the peat was frozen. Initially, efforts were made by the peat harvesting company to minimize or localize salt contamination of the peatland. It was hoped to remove the saline ice and snow from the peatland using machinery, however this was found to be ineffectual and efforts were ceased. Later tests on the peat showed it to be too saline for commercial use. Finally, a decision was taken to close the site to production in August 2001, and ideas for rehabilitation or reclamation for other uses were sought. A border wall was constructed with peat around the peatland in 2002 to prevent a reoccurrence of the 2000 storm surge.

Approximately 140 hectares (350 acres) have been harvested using the vacuum method. Drainage of the peatland was achieved by means of a series of drainage ditches placed 25-30 m apart running roughly north to south over the surface of the bog. These lead to larger drainage channels and then toward a water-pump in the western part of the bog. During the harvesting period, excess water was pumped into the sea. The pump was not in operation in the period between 2001 and 2006. The drainage channels have mostly collapsed in on themselves and there is currently very little or no lateral movement of water through the peat (Mouneimne and Price 2007).

Figure 2: Arial photograph of Pokesudie Bog showing the areas studied.

The surface of the bog in both study areas is almost totally bare. Some natural regeneration has occurred but this is very sparse (personal observation). The field lying furthest east in the severely affected area is separated from the rest of the peatland by a peat wall. Spontaneous regeneration, principally by *Juncus bufonius* (L.), *Juncus balticus* (Wild), and *Spartina pectinata* (Bosc ex Link) has occurred between summer 2004 and summer 2006. Percentage cover rates here are often 100% (personal observation). Plants established here are healthy and seeds are present on the majority of plants.

In the lesser affected area, tree stumps from the woody fen stage in the peatland's development can be seen protruding and breaking the surface. Following the application of an unknown amount of a custom formula ammonium orthophosphate ($(NH_4)_2$ HPO_4, (15-25-0)) fertilizer in the summer of 2003 the south western portion of this area, *Juncus bufonius* was seen to establish spontaneously. It quickly established a thick carpet of *Juncus bufonius* which grows and continues to spread from year to year. Other species such as *Eriophorum vaginatum* (L). and *Carex brunesscens* have been establishing within this area also but at much lower rates.

2.2. Physico-chemical conditions

Salinity (‰), pH, electrical conductivity (µS), bulk density ($g.cm^{-3}$) and volumetric soil water content ($m^3.m^{-3}$) for each experimental unit were measured.

In summer 2005, composite peat samples were collected for chemical analyses by mixing three sub-samples at each experimental unit. Sub-samples of peat of approximately 30 – 40 cm^{-3} were taken from the sides of experimental units closest to a drainage canal, the side closest to the dome centre of the field, and from the middle of the experimental unit. Analysis was carried out on the peat water in Sungro Horticulture laboratory, Lameque Island, New Brunswick. Approximately 200 ml of water was extracted using a vacuum pump. pH was measured using a Fisher Scientific, Accumet pH meter 10. Salinity and electric conductivity were measured using a Yellow Springs Instrument Co. Inc. Model 33 series 15121, S-C-T meter. Conductivity was corrected for temperature using correction factors supplied with the machine, and for H+ concentrations using the formula of Sjörs (1951). The excess of the peat samples were used to ascertain macro-nutrient (N, P, K) and base cation (K^+, Ca^{2+}, Mg^{2+}, Na^+) content in the peat.

An estimate of total N, P and K was made for both study areas to characterise the main nutrient conditions of the peat. These estimates were based on a mix of peat samples taken from each of the experimental units within each block. An equal amount of peat was taken from each of the peat samples used for water chemistry and mixed together in the lab to make a representative sample for each block. An average for each area was calculated based on these values.

For bulk density (BD) and volumetric water content (VWC), cores of a known volume were taken. The oxidized layer was scraped away from the surface of the peat (approximately 5cm deep) before cores were taken. Two cores were taken from each experimental unit, on two opposing side of the plot. These were placed in sealable plastic bags and taken to the lab where their wet weights were measured. Samples were then placed in an oven at 80°C for 48 hours, after which their dry weights were measured. BD was assessed by dividing the dry weight of a sample of peat by its volume. BD and VWC were calculated based on the average results for BD and VWC for each experimental unit. The formulae used to calculate these values are as follows;

Bulk density = $(M_{dry}) / V$

Volumetric water content = $((M_{wet} – M_{dry})) / V$

where M is the mass of peat and V is the volume of the core used.

Table 4: Mean physico-chemical conditions of the lesser and severely affected areas (± Standard deviation). Data are based on an aggregate of samples from each experimental unit within each respective area. Sampling was carried out in June 2005.

	Lesser affected	Severely affected
pH (water)	3.9 ± 0.1	3.3 ± 0.2
Salinity (‰) (water)	0 ± 0	2.1 ± 0.8
Ec (µS) (water)	139 ± 86	2854 ± 1051
Bulk density ($g.cm^{-3}$)	0.1	0.11
Volumetric water content ($m^3.m^{-3}$)	0.89 ± 0.1	0.89 ± 0.1
Ca (ppm) (peat)	2.7	34.9
Mg (ppm) (peat)	6	110
Na (ppm) (peat)	36	750
K (ppm) (peat)	507	858
P (ppm) (peat)	2590	2088
Total N (%) (peat)	0.6	0.4

3. Materials and methods

In an effort to identify species that could recolonise sea water contaminated peat, experiments were put in place at Pokesudie peatland in the summers of 2004, and 2005 to test the survival and growth capabilities of several plant species. Various species and introduction techniques were tested and are described below. Nomenclature follows Andrus (1980) for *Sphagnum* mosses and the United States Department of Agriculture plant database for vascular plants.

3.1. Experiment 1: Hay transfer with fertilization

To test the suitability of a hay transfer technique, a 15 month experiment was started in the lesser affected area in May 2004. Hay from communities dominated by more than 60% cover of either *Juncus bufonius* or *Carex brunesscens* were used. The hays were harvested at Pokesudie peatland in areas where spontaneous revegetation has occurred in an area not affected by the storm surge. Three blocks comprising two experimental units (4 x 6 m) were put in place using a completely randomized block design. Plant material from the previous year and the current season growth was harvested by hand using a scythe. Seeds from the previous year's growth were contained in this material. The harvest : spread ratio was 1:1. The hay was transported in large plastic bags and spread evenly by hand in the receiving experimental unit the next day. Boundary walls of peat approximately 30 cm high were constructed around the receiving parcels in order to prevent spring and autumn flood waters from spreading the hay treatments.

