The Influence of Salinity on the Growth and Reproduction of Marsh Plants

D. K. Kaushik
THE INFLUENCE OF SALINITY ON THE GROWTH
AND REPRODUCTION OF MARSH PLANTS

by

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of the requirements for the degree
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D. K. Kaushik
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INTRODUCTION

The water resources of the State of Utah are rapidly being developed for agriculture and industry. They are so extensively exploited that their continued and additional use must be justified on the basis of need and efficiency of utilization. To determine more accurately the quantity and quality of water needed to operate a marsh, a project was undertaken by the Utah Department of Fish and Game, the Engineering Experiment Station and the Cooperative Wildlife Research Unit at Utah State University. The study was divided into the two phases, one on quantity and one on quality of water. The present report deals with one aspect of the water quality phase, i.e. that of dealing with the effect of salinity and the salinity tolerance of important emergent aquatic plants.

A large amount of research has been conducted to determine the water requirements of agricultural crops, but relatively little is known about quality of water needed to assure good growth of the more important emergent waterfowl plants. Experiments were, therefore, conducted in the greenhouse at Utah State University and in the field at Ogden Bay Bird Refuge, to collect data that will assist in determining the quality of water needed to maintain the salt balance below the lethal level for the desirable plants. The experiments on effects of salinity were begun in the spring of 1961 and ended in the summer of 1962.

The objectives of this phase of study were as follows:

1. To determine the salinity tolerance limits for seed germination of some marsh plants.
2. To assess the influence of salinity on vegetative growth and development of some young and adult marsh plants.

3. To determine the maximum salinity tolerance limits of young and adult marsh plants.

4. To study the influence of salinity on reproductive growth and seed production of marsh plants.
REVIEW OF LITERATURE

A great deal of work had been accomplished on plant growth in relation to saline and alkaline soils. Magisted (1945) reviewed about 350 papers on the subject of plant relations in saline and alkali soils. Hayward (1945) reviewed 256 papers on plant growth under saline conditions. This latter review was based on the results of research in Australia, India, and the Western Hemisphere. Grillot (1954) reviewed 245 papers based on research in Europe, Africa, and the Middle East. Hayward and Bernstein (1958) reviewed 221 papers on plant growth and relationship on salt affected soils. They brought together published material from some areas, notably Japan and Russia, which have been somewhat neglected in previous reviews, along with the more commonly available publications. Because of language difficulties, the authors attempted a selective review of Russian and Japanese papers rather than complete coverage.

Plants tolerating salty soils and substrates have been classified as halophytes. Plants belonging to this group were said to be indicators of salt soils (U.S. Salinity Laboratory, 1954). A few plant families were recognized as having salt tolerant species, while others seemed to have many, still others few. Studies on relative salt tolerance had dealt mainly with those groups of plants which had some economic importance. These included forage, fibre, cereals, vegetables, fruit crops, and ornamental and roadside trees used by man to make his environment pleasant.

Although economic plants have received major attention in salt tolerance studies, some ecological and physiological investigations have
been made on marsh plants. The salt tolerance of marsh plants is of diagnostic significance for the classification of marsh land with respect to land use. Penfound and Hathaway (1938) listed the salinity ranges for the growth of many marsh species. Allen (1950) and Hinde (1954) emphasized the water level and salinity factors in determining the occurrence of marsh land species. Seashore plants were studied by Beibl (1953) who found halophyles more resistant to plasmolysis by sea water than glycophytes.

Moyle (1945) investigated the influence of chemical factors in the distribution of aquatic plants in Minnesota. He found that although water chemistry appeared to be the most important single factor influencing the general distribution of aquatic plants in Minnesota, field observations showed that the type of bottom soil and physical nature of the body of water greatly influenced the local distribution of a species within its range of chemical tolerance. Such species as *Najas marina* and *Zannichellia palustris* were found to tolerate a concentration of 1920 ppm of sulfate ion in Minnesota. Other species such as *Ruppia occidentales* and *Potamogeton pectinatus* were shown to tolerate much higher concentrations of sulfate ion in more arid regions. Ellis (1955) observed a correlation between alkalinity and the distribution of some free floating and submerged aquatic plants. Purser (1942) reported on the plant ecology of the coastal salt marshlands of San Diego County, California. As there was a fluctuation in the salinity of the soil in the different plant communities throughout the year, there was a general range within this for each community. He claimed that aeration played an important part rather than the maximum salinity or average total concentration, being one of the primary factors determining zonation in salt marshes at these
particular levels. *Spartina*, which was found to stand the greatest salt water immersion, possessed the largest air spaces in the leaves, stem, and especially in the rhizomes and the roots. *Salicornia* did not tolerate as much submergence as the *Spartina*. The plant had some intercellular spaces but they were less abundant than in *Spartina*. Gillham (1957) reported on vegetation of estuary in relation to water salinity. He said that up-river zonation of angiosperms was controlled largely by water salinity, but that plant composition and mobility of substrate were also important. Some species of marine algae had a wide range of salt tolerance and penetrated upstream into fresh water reaches. No fresh water algae was found to tolerate more than a trace of salt.

It may be summarized that voluminous amounts of research have been done on salt tolerance of plants that have some economic importance. However, very little has been accomplished in finding the effect of salinity in important aquatic and marsh plants under controlled greenhouse conditions. Some ecological observations have been made on the distribution of aquatic plants in saline marshes, estuaries, and coastal areas.
MATERIAL AND METHODS

Experimental Plants

Cattail (*Typha latifolia*), hardstem bulrush (*Scirpus acutus*), and alkali bulrush (*Scirpus paludosus*) were selected as experimental plants for the salinity study. Cattail seeds were collected in April 1961 from marshes in Ogden Bay Bird Refuge. Hardstem bulrush and alkali bulrush seeds were collected in August 1961 from experimental plants in drums at Ogden Bay Bird Refuge. Cattail seeds were stored dry in plastic bags and kept in the refrigerator at 4°C. Hardstem bulrush and alkali bulrush seeds were stored in bags made of muslin cloth, submerged in water contained in bottles, and stored at 4°C. Seeds of hardstem bulrush and alkali bulrush required treatment to break the dormancy. This was done by keeping the seeds in the freezer for 2 months before they were set for germination. Additional treatment of hardstem bulrush and alkali bulrush seeds was with dilute hydrochloric acid for 2 hours prior to the time they were set to germinate. In certain experiments, seeds were scarified and pricked apart from freezing and treated with hydrochloric acid.

For preliminary observations, young plants were brought to the greenhouse from marshes in Ogden Bay Bird Refuge. After acclimatization for about a week, these plants were given treatments of salts at different concentrations. Preliminary observations in the greenhouse were also made on plants grown from rhizomes brought from Ogden Bay Bird Refuge. From the experience thus gained of the behavior of these plants
in different salt concentrations in the greenhouse, amendments in methods and procedures were made in the final study on plants grown from seeds in the greenhouse. Different stages in the life of the plant were tested for effects of salinity. Seeds were used for finding the influence of salinity on germination. Newly germinated tender seedlings 15 days old were selected for finding the influence of salinity on growth and development of the hypocotyle and radicle. For experiments on the effect of salinity on vegetative growth and development of young plants, 30-day-old plants were selected. Sixty-day-old adult plants were selected as the experimental material to find the influence of the salinity on seed production, osmotic pressure, and ion accumulation.

In the field experiment at Ogden Bay Bird Refuge, the same species of cattail, hardstem bulrush, and alkali bulrush as used in the greenhouse were selected as the experimental plants for the salinity study. Experiments on effect of salinity on seed germination and effect on vegetative growth and development of young plants were carried out only in the greenhouse. Salinity tolerance studies on plants grown from young stage to maturity for chemical analysis, osmotic pressure, and for seed production were, however, carried out both in the field and the greenhouse.

Salinity Treatment Levels

Greenhouse experiments

Water culture method was followed in all the experiments in the greenhouse. Calcium chloride and sodium chloride in the ratio of 1:2 were used as salts for various levels of salinity concentrations. All treatments, including controls, contained basic nutritive solution which
included calcium nitrate, potassium nitrate, magnesium sulfate, superphosphate and iron chellate. A sample nutritive mixture and salt levels are given in Table 1. Various salt concentrations were used in different experiments, but in all the levels, the ratio of calcium chloride and sodium chloride was kept at 1:2. Seeds were sown in a wide range of salinity. After preliminary observations, lower levels of salt concentrations were selected for young plants than for treatments on adult plants.

In the greenhouse experiments, the unit of salinity measurements was milliequivalent per liter (m.e./l). Basic nutritive elements and the salts were weighed on Torsion balance and then dissolved in tap water. Solution was made in a drum of about 50 gallon capacity. Solution mixture was made separately for each level of treatment. Experimental containers were filled with the solution thus made for each level of salt treatments. pH of the solution was adjusted at 6 by using 0.1N sulfuric acid. For pH adjustment, a pH meter was used. Every other day pH was checked and adjusted. Additional iron chellate was added at irregular periods while adjusting the pH.

Field experiments

Sand culture method was followed in the field at Ogden Bay Bird Refuge. Here salts were applied on conductivity basis. The unit of measurement was m.mhos/cm at 25 °C (EC x 10^3). As in the greenhouse, calcium chloride and sodium chloride were used in the ratio of 1:2. Salts were dissolved in a 50-gallon drum. Sufficient salts were added to raise the conductance to a required level of salt treatment. Level of conductance was adjusted with the conductivity bridge. This bridge was battery operated and had a wide range of conductivity measurement.
Table 1. Nutritive solution and treatment mixture used for experiments on salinity study of aquatic plants

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<th>Nutritive solution</th>
<th>Salts mixture</th>
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<td>Ca(NO$_3$)$_2$</td>
<td>KN$_3$</td>
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<tr>
<td>0+(N.S.)</td>
<td>14.4</td>
<td>14.4</td>
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<tr>
<td>90+N.S.</td>
<td>14.4</td>
<td>14.4</td>
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<tr>
<td>120+N.S.</td>
<td>14.4</td>
<td>14.4</td>
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<tr>
<td>150+N.S.</td>
<td>14.4</td>
<td>14.4</td>
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<tr>
<td>180+N.S.</td>
<td>14.4</td>
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</table>

*Iron chelate was added at irregular periods while adjusting the pH at 6.
Four levels of salt concentrations were used as treatments. Average conductance in each of these levels in the summer 1961 and 1962 is given in Table 2. Plants in the drums were watered with the solution thus made. Treatment solutions were made separately for each level. Nutritive elements were added only once a month unlike experiments in the greenhouse where they were added each week.

Milli-equivalent per litre and mille-mhos/cm are interconvertible mathematically. They can also be converted to parts per million. Roughly their relative ratio can be expressed as: $50 \text{ m.e./l} = 3,200 \text{ ppm} = 5 \text{ m.mhos (EC x 10}^3).$

Seed Germination

Experiments on seed germination were done in the greenhouse only. The Mangelsdorf germinator (incubator) was used in the seed germination experiments (Figure 1). This germinator was electrically operated. The temperature inside the germinator could be adjusted to a desirable temperature. Seeds were placed on moist filter paper in petri dishes and set in the incubator for germination. In the regular seed germination experiments, the incubator was set at 75 F. In other experiments, however, a higher temperature was used to find the interaction of temperature and salinity on seed germination. Seeds were germinated in solutions of various salt concentrations. Duration of seed germination was varied in some experiments, but normally seeds were counted for germination 8 days after the treatment. pH of the treatment solution was adjusted to 6 in all salt levels by using 0.1N sulfuric acid. However, in other experiments pH was varied to find the interaction between pH and salinity on seed germination. Some experiments on seed germination were also
Table 2. Average conductance in experimental drums at Ogden Bay Bird Refuge in the summer 1961 and 1962. Conductance is expressed in m.mhos/cm (EC x $10^3$).

<table>
<thead>
<tr>
<th></th>
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<td>11.8</td>
<td>18.8</td>
<td>10.5</td>
<td>19.6</td>
</tr>
</tbody>
</table>
Fig. 1. Incubators used for seed germination in salinity tolerance study.

Fig. 2. Water culture equipment used to study the effect of salinity on young plants in the greenhouse.
conducted to learn the interaction of light, dark, and salinity. Further details of the experimental conditions are given under each experiment in the chapter on results.

Water Culture Method in the Greenhouse

Water culture method was followed in all of the experiments in the greenhouse. Nutritive solutions in containers were placed on the benches of the greenhouse and the plants under experiment were placed in these.

Methods and equipment for young plants

Rectangular plastic jars of about 1 liter capacity were used for experiments on the effect of salinity on young plants. All jars were painted black on the outside to protect roots from light. A coating of aluminium was placed on the black color to avoid undue heating of the treatment solution. Each jar accommodated six plants. Six holes were made around the peripheral portion of the jar cover. One plant was fixed in each hole with the roots hanging free in the treatment solution. Plants were fixed with cotton around the base of the stems. A complete set of the equipment used for salinity studies on young plants is shown in Figure 2.

Plants 30 days of age and of approximately the same size were selected for the experiment. These plants were grown in sand contained in small pots before they were subjected to salt treatments in water culture method. Normally, 4 to 5 times the number of the plants required for the experimental purpose were grown in these pots. One plant was grown in each pot. These plants were watered with tap water before they were transplanted in the experimental jars for salinity treatments in different salt concentrations. Plants were given 3 to 4 days to
acclimatize in the new environment before being subjected to the salinity treatment. Twenty jars were used in each experiment for one replication. Thus there were generally about 120 plants for each replication. After the preliminary observations, slightly lower salt concentrations were used for young plants than the salinity treatment levels applied for the adult plants. Slightly higher salt concentrations were used for the young plants of hardstem bulrush and alkali bulrush than for the young plants of cattail. Experimental plants were processed 30 days after the first treatment. The solutions in the jars were discarded and replaced each week.

