Effects of Water type on Sphagnum growth

Is the water composition a determining factor for the niche separation of Sphagnum species along the hummock-hollow gradient?

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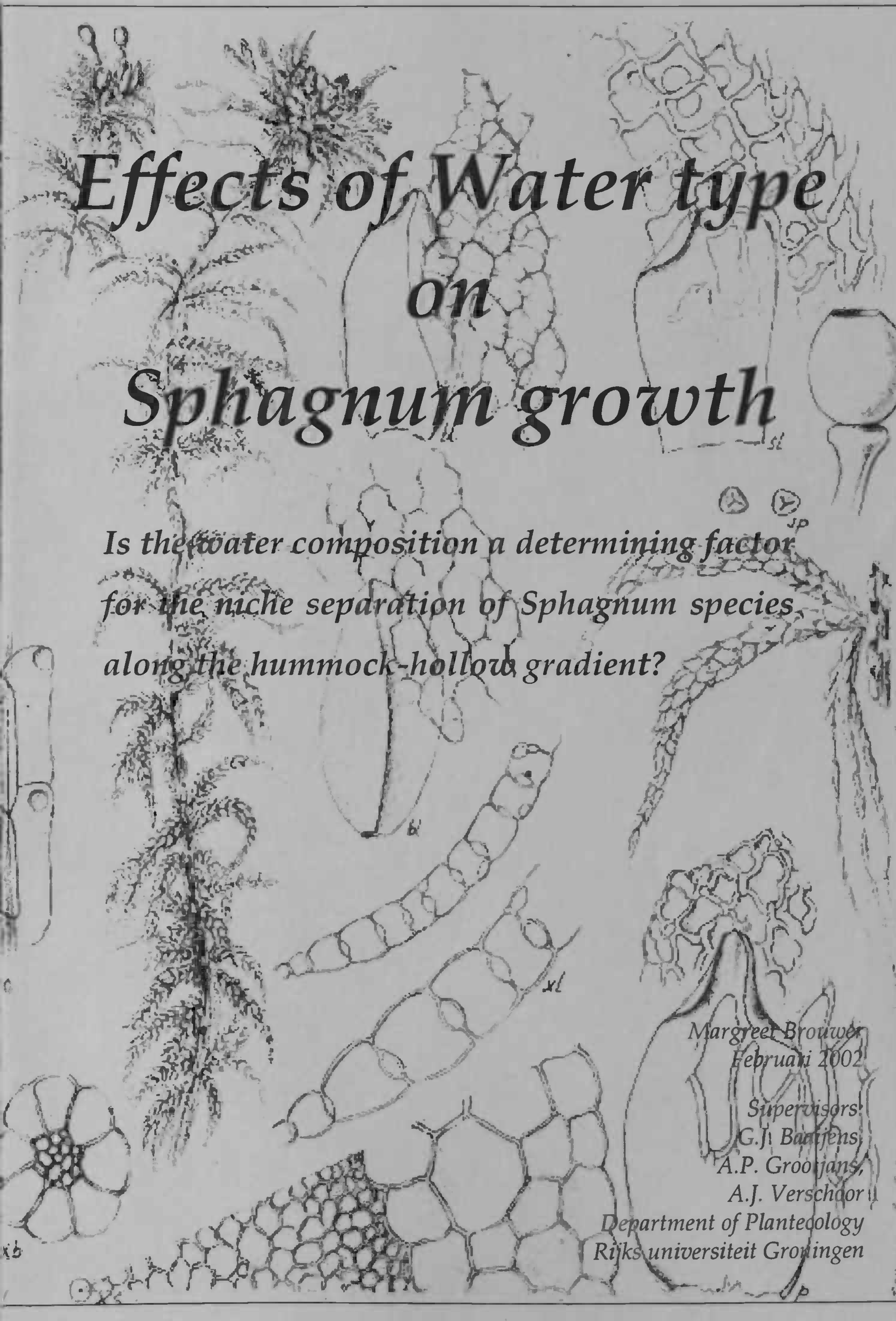

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Abstract

Some *Sphagnum* species grow only in the lag zone of bogs while others grow in the central and higher part of it. This vertical zonation is not the result of colonisation of an array of existing habitats above the water table: *Sphagnum* mosses build the hummock-hollow gradient themselves.

We hypothized that sites along the hummock-hollow gradient have a specific ionic ratio.

This ionic ratio, the ratio between bivalent cations (calcium and magnesium) monovalent cations (potassium and sodium) seems to give a good explanation for the occurrence of different *Sphagnum* species in the field.

The present research was done to reveal the influence of the ionic ratio on the biomass of *Sphagnum* under controlled conditions. If *Sphagnum* species grow on a rather species-specific ionic ratio, this ratio may be an important selecting mechanism in the occurrence of Sphagna along the hummock-hollow gradient.

Sphagnum magellanicum (hummock species), *Sphagnum recurvum* (intermediate species) and *Sphagnum majus* (hollow species) were treated with four water types. Each water types had a species-specific ionic ratio.

This pilot study seems to point out the ionic ratio as well as the total ion concentrations seem to influence the growth of *Sphagnum*.

However, *Sphagnum* species do not have a rather narrow tolerance for a species-specific ionic ratio.

Keywords: *Sphagnum magellanicum*, *Sphagnum recurvum*, *Sphagnum majus*, water types, *ionic ratio*, biomass increase.

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1. Introduction

1.1 Raised bogs

Bryologists of the 19th century already made the distinction between ombrotrophic and minerotrophic peatlands. Schimper (1898) wrote in his book Pflanzen geographie:

> 'Die Moore besitzen eine sehr ungleiche Vegetation, je nachdem ihre mineralische Unterlage kalkarm oder kalkreich ist. Sie werden im ersten Falle Hochmoore, im letzteren Wiesenmoore genannt............
> Die Charakterpflanze der Hochmoore ist das Torfmoos, *Sphagnum*, in Deutschland und in der Schweiz namentlich *Sphagnum cymbifolium*, desen schwammartige, wasseraufsaugende Polster allmählich in die Höhe wachsen, während ihre unteren Theile in Torf, sogenannten Moorstof übergehen. Dieses Aufwachsen verursacht, dass das Moor sich allmählich über das Niveau des Grundwassers erhebt, namentlich in der Mitte, da sie dem älteren Theil des Moors entspricht. Die allerdings schwache Convexität der Sphagnummoore, - das Centrum kann bis 4 m höher liegen als der Rand – hat zu ihrer Bezeichnung als Hochmoore geführt (Schimper 1898).'

1.2 Environmental aspects

Bryologists have long noted that some *Sphagnum* mosses grow only at the fringe of a bog, while other species grow in the central and higher part of it. This vertical zonation is not the result of colonisation of an array of existing habitats above the water table: *Sphagnum* mosses build the hummock-hollow gradient (Andrus 1983).

Plants respond on the concentrations of minerals in the soil solution. The sites along the hummock-hollow gradient have a specific *ionic ratio* (Baaijens 1994). This *ionic ratio* is determined by the water composition, to which extend the site is influences by rainwater (or brackish water) and to which extend by groundwater.

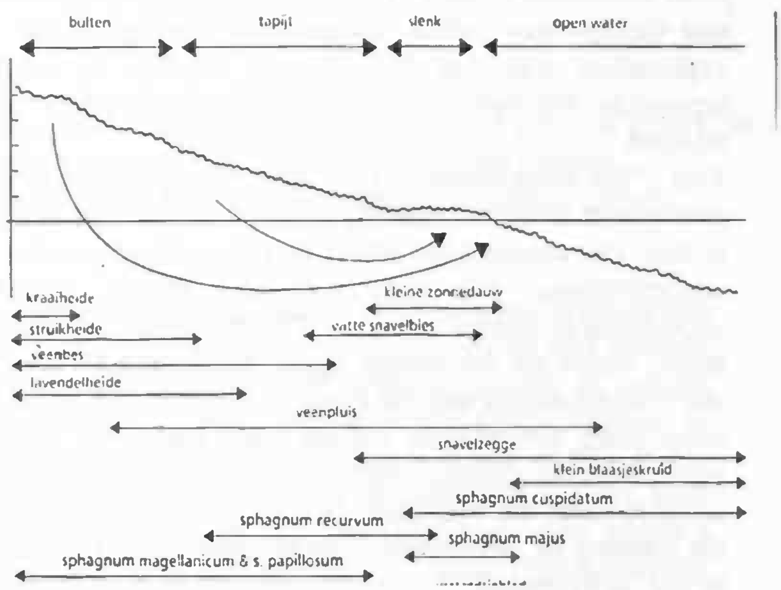

Figure 1.1: The hummock-hollow gradient. Each *Sphagnum* species has its own niche along the vertical zonation of a bog. The hummock species are ombrotrophic whereas the hollow species are mineralotrophic. "Toestand van de natuur" 1994

Along the hummock-hollow gradient the condition changes from infiltration (in the central part of the bog) to seepage (in the fringe of the bog). The *ionic ratio* in the water changes along this gradient.
The boarder between infiltration and seepage zones changes during the seasons. High water tables results in a shift towards the higher parts and low water tables in a shift in the opposite direction. Therefore, the *ionic ratio*s differ per season.

$$\textit{Ionic ratio}: \frac{Ca^{2+} + Mg^{2+}}{Na^{+} + K^{+}}$$

The *ionic ratio*, the ratio between bivalent cations (calcium and magnesium) and monovalent cations (potassium and sodium), seems to give a good explanation for the occurrence of *Sphagnum* species (Baaijens 1994).

1.3 Ion - antagonism

Koningsberger (1962) discussed the *ionic ratio* between bivalent and monovalent cations. "Ion-antagonism" was first discovered by Ringer, for the heart of a frog.

> 'Ringer (1883) observed that an isolated heart of a frog stopped beating if a solution of pure NaCl circulated through the heart. When a $CaCl_2$ solution was used, the same was observed. It appeared that the heart was damaged. During this empirical study of the heart it was discovered that when the heart was treated with a solution that contained a mixture of NaCl and $CaCl_2$ (proportion 9 Na^+ : 1 Ca^{2+}) the heart continued beating. This solution, containing a mixture of NaCl and $CaCl_2$ was called "balanced physiological salt solution". The explanation was that Na^+ as well as Ca^{2+} is toxic when given separately, but compensate each others toxic effect when given as a mixture.
> This "ion-antagonism" is a complex phenomenon, because the protoplasm contains naturally low ion concentrations. The complexity is that the antagonistic effect is the strongest under these low ion concentrations. The ions that are already present can cause unpredictable complications. Therefore only general rules can be made, which do not always apply. Under natural circumstances, low salt concentrations and the monovalent cations K^+ and Na^+ and on the other hand the bivalent cations Ca^{2+} and Mg^{2+} play a role in the protoplasm. In general, monovalent cations and especially Na^+, cause an increase in the hydration (swelling) of the protoplasm. They cause the opening of membranes. The bivalent cations, especially Ca^{2+}, lead to the dehydration. The presence of both monovalent and bivalent cations in an environment at the same time in the right concentrations is therefore important for the state of the protoplasm (Koningsberger 1962).'

Hyaline cells

Hyaline cells are situated in the network of the green chlorophyll cells (Beijerinck W. 1934). These empty hyaline cells have thick cell boundaries in which a lot of pores are situated. These pores are directly in contact with the environment. The hyaline cells therefore play an important role in the internal water regulation and the uptake of ions.
During a period of growth the number of new ion exchange sites are directly related to the amount of dry matter. (Clymo 1970).
Clymo (1963) discovered the source of ion exchange phenomena in *Sphagnum* and advanced the theory that the cation-exchange properties were due to unesterified polyuronic acids. Spearing (1972) carried out research on the cation exchange complex in *Sphagnum* species. Eight species of *Sphagnum* were used for research about the cation exchange capacity in relation to particular habitats along the hollow-hummock gradient. She found a very high correlation between the cation-exchange capacity and the content of galacturonic acid. A high correlation existed between the cation-exchange capacity and the optimum elevation for growth, measured in height above the water table. *Sphagnum* species have a pronounced capacity to exchange hydrogen ions for mineral cations, a feature of particular advantage in habitats where minerals needed for nutrition are short supply (Daniels 1985).

Not only animal and plant physiological research, but also soil scientist gave evidence of the importance of the ratio between bivalent and monovalent cations.
Russell (1973) writes about it in his book “Soil conditions and plant growth”.

> ‘In 1918 soil scientists discovered that the ratio between bivalent and monovalent ions in changing absolute concentrations in soil solution was remarkably constant….. Soils hold different species of cations with different binding efficiency, and correspondingly cations in solution have different powers of displacing a given exchangeable cation……Gapon investigated the relation between the activity ratio and the ratio of exchangeable ions…… The Gapon equation relates a monovalent ion to the bivalent ions in a soil……. The Gapon constant k gives a measure of the relative tightness of binding of cations to clay…… Gapon considered that the quantity k of ions could be a constant independent of the activity ratio. (Russell 1973).’