A custom formula of di-ammonium orthophosphate ($(NH_4)_2$ HPO_4) 15-25-0 fertilizer was broadcast spread on the surface of each experimental unit at a rate of 15 $g.m^{-2}$ at sowing time. Plant establishment was assessed in mid July 2005.

3.2. Experiment 2: Plug transfer technique with different densities

In order to test the suitability of the plug transfer technique and the influence of different planting densities using *Spartina pectinata* and *Juncus bufonius*, a 13 month experiment was started in June 2004. The experiment was located in the lesser affected area of Pokesudie Bog. Three blocks comprising four experimental units (4 x 6 m) were put in place using a completely randomised block design. Each species was planted at high and low densities. Both species were harvested from the salt marsh of Pokesudie Island. Cores of 2 cm in diameter were used to harvest *J. bufonius.* Each *J. bufonius* core contained an average of 4 plants. These cores were planted at low (70 cores per unit) and high (280 cores per unit) densities. *S. pectinata* were harvested individually and planted at low (3 $plants.m^{-2}$) and high (12 $plants.m^{-2}$) densities.

Fertilization of all parcels was carried out at the beginning of the second growing season in early June 2005. A slow release rock phosphate was broadcast spread at a rate of $25g.m^{-2}$. Plant establishment was assessed 13 months following transplantation.

3.3. Experiment 3: Plug transfer technique with sanding

The effect of substrate manipulation by the application of a layer of sand (~2-3 cm deep) on the growth of 3 species, *J. balticus, J. bufonius* and *S. patens* transplanted by plugs was tested in a 12 month experiment. The experiment was located in the severely affected area and lasted 12 months. Three blocks of 6 experimental units (4 x 6 m) spaced 2 meters apart were put in place using a completely randomised block design. Harvesting and planting was carried out in July 2004.

J. balticus: Plants were harvested from the high salt marsh located at Pointe Alexandre, Lamèque. Stands with an average height of 30 cm were selected. These were separated and cut into individual rhizome segments approximately 10 cmo long containing on average 3 stems. These were planted at a density of 12 rhizomes.m^{-2}.

J. bufonius: Plants were harvested from Pigeon Hill, an abandoned peatland situated near the sea and separated only by a sandy beach. Plants were harvested using a core of 2 cm diameter. Plant density within the cores was estimated at 4 plants per core. Plugs were planted at 30 cm intervals giving 12 cores.m^{-2}.

S. patens: Plants were harvested from the salt marsh at Pokesudie Island near the bridge joining the island to the mainland. Plugs of 6 cm diameter by 7 cm deep were used. Plant density within the cores was estimated at 7 plants per core. These were transplanted at a density of 3 cores.m^{-2}.

Fertilization of all parcels was carried out at the beginning of the second growing season in early June 2005. Slow release rock phosphate was broadcast spread at a rate of 25 g.m^{-2}. Plant establishment was assessed in July 2005.

3.4. Experiment 4: Hay transfer with and without fertilizer

Based on the first year's results obtained from experiments 1 to 3, experiment 4 was designed to test revegetation rates with again a hay transfer technique but based this time on vegetation assemblages (three communities) along with the use of fertilizer. The experiment established in August 2005 was located in the severely affected area. Four blocks comprising of 8 experimental units (4 x 6 m) spaced 2 meters apart were put in place using a completely randomized block design. Boundary walls of peat approximately 30 cm high were constructed around each experimental unit in order to prevent spring and autumn flood waters from spreading the hay treatments. Any vegetation present within the boundary walls was removed before any treatments were applied.

The hays were harvested in the first week of August 2005. The harvest:spread ratio used was 1:1. Donor sites were chosen using a criteria of >60% dominance by the target species. Hay was cut using a scythe and then collected by hand and stored in large plastic bags. Further collection of remaining material using a rake is usually carried out for this technique; however, due to the abundance of protruding wood and driftwood this was not done. Hays were spread the day following harvest. A half of a square bale of straw was spread in each parcel over the hays to ensure that a sufficient insulative layer was present.

Spartina hay: This hay came from an area of the peatland where spontaneous revegetation by *Spartina pectinata* has occurred. The target species was *Spartina pectinata*. The pasture is almost 100% *Spartina pectinata* with occasional occurrences of *Epilobium canadensis*, *Myrica gale* and *Eriophorum vaginatum*.

Juncus hay: This hay came from the lesser affected area of the peatland which has over a large area been revegetated principally by *Juncus bufonius* following the spreading of an unknown amount of a custom formula di-ammonium orthophosphate ($(NH_4)_2$ HPO_4, (15-25-0)) fertilizer, done two growing seasons previously in 2003 by the peat company. The target species was *Juncus bufonius.* Occasional occurrences of *Carex brunesscens, Eriophorum vaginatum* and *Eriophorum angustifolium* (Honck.) were noted.

Marsh hay: This hay came from the adjoining salt marsh in the mid marsh zone. The target species was *Spartina pectinata*. Other species present in the hay were *Salicornia maritime* (Wolff and Jefferies), *Epilobium angustifolium* (L.), *Triglochin maritime* (L.), *Agrostis capillaries* (L.) and *Festuca rubra* (L.) and.

A control treatment without any hay transferred was also included in the experiment.

Each hay transfer treatment was fertilized or not. A commercially available di-ammonium orthophosphate ($(NH_4)_2$ HPO_4, (10-25-10)) fertilizer was broadcast at a dose of 20 $g.m^{-2}$. Fertilization was carried out in early June 2006. Plant establishment was assessed in mid August 2006.

In this experiment, non-target species were found growing in experimental units where it was not initially introduced. Indeed, *Juncus bufonius* was present in all experimental units and *Spartina pectinata* was present in all but the control units. In the end we decided to assess both *Juncus bufonius* and *Spartina pectinata* in each experimental unit. A total vegetation cover estimate was also made for each experimental unit due to the rare, but significant presence of other species which if excluded would have not given a complete view such as *Eriophorum vaginatum* and *Carex brunesscens*.