Solutions in all the cultures were aerated for 2 hours daily by a compressor. Pressure in the compressor was fixed at 20 atmospheres by adjusting the air-line-regulator. A key-board with number of three-way valves was made so that each key on the board had a corresponding number on each jar. Keys and jars were connected with plastic tubing. Tubes were passed through the hole made in the center of the jar covers. Each tube ended in the jar with a carbon stone at its terminus for uniform aeration. The main key on the key-board was connected to the compressor.

Methods and equipment for adult plants

Round glass bottles of about 3-liter capacity were used for salinity study on adult plants. They were painted with black paint and a coating of aluminum over the black color. Each bottle was corked. The cork had a round hole in the center big enough to accommodate the stem of a fully mature experimental plant. The plants were similarly fixed through the hole with cotton around the stem. One plant was fixed in each bottle. Plants were given 3 to 4 days to acclimatize in the new environment before being subjected to the salinity treatment. As in the equipment for young
plants, each of the bottles was connected to the compressor for aeration by plastic tubing. A carbon stone was fixed at the terminal end of the plastic tubing in each bottle for uniform aeration. Inside arrangement of the bottles is illustrated in Figure 3. A similar but larger keyboard was made as in the equipment for young plants. All cultures were aerated for about 2 hours daily.

Plants were grown in sand contained in small pots before they were subjected to salt treatments in water culture method. These plants were watered with tap water before they were transplanted in the experimental bottles for salinity treatments in different salt concentrations. Plants 60 days of age and approximately the same size were selected for the experiment. About 150 to 200 plants were grown in the pots to permit selections of 50 plants of equal size for the experiment. Fifty bottles were allotted in one replication for each of the plants. A set of the experimental bottles with keyboard for regulating aeration is shown in Figure 4. Some of the plants of each species were allowed to grow to maturity for seed production in each of the treatment levels. Other plants were processed 60 days after the treatment for analysis. Throughout the experiment, solution in the bottles was discarded and replaced weekly.

**Sand Culture Method in the Field**

In the field experiment at Ogden Bay Bird Refuge, the sand culture method was followed. Plants were grown in sand contained in 50-gallon drums (Figure 5). These drums were fixed in the soil so that the top of the drums were emerging 6 to 9 inches above the level of the soil. A stand-pipe was fixed in one side of each drum to aid in circulation of
Fig. 3. Inside arrangement of the experimental bottle used to determine the effect of salinity on adult plants.
Fig. 4. Water culture equipment used to study the effect of salinity on adult plants in the greenhouse.

Fig. 5. Sand culture equipment used to study the effect of salinity on adult plants at Ogden Bay Bird Refuge.
the treatment solution. Before filling the drums with soil, a 2- to 3-inch layer of gravel was spread in the bottom of the drums. The drums were painted on the inside to protect them from rusting before they were placed in the soil.

Conductivity was the measure of salinity for the experiments in the field. Salt solution was added once in every fortnight. Plants were watered with tap water on an average of every third day. The solution in the drum was circulated by displacement method each time the plants were watered. Water was circulated by insertion of a solid pipe inside the stand-pipe of the drum. The solution was thus displaced into the top of the drum. Conductance was recorded every fortnight before applying the salts. Solution in the drum was thoroughly circulated before taking conductance measurements.

The salinity treatments were started in June 1961 and ended in August 1962. Growth measurements and samples for chemical analyses were collected in the late summer 1961 and 1962. Salinity treatments were stopped in fall of 1961 when the plants became dormant. Treatments were again started in May 1962.

**Experimental Measurements**

Physical data such as general appearance, abnormal growth, number of leaves emerging, number of spikelets appearing and various other measurements were recorded throughout the experiment in the greenhouse as well as in the field. After completion of the experiment, fresh and dry weight of plants were recorded under different salinity treatment levels. Fresh sample of leaves were stored in the freezer to find osmotic pressure of the cell sap by freezing-point depression (Loomis and Shull, 1939).
The samples were packed tightly in plastic bags in order to avoid any evaporation from the surface of the leaves. These leaves were later thawed and squeezed by hand to get a sample of the cell sap. Before taking the sap, the leaves were brushed and washed in distilled water to remove any extra salt sticking on the surface of the leaves. Water on the surface of leaves was thoroughly wiped off before squeezing for cell sap. A portion of the same sap was used for finding chloride accumulation in the leaves by the Conway cell method (Conway, 1947). Efforts were made to process the plant material for osmotic pressure and chloride accumulation shortly after the samples were secured.

Dried plant material was analyzed for sodium, potassium, calcium, and magnesium. Whole plants (stems, roots, leaves) were used as samples for the chemical analyses. The surface contamination was removed from the plants by brushing, and any excess salt appearing on the surface was washed off with distilled water. The samples were dried rapidly in an oven at 70 F. A weighed portion of the dried plant material was ashed with a mixture of perchloric acid and nitric acid (U. S. Salinity Laboratory, 1954). The concentration of sodium and potassium in the digest was determined by the use of the flame photometer (U. S. Salinity Laboratory, 1954). Calcium and magnesium were determined by EDTA titration method (Flaschka, Barnard and Broad, 1957-58) using Eriochrome Black T (Scharzenback and Biedermann, 1946) indicator for determination of calcium and magnesium, dye of Patton and Reeder (1956) for the direct titration of calcium. The microburette used in the Conway Cell Method was also used for the titration of calcium and magnesium.
Experimental Design

All the experiments in the greenhouse, including effect of salinity on seed germination, young plants, and experiments on adult plants were completely randomized. Three replications in different space and time were done for the majority of the experiments, although for some of the experiments only two replications were carried out. Sufficiently large sample sizes were taken to eliminate error.

Efforts were made to keep environmental conditions in the greenhouse as constant as possible throughout the experiments. In order to eliminate variation of sunlight-angle at different times of the day, the greenhouse roofing on the outside was sprayed with a thin coating of yellow chalk mixed with buttermilk. This also kept the temperature moderately uniform in the greenhouse. The temperature in the greenhouse was kept as close to 75 F as possible throughout the experiment by the use of a thermostat. The light and dark ratio was kept at 14 hours day:10 hours night by the use of fluorescent lights fixed above the benches in the greenhouse. The relative humidity was kept near saturation. This was accomplished by a constant flow of water onto a mesh of grassy material padded between a frame of wire netting placed along the walls of the greenhouse.

In the field experiment at Ogden Bay Bird Refuge, drums were chosen for treatment on the basis of existing salinity of the soils in the drums. Drums with low salinity were allotted for the controls and successively higher levels of conductance in the drums were assigned to higher levels of treatment. Conductance to higher levels was slowly raised subsequently. Large samples were collected for all physical measurements and for chemical analyses of plants.
RESULTS

Greenhouse Experiments on Salinity Tolerance

Greenhouse experiments on the salinity study were divided into three phases of the life cycle of plants: seed germination, young plants, and adult plants.

Salt tolerance of seeds

Maximum tolerance limits for germination of seeds.--Seeds were sown in salinity levels of 0, 30, 60, 90, 120, 150, 180, 210, 240 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Ten petri dishes with 10 seeds in each were used for each level of treatment. Two replications were run for seeds of each species of plants. A total of 900 seeds were used in one replication for each species. Thus, there were 100 seeds for each level in one replication. The results of seed germination were counted 8 days after the treatment (Table 3).

Seed germination was 60 and 70 percent in hardstem bulrush and alkali bulrush respectively as against 80 percent in cattail within an 8-day period in the controls. None of the species of the plants attained 100 percent germination within 8 days in any of the treatments including the controls.

Cattail seeds, however, germinated about 100 percent within 15 to 20 days in the base nutritive solution in some other experiments. Alkali bulrush similarly attained about 100 percent germination after 30 to 40 days when placed in nutritive solution. Hardstem bulrush never reached 100 percent germination in any experiment even in 90 days. There was,
Table 3. Effect of salinity on seed germination of aquatic plants after 8 days of incubation

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
<th>210</th>
<th>240</th>
</tr>
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</table>

**Cattail**

<table>
<thead>
<tr>
<th>Seeds sown</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent germination</td>
<td>80.0</td>
<td>79.0</td>
<td>61.0</td>
<td>30.0</td>
<td>3.0</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
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</tr>
</tbody>
</table>

**Hardstem bulrush**

<table>
<thead>
<tr>
<th>Seeds sown</th>
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<th>100</th>
<th>100</th>
<th>100</th>
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<th>100</th>
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<tbody>
<tr>
<td>Percent germination</td>
<td>60.0</td>
<td>50.1</td>
<td>41.0</td>
<td>33.0</td>
<td>18.5</td>
<td>13.0</td>
<td>7.5</td>
<td>1.0</td>
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**Alkali bulrush**

<table>
<thead>
<tr>
<th>Seeds sown</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent germination</td>
<td>62.5</td>
<td>59.0</td>
<td>51.5</td>
<td>44.0</td>
<td>17.0</td>
<td>14.0</td>
<td>6.0</td>
<td>3.0</td>
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</table>
however, a severe reduction in percentage germination in all the three species of plants as the salinity concentrations were increased.

There was no significant difference between the control and 30 m.e./l treatment, especially in cattail seeds. While 80 percent of the cattail seeds germinated in the control, only 0.5 percent seed germination was attained by these seeds when salt concentration was raised to 150 m.e./l.

Seed germination was 13 and 14 percent in hardstem bulrush and alkali bulrush respectively at 150 m.e./l treatment level within an 8-day period. None of the seeds of any species germinated at 240 m.e./l treatment level. As shown in Figure 6, there was an abrupt fall in percentage germination in cattail as the salinity treatments were raised beyond 30 m.e./l. In hardstem bulrush and alkali bulrush, seed germination declined steadily as the level of salinity treatments were raised. There was no significant difference between seed germination of hardstem bulrush and alkali bulrush at higher salt concentrations. Seed germination curves for hardstem bulrush and alkali bulrush almost coincide with each other at higher salinity concentrations. As shown in Figure 7, there was no seed germination in cattail at and beyond 180 m.e./l level. Hardstem bulrush and alkali bulrush seeds tolerated slightly higher salt concentrations. While only 1 percent of hardstem bulrush seed germinated at 210 m.e./l treatment level, 3 percent seeds of the alkali bulrush germinated at the same level.

It was thus concluded that although the cattail seed germination was higher in the control than the hardstem bulrush or alkali bulrush, its seeds were the least tolerant to higher salt concentrations. Salinity on the whole had great influence on seed germination of all the three species.
Fig. 6. Effect of salinity on germination of cattail, hardstem bulrush, and alkali bulrush seeds.
Fig. 7. Salt tolerance limits for seed germination of cattail, hardstem bulrush, and alkali bulrush. Salinity levels expressed in m.e./l are indicated above bars.
Time required for seed germination. -- Treatment levels used in this experiment were 0, 30, 60, 90, and 120 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. The experiment was replicated twice for each species. Five hundred seeds were used for each replication with 10 seeds in each of the 10 petri dishes. Thus, 100 seeds were used for each level of salt concentration. Seed germination was recorded 3, 4, 5, 6, 7, 8, 9, and 10 days after sowing (Table 4). The petri dishes with ungerminated seeds were placed back in the incubator to be examined the following day for more germination.

Maximum seed germination was attained within 6 to 8 days in cattail under all the treatments. Maximum seed germination was attained earliest in cattail and latest in alkali bulrush. In all of the three species, not only the percentage germination was reduced, but also the rate of seed germination was slowed, as the salt concentrations were increased. Cattail seeds showed almost negligible increase in seed germination after 7 to 8 days. Hardstem bulrush and alkali bulrush did show some 3 to 4 percent increase even after 9 to 10 days after sowing in different salt concentrations. There was no seed germination in any of the species at 120 m.e./l treatments level within the first 3 to 4 days. Some seeds germinated as early as 3 days after sowing when the salt concentration was decreased. In the control some seeds germinated within 24 hours, especially in cattail. There was maximum seed germination in the control of all the species as compared to seeds subjected to increasing salt concentrations. The rate of germination was rapid in the beginning 3 to 5 days in all the treatments. The rate of germination declined slowly with the advancement of days in treatment solution. This reduction in rate was more pronounced in seeds subjected to higher salt concentrations.
Table 4. Time required for seed germination of aquatic plants in different salt concentrations

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>Seeds sown</th>
<th>Days after sowing</th>
<th>Percent germination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
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<tr>
<td>Cattail</td>
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<td></td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>24.5</td>
<td>34.0</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>23.5</td>
<td>39.0</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
<td>17.0</td>
<td>30.0</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
<td>2.5</td>
<td>9.5</td>
</tr>
<tr>
<td>120</td>
<td>100</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Hardstem bulrush</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>3.0</td>
<td>13.0</td>
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<td>1.0</td>
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<tr>
<td>60</td>
<td>100</td>
<td>0.5</td>
<td>5.0</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>120</td>
<td>100</td>
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</tr>
<tr>
<td>Alkali bulrush</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>7.5</td>
<td>23.5</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>4.0</td>
<td>16.5</td>
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<tr>
<td>120</td>
<td>100</td>
<td>0.0</td>
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</tr>
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</table>
Seed germination in the control was obtained 3 to 4 days ahead of seeds sown in higher salt concentrations in all the species.

Thus salinity not only caused substantial reduction in percentage germination, but it also reduced the rate of germination in all species.

**Recovery of seeds in tap water after the salt treatments.**—This experiment was conducted to learn whether those seeds which did not germinate in higher salt concentrations would germinate when washed and set for regermination in water. Three high-treatment levels of 90, 120, and 150 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2 were selected as the salinity levels. Seeds were sown at these levels of salt treatments for 6, 8, 10, and 20 days. The seeds which did not germinate were washed and set for regermination in tap water. Recovery in water was assessed after 6 days (Table 5). The experiment was replicated three times. A total of 640 seeds were used for each replication. There were 160 seeds under each salt treatment level.

Percentage recovery of seed germination in the control of cattail was as low as 22.8 percent, while at 90 m.e./l treatment level recovery was as high as 85.4 percent. Recovery, however, again fell down at 120 and 150 m.e./l treatment levels to as low as 33.3 and 22.5 percent respectively in cattail. Percentage recovery decreased with increased number of days-treatment at all levels of the salt concentrations. While 22.5 percent of cattail seeds recovered when these were sown in 150 m.e./l treatment level for a period of 6 days, this recovery decreased to only 9.2 percent when the seeds were placed for 20 days in the same treatment solution.