The soil is therefore a important regulator of cation concentrations. For *Sphagnum*, which is a very good ion exchanger itself, this is an important feature.

Baaijens (1973) working on the ecology of various *Sphagnum* species found a remarkable species-specific linear correlation between bivalent and monovalent ions (Fig 1.2).

The decrease of K^+ with age in the *Sphagnum* moss plant is not compensated by an increase in Mg^{2+} and Ca^{2+} (as has been shown for many mire plants) but is compensated by the binding of Na^+ on the exchange sites. This might also be seen as evidence for a species-specific *ionic ratio* (Malmer 1988).

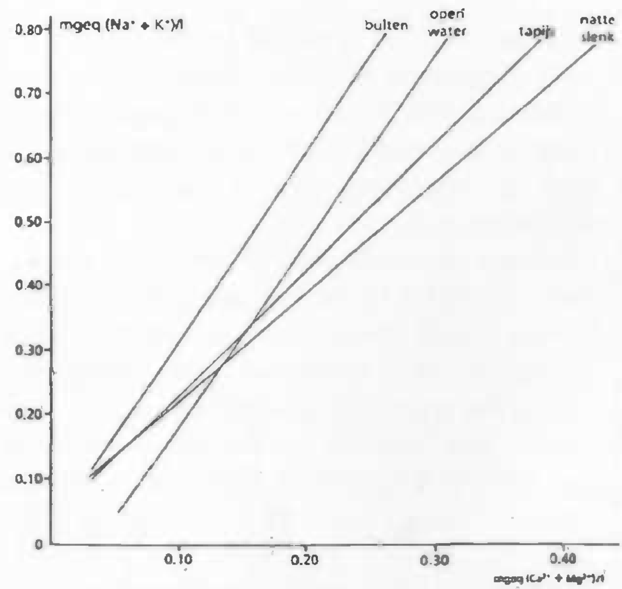

Figure 1.2: The slope of the correlation between bivalent and monovalent cations differs along the hummock-hollow gradient "Toestand van de natuur" 1994.

The present pilot study was carried out to reveal whether the water composition is a determining factor for the niche separation of *Sphagnum* along the hummock-hollow gradient. This research investigates the influence of the *ionic ratio* between bivalent and monovalent cations on the growth of *Sphagnum*. If *Sphagnum* species grow on a rather species specific *ionic ratio*, this ratio is a selecting mechanism in the appearance of plants along the hummock-hollow gradient.

1.4 The hypotheses are:

- ✓ *The ionic ratio between the most abundant bivalent and monovalent cations is an important factor for the biomass increase of Sphagnum species.*
- ✓ *Further more, each Sphagnum species is expected to have its own rather narrow tolerance for the species-specific ionic ratio.*
- ✓ *The ionic ratio is expected to be of more importance than the concentrations of the separate cations.*

1.5 The research

For this research three *Sphagnum* species were used. A hummock species: *Sphagnum magellanicum*, an intermediate species *Sphagnum recurvum* and a hollow species *Sphagnum majus*.

Figure 1.3
Sphagnum magellanicum

Figure 1.4
Sphagnum recurvum

Figure 1.5
Sphagnum majus

The species *Sphagnum magellanicum, Sphagnum recurvum* and *Sphagnum majus* were exposed to four water types. The water types were brackish water, rainwater and enriched- and groundwater. Each water types had a specific *ionic ratio*.

1.6 Expected results

Sphagnum magellanicum is an ombrotrophic species that normally can be found in the high central part of a bog. This hummock species is influenced by rainwater. According to the hypotheses, *Sphagnum magellanicum* will have the highest absolute biomass increase under the treatment with rainwater. For the competition experiment, *Sphagnum magellanicum* is expected to have a higher relative biomass increase than *Sphagnum majus* in the treatments with rainwater and brackish water.

Sphagnum recurvum is neither a typical hummock species nor a typical hollow species. *Sphagnum recurvum* will have the highest absolute biomass increase under the groundwater or the rainwater treatment.

Sphagnum majus is a minerotrophic species, therefore it is likely that this species will have a high absolute biomass increase under the treatments with groundwater and enriched groundwater and low for the treatments with rainwater and brackish water. In the competition experiment the expectation is that *Sphagnum majus* has a relative higher biomass increase than *Sphagnum magellanicum* in the treatments with groundwater and enriched groundwater.

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2. Materials & methods

The materials

2.1 Sphagnum

The three *Sphagnum* species were collected in the national park Dwingelerveld. The national park Dwingelerveld is situated in the Southwest of the province Drenthe in the Netherlands. The *Sphagnum* was collected in September 2001.

The three species that were selected are:

1. *Sphagnum magellanicum*
2. *Sphagnum recurvum*
3. *Sphagnum majus*

The *Sphagnum* species *Sphagnum magellanicum* and *Sphagnum majus* were collected from the "Grote veen" in the Dwingelerveld. The chosen collecting site, "Grote veen", exhibits many different *Sphagnum* species in large quantities. The *Sphagnum recurvum* was collected in Poort 2.

2.2 Water types

Four types of water were made, each with a specific *ionic ratio*. Water type 1 is the water type, which resembles brackish water. It will be called brackish water, although the composition was adjusted to obtain the calculated ionic ratio. Water type 2 resembles rainwater. Water type 3 and 4 were named groundwater and enriched groundwater, although the composition as well as the concentrations of ions is adjusted to obtain the determined *ionic ratio*s.

The *ionic ratio*s that were used for the different types of water are determined on the basis of measurements that were done in 1968 by Baaijens. For his research on *Sphagnum* he analysed water from different locations with different types of *Sphagnum*.

Sphagnum species

The Class of the *Sphagnopsida* belongs to the Bryophyta. This Class contains a single order, the *Sphagnales*, within which there is one monogeneric family, the *Sphaggnaceae*. *Sphagnum* appears to have no close relatives among other bryophytes and there is no fossil evidence through which this genus can be related to other mosses or liverworts.

The genus of *Sphagnum* has many species. The genus of *Sphagnum* is widespread. Nevertheless, the total number of species is indistinct due to the fact that many species of Sphagnum resemble each other. Numbers between 150 and 300 are mentioned.

Their unique and highly characteristic anatomy gives *Sphagnum* plants special properties, which makes many of them important ecologically and economically. *Sphagnum* species consist of a primary, erect stem with characteristic clusters of branches borne at more or less regular intervals. Growth of stem and branches is a result of successive divisions of tetrahedral apical cells, but, whereas stems can grow indefinitely, branches are strictly limited in length (Daniels R.E. 1985).

The four types of water that were made:
1. Brackish water, ratio 0.13
2. Rainwater, ratio 0.13
3. Local groundwater, ratio 0.26
4. Enriched groundwater, ratio 0.58

	Brackish water	Rainwater	Local groundwater	Enriched groundwater
ion	conc. mM	conc. mM	conc. mM	conc. mM
Na	18.98	0.55	0.53	0.53
K	0.33	0.01	0.01	0.01
Mg	1.93	0.06	0.03	0.03
Ca	0.57	0.02	0.11	0.28
SO4	1.27	0.04	0.08	0.08
Cl	19.88	0.57	0.22	0.56
HCO3	1.88	0.05	0.45	0.45

Table 2.1: Chemical composition of the various water types

Brackish water and rain water:
Brackish water and rainwater were derived from seawater by dilution. Seawater was made according to the recipe of Veldhuis and Admiraal (1978). Extra calcium was added in the form of calciumchloride. Brackish water was 25 times diluted seawater, rainwater was 865 times diluted seawater.
The correlation, found in the field, between calcium and magnesium as bivalent ions and sodium and potassium as monovalent ions gave the following equation on a *Sphagnum magellanicum* site:
$(Ca^{2+} + Mg^{2+}) = 0.335\ (Na^{+} + K^{+}) - 0.006$. This equation is expressed in mill-equivalents and leads to a *ionic ratio* of 0.16 expressed in concentrations. Instead of 0.16 the used *ionic ratio* was 0.13.

Local groundwater and enriched groundwater
The recipe for groundwater and enriched groundwater was made according MER (1987) The correlation between calcium plus magnesium and sodium plus potassium found in the field for *Sphagnum recurvum* can be put as the following equation:
$(Ca^{2+} + Mg^{2+}) = 0.497\ (Na^{+} + K^{+}) - 0.019$ This equation is also expressed in milli-equivalents. Expressed in concentrations, this leads to the *ionic ratio* of 0.25. The used *ionic ratio* in this experiment was 0.26. The ratio of 0.26 for groundwater was achieved by adding extra sodium in the form of $NaHCO_3$ to the water. For the enriched groundwater a *ionic ratio* of 0.58 was used. Enriched groundwater differs from groundwater in higher a concentration of $CaCl_2$.

Nutrients and trace elements
The same concentrations of nutrient and trace elements were added to all water types. The nutrient stock solution was made according to Rudolph and Voigt (1986), table 2.2.

Nutrient stock 5 ml to 200 l	conc. mM	Biomass g/l	endconc. µM
(NH4)2SO4	45.00	6.00	1.13
MgSO4.7H2O	40.00	10.00	1.00
CaSO4.2H2O	29.00	5.00	0.73
CaCl2	14.00	1.55	0.35
KH2PO4	15.00	2.00	0.38
KNO3	20.00	2.00	0.50
NH4NO3	1258.00	106.93	31.45
NaOH	110.00	4.40	2.75
FeCl3.6H2O	4.00	1.00	0.10
EDTA		1.38	
HNO3	120.00	7.56	3.00
NaNO3	292.00	24.82	7.30

Table 2.2: Recipe for nutrient stock.

In 200 liters of demineralized water 5 ml of stock solution was added, which corresponds to 1000 mm rain and 10.65 kg/N/hectare. The trace elements solution was made according the recipe of Pegtel and Beukema (1986).

Pumps
The pumps that were used are from the brand "Masterflex L/S". It is a cartridge pump head system. These cartridge pumps are designed to provide up to 12 simultaneously driven pump channels and the ability to provide nearly pulse free flow.
Two of these pumps were used with each 12 endings. Each tray contained two endings of the pumps. Each ending supplied 300-ml water per 24 hours this corresponds to 1000-mm precipitation per year on one hectare.

Methods

2.3 The set up

The three species of *Sphagnum* were transported to the green house of the University of Groningen in September 2001. All plants were cut at the length of 7 centimetres. Pots were filled with each thirty *Sphagnum* plant of one species. Ninety pots of each species were filled.
Besides the ninety mono cultere pots of each species, eighty pots were filled with each 15 plants of *Sphagnum magellanicum* and 15 plants of *Sphagnum majus*. Those pots were used for a competition experiment.
The pots with *Sphagnum* plants were put into trays. The total amount of trays used was 12. Three trays for every water type. The trays were placed randomly in the greenhouse. The water was pumped from

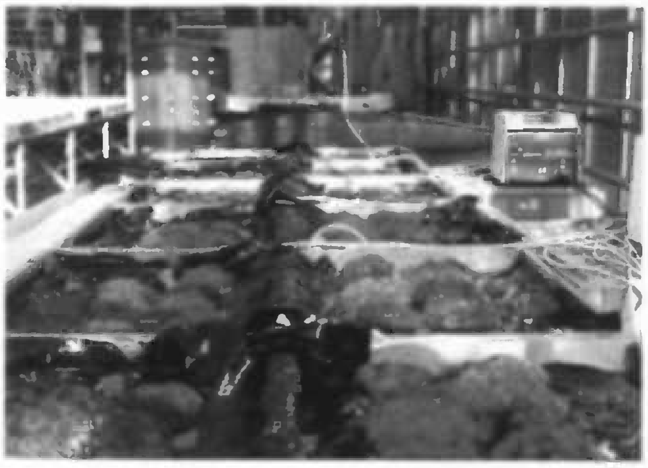

Figure 2.1: The set up of the experiment in the greenhouse in Haren, Groningen. It shows the trays, containing the pots with *Sphagnum*. This photo was taken just before the last harvest was done.

the stock supply into the trays at two corners of one of the two longest sides of the tray. At the opposite side of the tray an outlet system was made to create an outflow. The outlet was made 4 centimetres above the bottom of the tray. The trays could contain 8 liters of water before the overflow was reached.
The flow rate of the pumps was 0.6 liter per 24 hours per tray. In 13.3 days the water in the trays would be replaced when evaporation is not taken into account.