3.5. Plant performance

Plant establishment success was measured based on density, percent cover, height and health. The parameters measured to gauge the establishment are shown below. Although more than one species was often found growing in the experimental units, generally only the growth of the dominant species was assessed as other species were limited usually to single occurrences. A buffer area of 1 m from the perimeter wall was excluded from sampling so as to avoid edge effects. Six quadrats of 50 x 50 cm were selected at random within each experimental unit for estimating the following plant parameters;

- Number of stems m^{-2}: The number of stems within each quadrat was counted.
- Percentage groundcover: visual estimate of vegetal cover done by vertical projection over the peat surface within each quadrat.
- Height: Visual estimate of the average height of plants within each quadrat.
- Plant health. This qualitative assessment was based on the average health of all of the plants within each quadrat. A scale of 1 to 5 was used and is described in the following Table 5.

In instances where no plants were recorded in a quadrat, a missing data point was entered into the data for health and height, as inclusion of a zero value would include values for plants that did not exist.

Table 5: List of parameters used to describe the health of the plants.

Health index number	Description
1 : Signs of elevated stress	Less than 25% of the stem is green. No new stems growing. No indications of growth. High levels of necrosis of plant tissue.
2 : Signs of moderately elevated stress	25% to 50% of the stem is green. A few new stems growing. Annual growth weak or zero. Significant levels of necrosis of plant tissue.
3 : Weak signs of stress	50% to 75% of the stem is green. Presence of new stems. Evidence of growth of existing stems. Low levels of necrosis of plant tissue.
4 : Signs of stress hardly apparent	75% to 90% of the stem is green. Presence of many new stems. Strong growth of existing stems. Little or no necrosis of plant tissue.
5 : No stress apparent	Over 90% of the stem is green. Presence of many new stems. Strong growth of existing stems. No necrosis of plant tissue. Presence of seeds.

3.6. Statistical analysis

All statistical analyses were carried out using the GLM procedure of SAS (SAS Institute Inc. 1988). Log transformations were performed on heterogonous data. In experiment 4, log+1 transformations were carried out for all variables analysed with the exception of health data. Multiple comparisons (protected LSD) were used to discriminate significant differences between treatments.

4. Results

4.1. Experiment 1: Fertilization with hay transfer: Slightly affected area

Carex brunesscens had extremely low establishment rates, and was generally limited to between 1 and 5 stems per experimental unit, but due to the random positioning of quadrat, the few plants that did survive were never recorded within a sampling quadrat. *Juncus bufonius* however showed good establishment rates, and was even capable of establishing and becoming dominant in plots that received the *Carex brunesscens* community hay. Given these circumstances, *Juncus bufonius* establishment rates were followed in both hay transfer treatments and mean results are shown in figure 3.

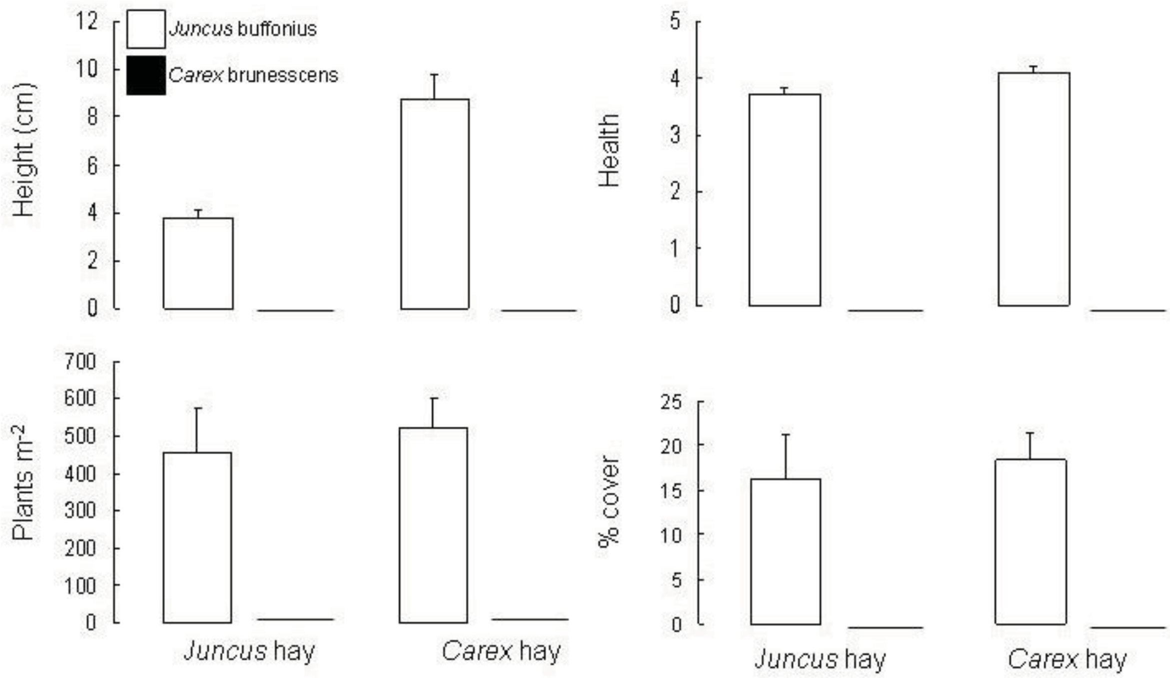

Figure 3 : Plant establishment success of two wetland species (*Juncus bufonius* and *Carex brunesscens*) introduced by the hay transfer technique from communities dominated by >60% *Juncus bufonius* for the *Juncus* hay and >60% *Carex brunesscens* for the *Carex* hay. Mean values (± SD) after 14 months of growth.

Juncus bufonius established equally well in both treatments. Indeed, the percentage groundcover, plant density and mean plant height of *Juncus bufonius* in the *Carex* hay and *Juncus* hay treated units did not differ significantly. The mean height of *Juncus bufonius* plants growing in parcels treated with the *Carex* hay was however significantly higher than those growing in units treated with the *Juncus* hay (F=29.67, P=0.0321).