Similarly for hardstem bulrush and alkali bulrush recovery decreased as the salt concentrations were increased. However, recovery was moderately
Table 5. Percentage seed germination recovery in tap water after the treatment in different salt concentrations

<table>
<thead>
<tr>
<th>Duration of initial treatment days</th>
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<th>Alkali bulrush</th>
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<tr>
<td></td>
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<td>Germ. not in germ. water</td>
<td>Germ. not in germ. water</td>
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<tr>
<td>6</td>
<td>82.5 17.5 22.8</td>
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<td>0 100 33.3</td>
</tr>
<tr>
<td>8</td>
<td>85.8 14.2 24.8</td>
<td>25.8 74.2 71.8</td>
<td>5.0 95.0 30.1</td>
</tr>
<tr>
<td>10</td>
<td>86.6 13.4 5.6</td>
<td>29.2 70.8 62.2</td>
<td>5.0 95.0 24.8</td>
</tr>
<tr>
<td>20</td>
<td>92.5 7.5 0</td>
<td>35.8 64.2 40.2</td>
<td>10.0 90.0 14.6</td>
</tr>
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Cattail

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>0</th>
<th>90</th>
<th>120</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>20.0</td>
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<td>5.0</td>
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<td>25.8</td>
<td>74.2</td>
<td>71.8</td>
<td>5.0</td>
</tr>
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<td>29.2</td>
<td>70.8</td>
<td>62.2</td>
<td>5.0</td>
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<td>20</td>
<td>35.8</td>
<td>64.2</td>
<td>40.2</td>
<td>10.0</td>
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</tbody>
</table>

Hardstem bulrush

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>0</th>
<th>90</th>
<th>120</th>
<th>150</th>
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</thead>
<tbody>
<tr>
<td>Germ. not in germ. water</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>35.8</td>
<td>64.2</td>
<td>40.2</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>29.2</td>
<td>70.8</td>
<td>62.2</td>
<td>5.0</td>
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<td>10</td>
<td>25.8</td>
<td>74.2</td>
<td>71.8</td>
<td>5.0</td>
</tr>
<tr>
<td>20</td>
<td>20.0</td>
<td>74.2</td>
<td>71.8</td>
<td>5.0</td>
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Alkali bulrush

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>0</th>
<th>90</th>
<th>120</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germ. not in germ. water</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>35.8</td>
<td>64.2</td>
<td>40.2</td>
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<td>29.2</td>
<td>70.8</td>
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<tr>
<td>20</td>
<td>20.0</td>
<td>74.2</td>
<td>71.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>
high in these plants even in the control. After 20 days in the control solution, where there was no recovery in cattail, 16.2 and 30.0 percent recovered in hardstem bulrush and alkali bulrush respectively in the controls. However, like cattail there was a progressive decrease in percentage recovery as the salt concentrations were increased. In hardstem bulrush, while 49.1 percent of seeds recovered in the control after 6 days treatment, only 23.8 percent recovered at 150 m.e./l treatment after the same period of treatment. The longer the period the seeds were placed in the treatment solution, the lower was the recovery of seeds. In hardstem bulrush 23.8 percent recovered after 6 days treatment in 150 m.e./l level; this recovery decreased to only 4.0 percent after 20 days in the treatment solution at the same level. Similar results were obtained for alkali bulrush seeds.

Recovery in alkali bulrush seeds in the control was 44.9 percent. This recovery decreased to 16.0 percent when subjected to 150 m.e./l treatment level. As in the other plants, the longer the period the seeds were placed in salinity, the lower was the recovery in alkali bulrush seeds.

It was assumed that lower recovery of seed germination at higher salt concentrations was due to the injury of seeds caused by salinity. The higher the salt concentration of the media, the larger the number of seeds that were deformed or injured (Figure 8). Also, this injury was in direct proportion to the length of period the seeds were placed in the salt treatments.

Water absorption by seeds.--It was suspected that salinity interfered in seed germination by increased osmotic concentration of the outside media which hindered water absorption required for germination.
Fig. 8. Cattail, hardstem bulrush, and alkali bulrush seed germination recovery in tap water after the salt treatments for 6 days.
This experiment, therefore, was conducted to ascertain whether or not this was true.

Water absorption was measured on the first, second, and third days after sowing in different treatments. The seeds were rinsed in distilled water for 1 minute to remove any foreign particle attached to the seeds before they were placed in treatment solution. The seeds were placed between folds of dry filter paper to soak extra water before they were weighed and set for germination. They were again weighed at the time of measurement for water absorption. Before the second weighing, seeds were similarly placed between folds of dry filter paper to soak extra water. The difference in weight between first and second weighing represented the water absorbed by the seeds.

Seeds were subjected to 0, 30, 60, 90, and 120 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2 for three replications. Since cattail seeds are small, 3,000 were sown on one replication. Thus, there were 600 seeds of cattail for each level of salt treatment. Two hundred seeds of cattail were measured for water absorption after 1, 2, and 3 days.

A similar experiment was set for hardstem bulrush and alkali bulrush in which 1,500 and 750 seeds were allotted in each replication. Water absorption by 100 and 50 seeds of hardstem bulrush and alkali bulrush respectively was measured after 1, 2, and 3 days (Table 6).

In cattail water absorption by seeds after 1 day in the control was 0.96 gram; this decreased steadily to 0.62 gram at 120 m.e./l treatment level. Water absorption at all levels increased after second and third day. The rate of water absorption was slow at higher salt concentrations. After 3 days, cattail seeds in the control had absorbed
Table 6. Water absorption by seeds of aquatic plants in different salt concentrations

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Water absorption (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Days: 1 2 3</td>
</tr>
<tr>
<td>Cattail (200 seeds)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.96 2.52 3.46</td>
</tr>
<tr>
<td>30</td>
<td>0.90 2.28 3.36</td>
</tr>
<tr>
<td>60</td>
<td>0.81 1.21 3.32</td>
</tr>
<tr>
<td>90</td>
<td>0.70 0.94 1.23</td>
</tr>
<tr>
<td>120</td>
<td>0.62 0.79 1.06</td>
</tr>
<tr>
<td>Hardstem bulrush (100 seeds)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.95 2.21 3.02</td>
</tr>
<tr>
<td>30</td>
<td>0.89 1.87 2.86</td>
</tr>
<tr>
<td>60</td>
<td>0.85 1.27 2.19</td>
</tr>
<tr>
<td>90</td>
<td>0.77 1.13 1.30</td>
</tr>
<tr>
<td>120</td>
<td>0.71 0.93 1.26</td>
</tr>
<tr>
<td>Alkali bulrush (50 seeds)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.97 2.23 2.86</td>
</tr>
<tr>
<td>30</td>
<td>0.95 2.03 2.93</td>
</tr>
<tr>
<td>60</td>
<td>0.92 1.84 2.82</td>
</tr>
<tr>
<td>90</td>
<td>0.85 1.55 2.21</td>
</tr>
<tr>
<td>120</td>
<td>0.78 1.06 1.57</td>
</tr>
</tbody>
</table>
water almost four times the water absorbed by these seeds after 1 day. At the 120 m.e./l level, water absorbed by seeds after 3 days was less than twice the water absorbed by these seeds after 1 day at the same level of salt treatment. While 3.46 grams of water was absorbed by cattail seeds in the control, only 1.06 grams of water was absorbed by the seeds at 120 m.e./l treatment level after 3 days.

Similar results were obtained for hardstem bulrush and alkali bulrush seeds. Water absorption was greater on second and third days than after 1 day in all treatment levels in both the species. Water absorption by seeds decreased as the salt concentrations were increased. The difference between amount of water absorbed by seeds in the control and the 120 m.e./l treatment level was lower in alkali bulrush than in the other two species. This difference was highest in cattail and medium in hardstem bulrush seeds. Water absorption by seeds after 3 days in different salt concentrations is shown in Figure 9.

In conclusion, salinity influenced the absorption of water by seeds. The amount and the rate of water absorption decreased as the salt concentrations of the media were increased. It was interesting that alkali bulrush seeds which showed maximum resistance to salt concentration in some of the earlier experiments also was the least affected in its rate of water absorption from the media of higher osmotic concentration.

**Effect of temperature, light, and salinity on seed germination.**--In this experiment some seeds were set for germination in petri dishes in a lighted incubator; others were set in a dark incubator. For arrangement of light, the incubator was placed under the fluorescent light falling on the glass at the top of the incubator. To darken the incubator,
Fig. 9. Water absorption in different salinity concentrations by cattail, hardstem bulrush, and alkali bulrush seeds.
the top of the glass was sealed with thick, black cardboard. Temperatures were set at 75 F, 85 F, and 95 F in the three incubators. Seeds were germinated at 0, 30, 60, 90 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Ten seeds were placed in each petri dish for germination and the experiment was replicated twice. A total of 1,040 seeds were set for germination in each replication and 40 seeds were allotted for each treatment condition (Table 7).

In cattail, there did not seem to be a significant difference in percentage of germination between seeds sown at 75 F and 85 F in all treatment levels. Seed germination percentage decreased from 82.5 percent at 85 F to 71.6 percent at 95 F in the control of cattail. Similar reduction was observed at other levels of salinity when temperature was raised to 95 F. At all treatment levels, seed germination in cattail was higher in the lighted incubator than in the darkened one. Darkness together with high salinity and high temperature reduced germination substantially in cattail. At 90 m.e./l treatment level (95 F) while 22.5 percent cattail seed germinated in light, germination was reduced to only 5.8 percent in the dark at the same level of treatment. Seed germination, however, decreased at all treatment combinations as the salt concentrations were increased.

In hardstem bulrush and alkali bulrush, as in cattail, temperature had no significant effect on seed germination. There was only a 2 to 3 percent reduction in hardstem bulrush seed germination at 95 F than the seeds at 85 F in all the salt concentrations. In the control of alkali bulrush, however, 95 F increased germination percentage by about 10 to 12 percent.

Unlike cattail seed, germination of the hardstem bulrush and alkali
Table 7. Effect of temperature, light, and salinity on seed germination of aquatic plants after 8 days of incubation

<table>
<thead>
<tr>
<th>Treatment (m.e./l)</th>
<th>Condition</th>
<th>Temperature (°F)</th>
<th>Percent germination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cattail</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Light</td>
<td>81.6</td>
<td>82.5</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>65.0</td>
<td>72.4</td>
</tr>
<tr>
<td>30</td>
<td>Light</td>
<td>81.6</td>
<td>79.2</td>
</tr>
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<td></td>
<td>Dark</td>
<td>54.2</td>
<td>66.7</td>
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<td>60</td>
<td>Light</td>
<td>63.3</td>
<td>65.0</td>
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<td></td>
<td>Dark</td>
<td>41.6</td>
<td>58.3</td>
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<tr>
<td>90</td>
<td>Light</td>
<td>36.7</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>17.5</td>
<td>21.6</td>
</tr>
<tr>
<td><strong>Hardstem bulrush</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Light</td>
<td>63.3</td>
<td>60.8</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>66.6</td>
<td>66.6</td>
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<tr>
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<td>49.1</td>
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<td>57.5</td>
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<td>Light</td>
<td>40.0</td>
<td>40.8</td>
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<td>Dark</td>
<td>45.8</td>
<td>45.8</td>
</tr>
<tr>
<td>90</td>
<td>Light</td>
<td>30.8</td>
<td>31.6</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>36.6</td>
<td>37.5</td>
</tr>
<tr>
<td><strong>Alkali bulrush</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Light</td>
<td>63.3</td>
<td>69.1</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>67.5</td>
<td>73.3</td>
</tr>
<tr>
<td>30</td>
<td>Light</td>
<td>59.1</td>
<td>63.3</td>
</tr>
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<td></td>
<td>Dark</td>
<td>61.6</td>
<td>65.8</td>
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<tr>
<td>60</td>
<td>Light</td>
<td>48.3</td>
<td>52.5</td>
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<td></td>
<td>Dark</td>
<td>51.6</td>
<td>48.3</td>
</tr>
<tr>
<td>90</td>
<td>Light</td>
<td>44.1</td>
<td>48.3</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>45.8</td>
<td>41.8</td>
</tr>
</tbody>
</table>
bulrush was on the whole higher in the darkened incubator than in the lighted one under all the treatments. Light together with high salinity reduced germination substantially in hardstem bulrush and alkali bulrush. At 90 m.e./l treatment level (95 F) 27.5 percent of the hardstem bulrush seeds germinated in the light. The germination increased to 35.8 percent in the dark at the same level of treatment. Similar results were obtained for alkali bulrush seeds. The percentage germination decreased with increase in salt concentration in all the species under all combinations of treatments.

In further investigations on the effect of temperature on germination it was found that the germination in all of the three species was reduced almost to nil when seeds were kept for germination at low temperature (about 45 F) in solution with or without salt added. No germination occurred in any of the species when the seeds were stored in the refrigerator at about 40 F. Germination was less than one third in all species when the seeds were placed outside the incubator and set for germination in petri dishes kept in a cooler place in the greenhouse. Germination in all species was also reduced substantially when the seeds were set for germination at temperatures higher than 95 F.

In conclusion, broadly, it can be stated that higher temperature along with higher salinity and darkness substantially reduced seed germination in cattail. In hardstem bulrush and alkali bulrush higher temperature, higher salinity, and exposure of seeds to light reduced germination to a considerable degree.

Effect of moisture content, pH, and salinity on seed germination.-- For this experiment, one set of seeds in petri dishes was sown on filter paper kept moistened with the treatment solution. In another set of petri
dishes 10 milliliter of the treatment solution was added so that the seeds of cattail were floating on the solution and submerged in hardstem bulrush and alkali bulrush due to the weight-volume relationship. Solution in one-half of the petri dishes was adjusted to pH 5.5-6.0 using 0.1 sulfuric acid, and in the other half pH was adjusted to 7.5-8.0 using 0.1 sodium hydroxide. The temperature in the incubator was set at 75 F. In the petri dishes with moist filter paper, drops of treatment solution were added at regular intervals to keep them moist throughout the experiment. Seeds were sown in 0, 30, 60, and 90 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Three replications were run, with 640 seeds used in each replication. Forty seeds were allotted for each treatment condition (Table 8).