The experiment started on the 29th of October. The three water types: enriched groundwater, groundwater and rainwater were given to the *Sphagnum* plants. The trays, which would be treated with brackish water, were only treated with brackish water temporally in the first period. The brackish treatment was expected to be fatal to all plants if it would last longer than two weeks. Due to osmoses the plant would probably die. To determine on wich species the treatment had the biggest impact, all species had to survive the brackish treatment. The brackish water treatment began at October 30, the second day of the experiment. After 10 days on November 9th the brackish water was replaced by rainwater.

1thHarvest		2nd Harvest		3rd Harvest		4th Harvest
	period 1		period 2		period 3	
Days: 0	Brackish treatment	27	High concentrations groundwater and enriched groundwater.	51	Brackish treatment	73

Table 2.3: Time scale of the experiment

On the 14 Th of November groundwater and enriched groundwater were introduced with a ten times higher concentration of ions. The nutrient supply and trace element supply did not change. This treatment lasted for 16 days, until November 30.
The brackish treatment as well as the high concentration treatment for enriched groundwater and groundwater was carried out by replacing the supply barrels. The water content of the trays was not replaced. The plants were exposed to the treatments longer than the mentioned time, because the water was replaced gradually. The refreshing of the water was dependent of the water flow trough the trays.
The treatment with brackish water was repeated on December 4th . This time the trays were emptied and filled again with brackish water so that the *Sphagnum* plant would be directly exposed to the brackish water.
To prevent differences in growth due to differences in the amount of available light, the place of each pot in the trays was changed at least every two weeks. On the 3rd of December plastic plates were introduced to the decrease the high evaporation rate.

2.4 Harvests
First harvest
At the beginning of the experiment on October 23rd, 10 pots of each *Sphagnum* species were dried to measure the initial dry weight.

Second harvest
On the 19th of November the second harvest was done. Per water treatment 6 or 7 pots of each species were dried. This harvest was done at the beginning of the high

concentration treatment for groundwater and enriched groundwater, but after the first brackish treatment.

Third harvest
The third harvest was done on the 13th December. Nine days after the trays with the brackish treatment were refreshed with brackish water.

Fourth harvest
The fourth harvest was at the 4th of January. This harvest was the final harvest, two and a half months after the beginning of the experiment.

2.5 Dry weight measurements
The *Sphagnum* plants were dried at 70°C for two days. According to the standard method of the laboratory of plantecology of the R*u*G. The harvested pots were identified by the name of the species, the water type and the tray number. The number of the tray was noted to reveal whether differences in biomass growth took place between trays containing the same water type.

2.6 Biomass increase
The pots with the three different species of *Sphagnum* harvested on the 23rd of October were used to determine the mean biomass per pot at the beginning of the experiment. The biomass increase was calculated by dividing the biomass of one pot of a species by this biomass at the beginning of the experiment.

2.7 Statistics
The first test that was the homogeneity of variances (Levenes) test. This test determined whether the groups of plants belonging to the same treatment, the same water type and the same harvest are homogeneous. An significance outcome above 5% means that the variances are homogeneous. For this test the dry weight measurements of the last harvests were used.
If the variances were homogeneous, the one-way ANOVA was allowed. The ANOVA test was also executed on the data of the dry weight measurements of the last harvest. The ANOVA tests whether the water treatments resulted in significant differences in the biomass at the end of the experiment.
Finally, Student-Newman-Keuls, Tukey and Duncan tests were done to reveal differences in the biomass of *Sphagnum* under different treatments.

3. Results

3.1 Sphagnum magellanicum

After the second harvest the biomass of *Sphagnum magellanicum* was the highest under the rainwater treatment (Table 3.1 and Figure 3.1).

	Harvest 1		Harvest 2		Harvest 3		Harvest 4	
Watertype	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error
Enriched groundwater	1.24	0.04	1.25	0.05	1.54	0.03	1.80	0.06
Groundwater	1.24	0.04	1.39	0.09	1.68	0.03	1.93	0.08
Rainwater	1.24	0.04	1.52	0.08	1.68	0.07	2.04	0.08
Brackish water	1.24	0.04	1.36	0.08	1.46	0.04	1.71	0.10

Table 3.1: Mean biomass and std error *Sphagnum magellanicum*

The enriched groundwater treatments had led to the lowest increase in biomass. The results of the third harvest gave a different outcome. The biomass of *Sphagnum magellanicum* had a very high increase under the groundwater and the enriched groundwater treatment. The steepness of the slope indicated a very high growth rate for *Sphagnum magellanicum* under the groundwater and enriched groundwater treatment. The biomass under the groundwater treatment had increased so much, that there was hardly any difference in biomass under the rainwater and the groundwater treatments. The brackish treatment gave the lowest biomass after this period.

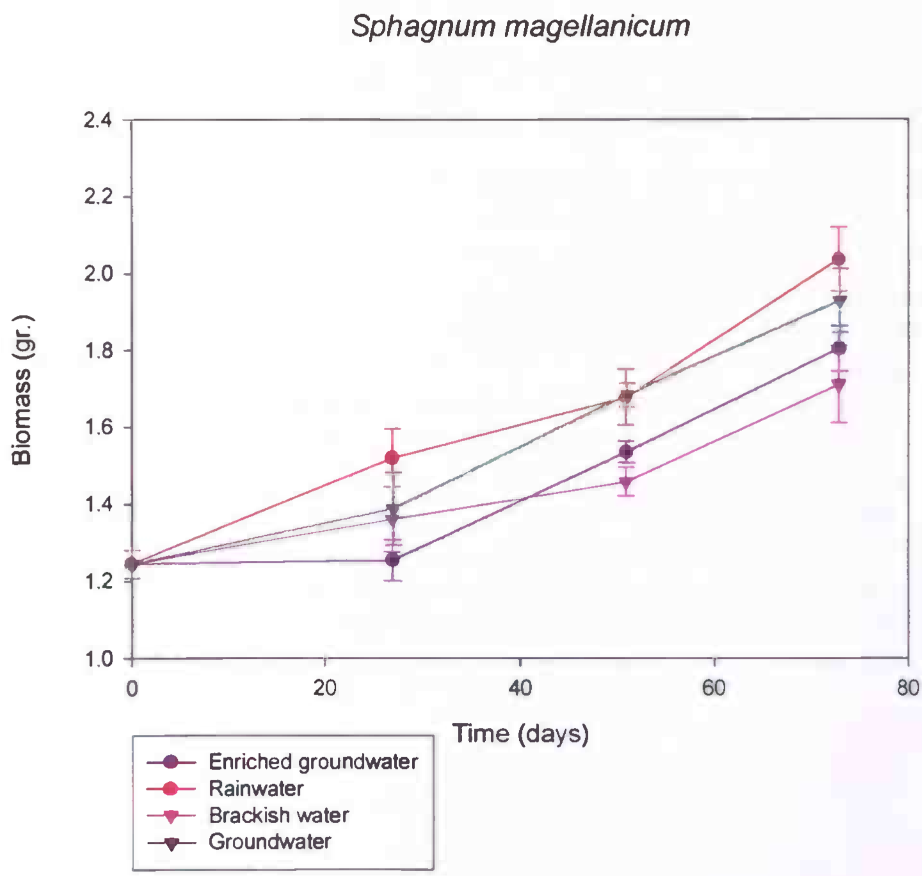

Figure 3.1: Biomass of *Sphagnum magellanicum*

In the last period, the growth rate of *Sphagnum magellanicum* under the rainwater treatment increased. This resulted in the highest biomass under the rainwater treatment at the end of the experiment. Finally, the lowest biomass *of Sphagnum magellanicum* was reached under the brackish treatment.

To test whether the observed differences were significant, the homogeneity of variances was used. This homogeneity of variances (Levenes test) had an outcome of 84%. The one-way ANOVA test was used to test whether the treatments resulted in significant different biomasses of *Sphagnum magellanicum* at the end of the experiment. This test was done on the data of the dry weight measurements of the last harvest.

The Ho hypothesis is: $\mu_{\text{enriched groundwater}} = \mu_{\text{groundwater}} = \mu_{\text{rainwater}} = \mu_{\text{brackish water}}$

The outcome of the ANOVA test was 5.8%, this is slightly above 5%. A significance above 5% means that the different water treatments did not result in different biomasses of *Sphagnum magellanicum* at the end of the experiment. The hypothesis that the biomass of *Sphagnum magellanicum* plants under the different treatments differs significantly from each other had to be rejected.
Finally, the Student Newman Keuls, Tukey and Duncan test were executed to reveal whether the water treatments resulted in different biomasses at the end of the experiment.
According to the Student-Newman-Keuls test and the Tukey test the four water types did not result in significant different biomasses of *Sphagnum magellanicum* at the end of the experiment. The Duncan test on the other hand did find significant difference in the final biomasses of plants belonging to different water types. It concluded that brackish water (type 3) and rainwater water (type 2) gave significant different biomasses of *Sphagnum magellanicum* at the end of the experiment.

During the second period of the experiment the groundwater and enriched groundwater was supplied with a ten times higher concentration. Figure 3.1 showed that the growth rate of *Sphagnum magellanicum* increased in this second period. To test whether the absolute mean biomass of *Sphagnum magellanicum* was significant different under different treatments the Student-Newman-Keuls test, Tukey test and Duncan test were used.
The absolute mean biomass of the second harvest was subtracted from the absolute biomasses of the third harvest. From this outcome, the exponent was taken to make the homogeneity of variances significant. These three tests all showed a significant difference in the biomass of *Sphagnum magellanicum* between the plants treated with the brackish water (type 3) and that treated with groundwater (type 4). The Student-Newman-Keuls test as well as the Duncan test gave a significantly difference between the brackish water and the groundwater treatment, and also a significant difference between the brackish water and the enriched groundwater
(type 1).

3.2 Sphagnum recurvum

After the second harvest, the plants treated with groundwater, had the highest absolute mean biomass (Table 3.2 and Figure 3.2).

	Harvest 1		Harvest 2		Harvest 3		Harvest 4	
Watertype	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error
Enriched groundwater	1.24	0.02	1.52	0.06	1.83	0.05	2.02	0.07
Groundwater	1.24	0.02	1.59	0.08	1.90	0.05	1.89	0.12
Rainwater	1.24	0.02	1.52	0.06	1.78	0.06	1.98	0.04
Brackish water	1.24	0.02	1.40	0.04	1.78	0.06	1.86	0.06

Table 3.2: Mean biomass and std error *Sphagnum recurvum*

The brackish water treatment resulted in the lowest absolute mean biomass of *Sphagnum recurvum*. In the second period, the steepness of the slopes was the same as in the first period except for the brackish treatment. This indicates that the growth rate during the second period was the same as in the first period, except for the brackish treatment. The third harvest showed that the biomass was still the highest under the groundwater treatment. The *Sphagnum recurvum* plants treated with brackish water grew in this second period faster than in the first period. The biomass of *Sphagnum recurvum* under the brackish treatment was nearly the same as that under the rainwater.

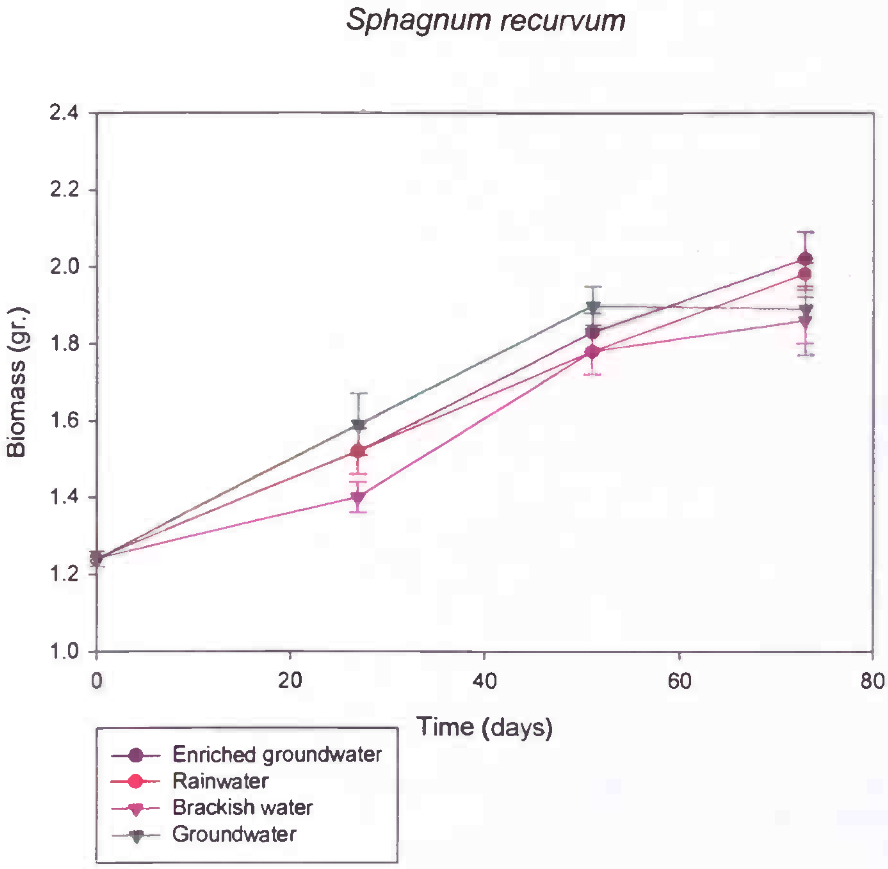

Figure 3.2: Biomass of *Sphagnum recurvum*

The third period gave other results. The grow rate of *Sphagnum recurvum* under the groundwater treatment decreased. At the end of the experiment the biomass was the highest under the enriched groundwater treatment. The rainwater treatment gave the second highest biomass. Under the brackish treatment, plants of this species had the lowest biomass.