4.2. Experiment 2: Plug transfer technique with different densities: Lesser affected area

Neither Juncus bufonius nor Spartina pectinata outperformed the other and vegetation establishment was low for all treatments: <9% groundcover. A species X initial planting density interaction was detected for the number of stems per m^{-2}, although given the differences in growth types of these two species this is not ecologically significant. No ecological advantage was observed for high initial planting density over low initial planting density for either species as plant establishment and growth was poor for all treatments. Experimental units were largely empty with only occasional clumps of vegetation scattered throughout. Signs of stress were apparent in all parcels, as shown by the poor health levels of the plants. Evidence of frost heaving was apparent on bare peat. Once the floodwater retreated away from the experimental units, the peat surface dried up very quickly and cracked.

Table 6: Summary table of 1 way ANOVAs assessing the effects of species reintroduced by plugs and initial planting density on percentage groundcover, plant density, plant height and plant health.

		Percentage cover (log+1)		Number of stems.m^{-2} (log+1)		Height (log+1)		Health	
Source	d.f.	F	*P*	F	*P*	F	*P*	F	*P*
Block	2								
Sp.	1	1.47	0.27	130.99	<0.0001	**44.78**	**0.001**	2.24	0.21
Density	1	0.06	0.82	0.81	0.40	2.54	0.17	0.39	0.57
Sp. X density	1	1.66	0.24	**13.62**	**0.01**	0.59	0.48	1.68	0.26
Error	6								
Total	11								

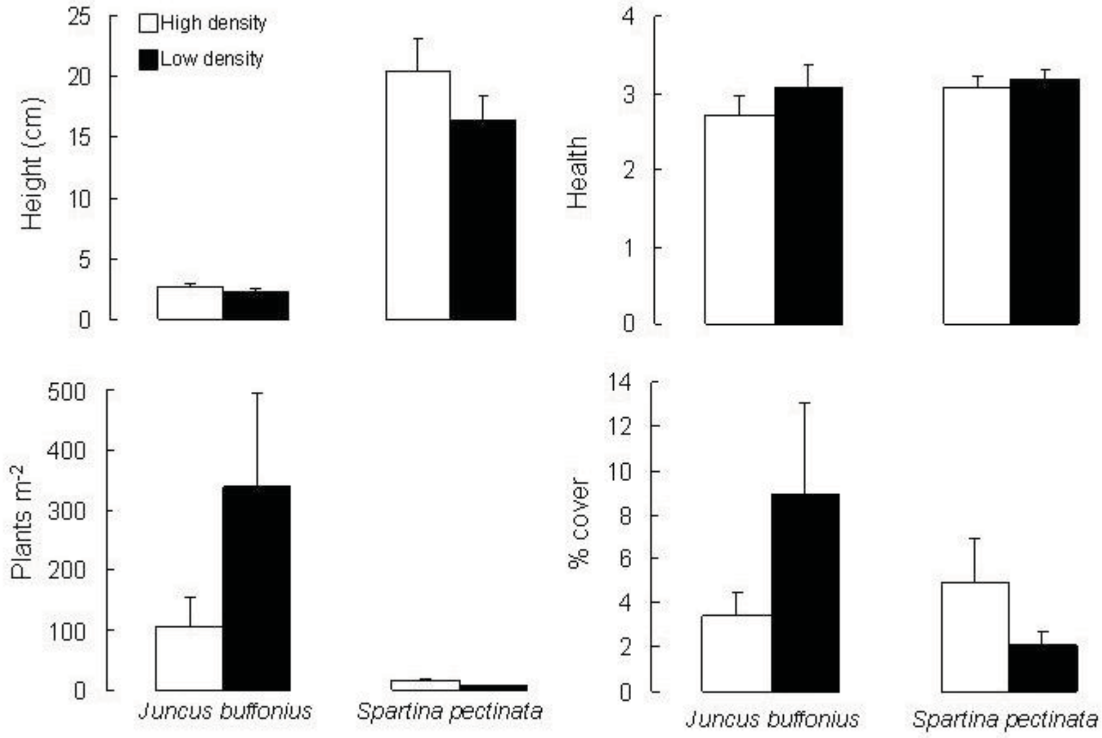

Figure 4: Revegetation parameters assessed for plug transplants of *Juncus bufonius* and *Spartina pectinata* at low and high initial planting densities. Mean values (± SD) after 11 months of growth.

4.3. Experiment 3: Plug transfer technique with sanding: Severely affected area

The application of sand resulted in a significantly higher percentage cover and higher plant density. The choice of species also had a significant effect on percentage cover. *Juncus balticus* had the highest percentage cover, followed by *Spartina patens* and then *Juncus bufonius*. An ANOVA could not be performed for either height or health due to the low number of repetitions and large variability. Therefore, comments can only be made on the tendencies that were noted in the field, regarding height and health. It would appear that the only species influenced by the application of a layer of sand was *Spartina* *patens*. In units treated with sand, *Spartina patens* appeared to grow taller than in parcels without sand. *Spartina patens* also seemed to be healthier when sand was applied.

In all experimental units, vegetation was concentrated around small clumps and was not uniformly spread over the peat surface (personal observations). Only the species that were initially introduced were found growing within the experimental units. The peat remained very wet until mid July then dried out quickly thereafter, forming a hard crust which cracked. Evidence of frost heaving was also quite apparent in all units.