In cattail there was a higher percentage germination in seeds kept moist than seeds floating under all treatment levels. In the controls, the difference between the seed germination of cattail in the moist and floating condition was about 10 to 12 percent. This gap further widened to about 14 to 15 percent as the salt concentrations were increased to 90 m.e./l treatment level.

For cattail seeds, pH of 5.5-6.0 gave 10 percent more germination in the control than in solution with pH 7.5-8.0. Seed germination was reduced in cattail under all treatment conditions as the salt concentrations were increased. Higher salinity together with pH around 7.5-8.0 and seeds set for germination in floating condition reduced germination in cattail to about one-fifth that in the controls.

Hardstem bulrush and alkali bulrush seeds responded differently to pH condition. Slight pH variation, unlike the effects upon cattail, had very little effect on seed germination of hardstem bulrush and alkali
Table 8. Effect of moisture content, pH, and salinity on seed germination of aquatic plants after 8 days of incubation

<table>
<thead>
<tr>
<th>pH</th>
<th>Germination treatments</th>
<th>Treatment (m.e./l)</th>
<th>Percent germination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

**Cattail**

<table>
<thead>
<tr>
<th>pH</th>
<th>Germination treatments</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5-6.0</td>
<td>Moist</td>
<td>82.5</td>
<td>80.0</td>
<td>63.3</td>
<td>37.5</td>
</tr>
<tr>
<td>5.5-6.0</td>
<td>Floating</td>
<td>70.0</td>
<td>65.0</td>
<td>57.5</td>
<td>23.3</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Moist</td>
<td>72.5</td>
<td>65.8</td>
<td>60.0</td>
<td>31.7</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Floating</td>
<td>60.0</td>
<td>53.3</td>
<td>45.0</td>
<td>15.8</td>
</tr>
</tbody>
</table>

**Hardstem bulrush**

<table>
<thead>
<tr>
<th>pH</th>
<th>Germination treatments</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5-6.0</td>
<td>Moist</td>
<td>61.6</td>
<td>52.5</td>
<td>44.1</td>
<td>33.3</td>
</tr>
<tr>
<td>5.5-6.0</td>
<td>Submerged</td>
<td>56.6</td>
<td>45.0</td>
<td>33.3</td>
<td>23.3</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Moist</td>
<td>62.5</td>
<td>55.8</td>
<td>44.1</td>
<td>33.3</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Submerged</td>
<td>58.0</td>
<td>44.1</td>
<td>34.1</td>
<td>25.8</td>
</tr>
</tbody>
</table>

**Alkali bulrush**

<table>
<thead>
<tr>
<th>pH</th>
<th>Germination treatments</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5-6.0</td>
<td>Moist</td>
<td>64.1</td>
<td>60.8</td>
<td>48.3</td>
<td>45.0</td>
</tr>
<tr>
<td>5.5-6.0</td>
<td>Submerged</td>
<td>49.1</td>
<td>40.0</td>
<td>31.6</td>
<td>19.1</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Moist</td>
<td>63.3</td>
<td>62.5</td>
<td>47.5</td>
<td>43.3</td>
</tr>
<tr>
<td>7.5-8.0</td>
<td>Submerged</td>
<td>50.0</td>
<td>45.0</td>
<td>30.8</td>
<td>18.3</td>
</tr>
</tbody>
</table>
bulrush. However, like cattail, there was more germination in seeds kept moist than from seeds submerged in the solution in both hardstem bulrush and alkali bulrush. In hardstem bulrush moist condition gave about 4 to 5 percent better germination than submerged condition in control. This gap was widened around 8 to 10 percent as the salt concentrations were increased to 90 m.e./l treatment level.

Among the three species studied, alkali bulrush seeds seemed to be most sensitive to submerged treatment. In this species seeds germinated 13 to 15 percent less in the control when they were sown in submerged condition than in the moistened treatment. Seed germination was reduced by about 25 percent when the salt concentration was increased to 90 m.e./l treatment level in the submerged treatment than in the moistened treatment.

High salinity together with constant submergence reduced the seed germination to a great extent in hardstem bulrush and alkali bulrush. In some other experiments, it was observed that the fluctuating condition between submergence and moist conditions had greatly improved seed germination in all three species and especially in alkali bulrush in which seed germination increased to about 20 to 30 percent over the stabilized level of the treatment solution.

In conclusion, salinity greatly influenced the seed germination under all the treatment combinations in all the three species. Moist conditions improved seed germination in all the species rather than floating or submergence. While slight changes in pH had significant effect on seed germination of cattail, it had almost no effect on seed germination of hardstem bulrush and alkali bulrush. High salinity, along with floating treatment and pH around 7.5–8.0 greatly reduced germination of seeds in cattail. Higher salinity levels with submergence of the
seeds greatly reduced the germination of hardstem bulrush and alkali bulrush. Alkali bulrush was most sensitive to submergence. Fluctuating levels of the treatment solution improved germination of all species. This condition was most suitable for seed germination of alkali bulrush.

Effect of salinity on germination of seeds stored in different conditions.--Seeds were stored in water, mud, or dry for 30 days. Seeds were divided into two groups under each of the above condition of storage: one-half of the seeds stored in water were kept frozen and the other half were kept at the room temperature (average 75 F). Similarly half of the seeds stored in mud and dry condition were frozen and the other half were kept at room temperature. These seeds were sown on filter paper moistened with salinity treatment levels of 0, 30, 60, and 90 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Three replications were run for each species. A total of 960 seeds were used in one replication for each species (Table 9).

In cattail, the seeds that were stored dry and frozen prior to germination gave the best results at all treatment levels. There was very poor germination in cattail seeds that were stored in mud, whether frozen or dry. Storage of cattail seeds in water gave slightly better germination than storage in mud. Seeds that were frozen, however, gave a higher percentage germination in all the treatment levels than seeds kept at room temperature. Seed germination decreased under all the storage conditions as the salt concentrations were increased.

In hardstem bulrush and alkali bulrush on the other hand, best germination was obtained in seeds that were stored in mud as compared to the seed stored in water or in dry condition. Germination of seeds that were stored dry was substantially reduced whether they were frozen or
Table 9. Effect of salinity on germination of seeds stored in different conditions after 8 days of incubation

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Stored in water</th>
<th>Stored in mud</th>
<th>Stored dry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frozen Room temp.</td>
<td>Frozen Room temp.</td>
<td>Frozen Room temp.</td>
</tr>
<tr>
<td>Stored in water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>38.3</td>
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<td>30</td>
<td>45.8</td>
<td>42.5</td>
<td>13.3</td>
</tr>
<tr>
<td>60</td>
<td>27.5</td>
<td>25.0</td>
<td>14.2</td>
</tr>
<tr>
<td>90</td>
<td>14.2</td>
<td>10.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Stored in mud</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>60.8</td>
<td>13.3</td>
<td>61.5</td>
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<td>30</td>
<td>50.8</td>
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<td>41.6</td>
<td>9.1</td>
<td>45.0</td>
</tr>
<tr>
<td>90</td>
<td>34.1</td>
<td>0.8</td>
<td>35.8</td>
</tr>
<tr>
<td>Stored dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>73.3</td>
<td>30.8</td>
<td>74.1</td>
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<tr>
<td>30</td>
<td>69.1</td>
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</tr>
<tr>
<td>Percent germination</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cattail

Hardstem bulrush

Alkali bulrush
kept at room temperature. In hardstem bulrush and alkali bulrush, there was no significant difference between germination of seeds stored in water or in mud. Storage of seeds in dry condition prior to sowing reduced the germination to about 70 to 80 percent at all levels of treatment in hardstem bulrush and alkali bulrush. However, like cattail, seeds that were frozen gave better germination at all treatment levels than seeds kept at room temperature. Germination decreased under all storage treatments as the salt concentrations were increased.

It was concluded that dry storage prior to sowing was good for germination of cattail seeds. Storage in water reduced germination in cattail to less than half and mud storage reduced germination to almost one-fourth at all treatment levels. For hardstem bulrush and alkali bulrush, mud storage seemed to be a better condition for storing seeds. Dry storage reduced germination by 70 to 80 percent at all levels of treatments in hardstem bulrush and alkali bulrush.

Seeds that were frozen gave better germination in all species. Seed germination reduced in all the species as the salt concentrations were increased under all the storage conditions. Higher salinity together with unsuitable conditions of storage of seeds prior to germination adversely affected the seed germination in all species.

**Salt tolerance of young plants**

**Growth and development of hypocotyle and radicle.**—To obtain the seedlings for this experiment, seeds were sown on filter paper moistened in treatment solution of 0, 30, 60, and 90 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2.

A total of 2,000 seeds of each species were sown in one replication and 500 seeds were allotted for each treatment. Three replications were
run for each species. A total of 50 seedlings, 15 days of age and of equal size, were selected from each treatment level for the experiments on growth of the hypocotyle and the radicle. Only five seedlings were placed in each petri dish. The salinity treatments were continued at the same levels as for seed germination. The seedlings were assessed for the growth and development of hypocotyle and radicle after 25 days. The hypocotyle (the greenish portion) and the radicle (the whitish portion) were cut apart with a blade in each seedling. The weight gained by the seedlings represented growth of the hypocotyle and the radicle. The ratio of the hypocotyle and the radicle (R/H) was calculated (Table 10).

While the hypocotyle in cattail weighed 1.53 grams in the control, the weight was reduced to only 0.31 gram when the salt concentration was raised to 90 m.e./l treatment level. The weight of the radicle also reduced from 1.66 gram in the control to only 0.17 gram when seedlings were subjected to 90 m.e./l treatment level. In cattail there was no significant difference between the control and 30 m.e./l treatment level. The growth of hypocotyle and radicle was reduced to a considerable degree beyond 30 m.e./l treatment level. The reduction in the growth of the radicle was more pronounced than the hypocotyle. The R/H ratio of cattail seedlings decreased from 1.08 in the control to only 0.54 in the seedlings at 90 m.e./l treatment level.

In hardstem bulrush and alkali bulrush similarly, the weights of the hypocotyle and the radicle were reduced as the salt concentrations were increased. The hypocotyle weighed 1.45 grams in the control of hardstem bulrush as against only 0.57 grams at 90 m.e./l treatment level. Similarly the growth of radicle was reduced from 1.59 grams in the control
Table 10. Effect of salinity on growth of hypocotyle and radicle in young seedlings of aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Percent germinated</th>
<th>Weight of hypocotyle (g/m)</th>
<th>Weight of radicle (g/m)</th>
<th>R/H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(g/m)</td>
<td>(g/m)</td>
<td></td>
</tr>
<tr>
<td>Cattail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>79.5</td>
<td>1.53</td>
<td>1.66</td>
<td>1.08</td>
</tr>
<tr>
<td>30</td>
<td>77.5</td>
<td>1.59</td>
<td>1.70</td>
<td>1.06</td>
</tr>
<tr>
<td>60</td>
<td>44.5</td>
<td>0.79</td>
<td>0.61</td>
<td>0.77</td>
</tr>
<tr>
<td>90</td>
<td>25.3</td>
<td>0.31</td>
<td>0.13</td>
<td>0.54</td>
</tr>
<tr>
<td>Hardstem bulrush</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>65.0</td>
<td>1.45</td>
<td>1.59</td>
<td>1.09</td>
</tr>
<tr>
<td>30</td>
<td>60.0</td>
<td>1.21</td>
<td>1.17</td>
<td>0.96</td>
</tr>
<tr>
<td>60</td>
<td>31.6</td>
<td>0.84</td>
<td>0.62</td>
<td>0.73</td>
</tr>
<tr>
<td>90</td>
<td>14.1</td>
<td>0.57</td>
<td>0.27</td>
<td>0.47</td>
</tr>
<tr>
<td>Alkali bulrush</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>70.8</td>
<td>1.64</td>
<td>1.81</td>
<td>1.10</td>
</tr>
<tr>
<td>30</td>
<td>47.5</td>
<td>1.48</td>
<td>1.63</td>
<td>1.10</td>
</tr>
<tr>
<td>60</td>
<td>43.3</td>
<td>1.26</td>
<td>1.31</td>
<td>1.03</td>
</tr>
<tr>
<td>90</td>
<td>16.6</td>
<td>0.93</td>
<td>0.90</td>
<td>0.96</td>
</tr>
</tbody>
</table>
of hardstem bulrush to only 0.27 gram at 90 m.e./l treatment level. In hardstem bulrush the growth and development of the radicle was affected more severely than the hypocotyle.

The R/H ratio in hardstem bulrush decreased from 1.09 in the control to only 0.47 in the treatment at 90 m.e./l level. Similar results were obtained in alkali bulrush. The reduction in the growth of hypocotyle and radicle of alkali bulrush, however, was not so pronounced as was in cattail and hardstem bulrush. The hypocotyle and radicle of alkali bulrush which weighed 1.64 grams and 1.81 grams respectively in the control weighed only 0.93 gram and 0.90 gram respectively at the 90 m.e./l treatment level (Table 10).

It was thus concluded that salinity had progressively reduced the growth and development of the hypocotyle and radicle as the salt concentrations were increased (Figure 10). The reduction in growth of radicle was more than the hypocotyle in all the three plants. This reduction was less pronounced in alkali bulrush than the other plants.