The homogeneity of variances test had an outcome of 1.1 %. An outcome below 5% indicates that the variances are not homogeneous. It is not allowed to execute the one-way ANOVA test

3.3 Sphagnum majus

After the second harvest the biomass was the highest for plants that were treated with groundwater (Table 3.3 and Figure 3.3).

	Harvest 1		Harvest 2		Harvest 3		Harvest 4	
Watertype	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error	Mean biomass (gr.)	Std error
Enriched groundwater	1.53	0.05	1.80	0.11	1.85	0.11	1.98	0.09
Groundwater	1.53	0.05	1.81	0.07	1.86	0.07	2.00	0.07
Rainwater	1.53	0.05	1.60	0.06	1.89	0.07	2.17	0.08
Brackish water	1.53	0.05	1.68	0.06	1.82	0.08	2.11	0.09

Table 3.3: Mean biomass and std error *Sphagnum majus*

The biomass under the enriched groundwater treatment was almost as high as that of the groundwater treatment.

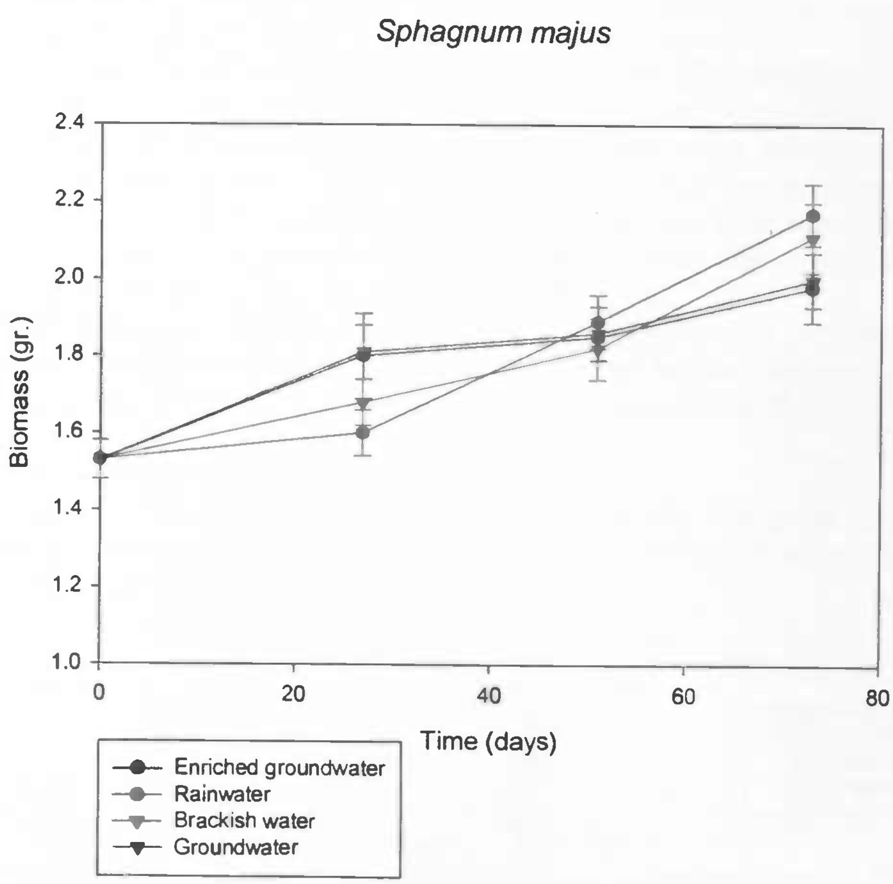

Figure 3.3: Biomass of *Sphagnum majus*

Remarkable is that the plants treated with brackish water appeared to have a higher biomass than the plants that grew under rainwater conditions.

In the third period, between the second and the third harvest, the growth rate of plants under the rainwater treatment increased. The decreasing steepness of the slope of the graphs of groundwater and enriched groundwater indicate a decrease in the growth rate under these treatments.

The trends in the third period, showed that plants under the brackish treatment had an increase in growth rate. Also the growth rate of plants under the enriched groundwater and the groundwater treatment increased, although this increase was much less than that of plants treated with brackish water. This resulted in the highest biomass for *Sphagnum majus* under the rainwater treatment, followed by the brackish treatment. After two-and-a half months, the groundwater treatment and the enriched groundwater treatment gave the lowest biomasses.

The homogeneity of variances tests gave a significance of 58.9%. The variances were homogeneous. The one-way ANOVA test was used to determine whether the biomasses at the end of the experiment were significant different among the different treatments.

The Ho hypothesis is: $\mu_{\text{enriched groundwater}} = \mu_{\text{groundwater}} = \mu_{\text{rainwater}} = \mu_{\text{brackish water}}$

The outcome of the one-way ANOVA is 41.5%. The different treatments did not result in differences in the final biomasses of *Sphagnum majus* among the groups with were treated with different water types.
Also for *Sphagnum majus* tests were used to investigate the growth during the second period of the experiment. The Student-Newman-Keuls test, Tukey test and Duncan test were used at the data that were calculated by subtracting the means biomass of the second harvest form the biomasses of the third harvest. The exponent of the data was used. The tree tests all gave the same result. In the second period of the experiment the growth of *Sphagnum majus* was the same for the four different treatments.

3.4 The competition experiment

The competition ratio was determined by dividing the mean relative biomass of *Sphagnum majus* by the mean relative biomass increase of *Sphagnum magellanicum*.

	Harvest 1	Harvest 2	Harvest 3	Harvest 4
watertype	Sph. Majus / Sph. Magellanicum			
Enriched groundwater	1.00	1.16	1.28	0.97
Groundwater	1.00	0.96	1.01	1.00
Rainwater	1.00	1.26	1.07	1.03
Brackish water	1.00	1.02	1.04	1.02

Table 3.4: Competitionratio *Sphagnum majus / Sphagnum magellanicum* for competition experiment.

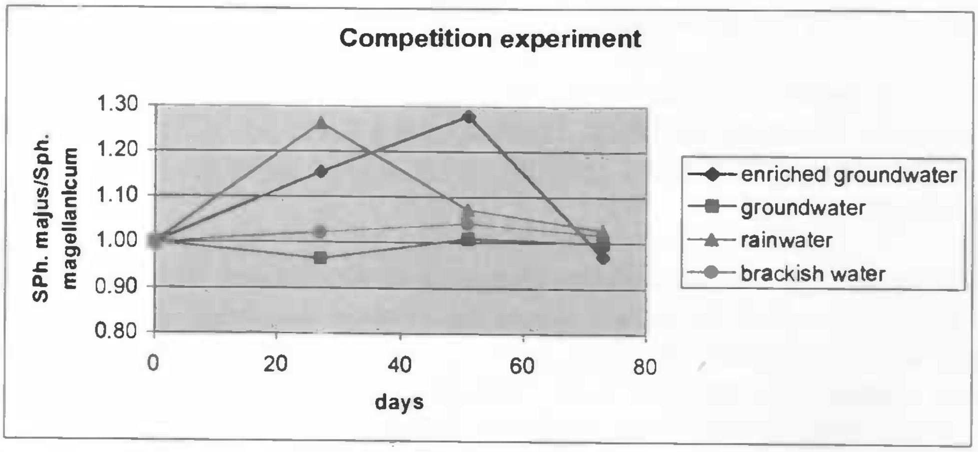

Figure 3.4: Competitionratio *Sphagnum majus / Sphagnum* magellanicum for the competition experiment.

In the first period of the experiment, the competition ratio increased a lot under the rainwater and the enriched groundwater. The competition ratios under the groundwater and brackish water treatment hardly changed.
In the second period, the competition ratio under the enriched groundwater treatment kept increasing, in contrast to that under the rainwater treatment, which decreased.
The competition ratios under the groundwater and brackish water treatment showed a slight increase. The data of the second harvest showed that only under the groundwater treatment the mean relative biomass increase for *Sphagnum magellanicum* was higher than that of *Sphagnum majus*.
The data of the third harvest showed that all water types resulted in competition ratios above one. During the last period of the experiment the competition ratios for all the water types decreased. The highest decrease was under the highest for the enriched groundwater treatment. For the water types enriched groundwater and groundwater this led to competition ratios slightly below one. For these water types it can be said that *Sphagnum magellanicum* had had a higher mean relative biomass than *Sphagnum majus* at the end of the experiment.
The water types rainwater and brackish water both had a competition ratio slightly above one. For this water types the opposite can be said: *Sphagnum majus* had had a higher mean relative biomass than *Sphagnum magellanicum*.

3.5 Non-competition experiment
The data of the mean biomass increase of the species *Sphagnum majus* and *Sphagnum magellanicum* form the first (non-competition) experiment were used to calculate the competition ratio.

	Harvest 1	Harvest 2	Harvest 3	Harvest 4
watertype	Sph. Majus / Sph. Magellanicum			
Enriched groundwater	1.00	1.16	0.98	0.89
Groundwater	1.00	1.06	0.91	0.84
Rainwater	1.00	0.85	0.91	0.86
Brackish water	1.00	1.002	1.01	1.001

Table 3.5: Competitionratio *Sphagnum majus / Sphagnum magellanicum* for non-competition experiment.

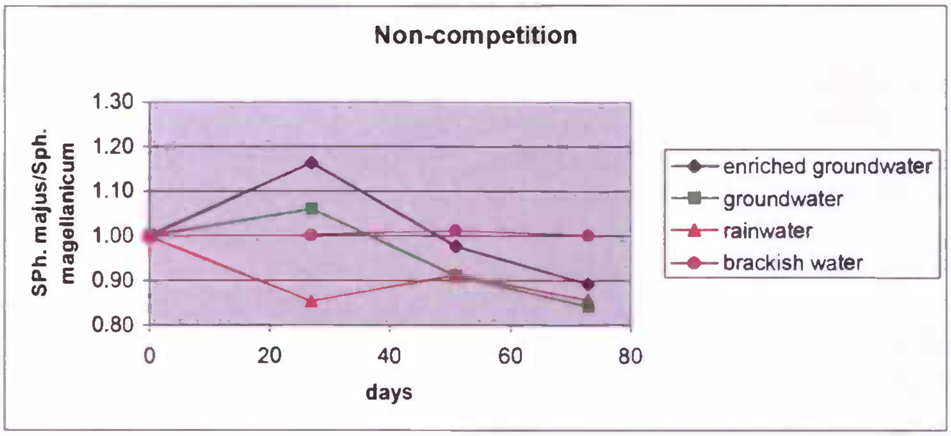

Figure 3.5: Competitionratio *Sphagnum majus / Sphagnum magellanicum* for non-competition experiment.

The competition ratios during the first period of the experiment increased under the enriched groundwater and groundwater treatment, but decreased under the rainwater treatment.
The data of the second harvest showed that for the non-competition experiment *Sphagnum magellanicum* had only under the rainwater treatment a higher mean relative biomass than *Sphagnum majus*.
In the second period, the competition ratios under the enriched groundwater and groundwater treatments decreased. In contrast to the rainwater competition ratio which increased. This resulted only for the brackish treatment a competition ratio slightly above one. The other treatments resulted in higher mean relative biomass increases for *Sphagnum magellanicum* than for *Sphagnum majus*.
During the last period of the experiment all competition ratios decreased. This resulted in competition ratios in favour for *Sphagnum magellanicum* for the water types enriched groundwater, groundwater and rainwater. At the end of the experiment the mean relative biomass was the same for *Sphagnum majus* as for *Sphagnum magellanicum* under the brackish treatment. The competition ratio under the brackish treatment did not change during the experiment. The curves of the competition ratios of the water types groundwater and enriched groundwater resemble each other.