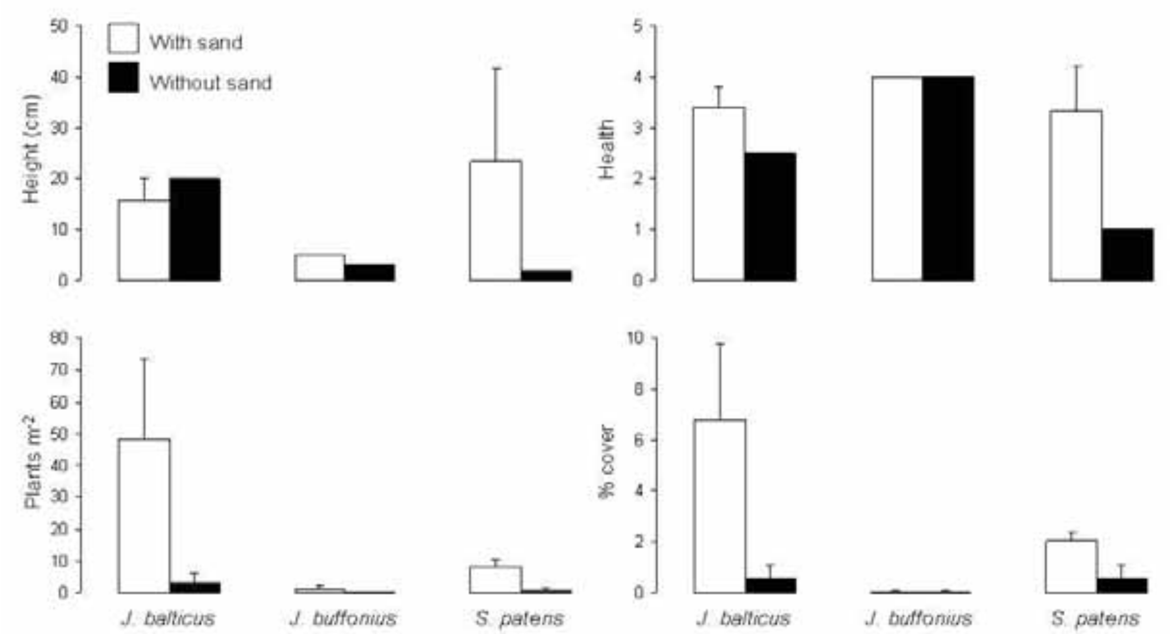

Figure 5: Revegetation parameters assessed for plug transplants using *Juncus balticus, Juncus bufonius* and *Spartina patens* reintroduced with sand and without sand. Mean values (± SD) after 12 months.

Table 7: Summary table of 1 way ANOVAs on the effects of species and sand treatment on 3 wetland species (*Juncus balticus*, *Juncus bufonius* and *Spartina patens*).

		% cover (log+1)		# stems.m^{-2} (log+1)	
Source	d.f.	F	*P*	F	*P*
Block	2				
Sp.	2	5.77	0.02	2.32	0.15
Sand	1	9.24	0.01	5.94	0.035
Sp. X sand	2	3.01	0.1	0.91	0.43
Error	10				
Total	17				

4.4. Experiment 4: Hay Transfers with and without fertilizer: Severely affected area

Non-target species were also found growing in experimental units where they were not initially introduced. Indeed, *Juncus bufonius* was present in all units and *Spartina pectinata* was present in all but the control units.

The highest percentage of total vegetation groundcover was achieved using the marsh hay and no fertilizer giving a mean cover of ~15%. Of this, 8.25% was made up of *Juncus bufonius* and 5.75% by *Spartina pectinata. Carex brunesscens* and *Eriophorum vaginatum* were also found growing in these units, though in very low densities. Percentage groundcover of *Juncus bufonius*, *Spartina pectinata* and total vegetation were significantly affected by the type of hay used (see table 8 and table 9). LSD tests revealed that for *Juncus bufonius*, the *Juncus* and marsh hays resulted in significantly higher groundcover than for the *Spartina* and control treatments. The marsh hay gave significantly higher groundcover than any other treatment when only *Spartina pectinata* was considered. The highest total groundcover was achieved using the marsh hay, followed by the *Juncus* hay. The *Spartina* hay and the control treatments resulted in the lowest total ground cover and these treatments did not differ significantly. There were no significant differences detected between any of the treatments regarding the effect of the type of hay used on average height of the plants. The type of hay used had a significant effect on the health of *Spartina pectinata* plants (F=19.78, P=0.0042).

The interaction hay x fertilizer was significant for the health of both *Juncus bufonius* (F=8.54, P=0.033) and *Spartina pectinata* (F=11.54, P=0.013). When this interaction was sliced by hay, the application of fertilizer was shown to only have a significant effect on the health of *Juncus bufonius* in the control and *Spartina* hay treated parcels (F=26.23, P=0.007 and F=13.38, P=0.02 respectively). The health of *Juncus bufonius* in the *Juncus* and marsh hay treated parcels did not differ whether fertilizer was used or not. The effect of fertilizer was only significant for *Spartina pectinata* in parcels treated with the *Spartina* hay (F=38.42, P=0.002).

When the interaction was sliced by fertilizer, the type of hay used only had a significant effect on the health of both *Juncus bufonius* and *Spartina pectinata* when no fertilizer was applied (F=11.35, P=0.02 and F=33.95, P=0.001 respectively). The only instance where a significant single effect of the use of fertilizer was detected was on the height of *Juncus bufonius* plants (F=11.76; P=0.02). *Juncus bufonius* was taller in fertilized parcels than it was in unfertilised parcels.