**Vegetative growth and root elongation.**—Young plants (30 days old) of cattail were subjected to six treatment levels: distilled water (DW), tap water (TW), and 0, 30, 60, and 90 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Six jars with six plants in each were allotted to one treatment level. A total of 216 young plants of cattail were used for two replications. Young plants of hardstem bulrush and alkali bulrush were subjected to five treatment levels: 0, 30, 60, 90, and 120 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. After preliminary observations that hardstem bulrush and alkali bulrush were somewhat more tolerant to salinity than cattail, one more treatment of 120 m.e./l was added for these plants. Eight jars
Fig. 10. Effect of salinity on growth of hypocotyle and radicle of cattail, hardstem bulrush, and alkali bulrush seedlings.
each containing six plants were allotted to each treatment level in hardstem bulrush and alkali bulrush. A total of 240 plants each of hardstem bulrush and alkali bulrush were used in one replication. Plants were assessed 30 days after the treatment. Total length, fresh weight, and number of leaves in the beginning and at the end of the treatment were recorded in each plant. Root elongation and hair-like growth was measured at the end of the experiment (Table 11).

Total length, fresh weight, and number of leaves of cattail plants grown in tap water were slightly higher than the plants grown in distilled water. Plants grown in the control were more healthy, tall, and their fresh weight was higher than all other treatments. The control plants of cattail attained the height of 40 cm as against 33.4 cm in the distilled water (Figure 11). The height of plants was reduced to only 17.9 cm at 90 m.e./l treatment level. The fresh weight similarly decreased from 24.9 grams in the control of cattail plants to only 9.1 grams in the plants subjected to 90 m.e./l treatment level. The number of leaves also reduced to 1.4 per plant at 90 m.e./l level as against 4.2 in the control.

In hardstem bulrush and alkali bulrush similarly the total length, fresh weight, and number of leaves per plant reduced as the salt concentrations were increased. In hardstem bulrush the total length of plants decreased from 39.2 cm in the control to only 11.5 cm in the plants grown in 120 m.e./l treatment level (Figure 12). While the fresh weight of hardstem bulrush plants at 120 m.e./l level was only 3.0 grams, control plants had attained the weight of 26.5 grams. Number of leaves per plant also reduced from 4.1 in the control to 2.2 in the hardstem bulrush plants subjected to 120 m.e./l treatment level. Similar response to salinity was observed in alkali bulrush. Total length was reduced from 41.4 cm in the
Table 11. Effect of salinity on vegetative growth and development of young aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Total length Begin. (cm)</th>
<th>Fresh weight Begin. (gm)</th>
<th>Total length End</th>
<th>Fresh weight End</th>
<th>No. of leaves Begin.</th>
<th>No. of leaves End</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cattail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.W.</td>
<td>10.5</td>
<td>33.4</td>
<td>7.6</td>
<td>20.1</td>
<td>2.9</td>
<td>3.9</td>
</tr>
<tr>
<td>T.W.</td>
<td>10.6</td>
<td>35.5</td>
<td>7.6</td>
<td>20.3</td>
<td>2.8</td>
<td>4.1</td>
</tr>
<tr>
<td>0</td>
<td>10.6</td>
<td>40.0</td>
<td>7.4</td>
<td>24.9</td>
<td>2.8</td>
<td>4.2</td>
</tr>
<tr>
<td>30</td>
<td>10.8</td>
<td>32.6</td>
<td>7.7</td>
<td>19.5</td>
<td>2.9</td>
<td>3.8</td>
</tr>
<tr>
<td>60</td>
<td>10.8</td>
<td>27.5</td>
<td>7.8</td>
<td>14.8</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>90</td>
<td>10.7</td>
<td>17.9</td>
<td>7.6</td>
<td>9.1</td>
<td>2.8</td>
<td>1.4</td>
</tr>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hardstem bulrush</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>9.6</td>
<td>39.2</td>
<td>4.5</td>
<td>26.5</td>
<td>2.0</td>
<td>4.1</td>
</tr>
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<td>9.6</td>
<td>35.2</td>
<td>4.5</td>
<td>23.5</td>
<td>2.1</td>
<td>4.1</td>
</tr>
<tr>
<td>60</td>
<td>9.5</td>
<td>30.4</td>
<td>4.6</td>
<td>18.4</td>
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<td>3.0</td>
</tr>
<tr>
<td>90</td>
<td>9.6</td>
<td>19.5</td>
<td>4.5</td>
<td>8.1</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>120</td>
<td>9.5</td>
<td>11.5</td>
<td>4.5</td>
<td>3.0</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkali bulrush</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>10.5</td>
<td>41.4</td>
<td>7.5</td>
<td>26.5</td>
<td>3.2</td>
<td>15.5</td>
</tr>
<tr>
<td>30</td>
<td>10.5</td>
<td>39.8</td>
<td>7.6</td>
<td>25.3</td>
<td>3.2</td>
<td>13.9</td>
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<tr>
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<td>10.5</td>
<td>35.1</td>
<td>7.5</td>
<td>22.1</td>
<td>3.2</td>
<td>11.9</td>
</tr>
<tr>
<td>90</td>
<td>10.6</td>
<td>32.0</td>
<td>7.5</td>
<td>19.8</td>
<td>3.2</td>
<td>7.4</td>
</tr>
<tr>
<td>120</td>
<td>10.5</td>
<td>20.3</td>
<td>7.6</td>
<td>8.6</td>
<td>3.2</td>
<td>6.2</td>
</tr>
</tbody>
</table>
Fig. 11. Effect of salinity on young cattail plants (1) distilled water, (2) tap water, (3) 0 m.e./l, (4) 30 m.e./l, (5) 60 m.e./l, (6) 90 m.e./l.
Fig. 12. Effect of salinity on young hardstem bulrush plants (1) 0 m. e./l, (2) 30 m. e./l, (3) 60 m. e./l, (4) 90 m. e./l, (5) 120 m. e./l.

Fig. 13. Effect of salinity on young alkali bulrush plants (1) 0 m. e./l, (2) 30 m. e./l, (3) 60 m. e./l, (4) 90 m. e./l, (5) 120 m. e./l.
control of alkali bulrush to 20.3 cm in plants given treatment of 120 m.e./l (Figure 13). While alkali bulrush plants at 120 m.e./l treatment level weighed 8.6 grams, the weight of the control plants was 26.5 grams. Similarly number of leaves per plant decreased from 15.5 in the control of alkali bulrush to only 6.2 when they were subjected to 120 m.e./l treatment level (Figure 14).

Cattail plants grown in distilled water attained a mean root length of 19.6 cm (Table 12). The root elongation reached the maximum in the control for all the species (Figure 15). While roots were as long as 26.6 cm in the control of cattail plants, their length reduced to only 8.2 cm as the salt concentration was increased to 90 m.e./l treatment level (Figure 16). Root hair-like growth in cattail reduced from 2.5 cm in control to only 0.8 cm at 90 m.e./l level. Similarly in hardstem bulrush (Table 12) and alkali bulrush (Table 12) root elongation and root hair-like growth reduced as the salt concentrations were increased. The root length of hardstem bulrush plant was 6.4 cm at 120 m.e./l treatment level as against 24.3 cm in the control (Figure 17). Root hair-like growth in hardstem bulrush was 2.3 cm and it reduced to 0.7 cm as the salt concentration was raised to 120 m.e./l treatment level. In alkali bulrush root length reduced from 27.4 cm in control to only 9.4 cm at 120 m.e./l treatment level (Figure 18). The root hair-like growth in alkali bulrush was only 0.8 cm at 120 m.e./l level as against 3.1 cm in the control.

It was thus concluded that salinity had a great influence on vegetative growth and development of young plants in all the species. The total length, fresh weight, and number of leaves per plant were reduced considerably as the salt concentrations were increased. The root
Fig. 14. Effect of salinity on growth and development of leaves in young plants of cattail, hardstem bulrush, and alkali bulrush.

Fig. 15. Effect of salinity on root elongation of young plants of cattail, hardstem bulrush, and alkali bulrush.
Table 12. Effect of salinity on root elongation and hair-like root growth of young aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>D.W.</th>
<th>T.W.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cattail**

<table>
<thead>
<tr>
<th>Root elongation (cm)</th>
<th>19.6</th>
<th>21.1</th>
<th>26.6</th>
<th>20.0</th>
<th>14.6</th>
<th>8.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hair-like root growth (cm)</td>
<td>1.9</td>
<td>2.1</td>
<td>2.5</td>
<td>1.8</td>
<td>1.2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Hardstem bulrush**

<table>
<thead>
<tr>
<th>Root elongation (cm)</th>
<th>24.3</th>
<th>18.4</th>
<th>11.6</th>
<th>8.5</th>
<th>6.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hair-like root growth (cm)</td>
<td>2.3</td>
<td>2.1</td>
<td>1.5</td>
<td>1.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Alkali bulrush**

<table>
<thead>
<tr>
<th>Root elongation (cm)</th>
<th>27.4</th>
<th>25.3</th>
<th>22.4</th>
<th>18.5</th>
<th>9.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of hair-like root growth (cm)</td>
<td>3.1</td>
<td>2.8</td>
<td>2.5</td>
<td>1.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Fig. 16. Effect of salinity on root elongation of young cattail plants (1) tap water, (2) 0 m. e./1, (3) 30 m. e./1, (4) 60 m. e./1, (5) 90 m. e./1.

Fig. 17. Effect of salinity on root elongation of young hardstem bulrush plants (1) 0 m. e./1, (2) 30 m. e./1, (3) 60 m. e./1, (4) 90 m. e./1, (5) 120 m. e./1.
Fig. 18. Effect of salinity on root elongation of young alkali bulrush plants (1) 0 m.e./l, (2) 30 m.e./l, (3) 60 m.e./l, (4) 90 m.e./l, (5) 120 m.e./l.
elongation and the root hair-like growth were also reduced as the salt treatment concentrations were increased.

**Effect of salinity, pH, and aeration on growth of young plants.**

For this experiment only two levels of salt concentrations were used, 0 and 60 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. Half of the plants in each of these salinity treatment levels were grown in solution with pH 5.5-6.0 and the other half in pH 7.5-8.0. Further subdivision was made in each of the pH treatment levels: roots in half the number of plants were aerated and the other half were not aerated (Table 13). The experiment was replicated twice. A total of 32 jars with 192 plants of each species were used for two replications.

For cattail, pH 5.5-6.0 seemed better for growth than pH 7.5-8.0. Total length, fresh weight, number of leaves, and length of roots were lower in plants grown in pH 7.5-8.0 as compared to plants at pH 5.5-6.0. Total length in cattail was reduced from 43.9 cm to 39.7 cm when the pH was raised from 5.5-6.0 to 7.5-8.0 in the control. Cattail plants attained total length of 21.6 cm when they were subjected to pH 7.5-8.0 at 60 m.e./l treatment level as against 26.9 cm at pH 5.5-6.0 in the same salt concentration. A similar reduction was observed in fresh weight, number of leaves, and root growth in plants grown in solution with pH 7.5-8.0. Aeration of treatment solution greatly influenced the growth of plants. The most significant part of the plant affected by aeration was the root growth. In the control, while cattail plants attained root length of 26.9 cm when aerated, the length was reduced to 18.4 cm when not aerated. Similarly at 60 m.e./l treatment level root growth in cattail plants was only 7.8 cm when not aerated as against 11.9 cm when the roots were aerated in the same salt concentration. In cattail, higher pH, non-aeration
Table 13. Effect of salinity, pH and aeration on growth of young aquatic plants

<table>
<thead>
<tr>
<th>Treatment Condition (m.e./l.)</th>
<th>Total length (cm)</th>
<th>Fresh weight (gm)</th>
<th>Number of leaves</th>
<th>Length of top of root (cm)</th>
<th>Length of root of plant (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerated (pH 5.5-6.0)</td>
<td>11.5</td>
<td>43.9</td>
<td>10.6</td>
<td>27.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Not aerated (pH 5.5-6.0)</td>
<td>11.3</td>
<td>36.0</td>
<td>9.9</td>
<td>22.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Hardstem bulrush</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerated (pH 5.5-6.0)</td>
<td>11.1</td>
<td>39.7</td>
<td>9.8</td>
<td>25.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Not aerated (pH 5.5-6.0)</td>
<td>11.1</td>
<td>32.3</td>
<td>10.1</td>
<td>19.1</td>
<td>3.3</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Aerated (pH 5.5-6.0)</td>
<td>11.2</td>
<td>26.9</td>
<td>10.1</td>
<td>14.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Not aerated (pH 5.5-6.0)</td>
<td>11.0</td>
<td>20.3</td>
<td>9.9</td>
<td>9.9</td>
<td>3.2</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerated (pH 7.5-8.0)</td>
<td>10.9</td>
<td>21.6</td>
<td>9.7</td>
<td>12.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Not aerated (pH 7.5-8.0)</td>
<td>10.9</td>
<td>17.3</td>
<td>10.1</td>
<td>9.1</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Hardstem bulrush

<p>| Aerated (pH 5.5-6.0) | 8.6  | 40.4 | 4.5  | 24.4 | 2.0  | 3.7  | 16.1 | 24.3 |
| Not aerated (pH 5.5-6.0) | 8.5  | 32.3 | 4.5  | 18.4 | 2.0  | 3.1  | 18.9 | 13.4 |</p>
<table>
<thead>
<tr>
<th>Treatment Condition (m.e./l.)</th>
<th>Total length (cm) Begin</th>
<th>End</th>
<th>Fresh weight (gm) Begin</th>
<th>End</th>
<th>Number of leaves</th>
<th>Length of top of leaves (cm) Begin</th>
<th>End</th>
<th>Length of root (cm) Begin</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>7.5 24.4</td>
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<tr>
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<td>7.5 20.5</td>
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<tr>
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<td>7.6 15.4</td>
<td>3.1 5.1</td>
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<tr>
<td>Aerated (pH 7.5-8.0)</td>
<td>9.6 32.5</td>
<td>7.6 21.4</td>
<td>3.2 9.6</td>
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<td>19.3</td>
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<tr>
<td>Not aerated (pH 7.5-8.0)</td>
<td>9.6 27.3</td>
<td>7.7 15.5</td>
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</table>
together with high salinity greatly hampered the vegetative growth and root elongation.