4. Discussion

In the following paragraphs the three parts of the hypothesis will be discussed. An attempt will be made to draw a conclusion about the importance of the *ionic ratio* for the growth and occurrence of different species of *Sphagnum*.
The statistical analysis pointed out that no significant difference in the biomass increase of the *Sphagnum* species were found between the different water treatments. But the trends that were found in this pilot study will be discussed briefly here.

1. *The hypothesis was that the biomass increase of Sphagnum species is influenced by the ionic ratio between bivalent and monovalent cations (calcium, magnesium, potassium and sodium).*
2. *The ionic ratio was expected to be of more importance than the concentrations of the separate cations.*
3. *The Sphagnum species were expected to have its own rather narrow tolerance for the species-specific ionic ratio.*

4.1 The influence of the ionic ratio

✓ *The hypothesis was that the biomass increase of Sphagnum species is influenced by the ionic ratio between bivalent and monovalent cations (calcium, magnesium, potassium and sodium). Whereby, in analogy of their occurrence, Sphagnum magellanicum would grow the best under the rainwater treatment and Sphagnum majus under the groundwater or enriched groundwater type.*

✓ *Trends showed that the first part of the hypothesis seems to be correct. It seemed that there was a (not significant) effect of the ionic ratio between bivalent and monovalent cations found. But the trends did not meet the expectations.*

Final results

After the final period of the experiment, *Sphagnum magellanicum* had the highest biomass increase under the rainwater and groundwater treatment. The statistical analysis showed that the biomasses of *Sphagnum magellanicum* was significantly lower under the brackish treatment than under the rainwater treatment. The trends described for *Sphagnum magellanicum* were near significance.
Sphagnum recurvum had the highest biomass increase under the enriched groundwater and rainwater treatment. The high biomass increase under the enriched groundwater treatment was not expected. The homogeneity of variances test pointed out that the variances were not homogeneous.
Sphagnum majus had a high biomass increase under the rainwater and the brackish water treatment. The last harvest gave a very unexpected outcome. The lowest biomasses were found for plants treated with groundwater and enriched groundwater. The statistical test showed that also for *Sphagnum majus* applied that the trends described were not significant.
In the first period of the experiment the development of the competition ratios under the rainwater and the groundwater treatments were the opposite between the non-competition and the competition experiment. The rainwater treatment resulted for the competition experiment in a higher relative biomass for *Sphagnum majus* and in the non-competition experiment for *Sphagnum magellanicum*. For the groundwater type the opposite results were found in the first period.

The competition experiment and the non-competition experiment showed that *Sphagnum magellanicum* had a higher relative biomass than *Sphagnum majus* under the groundwater and enriched groundwater after the final harvest. For the rainwater treatment contrasting results were found. In the competition experiment *Sphagnum majus* won the competition, in the non-competition experiment *Sphagnum magellanicum* had a higher relative biomass.

The competition ratios and the development of the competition ratios in the competition experiment did not resemble that of the non-competition experiment. The differences in the development were the largest under the rainwater and the enriched groundwater treatments. This suggest that there had been competition.

Although the results do not meet the expectations, very striking is that all species grew under all treatments.

Rainwater effects
It seemed that the three species all responded very well to the rainwater treatment. The rainwater was the water type, which contained the smallest amounts of ions. It might be that the species responded very well on this water type because of the low concentrations. Probably the concentrations of ions were too low to cause any harm to the plants. Presumably, the growth can be explained by the store of cations in and on the plants, which may have prevented a shortage of cations. Vertical distribution of elements in peat are among other things due to removal and relocation (Damman 1986).

Tolerance of brackish water
Very striking is the tolerance of the species to the brackish water.
For *Sphagnum magellanicum*, as well as for *Sphagnum majus* the biomass increase under the brackish treatment was higher in the third than in the second period. This indicates that both species seemed to respond positive to the brackish treatment. This was not expected, but corresponds to the results of the competition experiment. The effect of the brackish water on the biomass increase had been nearly the same for *Sphagnum magellanicum* and *Sphagnum majus* during the whole experiment.
It has been demonstrated experimentally that the treatment of non-coastal mosses with artificial seawater reduced the photosynthetic rate and provoked the reduction of chlorophyll concentrations and of protein synthesis (Grosvernier 1997). It was, therefore, not expected that the plants could survive a period of 3 weeks on brackish water, not to mention that they even grew.
However, it is known from field observations that *Sphagnum* species can withstand a short pulse of brackish water.

> 'In an attempt to sketch the conditions under which the bogs around the Dutch IJ originated, the period before the isolation of the Zuiderzee is important. These bogs tell something about peat development under brackish conditions. The Zuiderzee contained brackish water before the afsluitdijk was build as a barrier between the Zuiderzee and the North Sea. To conserve the polder and the water level in the ditches this brackish water was let in. This letting in of brackish water made it possible to maintain a rainwater lens in the

pastures. The thickness of this lens was more or less determined by the under laying brackish water. In the transitional area from land to open water, a rainwater lens could be found on top of this brackish water. Peat developed in this rainwater lens. The salt concentrations in the under laying ground were variable. The formed peat was now and than exposed to brackish water due to dry weather. It is known that the peat could withstand this short brackish water pulses (Baaijens 1994).'

4.2 Ratio versus concentrations

✓ *The ionic ratio was expected to be of more importance than the concentrations of the separate cations.*

✓ *The second part of the hypothesis can not unambiguously be answered. Whether the ratio is more important than the concentrations of separate cations is not really clear.*

High ion concentrations

For the three species the result of the last harvest pointed out, that the biomass increase under the rainwater treatment was higher than under the brackish treatment. But all species did grow under the brackish conditions. Apparently, the concentrations do have an effect of the growth of *Sphagnum*.

In the second period, the groundwater and enriched groundwater treatments were supplied in a ten times higher concentration than in the other two periods. Figure 3.1 indicates that *Sphagnum magellanicum* responded positively to this high ionic concentrations. The mean absolute biomass of *Sphagnum magellanicum* increased in this period faster, compared to the increase during the first period. Presumably, the carbon supply limited the biomass increase in the first period. This positive response of *Sphagnum magellanicum* was provoked by the high CO_2 concentration, which resulted from the increased HCO_3^- concentration. This response was tested statistically. According the Student-Newman-Keuls, Tukey and Duncan test the brackish water treatment resulted in a significantly lower biomass than the groundwater treatment in this period. Apparently, the high ion concentrations had a positive response to the biomass increase of *Sphagnum magellanicum*.

Sphagnum recurvum did not respond positively, nor negatively on the ten times higher ion concentrations during the second period.

Figure 3.3 showed a decrease in the steepness of the slope for *Sphagnum majus* under the groundwater and enriched groundwater treatments in the second period. Apparently, the ten times higher concentrations of minerals for both water types resulted in a negative response to the biomass increase of *Sphagnum majus*. The statisitcal analysis pointed out that the groundwater and the enriched groundwater types did not result in significantly lower biomasses under these treatments in the second period.

Remarkable is, that the results of the competition experiment were the opposite. In the second period of the competition experiment, *Sphagnum majus* had a higher relative biomass increase than *Sphagnum magellanicum* under the groundwater and enriched groundwater treatments. In the competition experiment it was found that *Sphagnum magellanicum* responded negatively and *Sphagnum majus* positively to the ten times higher concentrations in the groundwater and enriched groundwater treatments.

The negative response of *Sphagnum majus* to the high concentrations and the positive response of *Sphagnum magellanicum* in the non-competition experiment, might be explained by the fact that water fluctuations and therefore changes in water composition are more common on the central part of a bog than at the fringes. In the summer months during warm weather *Sphagnum* evaporates much water, creating an upward water transport. This water transports ions to the surface of the bog. Evaporation at the bog surface increases the ionic concentrations of the bog (Damman 1986). Presumably, the hummock species are better adapted to withstand strong fluctuations in the concentration of ions.
The opposite results found in the competition experiment might be ascribed to the competition.

Apparently, the concentrations of the separate ions do have an influence but whether this influence is more important than the *ionic ratio* can not be concluded.

4.3 Narrow tolerance for specific ratio

- ✓ *The Sphagnum species were expected to have its own rather narrow tolerance for the species-specific ionic ratio.*
- ✓ *The third part of the hypothesis has to be rejected. The Sphagnum species do not seem to have an own narrow tolerance for the species-specific ionic ratio.*

Death under groundwater treatment

The tolerance for the *ionic ratio* of the water type seems to be wider than was expected. The plants grew under all the water treatments.
However, before the last harvest was done the plants treated with groundwater seemed to die, whereas the plants treated with enriched groundwater did not die. The plants under the groundwater treatment all coloured dark brown. Only for *Sphagnum recurvum* this dying was found in the dry weight measurements, probably because it had just started.
Presumably, the death of the plants might be ascribed to the relation between calcium and bicarbonate concentrations. In the second period of the experiment, groundwater and enriched groundwater was supplied in ten times higher concentrations. Both water types contained therefore relative high amounts of $NaHCO_3$. The high concentration of bicarbonate in the second period, increased in the third period as a result of the high evaporation. The bicarbonate concentration might have increased up to a toxic level. The same high concentration of bicarbonate turned out to be non-toxic for the plants under the enriched groundwater type. The higher calcium concentration in this water type might have compensated for the toxic concentration of bicarbonate. Calcium presumably compensates the toxicity of bicarbonate to a certain extend. If this assumption is true, it might be that species tolerate several well-defined *ionic ratios*.

5. Anomalies

5.1 Vulnerable capitulum

In the period shortly before the experiment, the capitula of the plants became vulnerable. Before the beginning of the experiment, the plant had been treated with demineralised water. Research pointed out that the capitulum of *Sphagnum* plants contains high concentrations of nitrogen, phosphor and potassium (Damman 1986, Malmer 1988). The large difference in ion concentration between the demineralised water and the capitula might have caused the vulnerable capitula. Probably the capitula swelled up because of water absorbing. This should correspond with the knowledge that monovalent cations cause an increase in the hydration (swelling) of the protoplasm. They cause the opening of membranes (Koningsberger 1962).
In the course of the experiment, the capitula became less vulnerable. The high difference in concentration between the capitula and the environmental water became smaller which resulted in less cell elongation. It might also be that ions were removed from the capitula to other part of the plants to refill a possible deficiency of ions.

5.2 Innovations

Sphagnum majus had a lower relative biomass increase than the other two species. The mean biomass increase of *Sphagnum majus* would have been even lower if the formed innovations were not included in the dry weight measurements.
Sphagnum majus was the species which had far the most innovations formed. Innovations are branches, which are formed on the stem and resemble the parent shoot in all respect. The formation of innovations is initiated in the capitulum. It seems that there is evidence for a relationship between both capitulum dry weight and the length of the interfasicle of *Sphagnum* and the nitrogen supply. Furthermore it is possible that innovation are also initiated in response to short-term fluctuations in the supply of one or more mineral elements. It is known that the amount of innovations is high in a rheotrophic environment (Baker and Boatman 1989). This importance of the water type was not observed in this experiment. It was observed that *Sphagnum majus* formed far the most innovations, but the amount of innovations was not dependent of the water type. Besides the importance water type, water flow is important. It is known that flowing water results in more innovations than standing water (Baker and Boatman 1989).

5.3 The red colour of Sphagnum magellanicum

During the last harvest it was observed that when the *Sphagnum magellanicum* plants were squeezed out, the red colour came out of the plant. This was found for *Sphagnum magellanicum* plants, which were treated with groundwater. The plants became dark brown at the end of the experiment. Apparently the chlorophyll cells which lay besides the hyaline cells were broken. This meets the observation that these plants were dying. If it were not broken chlorophyll cells, which caused the leaching of the red colour, it could be that it were red alga that were squeezed out.

5.4 Salt crystals

At the end of the experiment it was observed that especially *Sphagnum recurvum* plants which were treated with brackish water formed white salt crystals. This might be salt crystals containing calcium or it could be salt crystal of sodiumchloride.

5.5 The high biomass increase

It is known that *Sphagnum* species do grow very slowly. Astonishing therefore, were the high biomass increases that were found during this experiment. In two-and-a half months *Sphagnum magellanicum* had a mean biomass increase of 64% under the rainwater treatment, *Sphagnum recurvum* a mean biomass increase of 63% under the enriched groundwater treatment and *Sphagnum majus* a mean biomass increase of 40% under the rainwater treatment.

The high relative biomass increase indicates that the growing conditions were near optimal, although the conditions under which the plants grew in the greenhouse could be improved.

The species all had a high mean biomass increase, however the mean biomass increase of *Sphagnum majus* was much less than that of the other two species. *Sphagnum majus* is a rare species, which is not often found in the field. It might be that the fact that this species grows much slower than the other two species is an indication for the reason why it is rare. It is recommended to choose an other hollow species if the experiment will be done again. Probably fast growing species are more sensitive for harmful treatments.