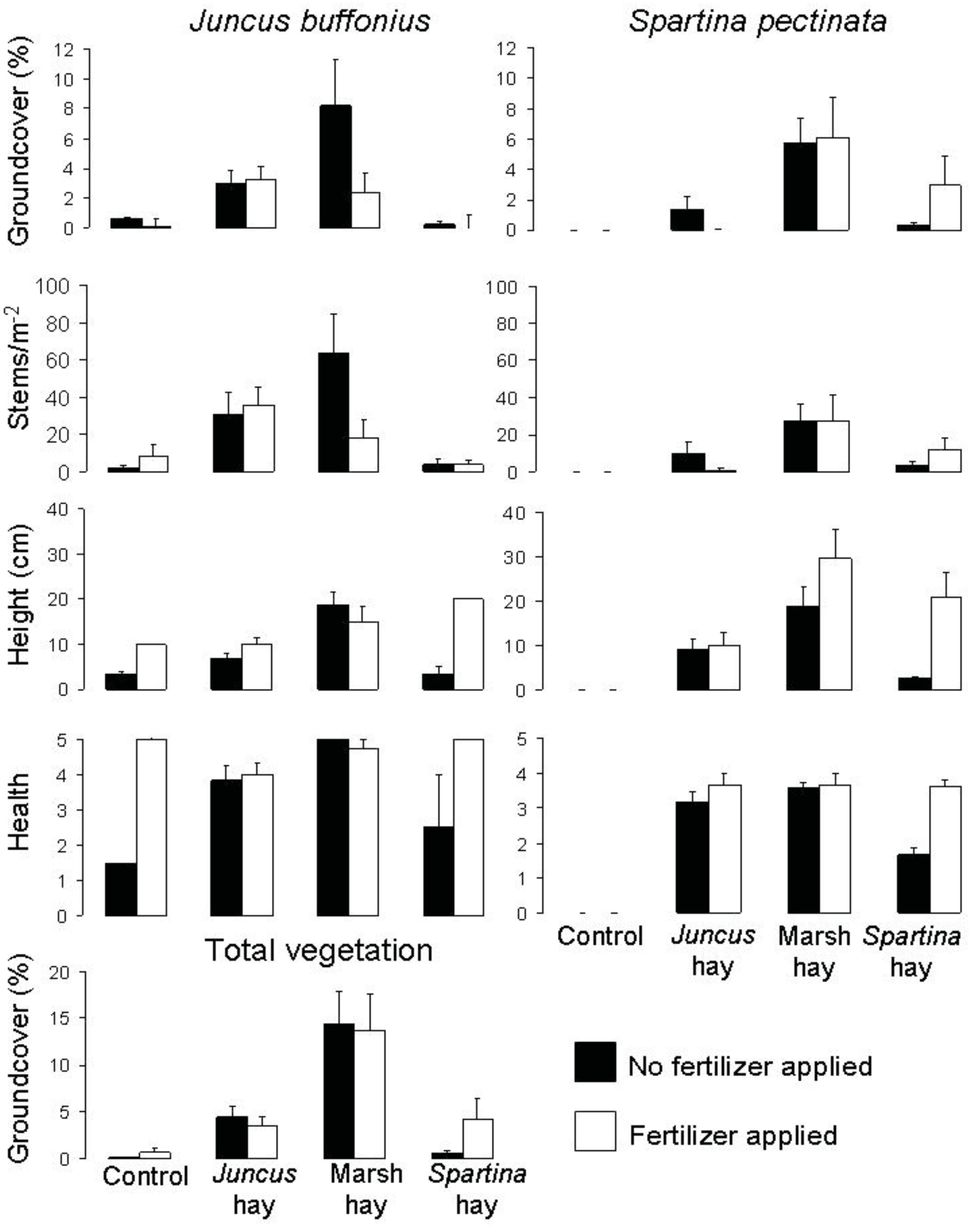

Figure 6: Revegetation parameters assessed after 11 months of transferring 3 hay communities which were dominated by more than 60% of *Juncus bufonius* for *Juncus* hay and more than 60% of *Spartina pectinata* for both marsh and *Spartina* hays. Mean values (± SD) after 12 months.

Table 8: Summary table of 2 way ANOVAs for the effects of the transfer of three hay communities (*Juncus* hay, marsh hay, *Spartina* hay and control) with and without fertilizer on the parameters examined for *Juncus bufonius*, *Spartina pectinata* and total vegetal groundcover.

		Juncus bufonius		*Spartina pectinata*		total cover	
source	d.f.	F	*P*	F	*P*	F	*P*
percentage groundcover							
block	3						
hay	3	**6.05**	**0.004**	**6.86**	**0.002**	**11.97**	**0.0001**
fertilizer	1	0.04	0.84	0.02	0.90	0.01	0.9432
hay X fertilizer	3	0.77	0.5240	0.46	0.71	0.38	0.77
error	21						
total	31						
stem density							
block	3						
hay	3	**8.65**	**0.0006**	**3.63**	**0.03**		
fertilizer	1	0.0	0.99	0.0	0.96		
hay X fertilizer	3	0.23	0.87	0.06	0.98		
error	21						
total	31						
plant height							
block	3						
hay	3	3.6	0.10	5.51	0.06		
fertilizer	1	**11.76**	**0.02**	4.42	0.09		
Hay X fertilizer	3	1.95	0.24	1.89	0.22		
error	21						
total	31						
plant health							
block	3						
hay	3	5.99	0.06	19.78	0.0042		
fertilizer	1	28.35	0.006	11.24	0.020		
hay X fertilizer	3	**8.54**	**0.033**	**11.54**	**0.013**		
error	21						
total	31						

5. Discussion

The establishment rates of plants at Pokesudie Bog were low compared to studies using the moss layer transfer method (Ferland and Rochefort, 1997). Vegetation establishment on harvested peatlands affected by the same complicating factors as those at Pokesudie has not been studied in great detail, and thus comparison of these results is difficult as little reference work exists with which to compare.

5.1. Fertilisation with hay transfer: Lightly affected area

The experiment comparing the establishment of vegetation following hay transfers of *Juncus bufonius* and *Carex brunesscens* in the lesser affected area revealed that *Juncus bufonius* is capable of establishing from seed when introduced using a hay transfer method. *Carex brunesscens* was eliminated as a potential species for use in the rehabilitation of saline water affected peatlands as it failed to colonize at any ecologically significant rates. That *Juncus bufonius* established in and dominated units where no seeds of the former were thought to have been present shows that it is capable of arriving, most likely with the floodwaters, and taking advantage of improved local conditions, i.e. the presence of fertilizer. Within 5 months of growth the experimental units were seen to have a healthy carpet of *Juncus bufonius* growing within them. The areas surrounding the experimental units were devoid of vegetation. The lack of signs of frost heaving and dry cracked peat suggest also that the established carpets of vegetation provide ample insulation to negate these phenomena.

5.2. Plug transfer technique with different densities: Lightly affected area

Planting at higher rather than lower initial planting density does not improve final vegetal groundcover rates for either *Juncus bufonius* or *Spartina pectinata,* thus the first hypothesis, that higher density would improve revegetation was rejected. Neither species established populations that would be viable or interesting for the restoration of peatlands that have been contaminated by sea water. The groundcover achieved using plug transfer of *Juncus bufonius* and *Spartina pectinata* were much lower than expected. It was thought that mature plants would be better able to tolerate the stresses present (Zedler et al, 2003) at Pokesudie Bog than germinating plants would, as has been suggested by another study at Pokesudie that used core transplants of mature plants (Montemayor, 2006). The poor establishment and health of the plants found within the experimental units which were in place over a longer time period did not seem to support the ideas expressed in the latter studies. In fact, very high mortality was observed, though not quantified, following the transfer of plugs of *Juncus bufonius*. The mortality was considered at the time to be high enough that the treatment would result in no new plants establishing. *Juncus bufonius* is an annual plant; relying on the seeds it produces to establish the next growing season's population. Its root system is shallow and very fine, and not likely to be able to withstand the physical stress caused during removal and transfer by means of a plug, implying that *Juncus bufonius* is not suited to the plug transfer technique. It is almost certain that the *Juncus bufonius* plants found within the experimental units established from seed that arrived with the floodwaters, as may have happened in the initial experiment comparing establishment following hay transfers of *Juncus bufonius* and *Carex brunesscens*. This shows that establishment is not only possible through seeding, but can be quite successful. The results of experiment two also suggest that if the stabilisation of the substrate through plant cover is the goal of rehabilitation then the plug transfer method at the densities tested is not a suitable introduction method if these species are used. This is due to the establishment of these species using plug transplants being very clumped and sparse, thus the effects of desiccation and frost heaving were very evident on the peat surface. This resulted in high mortality rates.