In hardstem bulrush and alkali bulrush, pH variation had no significant effect on the growth of plants, although on the whole, unlike cattail, pH 7.5-8.0 was somewhat better for the growth of hardstem bulrush and alkali bulrush. Aeration of the treatment solution like cattail did have significant influence on the growth, especially of roots in these plants. In hardstem bulrush while the length of root was 24.3 cm in the control when they were aerated, the length decreased to only 13.4 cm when not aerated. At 60 m.e./l treatment level, in hardstem bulrush plants, the root growth was only 8.5 cm when not aerated as against 10.4 cm when aerated in the same salt concentration. A similar effect of aeration on root growth was observed in alkali bulrush plants. In the control the root length was 18.5 cm when the solution was not aerated as compared to 25.5 cm in aerated solution. Root length in alkali bulrush was reduced from 18.5 (aerated) to 12.5 (not aerated) in the 60 m.e./l treatment level.

In conclusion, non-aeration of the solution specifically reduced the root growth. Non-aeration together with higher salinity greatly hampered the vegetative growth and root elongation in all the species. Slight variation in pH, which had some effect on vegetative growth and development of cattail, had very little effect on the growth of hardstem bulrush and alkali bulrush plants.

On the whole, young alkali bulrush plants were placed as the most salt tolerant, young cattail plants the least tolerant, and young hardstem bulrush were classified as the median salt tolerant plants (Figure 19).
Fig. 19. Salt tolerance limits for young cattail, hardstem bulrush, alkali bulrush plants. Salinity levels expressed in m.e./l are indicated above bars.
Salt tolerance of adult plants

Plants were subjected to 0, 90, 120, 150, and 180 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. A total of 150 plants of each species were used for three replications and 30 plants were allotted for each treatment level. Of the total 30 plants under one treatment level, 18 of these plants were dried and dissolved for chemical analysis. Six of these plants were stored fresh in the refrigerator and later assayed for osmotic pressure and chloride accumulation in the plant cell sap. The remaining six plants were allowed to grow to maturity for flowering and seed production. Salt treatments in the plants for seed production were continued at the same level as they received during the vegetative phase.

Vegetative growth and development.--Diameter of the plant decreased as the salt concentrations were increased (Figure 20). The diameter of cattail stems decreased from 16.9 cm in the control plants to 11.7 cm when the salt concentration was raised to 180 m.e./l treatment level (Table 14). The diameter of the cattail at 90 m.e./l treatment level was 92.2 percent of diameter of the controls (Table 15). The diameter was reduced to 69.2 percent of the control as the salt level was increased to 180 m.e./l. In other words, the percentage reduction in the diameter of cattail plants was 17.8 percent at 90 m.e./l treatment level, and 30.8 percent at 180 m.e./l level.

Similar results were obtained in hardstem bulrush and alkali bulrush plants. In hardstem bulrush, the diameter of the plants decreased from 13.9 cm in the control to only 8.2 cm at 180 m.e./l treatment level (Table 14). Reduction in the diameter of hardstem bulrush plants was 8 percent at 90 m.e./l treatment level (Table 15). The percent reduction
Fig. 20. (a). Cattail

Fig. 20. (b). Hardstem bulrush

Fig. 20. (c). Alkali bulrush

Fig. 20. Effect of salinity on root growth and stem thickness of cattail, hardstem bulrush, and alkali bulrush plants (1) 0 m.e./l, (2) 90 m.e./l, (3) 120 m.e./l, (4) 150 m.e./l, (5) 180 m.e./l.
Table 14. Effect of salinity on vegetative growth of adult aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Diameter (cm)</th>
<th>Total length (cm)</th>
<th>Weight of top Fresh (gm)</th>
<th>Weight of top Dry (gm)</th>
<th>Weight of root Fresh (gm)</th>
<th>Weight of root Dry (gm)</th>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cattail</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
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Table 15. Effect of salinity on height and diameter of aquatic plants

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<th>Treatment (m.e./l.)</th>
<th>Height (cm)</th>
<th>% of control</th>
<th>Diameter (cm)</th>
<th>% of control</th>
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<tr>
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<td>Hardstem bulrush</td>
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<tr>
<td>0</td>
<td>139.7</td>
<td>100.0</td>
<td>153.3</td>
<td>100.0</td>
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<td>133.9</td>
<td>95.8</td>
<td>146.0</td>
<td>95.2</td>
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<td>74.2</td>
<td>130.1</td>
<td>84.8</td>
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<td>60.7</td>
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<td>79.1</td>
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<td>44.4</td>
<td>51.2</td>
<td>8.2</td>
<td>59.6</td>
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was 40.4 in hardstem bulrush plants at 180 m.e./l level. Similarly the
diameter of alkali bulrush plants at 180 m.e./l level was 2.4 cm, as
against 4.5 cm in the control plants (Table 14). There was, however, no
reduction in the diameter of alkali bulrush plants at 90 m.e./l level
(Table 15). The diameter of alkali bulrush was reduced by 18.5 percent
at 120 m.e./l level. The reduction in the diameter of alkali bulrush
plants was 46.5 percent at 180 m.e./l treatment level.

The height of all the species was also severely reduced by the
salinity (Figures 21, 22, 23). The average total length of cattail
plants at 180 m.e./l treatment level was only 62.1 cm as against 139.7 cm
in control (Table 14). While percentage reduction in height of cattail
plants at 90 m.e./l treatment level was only 4.2, the reduction was 55.6
percent when the salt concentration was raised to 180 m.e./l (Table 15).

The average total length in hardstem bulrush was reduced from
153.3 cm in the control to only 79.0 cm at 180 m.e./l treatment level
(Table 14). While reduction in hardstem bulrush was only 4.8 percent
in the plants at 90 m.e./l treatment level, the reduction was 48.8 percent
at 180 m.e./l level (Table 15). Effect of salinity on alkali bulrush
plants was not so severe as in the other two species (Table 14). While
the alkali bulrush plants in the control attained a total height of 76.1
cm, it was reduced to 44.5 cm when the salt concentration was increased
to 180 m.e./l level. The treatment level of 90 m.e./l had no signifi-
cant effect on the height of the alkali bulrush plants (Table 15). There
was only a 7.2 percent reduction in the height of alkali bulrush plants
at 120 m.e./l as against 25.8 and 12.2 percent reduction in cattail and
hardstem bulrush respectively at the same level of treatment. Influence
of salinity on weight and height of the plants is illustrated in Figure 24.
Fig. 21. Effect of salinity of growth of cattail plants (1) 0 m.e./l, (2) 90 m.e./l, (3) 120 m.e./l, (4) 150 m.e./l, (5) 180 m.e./l.

Fig. 22. Effect of salinity on growth of hardstem bulrush plants (1) 0 m.e./l, (2) 90 m.e./l, (3) 120 m.e./l, (4) 150 m.e./l, (5) 180 m.e./l.
Fig. 23. Effect of salinity on growth of alkali bulrush plants
(1) 0 m.e./l, (2) 90 m.e./l, (3) 120 m.e./l, (4) 150 m.e./l, (5) 180 m.e./l.
Fig. 24. Effect of salinity on fresh weight and height of cattail, hardstem bulrush, and alkali bulrush plants.
The number of leaves per plant progressively decreased with increasing salt concentrations in all the species. Control plants of cattail had 7.5 leaves per plant as against only 3.5 when the salt concentration was increased to 180 m.e./l. In hardstem bulrush, the plants given treatment of 180 m.e./l had only 2.8 leaves per plant as against 8.8 in the control. Similarly in alkali bulrush leaves per plant reduced from 16.3 in the control to only 7.2 at 180 m.e./l treatment level.

Fresh and dry weight of the top of the plant as well as that of the root was progressively reduced as the salt concentrations were increased. In cattail fresh and dry weight of the top decreased from 78.1 and 6.9 grams respectively in the control to 40.0 and 4.3 grams respectively in the plants at 180 m.e./l level (Table 14). Similarly the fresh and dry weight of root in the control were 16.2 and 1.4 grams respectively as against 8.6 and 1.0 grams respectively at 180 m.e./l treatment level. Total dry weight was reduced from 8.3 grams in the control to 5.3 grams at 180 m.e./l in cattail plants (Table 16). Dry weight of cattail plants, however, at 90 m.e./l was slightly higher than the controls. Total fresh weight in cattail plants reduced from 94.4 grams in the control to only 49.3 grams at 180 m.e./l treatment level (Table 17). There was only 8.1 percent reduction in the total fresh weight of cattail plants at 90 m.e./l level; the reduction was 48.1 percent as the salt concentration was raised to 180 m.e./l level.

In hardstem bulrush as in cattail the fresh and dry weights of the top and of the root were reduced at higher salinity levels. Fresh and dry weight of the top in the control plants was 86.6 and 5.2 grams as against 43.5 and 4.9 grams respectively in hardstem bulrush plants at 180 m.e./l treatment level (Table 14).
Table 16. Effect of salinity on dry weight of aquatic plants

<table>
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<th>Vegetative part</th>
<th>Treatment (m.e./l.)</th>
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<th>120</th>
<th>150</th>
<th>180</th>
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<td>4.3</td>
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<td>8.6</td>
<td>6.8</td>
<td>5.8</td>
<td>5.3</td>
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<td>Green top (A)</td>
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<td>5.9</td>
<td>6.5</td>
<td>5.7</td>
<td>4.9</td>
</tr>
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<td>1.1</td>
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<td>7.0</td>
<td>7.6</td>
<td>6.6</td>
<td>5.8</td>
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<td>Green top (A)</td>
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<td>2.2</td>
<td>2.1</td>
<td>1.9</td>
<td>1.3</td>
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<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
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<td>Total</td>
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<td>2.9</td>
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Table 17. Effect of salinity on moisture content and percent reduction of fresh and dry weight of aquatic plants

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<th>Dry weight (gm)</th>
<th>Moisture percent</th>
<th>On relative basis</th>
<th>Percent reduction</th>
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<td>88.9</td>
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<tr>
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</tr>
<tr>
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<tr>
<td>Alkali bulrush</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>0</td>
<td>60.8</td>
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<td>94.8</td>
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</tr>
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<td>98.5</td>
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<td>93.5</td>
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<td>2.3</td>
<td>92.3</td>
<td>50.3</td>
<td>73.9</td>
</tr>
</tbody>
</table>
Similarly the fresh and dry weight of the root in hardstem bulrush was only 8.5 and 0.9 grams respectively at 180 m.e./l level as compared to 17.5 and 1.0 grams respectively in the controls. Total dry weight in hardstem bulrush root reduced from 6.3 grams in the control to 5.8 at 180 m.e./l level (Table 16). Like cattail, dry weight of plants in hardstem bulrush at 90 m.e./l level was slightly higher than the controls. Total fresh weight in hardstem bulrush reduced from 117.4 grams in the control to only 52.1 grams at 180 m.e./l treatment level (Table 17). There was 16.8 percent reduction in the total fresh weight of hardstem bulrush plants at 90 m.e./l level; the reduction was 55 percent as the salt concentrations were raised to 180 m.e./l level.

In alkali bulrush, as in the other plants, the fresh and dry weight of the top decreased from 41.7 and 2.1 grams respectively in the control to 22.2 and 1.4 grams respectively at 180 m.e./l treatment level (Table 14). The fresh and dry weight of the root in alkali bulrush similarly was reduced from 18.9 and 0.9 grams respectively in the control to 8.3 and 0.6 grams respectively in the plants at 180 m.e./l treatment level. The total dry weight of plants in the control of alkali bulrush was 3.0 grams as against 1.9 grams at 180 m.e./l level (Table 16). As in the other plants, there was no significant difference in dry weight of plants at 0 and 90 m.e./l level. Total fresh weight in alkali bulrush was reduced from 60.8 grams in the control to 28.2 grams at 180 m.e./l level (Table 17). There was 49.7 percent reduction in total fresh weight in alkali bulrush plants at 180 m.e./l treatment level as against only 1.5 percent reduction in plants at 90 m.e./l treatment level.

The moisture content of the plants showed a general reduction as the salt concentrations were increased. In cattail percentage moisture
decreased steadily from 91.1 percent in the control to 88.9 percent in plants at 180 m.e./l level (Table 17). Similarly hardstem bulrush plants receiving 180 m.e./l treatment level had 88.5 percent moisture as against 94.4 percent in the controls (Table 17). A similar but slow drop in moisture content was observed in alkali bulrush plants (Table 17). It decreased from 94.8 percent of moisture in the control plants of alkali bulrush to 92.3 percent at 180 m.e./l level.

It was therefore concluded that salinity had greatly reduced the vegetative growth and development of all the experimental plants. Diameter, total length, number of leaves per plant, fresh and dry weight were reduced considerably as the salt concentrations were increased. Plants absorbed comparatively lower quantity of moisture from the substrate of higher osmotic concentration. On the whole, alkali bulrush was placed as the most salt tolerant species in respect of their vegetative growth and development.

**Symptoms.**—Plants grown in higher salt concentrations were pale, weak, and unhealthy looking as compared to the control plants. At higher salt concentrations, necrotic regions and some mottling of leaves was apparent, especially in cattail. Leaves of the plants at higher salt concentrations were lighter than normal green color in the control of all the species. Chlorosis of leaves was more pronounced and distinct in cattail than in hardstem bulrush and alkali bulrush plants. After a few days treatment in higher salt concentrations, the leaf tips curled downward. This symptom was soon followed by tip burn. Plants at higher salt treatment were dwarf and the root growth was comparatively much less than in the controls of all species. Characteristic thick hair-like root growth with comparatively longer thread developed in the control plants
as against sparse and shorter thread development in plants receiving higher salt concentrations. Rhizomes and stolon-like side growth of stem was much thicker in the control than at the higher salt treatments.

Apart from general symptoms given above, chlorosis and tip burn were studied in detail on quantitative basis. In cattail, while control plants were healthy green, chlorosis and tip burn appeared at 90 m.e./l treatment level (Table 18). At this level, 4.9 percent and 2.7 percent of the leaves developed chlorosis and tip burn respectively. Chlorosis and tip burn increased with higher salt concentrations. At 180 m.e./l level, 64.6 and 65.5 percent of the leaves showed chlorosis and tip burn respectively in the cattail plants. While cattail plants developed the first symptoms of chlorosis and tip burn as early as 7.5 days after the treatment at 180 m.e./l level, these plants took as many as 30.5 days for appearance of first symptoms at 90 m.e./l treatment level. The higher the salt concentrations were increased, the larger were the percentage of leaves with chlorosis and tip burn (Figure 25). Symptoms of chlorosis and tip burn were apparent in shorter periods at higher salt concentrations.