6. Future focus

In this chapter it will be discussed how to improve the set up of the experiment to obtain clear result when the study will be continued.

6.1 Variation

The large variation in the dry weight of plants belonging to the same species, which were treated with the same water type must be reduced.

The large variation partly originated from the fact that the plants used in this experiment were not gathered at the same time. Because the estimation of the amount of plants that were needed to fill the pots was inaccurate. Therefore the plants of one species were not collected nor cut at the same day. This must have contributed to the high variation in dry weight per pot of the same species under the same treatment.

An other factor, which must have played a role in the large variation in groups, is the functioning of the pumps. The pumps regulated the input of water. These pump however, did not function optimal. This resulted in different volumes of water, which were pumped in the trays. Plants of the same species, which were treated with the same water type, were exposed to different water levels as well as different ion supplies. The pumps will function in a better way if the flow rate is higher.

An other factor was the amount of already bounded cations on the cation exchange complexes. The plants could use their own cation store especially in the beginning of the experiment. Each individual plant will have had a specific composition of cations bounded.

Thermal pumps play a role in the water transport in the upper layer of the peat. This is the result of differences in the temperature between day and night. The circular water flow transports ions (Baaijens). Plant standing on different locations of the thermal pumps will have different ion supplies. This difference in the composition of bounded cations will have led to different reactions of plants belonging to the same species, which were treated to the same water type. The adjusting time as well as the time, which is needed to harm the plants with a treatment, will have been different.

The cations bounded at the cation-exchange-complex in the field should be removed before the beginning of the experiment. This could be established by a starvation period in which the plants do only get demineralized water.

6.2 Evaporation

Not only would better results be found if the variation should be limited, but also the experimental set up should be improved.

It is known that *Sphagnum* species evaporate a lot. When the temperature rises from 9 to 25 degrees Celsius, the evaporation increases with 90% (Gaudig 2001). In the greenhouse in Haren the temperature was between 20 and 25 degrees Celsius. The evaporation was at least as high as the water supply. The absence of water transported through the outlets of the trays resulted in that the fact that no ions were removed by an overflow of water. The high evaporation caused an increasing ion concentration in the trays during the experiment. This will have effected the biomass increase of the plants because it was shown that the high concentrations in groundwater and enriched groundwater resulted in a response of the biomass increase of all *Sphagnum* species.

To prevent the high evaporation plastic plates must be placed in the tray at the beginning of the experiment.

6.3 Light penetration

The plastic plates do not only affect the evaporation but also the penetration depth of the light. Without plates the light can penetrate over the whole depth of 7 cm. (The height of the pots is 7 cm.) In the field only 1% of total light is transmitted below 2-cm depth. In the field the low carbon fixation activity of moss plants below the capitulum is at least partly due to shading from the top parts of the moss plant (Malmer 1988). The deeper penetration of light might stimulate photosynthesis in lower part of the plants. This will not only affect the carbon fixation, but probably also the demand for nutrients. Not only will the plates limit the evaporation but it will also lead to an experiment, which is more similar to the field situation.

6.4 Constant treatments

A constant water composition is important for the interpretation of the results. Therefore, if this study would be done again it would be recommended that the brackish treatment will not be rainwater alternating brackish water, but only brackish water. It has been shown that the three species in this experiment could all not only survive a period of more than three weeks of brackish water but also could grow on it. To investigate which ions are absorbed by the *Sphagnum* plant and which are leaked it would be interesting to analyse the supply water as well as the water in the trays. This analysis can only give a good picture if the concentrations of ions in the water supply are constant.

6.5 Length of the plants

Important ions for the growth of *Sphagnum* are mainly stored in the capitulum of *Sphagnum*. For N, P and K, concentrated in the growing capitulum, the direct influx of solutes to the chlorophyllose cells in the growing parts of the plants is the dominant process. Experimental studies are lacking but the high retention of N, P and K combined with the decreasing concentrations downwards along the moss plants, strongly support the hypothesis that within the living parts of the moss a relocation of these elements takes place continuously from the older, aging parts to the younger parts, most actively growing ones (Malmer 1988). The increase of Na^+ with age in the intermediate parts, its decrease in the lower, metabolically less active parts, and the low values in the peat are clear indications of a selective accumulation of this element, too. The accumulation is parallel to the decrease in concentration of K but falls short of compensating it stoichiometrically. Perhaps only that K^+ removed from exchange sites is replaced (Malmer 1988). This relation, whereby a cation replaces a removed cation, is not restricted to Na^+ and K^+, but also for Mg^{2+} and Ca^{2+} such a relation is discovered. Mg^{2+} lost from the lower segments is replaced by Ca^{2+} on the exchange sites since the sum $Mg^{2+} + Ca^{2+}$ remains constant. The cations Mg^{2+} and Ca^{2+} do not play an important role in the capitulum, these cations are found in higher concentration in the lower segments (at least up to 12 cm from the capitulum) of the plants (Malmer 1988). It might be that other results would be found if the plants used in this experiment were not cut at the length of 7 cm, but at least up to 12 cm. The demand for Ca^{2+} compared to the demand for K^+ would probably increase.

6.6 Competition experiment

The competition experiment might be limited by the low density of plants per pot, the density was much lower than in a field situation. Besides the low density, the competition will be limited by the fact that the plants of both species were not confusedly put in the pots, but one species on one side and the other on the opposite site. Therefore it is possible that there has not been a strong competition for light and nutrients.

7. Conclusion

To reveal whether the water composition is a determining factor for the niche separation of *Sphagnum* species along the hummock-hollow gradient this experimental study was done.
An unambiguous conclusion can not be drawn from the results of this pilot experiment. Although the results are not unambiguous, remarkable trends were found.

- ✓ This pilot study seems to point out the *ionic ratio* as well as the absolute concentrations seem to influence the growth of *Sphagnum* (although the results were not significant). The *Sphagnum* species do not seem have a rather narrow tolerance for a species-specific *ionic ratio*.
- ✓ Hummock species appeared to response positive to high ion concentrations in groundwater and enriched groundwater, whereas the hollow species had a negative biomass increase in response to this high concentrations. This response was probably the result of the high CO_2 concentration provoked by the high bicarbonate concentration.
- ✓ Further more, it was remarkable that not only all species survived the brackish treatment, but they even grew.
- ✓ All species seemed to die under the groundwater treatment but not under the enriched groundwater treatment at the end of the experiment. Presumably, the relation between the relative concentrations of calcium and bicarbonate played a role.

Further research is recommended (on a longer time-scale) to investigate the long-term response of different *Sphagnum* species to different water types. Continuation of the research is not only needed to answer the question whether the water composition is a determining factor for the niche separation of *Sphagnum* species along the hummock-hollow gradient, but also to investigate the anomalies that were found during the experiment.

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Appendix I
Harvest 1
Sphagnum magellanicum, Sphagnum recurvum and Sphagnum majus.
Biomass (gr.)

Sph. majus	*Sph. magellanicum*	*Sph. recurvum*
Biomass (gr.)		
1.55	1.18	1.22
1.70	1.01	1.18
1.73	1.23	1.15
1.50	1.19	1.20
1.25	1.31	1.28
1.46	1.21	1.25
1.56	1.37	1.18
1.70	1.30	1.32
1.34	1.42	1.35
1.55	1.22	1.24

Appendix II
Harvest 2
Sphagnum magellanicum
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. magellanicum*	1.118
1	Enriched groundwater	*Sph. magellanicum*	1.395
6	Enriched groundwater	*Sph. magellanicum*	1.143
6	Enriched groundwater	*Sph. magellanicum*	1.475
10	Enriched groundwater	*Sph. magellanicum*	1.125
10	Enriched groundwater	*Sph. magellanicum*	1.249
10	Enriched groundwater	*Sph. magellanicum*	1.273
2	Rainwater	*Sph. magellanicum*	1.716
2	Rainwater	*Sph. magellanicum*	1.609
5	Rainwater	*Sph. magellanicum*	1.262
5	Rainwater	*Sph. magellanicum*	1.464
9	Rainwater	*Sph. magellanicum*	1.621
9	Rainwater	*Sph. magellanicum*	1.246
9	Rainwater	*Sph. magellanicum*	1.718
3	Brackish water	*Sph. magellanicum*	1.463
3	Brackish water	*Sph. magellanicum*	1.174
8	Brackish water	*Sph. magellanicum*	1.399
8	Brackish water	*Sph. magellanicum*	1.324
8	Brackish water	*Sph. magellanicum*	1.384
12	Brackish water	*Sph. magellanicum*	1.745
12	Brackish water	*Sph. magellanicum*	1.03
4	Groundwater	*Sph. magellanicum*	1.602
4	Groundwater	*Sph. magellanicum*	1.369
7	Groundwater	*Sph. magellanicum*	1.29
7	Groundwater	*Sph. magellanicum*	0.979
11	Groundwater	*Sph. magellanicum*	1.411
11	Groundwater	*Sph. magellanicum*	1.302
11	Groundwater	*Sph. magellanicum*	1.762

Appendix III
Harvest 3
Sphagnum magellanicum
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. magellanicum*	1.42
1	Enriched groundwater	*Sph. magellanicum*	1.493
1	Enriched groundwater	*Sph. magellanicum*	1.579
6	Enriched groundwater	*Sph. magellanicum*	1.592
6	Enriched groundwater	*Sph. magellanicum*	1.48
10	Enriched groundwater	*Sph. magellanicum*	1.547
10	Enriched groundwater	*Sph. magellanicum*	1.638
2	Rainwater	*Sph. magellanicum*	1.515
2	Rainwater	*Sph. magellanicum*	1.455
2	Rainwater	*Sph. magellanicum*	1.995
5	Rainwater	*Sph. magellanicum*	1.776
5	Rainwater	*Sph. magellanicum*	1.707
9	Rainwater	*Sph. magellanicum*	1.773
9	Rainwater	*Sph. magellanicum*	1.526
3	Brackish water	*Sph. magellanicum*	1.59
3	Brackish water	*Sph. magellanicum*	1.385
3	Brackish water	*Sph. magellanicum*	1.304
8	Brackish water	*Sph. magellanicum*	1.545
8	Brackish water	*Sph. magellanicum*	1.467
12	Brackish water	*Sph. magellanicum*	1.408
12	Brackish water	*Sph. magellanicum*	1.506
4	Groundwater	*Sph. magellanicum*	1.707
4	Groundwater	*Sph. magellanicum*	1.635
4	Groundwater	*Sph. magellanicum*	1.814
7	Groundwater	*Sph. magellanicum*	1.729
7	Groundwater	*Sph. magellanicum*	1.642
11	Groundwater	*Sph. magellanicum*	1.565
11	Groundwater	*Sph. magellanicum*	1.695

Appendix IV
Harvest 4
Sphagnum magellanicum
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. magellanicum*	2.045
1	Enriched groundwater	*Sph. magellanicum*	1.668
6	Enriched groundwater	*Sph. magellanicum*	1.729
6	Enriched groundwater	*Sph. magellanicum*	1.965
6	Enriched groundwater	*Sph. magellanicum*	1.708
10	Enriched groundwater	*Sph. magellanicum*	1.85
10	Enriched groundwater	*Sph. magellanicum*	1.657
2	Rainwater	*Sph. magellanicum*	2.201
2	Rainwater	*Sph. magellanicum*	1.872
5	Rainwater	*Sph. magellanicum*	2.468
5	Rainwater	*Sph. magellanicum*	1.959
5	Rainwater	*Sph. magellanicum*	1.897
9	Rainwater	*Sph. magellanicum*	1.879
9	Rainwater	*Sph. magellanicum*	1.97
3	Brackish water	*Sph. magellanicum*	1.371
3	Brackish water	*Sph. magellanicum*	2.329
8	Brackish water	*Sph. magellanicum*	1.551
8	Brackish water	*Sph. magellanicum*	1.587
8	Brackish water	*Sph. magellanicum*	1.857
12	Brackish water	*Sph. magellanicum*	1.698
12	Brackish water	*Sph. magellanicum*	1.657
4	Groundwater	*Sph. magellanicum*	1.696
4	Groundwater	*Sph. magellanicum*	1.904
7	Groundwater	*Sph. magellanicum*	1.818
7	Groundwater	*Sph. magellanicum*	2.202
7	Groundwater	*Sph. magellanicum*	1.964
7	Groundwater	*Sph. magellanicum*	2.335
11	Groundwater	*Sph. magellanicum*	1.823
11	Groundwater	*Sph. magellanicum*	1.683

Appendix V
Harvest 2
Sphagnum recurvum
Biomass (gr.)