5.3. Plug transfer technique with sanding: Severely affected area

Sand application had a statistically significant effect on the percentage cover achieved when plugs of *Spartina patens*, *Juncus bufonius* and *Carex brunesscens* were transplanted into the saline area of Pokesudie Bog, confirming hypothesis three. However; in terms of usefulness for restoration projects, the gains are so small ecologically speaking as to not merit the extra time and cost required in the sand application. Overall there was little visual difference between the treatments. Vegetation was sparse, relatively unhealthy and the evidence of frost heaving and exposure of rhizomes of *Juncus balticus* and *Spartina patens* throughout suggests that none of the combinations of factors in this experiment would lead to the successful revegetation of saline peat substrates. Revegetation rates in experiment three were visibly lower than those achieved in experiments carried out in the lesser affected area of Pokesudie Bog. This was likely due to the added stress of elevated salinity levels that the plants had to deal with in the severely affected area. The results do show some interesting points however. This experiment shows that the plants used are capable of surviving transplantation to saline peat substrates by means of a plug transfer and also of establishing populations in the following growing season, even if these populations are very sparse.

5.4. Hay transfers with and without fertilizer: Severely affected area

The hypothesis suggesting that a hay transfer treatment would result in significantly higher vegetation establishment rates than control treatments was rejected as the *Spartina* hay treatment resulted in a total percentage groundcover that did not differ significantly from the control treatment. The total percentage groundcover achieved using these two treatments were relatively low, as was that achieved for the *Juncus* hay treatment. This seems to suggest that hay transfers of communities dominated by either of these target species would not be suitable for rehabilitation of saline peat substrates. However, a significantly higher total percentage groundcover was achieved when hay from the *Spartina pectinata* dominated marsh community was used. Further considerations such as the influence of the location of hay sourcing on revegetation results may need to be taken into account. It has been previously noted that individuals of *Spartina patens* can have different growth forms depending on their location along the salt gradient within a salt marsh (Pezeshki and DeLaune; 1997). It may be possible that *Spartina pectinata* established in the salt marsh area were produced by plants that have been naturally selected to be more tolerant of elevated salinity levels than those found in the naturally revegetated area of Pokesudie bog resulting in two separate ecotypes based on topographical location. Plants established from seeds contained in the marsh hay would thus have a higher tolerance for salinity.

Also noteworthy is the fact that the highest percentage groundcover achieved by *Juncus bufonius* was noted in parcels treated with hay that came from the salt marsh area. In a pre-harvest examination of the species present in the parcels from where the marsh hay was harvested there were no occurrences of *Juncus bufonius*. The specific percentage groundcover results for *Spartina pectinata* in experiment four also highlight some important information. No seeds of *Spartina pectinata* were contained within the *Juncus* hay, yet it too managed to establish in parcels that were treated with the *Juncus* hay. Since only the aboveground material was harvested for the hays, it is impossible that rhizome fragments were contained within it. This confirms again that *Spartina pectinata* is capable of establishing from seed in saline peat areas.

The health of plants present in the experimental units of the final hay transfer experiment in the saline area was generally high. Most Juncus bufonius plants produced large amounts of seeds. Although *Spartina pectinata* plants did not produce many seeds, the plants that were present had very good states of health. A hay x fertilizer interaction was noted for *Juncus bufonius* growing in the control and *Spartina* hays. However; this significant effect was based on data taken from relatively few plants and is not likely to reflect any truly important influence in ecological terms. Likewise, the single effect noted for the effect of fertilizer on the height of *Juncus bufonius* found growing in the control and *Spartina* hay treatments is based on relatively few plants and not likely to be representative of reality.

5.5. Recommended technique

The most successful plant introduction technique tested was the hay transfer method. The highest rates of total vegetation groundcover were achieved using this method. The vegetation was dominated almost exclusively by *Juncus bufonius* in the hay transfer experiment in the lesser affected area. *Juncus bufonius* formed a large part of the vegetal cover of most treatments in the final experiment. *Spartina pectinata* also made up a substantial amount of the total percentage groundcover in the final hay transfer experiment. However, the choice of hay used in the hay transfer was seen to have a large impact on the revegetation rate achieved. In experiment four, the highest total vegetation groundcover was achieved using the marsh hay transfer without fertilizer application. This hay was selected for its dominance by *Spartina pectinata*, yet more than half of the total vegetal cover in parcels treated with this combination of factors was made up of *Juncus bufonius*, despite the fact that neither plants of *Juncus bufonius* nor its seeds were present within the hay at harvest time.

5.6. Recommended species

The species most suited for the restoration program at Pokesudie bog seems to be *Juncus bufonius*, followed closely by *Spartina pectinata*. Overall, these two species had rates of percentage groundcover that were superior to those achieved using the other species; *Juncus balticus*, *Spartina patens* and *Carex brunesscens*. *Juncus bufonius* was used in all experiments, two of which were in the low and high salinity areas respectively, and was observed to perform best when introduced using the hay transfer technique. It also established quickly from the high number of seeds in the area and the established plants produced seeds to provide for the next season's population.

Where *Juncus bufonius* established, it usually formed thick carpets of interlacing stems, which offered very good shade not only from the sun but also from wind to the underlying peat. The effects of frost heaving were much less noticeable within parcels where *Juncus bufonius* was found when compared to control parcels or to areas outside of the test parcels. The peat surface was far less churned up than in areas that were bare and uprooted vegetation was extremely rare. *Spartina pectinata* also had a positive effect in reducing the effects of frost heaving, however, due to its taller growth form than *Juncus bufonius;* the effect was less noticeable than for *Juncus bufonius*, owing possibly to higher air and water movement around the less dense stems and the light leaf canopy which was easily blown in the wind.