Similar responses were observed in hardstem bulrush and alkali bulrush. In these plants, however, unlike cattail, symptoms did not appear until the salt concentration was increased to 120 m.e./l treatment level. In hardstem bulrush 14.7 and 11.5 percent of the leaves were chlorotic and had tip burn respectively at 120 m.e./l level (Table 18). Chlorosis and tip burn percentages increased to 81.4 and 80.9 percent respectively in hardstem bulrush as the salt concentration was raised to 180 m.e./l treatment level. While hardstem bulrush took only 8.5 days for the first symptoms to appear at 180 m.e./l level, 38.8 days
Table 18. Tip burn and chlorosis caused by salinity in aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./1.)</th>
<th>Percent survival</th>
<th>Number of leaves per plant</th>
<th>Percent chlorosis in leaves</th>
<th>Percent tip burn in leaves</th>
<th>First symptom after treatment (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cattail</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>100.0</td>
<td>7.5</td>
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</tr>
<tr>
<td>90</td>
<td>93.3</td>
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<td>4.9</td>
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<td>7.5</td>
</tr>
<tr>
<td><strong>Hardstem bulrush</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>100.0</td>
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<td>0.0</td>
<td>0.0</td>
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<tr>
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<td>38.8</td>
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<td>46.6</td>
<td>19.3</td>
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<td>2.8</td>
<td>81.4</td>
<td>80.9</td>
<td>8.5</td>
</tr>
<tr>
<td><strong>Alkali bulrush</strong></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>2.4</td>
<td>5.5</td>
<td>51.1</td>
</tr>
<tr>
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<td>11.0</td>
<td>28.1</td>
<td>33.1</td>
<td>32.2</td>
</tr>
<tr>
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<td>80.0</td>
<td>7.2</td>
<td>61.1</td>
<td>72.0</td>
<td>13.9</td>
</tr>
</tbody>
</table>
Fig. 25. Effect of salinity on tip burn and chlorosis of cattail, hardstem bulrush, and alkali bulrush plants.
elapsed at 120 m.e./l level before appearance of the first symptoms in these plants. Similarly in alkali bulrush 61.1 and 72.0 percent of the leaves were chlorotic and had tip burn respectively at 180 m.e./l level as against only 2.4 and 5.5 percent of leaves having these symptoms at 120 m.e./l treatment level (Table 18). While alkali bulrush plants at 180 m.e./l level took only 13.9 days for first symptoms to appear, 51.1 days were taken by the plants subjected to 120 m.e./l salt treatment level.

It was thus concluded that higher salt concentrations had not only increased chlorosis and tip burn of plants but also these symptoms appeared in shorter periods at higher salt concentrations. In alkali bulrush the percentage of plants with chlorosis and tip burn was less and the symptoms appeared later than in cattail and hardstem bulrush at the same level of the salinity treatment. Chlorosis and tip burn appeared earliest in cattail and these symptoms were more severe than in hardstem bulrush and alkali bulrush.

**Survival and mortality.**—Survival and mortality data were collected under two sets of experiments. Experiment I consisted of the regular experiment in which all other observations such as length, weight, etc. were recorded. In the regular experiment, the treatment concentrations were 0, 90, 120, 150, and 180 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. In order to find the upper limit of tolerance of these plants to salinity, another experiment was conducted (Experiment II), in which treatments were 200, 220, and 240 m.e./l of calcium chloride and sodium chloride in the ratio of 1:2. In Experiment II, however, only mortality and survival data were collected. Plants for Experiment II were grown exactly the same as those for I. A plant was considered dead when the top green part of the plant was completely
dry and yellow down to the cork level of the bottles.

In cattail mortality started at salt treatments as low as 90 m.e./l (Table 19). While only 6.6 percent of the cattail plants had died at 90 m.e./l level, mortality reached 26.6 percent at the 120 m.e./l level. In Experiment I, 46.6 percent of cattail plants had died at 180 m.e./l level. Mortality percentage increased significantly to 87.4 in Experiment II at the 200 m.e./l level and none of the cattail plants survived at and beyond the 220 m.e./l level of salt concentrations (Figure 26). The higher the salt concentration, the less the number of days that were taken by the plants to die after the treatment. While in cattail first mortality started 34.6 days after the treatment at 90 m.e./l, 25.8 days were taken to start killing in cattail at the 180 m.e./l treatment level. The average number of days from first treatment to death decreased to only 8.9 at the 200 m.e./l level. At 220 and 240 m.e./l, all cattail plants were killed within 6.0 and 3.3 days respectively.

In hardstem bulrush, unlike cattail, none of the plants died at the 90 m.e./l level (Table 19). Mortality in hardstem bulrush started at the 120 m.e./l treatment level. In hardstem bulrush, while only 6.6 percent of plants died at 120 m.e./l level, mortality increased to 40.0 percent at the 180 m.e./l treatment level. In Experiment II, mortality in hardstem bulrush increased significantly from 66.6 percent at the 200 m.e./l level to 91.6 percent at the 240 m.e./l treatment level (Figure 26). Like cattail the average number of days from first treatment to death decreased as the salt concentrations were increased. Between the 120 to 180 m.e./l levels, however, there was no difference in the death rate of hardstem bulrush plants. While it took about 23 days to start killing the hardstem bulrush plants at 180 m.e./l, mortality started 10
Table 19. Effect of salinity on mortality of aquatic plants

<table>
<thead>
<tr>
<th>Treatments (m.e./l.)</th>
<th>Cattail</th>
<th>Hardstem bulrush</th>
<th>Alkali bulrush</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>Mortality (%)</td>
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<td>6.6</td>
<td>26.6</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>34.6</td>
<td>32.2</td>
</tr>
<tr>
<td>Average number</td>
<td>of days</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>to death</td>
<td></td>
<td>0</td>
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</tbody>
</table>

Mortality (%) refers to the percentage of mortality at each salinity level. Average number of days to death indicates the average number of days it took for the plants to die at each salinity level.
Fig. 26. Salt tolerance limits of adult cattail, hardstem bulrush, and alkali bulrush plants. Salinity levels expressed in m.e./l are indicated above bars.
days after the treatment in the plants at 200 m.e./l treatment level. Plants started dying as early as 4.1 days after the first treatment at 240 m.e./l and within this short period 91.6 percent of the hardstem bulrush plants were killed.

In alkali bulrush mortality started when the salt treatment was raised to the 180 m.e./l level. While only 20 percent of the alkali bulrush plants died at 180 m.e./l, mortality increased to 66.6 percent when the salt concentration was increased to the 240 m.e./l treatment level (Figure 26). The average number of days from first treatment to death decreased from 49.3 days in alkali bulrush plants treated at 180 m.e./l to only 8.3 days at 240 m.e./l. While it took 49.3 days to kill 20 percent of the plants at 180 m.e./l, only 8.3 days were taken to kill 66.6 percent of alkali bulrush plants at 240 m.e./l treatment level.

It was, therefore, concluded that mortality increased proportionately as the salt concentrations were increased in all the plants. While mortality started in cattail at a salinity as low as 90 m.e./l, mortality commenced in alkali bulrush at salt concentrations as high as 180 m.e./l. While all cattail were killed at and beyond 220 m.e./l, 8.4 and 33.4 percent of hardstem bulrush and alkali bulrush plants were still surviving respectively at 240 m.e./l. Furthermore, in cattail more plants were killed within a shorter time at the same level of treatment than hardstem bulrush and alkali bulrush plants. All cattail plants were killed within 3.3 days at 240 m.e./l level; it took 4.1 days to kill 91.6 percent of hardstem bulrush and 8.3 days to kill 66.6 percent of alkali bulrush plants at the same level of salt treatment. Alkali bulrush was placed as the most resistant, cattail the least resistant, and hardstem bulrush was considered as the median salt tolerant plant.
Reproductive growth and development.—Cattail and hardstem bulrush never flowered in the greenhouse in any treatment levels including the controls. Within 3 months all plants of cattail and hardstem bulrush at 180 m.e./l level had died without flowering. Others that survived longer did not flower before they matured and withered. By this time these plants were about 7 months of age. In the field experiment, however, cattail and hardstem bulrush plants flowered and, therefore, data on the influence of salinity on seed production for these plants was available for the field experiment only.

Alkali bulrush plants, however, flowered in the greenhouse. While 80.6 seeds per plant were produced in the controls, seed production was reduced to only 25.5 seeds per plant at 180 m.e./l treatment level (Table 20). Maximum seed was produced by plants at 90 m.e./l level. Number of spikelets per plant decreased as the salt concentrations were raised. While there were only 5.3 spikelets per plant at 180 m.e./l level, control plants had 13.4 spikelets per plant (Figure 27). There were more spikelets in the plants that received 90 m.e./l treatment than all other levels. Seeds per spikelet similarly decreased from 6.6 in the control to 4.3 at 180 m.e./l level. Here again seeds per spikelet were slightly more numerous in plants given 90 m.e./l treatment. Also fresh weight per spikelet was reduced from 0.26 gram in the control to only 0.09 gram at 180 m.e./l treatment level. Size of the spikelets also decreased as the salt concentrations were increased (Figure 28). It was also observed that salinity seemed to have produced early maturity in alkali bulrush plants at higher salt concentrations. The flower buds appeared at higher salt concentrations 6 to 7 days earlier than in the control plants. It was also noticed that after plucking all spikelets for seed production
Table 20. Effect of salinity on seed production of alkali bulrush plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Number of seeds per plant</th>
<th>Number of spikelets per plant</th>
<th>Number of seeds per spikelet</th>
<th>Fresh weight per spikelet (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>90</td>
<td>101.3</td>
<td>14.1</td>
<td>6.9</td>
<td>0.25</td>
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<tr>
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<td>60.3</td>
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<td>5.9</td>
<td>0.24</td>
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<td>150</td>
<td>40.6</td>
<td>8.8</td>
<td>4.5</td>
<td>0.17</td>
</tr>
<tr>
<td>180</td>
<td>25.5</td>
<td>5.3</td>
<td>4.3</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Fig. 27. Effect of salinity on quantity of spikelet and seed production in alkali bulrush plants.
Fig. 28. Effect of salinity on size of the spikelets in alkali bulrush plants (1) 0 m.e./l, (2) 90 m.e./l, (3) 120 m.e./l, (4) 150 m.e./l, (5) 180 m.e./l.
assessment, some more spikelets appeared within the next 2 weeks in the controls but none in plants at higher salt concentrations. This suggested that the reproductive phase of the plants receiving no salts is prolonged and they reach maturity at a later stage than the plants given the salt treatments. Symptoms of maturity and old age appeared earlier at higher salinity. Plants shrivelled and withered earlier as the salt treatments were increased.

**Accumulation of ions and osmotic pressure.**—While the control plants of cattail had absorbed only 6.4 m.e./100 gram of dry weight of sodium, this ion progressively increased in the plant as the salt concentrations of the media were increased, and at the 180 m.e./l treatment level the sodium concentration in cattail was as high as 178.0 m.e./100 gram dry weight (Table 21). Cattail plants contained 32.8 m.e./100 gram dry weight of potassium at the 180 m.e./l level as against only 8.5 m.e./100 gram dry weight in the controls. Calcium and magnesium similarly were accumulated in the plants as the salt concentrations of the substrate were increased. Calcium increased from 52.5 m.e./100 gram dry weight in the cattail controls to 243.9 m.e./100 gram dry weight in the plants at the 180 m.e./l treatment level. Magnesium was 31.6 m.e./100 gram dry weight in the controls and increased to 43.3 m.e./100 gram dry weight in the plants at the 180 m.e./l treatment level.

In hardstem bulrush, similarly, the ion accumulation increased as the salt concentrations were increased (Table 21). There were 160.0 m.e./100 gram dry weight of sodium in the plants at 180 m.e./l treatment as against only 5.2 m.e./100 gram dry weight in the control plants. Potassium increased from 8.1 m.e./100 gram dry weight in the controls to 78.4 m.e./100 gram dry weight in the plants given 180 m.e./l. While
Table 21. Effect of salinity on chemical composition of aquatic plants

<table>
<thead>
<tr>
<th>Treatment (m.e./l.)</th>
<th>Chemical composition of plants (m.e./100 gm dry wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na⁺</td>
</tr>
<tr>
<td>Cattail</td>
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<td>0</td>
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<td>120</td>
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<td>90</td>
<td>52.1</td>
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<td>120</td>
<td>80.0</td>
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<td>150</td>
<td>90.6</td>
</tr>
<tr>
<td>180</td>
<td>107.5</td>
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</table>
plants at 180 m.e./l absorbed 161.2 m.e./100 gram dry weight of calcium, control plants contained only 74.4 m.e./100 gram dry weight of calcium. Magnesium also increased from 41.1 m.e./100 gram dry weight in the controls to 45.2 m.e./100 gram dry in plants at 180 m.e./l.

Sodium was only 4.1 m.e./100 gram dry weight in the control plants of alkali bulrush, and increased to 107.5 m.e./100 gram dry weight at the 180 m.e./l level. While control plants had only 13.7 m.e./100 gram dry weight of potassium, they had 92.2 m.e./100 gram dry weight at the 180 m.e./l treatment level. Alkali bulrush plants at 180 m.e./l contained 146.7 m.e./100 gram dry weight of calcium as against 95.0 m.e./100 gram dry weight of calcium in the control plants. Alkali bulrush, however, unlike other plants behaved differently to the accumulation of magnesium. In alkali bulrush magnesium decreased from 37.1 m.e./100 gram dry weight in the control plants to 34.7 m.e./100 gram dry weight at the 180 m.e./l treatment level.