Tray	Water type	Species	Biomass(gr.)
1	Enriched groundwater	*Sph. recurvum*	1.488
1	Enriched groundwater	*Sph. recurvum*	1.468
6	Enriched groundwater	*Sph. recurvum*	1.743
6	Enriched groundwater	*Sph. recurvum*	1.431
6	Enriched groundwater	*Sph. recurvum*	1.33
10	Enriched groundwater	*Sph. recurvum*	1.695
10	Enriched groundwater	*Sph. recurvum*	1.454
2	Rainwater	*Sph. recurvum*	1.57
2	Rainwater	*Sph. recurvum*	1.534
5	Rainwater	*Sph. recurvum*	1.817
5	Rainwater	*Sph. recurvum*	1.524
5	Rainwater	*Sph. recurvum*	1.336
9	Rainwater	*Sph. recurvum*	1.466
9	Rainwater	*Sph. recurvum*	1.419
3	Brackish water	*Sph. recurvum*	1.475
3	Brackish water	*Sph. recurvum*	1.426
3	Brackish water	*Sph. recurvum*	1.264
8	Brackish water	*Sph. recurvum*	1.494
8	Brackish water	*Sph. recurvum*	1.495
12	Brackish water	*Sph. recurvum*	1.282
12	Brackish water	*Sph. recurvum*	1.382
4	Groundwater	*Sph. recurvum*	1.492
4	Groundwater	*Sph. recurvum*	1.337
4	Groundwater	*Sph. recurvum*	1.897
7	Groundwater	*Sph. recurvum*	1.379
7	Groundwater	*Sph. recurvum*	1.700
11	Groundwater	*Sph. recurvum*	1.706
11	Groundwater	*Sph. recurvum*	1.649

Appendix VI
Harvest 3
Sphagnum recurvum
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. recurvum*	1.764
1	Enriched groundwater	*Sph. recurvum*	2.018
6	Enriched groundwater	*Sph. recurvum*	1.888
6	Enriched groundwater	*Sph. recurvum*	1.629
10	Enriched groundwater	*Sph. recurvum*	1.908
10	Enriched groundwater	*Sph. recurvum*	1.741
10	Enriched groundwater	*Sph. recurvum*	1.872
2	Rainwater	*Sph. recurvum*	1.585
2	Rainwater	*Sph. recurvum*	1.798
5	Rainwater	*Sph. recurvum*	1.906
5	Rainwater	*Sph. recurvum*	1.727
9	Rainwater	*Sph. recurvum*	1.605
9	Rainwater	*Sph. recurvum*	1.859
9	Rainwater	*Sph. recurvum*	2.008
3	Brackish water	*Sph. recurvum*	1.586
3	Brackish water	*Sph. recurvum*	1.678
8	Brackish water	*Sph. recurvum*	1.968
8	Brackish water	*Sph. recurvum*	1.889
12	Brackish water	*Sph. recurvum*	1.926
12	Brackish water	*Sph. recurvum*	1.778
12	Brackish water	*Sph. recurvum*	1.63
4	Groundwater	*Sph. recurvum*	1.813
4	Groundwater	*Sph. recurvum*	1.91
7	Groundwater	*Sph. recurvum*	1.728
7	Groundwater	*Sph. recurvum*	1.996
7	Groundwater	*Sph. recurvum*	1.907
11	Groundwater	*Sph. recurvum*	2.103
11	Groundwater	*Sph. recurvum*	1.817

Appendix VII
Harvest 4
Sphagnum recurvum
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. recurvum*	2.137
1	Enriched groundwater	*Sph. recurvum*	2.182
1	Enriched groundwater	*Sph. recurvum*	1.803
6	Enriched groundwater	*Sph. recurvum*	2.324
6	Enriched groundwater	*Sph. recurvum*	1.882
10	Enriched groundwater	*Sph. recurvum*	1.942
10	Enriched groundwater	*Sph. recurvum*	1.874
2	Rainwater	*Sph. recurvum*	1.968
2	Rainwater	*Sph. recurvum*	2.014
2	Rainwater	*Sph. recurvum*	1.993
5	Rainwater	*Sph. recurvum*	1.903
5	Rainwater	*Sph. recurvum*	2.055
9	Rainwater	*Sph. recurvum*	2.101
9	Rainwater	*Sph. recurvum*	1.805
3	Brackish water	*Sph. recurvum*	1.66
3	Brackish water	*Sph. recurvum*	1.896
3	Brackish water	*Sph. recurvum*	2.135
8	Brackish water	*Sph. recurvum*	2.008
8	Brackish water	*Sph. recurvum*	1.894
8	Brackish water	*Sph. recurvum*	1.694
12	Brackish water	*Sph. recurvum*	1.757
12	Brackish water	*Sph. recurvum*	1.83
4	Groundwater	*Sph. recurvum*	2.106
4	Groundwater	*Sph. recurvum*	1.792
4	Groundwater	*Sph. recurvum*	2.252
7	Groundwater	*Sph. recurvum*	1.835
7	Groundwater	*Sph. recurvum*	2.229
11	Groundwater	*Sph. recurvum*	1.607
11	Groundwater	*Sph. recurvum*	1.392

Appendix VIII

Harvest 2

Sphagnum majus

Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. majus*	1.405
1	Enriched groundwater	*Sph. majus*	1.959
1	Enriched groundwater	*Sph. majus*	1.872
6	Enriched groundwater	*Sph. majus*	1.643
6	Enriched groundwater	*Sph. majus*	1.641
10	Enriched groundwater	*Sph. majus*	1.74
10	Enriched groundwater	*Sph. majus*	2.339
2	Rainwater	*Sph. majus*	1.428
2	Rainwater	*Sph. majus*	1.589
2	Rainwater	*Sph. majus*	1.908
5	Rainwater	*Sph. majus*	1.417
5	Rainwater	*Sph. majus*	1.558
9	Rainwater	*Sph. majus*	1.71
9	Rainwater	*Sph. majus*	1.594
3	Brackish water	*Sph. majus*	1.469
3	Brackish water	*Sph. majus*	1.81
8	Brackish water	*Sph. majus*	1.564
8	Brackish water	*Sph. majus*	1.795
12	Brackish water	*Sph. majus*	1.757
12	Brackish water	*Sph. majus*	1.835
12	Brackish water	*Sph. majus*	1.53
4	Groundwater	*Sph. majus*	1.804
4	Groundwater	*Sph. majus*	1.957
7	Groundwater	*Sph. majus*	1.691
7	Groundwater	*Sph. majus*	1.904
11	Groundwater	*Sph. majus*	1.566
11	Groundwater	*Sph. majus*	1.963

Appendix IX

Harvest 3

Sphagnum majus

Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. majus*	2.233
1	Enriched groundwater	*Sph. majus*	2.196
6	Enriched groundwater	*Sph. majus*	1.648
6	Enriched groundwater	*Sph. majus*	1.556
6	Enriched groundwater	*Sph. majus*	1.586
10	Enriched groundwater	*Sph. majus*	1.893
10	Enriched groundwater	*Sph. majus*	1.836
2	Rainwater	*Sph. majus*	2.039
2	Rainwater	*Sph. majus*	1.928
5	Rainwater	*Sph. majus*	1.626
5	Rainwater	*Sph. majus*	2.068
5	Rainwater	*Sph. majus*	1.87
9	Rainwater	*Sph. majus*	1.684
9	Rainwater	*Sph. majus*	2.007
3	Brackish water	*Sph. majus*	1.718
3	Brackish water	*Sph. majus*	1.631
8	Brackish water	*Sph. majus*	2.006
8	Brackish water	*Sph. majus*	2.146
8	Brackish water	*Sph. majus*	1.915
12	Brackish water	*Sph. majus*	1.799
12	Brackish water	*Sph. majus*	1.533
4	Groundwater	*Sph. majus*	1.673
4	Groundwater	*Sph. majus*	1.685
7	Groundwater	*Sph. majus*	2.067
7	Groundwater	*Sph. majus*	2.059
11	Groundwater	*Sph. majus*	1.746
11	Groundwater	*Sph. majus*	1.924
11	Groundwater	*Sph. majus*	2.065

Appendix X
Harvest 4
Sphagnum majus
Biomass (gr.)

Tray	Water type	Species	Biomass (gr.)
1	Enriched groundwater	*Sph. majus*	2.054
1	Enriched groundwater	*Sph. majus*	1.653
6	Enriched groundwater	*Sph. majus*	2.03
6	Enriched groundwater	*Sph. majus*	1.809
10	Enriched groundwater	*Sph. majus*	1.796
10	Enriched groundwater	*Sph. majus*	2.329
10	Enriched groundwater	*Sph. majus*	2.222
2	Rainwater	*Sph. majus*	2.32
2	Rainwater	*Sph. majus*	1.966
2	Rainwater	*Sph. majus*	1.926
5	Rainwater	*Sph. majus*	2.06
5	Rainwater	*Sph. majus*	2.525
9	Rainwater	*Sph. majus*	2.319
9	Rainwater	*Sph. majus*	2.058
9	Rainwater	*Sph. majus*	2.024
3	Brackish water	*Sph. majus*	2.353
3	Brackish water	*Sph. majus*	2.351
3	Brackish water	*Sph. majus*	2.191
8	Brackish water	*Sph. majus*	2.437
8	Brackish water	*Sph. majus*	1.923
12	Brackish water	*Sph. majus*	1.688
12	Brackish water	*Sph. majus*	2.01
12	Brackish water	*Sph. majus*	1.939
4	Groundwater	*Sph. majus*	1.69
4	Groundwater	*Sph. majus*	2.212
4	Groundwater	*Sph. majus*	1.929
7	Groundwater	*Sph. majus*	1.934
7	Groundwater	*Sph. majus*	2.294
7	Groundwater	*Sph. majus*	2.016
11	Groundwater	*Sph. majus*	1.848
11	Groundwater	*Sph. majus*	2.064

Appendix XI

Relative biomass

Table 1: Relative biomass *Sphagnum magellanicum*

Table 2: Relative biomass *Sphagnum recurvum*

Table 3: Relative biomass *Sphagnum majus*

	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Water type	Biomass increase	Biomass increase	Biomass increase	Biomass increase
Enriched groundwater	1.00	1.01	1.23	1.45
Groundwater	1.00	1.12	1.35	1.55
Rainwater	1.00	1.22	1.35	1.64
Brackish water	1.00	1.09	1.17	1.37

Table 1: Mean biomass increase of *Sphagnum magellanicum*

	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Water type	Biomass increase	Biomass increase	Biomass increase	Biomass increase
Enriched groundwater	1.00	1.23	1.48	1.63
Groundwater	1.00	1.29	1.53	1.53
Rainwater	1.00	1.23	1.44	1.60
Brackish water	1.00	1.13	1.44	1.50

Table 2: Mean biomass increase of *Sphagnum recurvum*.

	Harvest 1	Harvest 2	Harvest 3	Harvest 4
Water type	Biomass increase	Biomass increase	Biomass increase	Biomass increase
Enriched groundwater	1.00	1.17	1.21	1.29
Groundwater	1.00	1.18	1.23	1.30
Rainwater	1.00	1.04	1.23	1.40
Brackish water	1.00	1.09	1.19	1.38

Table 3: Mean biomass increase of *Sphagnum majus*.