The species that were least suited to the rehabilitation appear to be *Carex brunesscens*, *Juncus balticus* and *Spartina patens*. The limited ability of *Spartina patens* to oxygenate its rhizosphere in anoxic soil (Bertness et al, 1991b) likely hindered its colonization potential when faced with frequent and prolonged periods of inundation encountered at Pokesudie. It is also unlikely that *Juncus balticus* would be a suitable species to use given the amount of extra effort required through sand application to achieve even small increases in the percentage groundcover. The failure of *Carex brunesscens* to establish at ecologically viable rates rules this species out for use in the final rehabilitation project.

Generally, the species used which normally spread by rhizome (*Spartina pectinata*, *Spartina patens* and *Juncus balticus*) did not show as promising results for colonization potential as *Juncus bufonius*. In experiments using plug transplants, the plants that grew in the season following transplantation seemed to arise almost solely from the rhizomes of the introduced plugs. Although seeds were sometimes produced on these plants, comparatively few plants managed to establish themselves far from possible parent plants.

6. Conclusion

6.1. General observations

Something that should also be noted is that the experiments in which *Juncus bufonius* were introduced by hay transfer had border walls constructed around the experimental units. From personal field observations, it was noted that raised peat or trunks of trees containing small pockets of peat in areas that were covered by the floodwaters were often colonised by *Juncus bufonius*. It is possible that an obstruction to the flow of water aids seeds of *Juncus bufonius* to take hold and establish themselves, although this was not tested in the experimental design. *Spartina pectinata* also seemed to perform better in experiment four with its border walls than it did in experiment two. Evidence of peat movement was clearly visible in the experiments testing planting density and sand application respectively. Newly established plants of *Juncus balticus, Spartina pectinata* and occasionally *Spartina patens* could be seen to be establishing from the same rhizome as their parent plants. This is certain as the rhizome was exposed above the peat surface and was seen to stretch from the parent plant to the new growths. By the end of the summer, these rhizomes had become desiccated the base of many of the new and parent plants had been eroded due to exposure. The plants were observed to have died by mid-summer. The presence of exposed rhizomes and roots indicates that for these experiments, peat movement is still a large problem. The experimental units in these experiments did not have any boundary walls constructed around their perimeters, and thus any wave action during times of flooding would not have any barrier to slow it down. This would result in un-hindered mixing and movement of the surface peat in the water leading to the exposure of bare rhizomes leading to poor health and mortality.

Large differences were noted for the groundcover rates achieved using the plug transfer and hay transfer methods. A possible explanation as to why this may be is that the density at which plants were transferred in the plugs was far less than the number of seeds that may have been introduced within the hays or that may have arrived within the floodwater. The germination rate, while not quantified, appeared to have been very high.

6.2. General conclusions

The ability to produce and establish from seed appears to be a very important aspect to consider for the restoration of saline contaminated cutover peatlands, as it seems plants establishing by this means are able to colonise the site quicker than those spreading only through rhizomatous growth. Therefore, the introduction method that is most likely to be successful is the hay transfer method of upper salt marsh communities. High density plug transfers, sand addition and fertilizer application did not seem no infer any biologically significant benefits. The extra cost and time required are therefore not merited, since higher revegetation can be achieved in using a simple hay transfer of the upper marsh community in less time and at a lower cost.

Since only the presence or absence of fertilizer was tested, further examination of this factor is recommended. Possible avenues of research include the examination of different types of fertilizer, different doses of fertilizer and the effects of re-application. The doses selected in this experiment were based on estimates of the amount of fertilizer that was spread in the southwestern corner of the low salinity area where a *Juncus bufonius* lawn is now established. It may be that the dose used in these experiments was simply too low for any ecologically significant effect to be manifested. In the hay transfer experiments, quick release orthophosphate fertilizers were used, whereas in the planting density experiment, slow release rock phosphate was used. It may be more suitable to use a fertilizer that makes phosphorus available quickly so as to aid plant establishment and boost growth from seed to mature plant more quickly.

In areas outside of the experimental units where the floodwater was newly retreated, both individual plants and small clumps of *Juncus bufonius* could be seen establishing, though not at the same rate as within the parcels. However; where artificial ponds had been excavated, often reaching the underlying mineral layer, *Juncus bufonius* was able to capitalize on the extra availability of nutrients, establishing thick and healthy carpets with rates of cover approaching 100%. The difference made by the extra availability of these nutrients can be clearly seen in the field. Rings of *Juncus bufonius* with very well defined edges surround these lakes. From year to year these rings slowly grow in size; however this growth has not been quantified.

The eastern most field in the high salinity area is separated from the rest of the previously harvested area by a peat wall that was constructed to prevent further saltwater contamination of the site. Areas of natural vegetation ranging from that typical of peatlands to salt marsh border this field on its eastern and northern sides respectively. Since experimental work began at Pokesudie bog, this field has been naturally revegetated by various species, predominantly *Juncus bufonius*, *Carex brunessscens*, *Juncus balticus*, and *Spartina pectinata*. Bare peat areas are uncommon. This field is flooded in the spring and autumn at levels closely resembling those of the rest of the area, however the surface of the water in these areas is far less disturbed and there is little evidence of wave erosion or frost heaving. This seems to support the suggestion that revegetation rates at Pokesudie can be increased by breaking up open areas of water through the construction of barriers as done in experiments one and four, once a suitable seed bank is present.

6.3. Implications for rehabilitation plans

Results from the experiments carried out at Pokesudie, while not dramatically successful, have been useful in improving the focus of further research concerning the rehabilitation of saline bare peat substrates. The most cost and time effective method for the rehabilitation of Pokesudie bog appears to be the use of the hay transfer method using hay from the upper salt marsh community. Given that all the machinery required to carry out this type of rehabilitative work is commonplace on many farms, the cost and time required to carry it out is likely to be very low compared to labour intensive rehabilitations that use plug transfers. The higher vegetal cover achieved in experiments that had boundary walls constructed around them suggests that breaking up open water areas in Pokesudie by means of physical barriers may improve vegetation establishment. A suggested means of doing this on a large scale is by using an agricultural plough to create “hills” in a criss-cross manner across the peat surface. Hays could be harvested using the same machinery used to harvest hay for feeding purposes on farms and spread using a hay spreader, much in the same manner as it is used in the Canadian approach. In using such a methodology, rehabilitation work could be carried out over large areas in very little time and at a relatively low cost.

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