Appendix XII

Harvest 2

Competition ratio: relative biomass increase *Sphagnum majus* / *Sphagnum magellanicum*

Water type	Competition ratio
Enriched groundwater	0.855
Enriched groundwater	1.068
Enriched groundwater	1.161
Enriched groundwater	1.420
Enriched groundwater	1.358
Enriched groundwater	0.980
Enriched groundwater	1.243
Rainwater	1.473
Rainwater	1.293
Rainwater	1.384
Rainwater	1.037
Rainwater	1.262
Rainwater	1.134
Brackish water	0.956
Brackish water	1.002
Brackish water	1.278
Brackish water	0.883
Brackish water	1.094
Brackish water	0.924
Groundwater	0.762
Groundwater	1.064
Groundwater	1.031
Groundwater	1.045
Groundwater	0.887
Groundwater	0.994

Appendix XIII
Harvest 3
Competition ratio: relative biomass increase *Sphagnum majus / Sphagnum magellanicum*

Water type	Competition ratio
Enriched groundwater	1.597
Enriched groundwater	1.658
Enriched groundwater	1.212
Enriched groundwater	0.935
Enriched groundwater	1.064
Enriched groundwater	1.209
Rainwater	1.127
Rainwater	1.188
Rainwater	1.250
Rainwater	0.843
Rainwater	0.848
Rainwater	1.189
Brackish water	1.003
Brackish water	0.876
Brackish water	1.192
Brackish water	1.131
Brackish water	1.177
Brackish water	0.878
Groundwater	1.156
Groundwater	0.752
Groundwater	1.047
Groundwater	0.922
Groundwater	1.327
Groundwater	0.851

Appendix XIV
Harvest 4

Competition ratio: relative biomass increase *Sphagnum majus* / *Sphagnum magellanicum*

Water type	Competition ratio
Enriched groundwater	0.784
Enriched groundwater	1.248
Enriched groundwater	0.941
Enriched groundwater	0.996
Enriched groundwater	0.830
Enriched groundwater	1.206
Enriched groundwater	0.974
Enriched groundwater	0.791
Rainwater	0.923
Rainwater	1.094
Rainwater	1.138
Rainwater	0.969
Rainwater	1.088
Rainwater	0.962
Rainwater	0.917
Rainwater	0.905
Brackish water	0.813
Brackish water	1.229
Brackish water	1.073
Brackish water	0.987
Brackish water	1.177
Brackish water	1.046
Brackish water	0.933
Brackish water	0.888
Groundwater	0.973
Groundwater	0.786
Groundwater	1.048
Groundwater	1.183
Groundwater	1.003
Groundwater	1.251
Groundwater	0.818
Groundwater	1.170

Appendix XV

Chemical composition of various water types
Table 1: Water recipes in mM
Table 2: Water recipes in mg/l

Salts	Groundwater conc. mM	Enriched groundwater conc. mM	Seawater conc. mM	Brackish water conc. mM	Rainwater conc. mM
NaCl	*	*	371.94	14.88	0.43
Na_2SO_4	0.04	0.04	27.67	1.11	0.03
K_2SO_4	0.01	0.01	4.11	0.16	0.00
$MgSO_4$	0.03	0.03	*	*	*
$CaCl_2$	0.11	0.28	14.30	0.57	0.02
$NaHCO_3$	0.45	0.45	47.11	1.88	0.05
$MgCl_2$	*	*	48.18	1.93	0.06

Table 1: Chemical composition of various water types in mM

Salts	Groudwater mass mg/l	Enriched groundwater mass mg/l	Seawater mass g/l	Brackish water mass g/l	Rainwater mass mg/l
NaCl	*	*	21.74	0.87	25.13
Na_2SO_4	5.58	5.58	3.93	0.16	4.54
K_2SO_4	1.05	1.05	0.72	0.03	0.83
$MgSO_4$	3.85	3.85	*	*	*
$CaCl_2$	13.57	32.66	1.59	0.06	1.83
$NaHCO_3$	37.80	37.80	3.96	0.16	4.58
$MgCl_2$	*	*	4.59	0.18	5.30

Table 2: Chemical composition of various water types in mg/l

Appendix XVI

Water analysis on supply water

Table 1: EGV and pH of water types

Table 2: Ion composition of the water types

Water type	Period	EGV μS	pH (lab)
Groundwater	1	92	9.45
Enriched groundwater	1	123	9.50
Rainwater	1	79	5.95
Brackish water	1	2343	9.25
Groundwater	2	750	8.70
Enriched groundwater	2	1086	8.10
Rainwater	2	149	6.90
Groundwater	3	98	7.45
Enriched groundwater	3	140	7.50
Rainwater	3	105	7.25

Table 1: EGV and pH of water typres

Water type	Period	**CO3** mg/l	**OH** mg/l	**HCO3** mg/l	**Cl** mg/l	**SO4** mg/l	**Na** mg/l	**K** mg/l	**Ca** mg/l	**Mg** mg/l	**Fe** mg/l	**PO4** mg/l
Groundwater	1	9.72	2.58		6.86	4.49	10.90	0.70	6.36	0.30	0.00	0.00
Enriched groundwater	1	6.12		17.45	14.62	5.26	11.40	0.83	9.65	0.19	0.00	0.00
Rainwater	1			4.03	16.81	2.07	10.51	0.50	2.21	0.03	0.01	0.00
Brackish water	1	13.08		87.84	616.44	74.71	400.01	19.04	22.29	20.69	0.00	0.00
Groundwater	2	7.92		217.16	58.58	65.04	111.09	6.33	20.49	5.74	0.00	0.00
Enriched groundwater	2			178.49	162.00	43.44	108.92	6.21	71.40	6.05	0.04	0.00
Rainwater	2			43.55	23.12	4.80	26.55	0.67	2.26	0.80	0.02	0.00
Groundwater	3			27.33	6.51	7.48	11.24	0.61	5.60	0.34	0.00	0.02
Enriched groundwater	3			25.50	17.09	6.91	10.93	0.57	9.66	0.19	0.03	0.01
Rainwater	3			7.69	19.51	4.08	11.80	0.47	1.70	0.86	0.03	0.02

Table 2: Ion composition of the water types

Appendix XVII

EGV values of trays with enriched groundwater.

Supply normal enriched groundwater had EGV:124 us/cm

Day	Enriched groundwater (tray 1) µs/cm	Enriched groundwater (tray 6) µs/cm	Enriched groundwater (tray 10) µs/cm
29 Oct	77	77	80
30 Oct	80	82	82
31 Oct	81	83	83
1-Nov	83	85	84
2-Nov	84	87	86
5-Nov	89	89	92
6-Nov	89	89	98
9-Nov	94	92	96
12-Nov	97	93	100
13-Nov	97	96	102
14-Nov	98	98	102
14-Nov	94	95	107
15-Nov	112	118	128
16-Nov	158	148	155
19-Nov	275	324	209
27-Nov	637	488	308
28-Nov	677	519	323
30-Nov	726	559	422
4-Dec	669	535	337
7-Dec	614	523	330
11-Dec	548	485	319
18-Dec	486	442	297
21-Dec	473	431	284

Appendix XVIII
EGV values of trays with groundwater.

Supply normal groundwater had EGV: 92 us/cm

Day	Groundwater (tray 4) µs/cm	Groundwater (tray 7) µs/cm	Groundwater (tray 11) µs/cm
29 Oct	45	44	45
30 Oct	45	46	45
31 Oct	46	47	47
1-Nov	47	47	47
2-Nov	47	48	48
5-Nov	49	51	50
6-Nov	49	52	51
9-Nov	51	54	53
12-Nov	53	57	54
13-Nov	53	57	56
14-Nov	56	57	56
14-Nov	59	63	64
15-Nov	66	73	79
16-Nov	92	79	93
19-Nov	153	97	166
27-Nov	350	139	402
28-Nov	379	148	427
30-Nov	409	138	460
4-Dec	376	120	437
7-Dec	346	122	400
11-Dec	305	115	376
18-Dec	254	114	340
21-Dec	243	153	326

Appendix XIX
EGV values of trays with rainwater.

Supply normal rainwater had EGV: 79 us/cm

Day	Rainwater (tray 2) µs/cm	Rainwater (tray 5) µs/cm	Rainwater (tray 9) µs/cm
29 Oct	86	88	91
30 Oct	88	90	93
31 Oct	91	92	96
1-Nov	92	94	93
2-Nov	94	96	96
5-Nov	99	101	103
6-Nov	100	102	104
9-Nov	105	107	108
12-Nov	109	111	111
13-Nov	111	112	112
14-Nov	111	113	114
14-Nov	104	108	109
15-Nov	104	111	111
16-Nov	102	110	112
19-Nov	105	107	112
27-Nov	123	115	114
28-Nov	126	115	115
30-Nov	132	116	116
4-Dec	133	122	128
7-Dec	114	121	129
11-Dec	122	117	132
18-Dec	135	118	135
21-Dec	129	117	137

Appendix XX
EGV values of trays with brackish water.

Supply normal groundwater had EGV: 2343 us/cm

Day	Brackish water (tray 3) µs/cm	Brackish water (tray 8) µs/cm	Brackish water (tray 12) µs/cm
29 Oct	88	91	86
30 Oct	91	178	88
31 Oct	223	241	216
1-Nov	350	336	354
2-Nov	406	449	460
5-Nov	761	686	700
6-Nov	832	760	758
9-Nov	1039	1041	1021
12-Nov	1020	1060	1123
13-Nov	983	1022	767
14-Nov	978	1017	780
14-Nov	922	942	702
15-Nov	869	949	740
16-Nov	859	950	743
19-Nov	837	960	746
27-Nov	919	1019	946
28-Nov	945	1048	998
30-Nov	959	1055	1070
4-Dec	941	1086	775
7-Dec	2560	2340	2450
11-Dec	2700	2360	2460
18-Dec	2930	2430	2470
21-Dec	3100	2430	2490

Appendix XXI

Sphagnum magellanicum: Statistical tests

1. Homogeneity of variances
2. One-way ANOVA
3. Student-Newman-Keuls test, Tukey test and Duncan test for last harvest
4. Student-Newman-Keuls test, Tukey test and Duncan test for second period.

Test of Homogeneity of Variances

W.END

Levene Statistic	df1	df2	Sig.
.273	3	26	.844

Table 1: Homogeneity of variances test for *Sphagnum magellanicum*

ANOVA

W.END

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.453	3	.151	2.833	.058
Within Groups	1.385	26	5.325E-02		
Total	1.837	29			

Table 2: One-way ANOVA test for *Sphagnum magellanicum*.

MAG.END

	WATERTYP	N	Subset for alpha = .05	
			1	2
Student-Newman-Keuls a,b	3.00	8	1.7104	
	1.00	7	1.8031	
	4.00	8	1.9281	
	2.00	7	2.0351	
	Sig.		.053	
Tukey B a,b	3.00	8	1.7104	
	1.00	7	1.8031	
	4.00	8	1.9281	
	2.00	7	2.0351	
Duncan a,b	3.00	8	1.7104	
	1.00	7	1.8031	1.8031
	4.00	8	1.9281	1.9281
	2.00	7		2.0351
	Sig.		.096	.076

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.467.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 3: Student-Newman-Keuls, Tukey and Duncan test for *Sphagnum magellanicum*.

MAGEXP

	WATER	N	Subset for alpha = .05 1	2
Student-Newman-Keuls [a]	3.00	7	1.1099	
	2.00	7	1.1940	1.1940
	1.00	7		1.3284
	4.00	7		1.3497
	Sig.		.303	.146
Tukey HSD [a]	3.00	7	1.1099	
	2.00	7	1.1940	1.1940
	1.00	7	1.3284	1.3284
	4.00	7		1.3497
	Sig.		.052	.234
Duncan [a]	3.00	7	1.1099	
	2.00	7	1.1940	1.1940
	1.00	7		1.3284
	4.00	7		1.3497
	Sig.		.303	.076

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.000.

Table 4: Student-Newman-Keuls, Tukey and Duncan test for period two, *Sphagnum magellanicum.*

Appendix XXII

Sphagnum recurvum: Statistical tests

1. Homogeneity of variances

Test of Homogeneity of Variances

REC.END

Levene Statistic	df1	df2	Sig.
4.544	3	25	.011

Table 1: Homogeneity of variances test for *Sphagnum recurvum*.

Appendix XXIII

Sphagnum majus: statistical analysis.

1. Homogeneity of variances
2. One-way ANOVA
3. Student-Newman-Keuls test, Tukey test and Duncan test for last harvest
4. Student-Newman-Keuls test, Tukey test and Duncan test for second period.

Test of Homogeneity of Variances

MAJ.END

Levene Statistic	df1	df2	Sig.
.652	3	27	.589

Table 1: Homogeneity of variances test for *Sphagnum* majus.

ANOVA

MAJ.END

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.155	3	5.177E-02	.984	.415
Within Groups	1.420	27	5.259E-02		
Total	1.575	30			

Table 2: One-way ANOVA test for *Sphagnum majus*.

MAJ.END

	WATERTYP	N	Subset for alpha = .05 1
Student-Newman-Keuls[a,c]	1.00	7	1.9847
	4.00	8	1.9984
	3.00	8	2.1115
	2.00	8	2.1498
	Sig.		.502
Tukey B[a,b]	1.00	7	1.9847
	4.00	8	1.9984
	3.00	8	2.1115
	2.00	8	2.1498
Duncan[a,b]	1.00	7	1.9847
	4.00	8	1.9984
	3.00	8	2.1115
	2.00	8	2.1498
	Sig.		.207

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.724.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 3: Student-Newman-Keuls, Tukey and Duncan test for *Sphagnum majus*.

EXP.MAJ

	WATER	N	Subset for alpha = .05 1
Student-Newman-Keuls [a]	1.00	7	1.0889
	4.00	7	1.0908
	3.00	7	1.1775
	2.00	7	1.3535
	Sig.		.229
Tukey B [a]	1.00	7	1.0889
	4.00	7	1.0908
	3.00	7	1.1775
	2.00	7	1.3535
Duncan [a]	1.00	7	1.0889
	4.00	7	1.0908
	3.00	7	1.1775
	2.00	7	1.3535
	Sig.		.083

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 7.000.

Table 4: Student-Newman-Keuls, Tukey and Duncan test for period two, *Sphagnum majus*.