Cattail accumulated more sodium than did hardstem bulrush and alkali bulrush plants (Figure 29). Hardstem bulrush absorbed slightly less sodium than cattail. Alkali bulrush plants accumulated comparatively less sodium. Potassium was accumulated least by cattail and most by alkali bulrush plants (Figure 29). Calcium was taken more by cattail plants than hardstem bulrush and alkali bulrush plants (Figure 29). The control plants of cattail and hardstem bulrush which had lower concentrations of calcium than alkali bulrush accumulated more calcium at higher treatment levels than did alkali bulrush plants. Magnesium increased in cattail and hardstem bulrush as the salt concentrations were increased (Figure 29). The absorption rate of magnesium was higher in cattail than in hardstem bulrush. Alkali bulrush on the other hand
Fig. 29. Effect of salinity on chemical composition of cattail, hardstem bulrush, and alkali bulrush plants.
seemed to have eliminated magnesium and its concentration in the plants
was reduced as the salt concentrations of the media were increased.

Chloride also increased in the plants as the salt concentrations of
the substrate were increased (Table 22). Chloride accumulation in the
plant cell sap showed very close correlation with osmotic pressure of
the cell sap. In cattail, while control plants had an osmotic pressure
of only 0.7 atmosphere, it increased as the salt treatments were raised,
and at the 180 m.e./l level osmotic pressure was as high as 12.7 atmos-
pheres (Table 22). Chloride accumulation in cattail plants increased
from 6.3 m.e./l in the controls to 193 m.e./l in plants given the 180
m.e./l level (Figure 30).

Hardstem bulrush plants at 180 m.e./l treatment level developed
an osmotic pressure of 10.7 atmospheres as against only 0.7 atmosphere.
in the control plants (Table 22). Chloride accumulation in the cell sap
of hardstem bulrush controls was only 7.9 m.e./l as compared to 189.1
m.e./l in plants at the 180 m.e./l level (Figure 30).

Similarly in alkali bulrush, while osmotic pressure in the plants
at the 180 m.e./l treatment level was 8.1 atmospheres, it was only 0.9
atmosphere in the controls (Table 22). Chloride was only 7.5 m.e./l
in the alkali bulrush controls. It increased to 164.1 m.e./l in plants
at 180 m.e./l treatment level (Figure 30). Comparatively osmotic
pressure and chloride accumulation were less in alkali bulrush plants
than in cattail and hardstem bulrush plants at the same levels of
treatment.

Field Experiments on Salinity Tolerance

Sand culture method was followed for experiments in the field.
Table 22. Effect of salinity on osmotic pressure and chloride accumulation of aquatic plants

<table>
<thead>
<tr>
<th>Treatments (m.e./l)</th>
<th>0</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic pressure</td>
<td>0.7</td>
<td>6.4</td>
<td>9.5</td>
<td>10.6</td>
<td>12.7</td>
</tr>
<tr>
<td>(Atm.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride accumulation</td>
<td>6.3</td>
<td>75.6</td>
<td>98.5</td>
<td>133.3</td>
<td>195.0</td>
</tr>
<tr>
<td>(m.e./l.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardstem bulrush</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic pressure</td>
<td>0.7</td>
<td>5.9</td>
<td>8.2</td>
<td>9.9</td>
<td>10.7</td>
</tr>
<tr>
<td>(Atm.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride accumulation</td>
<td>7.9</td>
<td>81.0</td>
<td>114.8</td>
<td>155.8</td>
<td>189.1</td>
</tr>
<tr>
<td>(m.e./l.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkali bulrush</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osmotic pressure</td>
<td>0.9</td>
<td>2.6</td>
<td>5.1</td>
<td>6.0</td>
<td>8.1</td>
</tr>
<tr>
<td>(Atm.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride accumulation</td>
<td>7.5</td>
<td>67.5</td>
<td>100.5</td>
<td>131.6</td>
<td>164.1</td>
</tr>
<tr>
<td>(m.e./l.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 30. Effect of salinity on osmotic pressure and chloride accumulation in cattail, hardstem bulrush, and alkali bulrush plants.
Calcium chloride and sodium chloride in the ratio of 1:2 were used. The unit of salinity treatment measurement was on a conductance basis. The conductance in the experimental drums used in 1961 and 1962 is shown in Table 2.

Observations on the influence of salinity on plants were recorded in the summer of 1961 and 1962. Plants were processed in the last week of August each summer.

In the summer of 1961, the conductance could not be raised sufficiently high to make a significant difference in the growth of plants. Application of the salts was started late in summer 1961 when the plants had already sprouted and they had attained 20 to 30 cm height. In summer 1962, however, salts were applied early enough before the plants started growing after the winter dormant season.

The average height of cattail plants (Table 23) was 134.0 cm in the treatment level of 4.2 m.mhos (control) and it decreased to 131.2 cm at the 12.5 m.mhos treatment level in the summer of 1961. However, none of the cattail plants survived in the summer of 1962 when the salt concentrations were raised to 17.4 m.mhos. The average height of cattail plants at 12.8 m.mhos level was only 52.4 cm as against 161.0 cm at 3.7 m.mhos (control) in the summer 1962 (Figure 31).

In hardstem bulrush (Table 23), the average height of the plants was 178.0 cm at 3.7 m.mhos treatment level. It decreased to 168.4 cm at 11.8 m.mhos in the summer of 1961. In summer 1962 the height of hardstem bulrush plants was reduced from 180.3 cm in the control (3.2 m.mhos) level to only 72.5 cm in plants receiving the treatment of 12.4 m.mhos (Figure 32).

Similarly the height of alkali bulrush plants decreased as the salt
Table 23. Effect of salinity on vegetative growth, survival, and chemical composition of aquatic plants at Ogden Bay Bird Refuge

<table>
<thead>
<tr>
<th>Cond. (m.mhos)</th>
<th>Ave. ht. (cm)</th>
<th>Surv. per drum</th>
<th>August 1961</th>
<th>Ave. ht. (cm)</th>
<th>Surv. per drum</th>
<th>August 1962</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP Cl− Na+ K+ Ca++ Mg++ (atm) (m.e./1) (m.e./100 gm dry wt.)</td>
<td>OP Cl− Na+ K+ Ca++ Mg++ (atm) (m.e./1) (m.e./100 gm dry wt.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cattail</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.2(A)</td>
<td>134.0</td>
<td>17.3</td>
<td>1.3</td>
<td>7.2</td>
<td>5.6</td>
<td>8.8</td>
</tr>
<tr>
<td>6.5(B)</td>
<td>136.0</td>
<td>16.3</td>
<td>2.1</td>
<td>22.3</td>
<td>41.3</td>
<td>9.2</td>
</tr>
<tr>
<td>8.6(C)</td>
<td>135.1</td>
<td>14.3</td>
<td>3.1</td>
<td>37.3</td>
<td>57.3</td>
<td>11.6</td>
</tr>
<tr>
<td>12.5(D)</td>
<td>131.2</td>
<td>12.3</td>
<td>6.2</td>
<td>81.7</td>
<td>92.0</td>
<td>14.0</td>
</tr>
<tr>
<td><strong>Hardstem bulrush</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7(A)</td>
<td>178.0</td>
<td>135.0</td>
<td>1.2</td>
<td>7.2</td>
<td>4.9</td>
<td>9.3</td>
</tr>
<tr>
<td>5.6(B)</td>
<td>175.5</td>
<td>129.0</td>
<td>2.8</td>
<td>14.7</td>
<td>37.6</td>
<td>24.0</td>
</tr>
<tr>
<td>8.6(C)</td>
<td>174.8</td>
<td>99.3</td>
<td>3.1</td>
<td>30.7</td>
<td>56.6</td>
<td>29.0</td>
</tr>
<tr>
<td>11.8(D)</td>
<td>168.4</td>
<td>91.3</td>
<td>3.7</td>
<td>35.0</td>
<td>96.6</td>
<td>34.0</td>
</tr>
<tr>
<td><strong>Alkali bulrush</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.9(A)</td>
<td>98.3</td>
<td>155.5</td>
<td>1.3</td>
<td>7.0</td>
<td>4.6</td>
<td>7.5</td>
</tr>
<tr>
<td>6.4(B)</td>
<td>98.8</td>
<td>157.0</td>
<td>3.2</td>
<td>18.0</td>
<td>16.0</td>
<td>25.6</td>
</tr>
<tr>
<td>8.9(C)</td>
<td>83.6</td>
<td>146.6</td>
<td>3.6</td>
<td>29.3</td>
<td>32.6</td>
<td>30.0</td>
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<tr>
<td>10.5(D)</td>
<td>95.2</td>
<td>135.3</td>
<td>5.2</td>
<td>78.0</td>
<td>83.3</td>
<td>35.0</td>
</tr>
</tbody>
</table>
Fig. 31. Effect of salinity on cattail at Ogden Bay Bird Refuge in May 1962 (A) 3.7 m. mhos, (B) 9.1 m. mhos, (C) 12.8 m. mhos, (D) 17.4 m. mhos.

Fig. 32. Effect of salinity on hardstem bulrush at Ogden Bay Bird Refuge in May 1962 (A) 3.2 m. mhos, (B) 8.3 m. mhos, (C) 12.7 m. mhos, (D) 18.8 m. mhos.
concentrations were increased (Table 23). Reduction in the height of alkali bulrush was only 2 to 3 cm at higher salt concentration in summer 1961. Height of alkali bulrush plants decreased from 101.9 cm in the control (4.1 m.mhos) to only 39.6 cm in plants given salt concentration of 19.6 m.mhos in 1962 (Figure 33).

Survival of plants decreased as the salt concentrations were increased. In cattail 17.3 plants per drum survived in the control (4.2 m.mhos) as against 12.3 at 12.5 m.mhos level in the summer 1961 (Table 23). Survival was reduced to only five plants per drum in salinity treatment level of 12.8 m.mhos in the summer of 1962. At the 18.4 m.mhos level, none of the cattail plants survived in 1962.

Similarly in hardstem bulrush (Table 23) while 91.3 plants survived in each drum at 11.8 m.mhos, 178.0 plants were alive in the control (13.7 m.mhos level) in the summer of 1961. None of the hardstem bulrush plants survived at the 18.8 m.mhos level in 1962. Only 2.2 hardstem bulrush plants per drum survived at the 12.7 m.mhos level as against 180.3 plants at 3.2 m.mhos in the summer of 1962.

Similar results were obtained in alkali bulrush plants (Table 23). At 3.9 m.mhos (control) 155.5 alkali bulrush plants survived. The survival decreased to 135.3 at the 10.5 m.mhos treatment level in the summer of 1961. Unlike other experimental plants 14.6 alkali bulrush plants per drum survived at salt concentration as high as 19.6 m.mhos in the summer of 1962.

Except for dwarfishness and yellowing of leaves, such symptoms as chlorosis and tip burn that were so characteristic of the plants at higher salt treatments in greenhouse experiments were not so distinct in the experimental plants of the field.
Fig. 33. Effect of salinity on alkali bulrush at Ogden Bay Bird Refuge in May 1962 (A) 4.1 m. mhos, (B) 8.2 m. mhos, (C) 12.4 m. mhos, (D) 19.6 m. mhos.
The influence of salinity on seed production was recorded in the field experiments. In cattails the number of spikes per drum decreased from 8.6 in the control (4.2 m.mhos level) to 6.3 in the plants at the 12.5 m.mhos level in summer 1961 (Table 24). While at the 17.4 m.mhos treatment level all cattail plants died, at the 12.8 m.mhos level the few plants that survived did not flower. Cattail plants at 9.1 m.mhos produced only 3.3 spikes per drum as against 8.3 in the control plants (3.7 m.mhos) in 1962. Fresh weight, length and diameter of each spike in cattail plants decreased as the salt concentrations were increased.

While spike in the control plants of cattail had fresh weight and length of 21.3 grams and 23.4 cm respectively, it decreased to 14.5 grams and 16.8 cm in the plants given 9.1 m.mhos.

Similarly, salinity greatly influenced the seed production in hardstem bulrush and alkali bulrush plants. Not only number of spikelets per plant decreased but also the number of seeds per spikelet reduced as the salt concentrations were increased. In hardstem bulrush, 110 spikelets per drum were produced in the control plants (3.7 m.mhos level) as against 63.3 produced in the plants at 11.8 m.mhos in the summer of 1961 (Table 24). In summer 1962 hardstem bulrush plants produced only 25.8 spikelets per drum at 12.7 m.mhos as compared to 103.3 in the control plants (3.2 m.mhos). Hardstem bulrush plants produced a maximum number of seeds at the 8.3 m.mhos treatment level in the summer of 1962. In hardstem bulrush the number of seeds per spikelet decreased as the salt concentrations were increased to higher levels. Seed production was also reduced in alkali bulrush at higher salt concentrations (Table 24). In 1961, when the salinity concentrations were comparatively low, seed production was not much affected in alkali bulrush plants. In 1962,
Table 24. Effect of salinity on seed production of aquatic plants at Ogden Bay Bird Refuge

<table>
<thead>
<tr>
<th>August 1961</th>
<th>August 1962</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Fresh</td>
<td>No. of Fresh</td>
</tr>
<tr>
<td>Cond. spikes</td>
<td>Cond. spikes</td>
</tr>
<tr>
<td>(m.mhos) per spike</td>
<td>(m.mhos) per spike</td>
</tr>
<tr>
<td>(gm)</td>
<td>(cm)</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Cattail</td>
<td></td>
</tr>
<tr>
<td>4.2(A)</td>
<td>8.6</td>
</tr>
<tr>
<td>6.5(B)</td>
<td>7.3</td>
</tr>
<tr>
<td>8.6(C)</td>
<td>8.0</td>
</tr>
<tr>
<td>12.5(D)</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardstem bulrush</td>
<td></td>
</tr>
<tr>
<td>3.7(A)</td>
<td>110.0</td>
</tr>
<tr>
<td>5.6(B)</td>
<td>101.6</td>
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<td>8.6(C)</td>
<td>77.0</td>
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<td>11.8(D)</td>
<td>68.3</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkali bulrush</td>
<td></td>
</tr>
<tr>
<td>3.9(A)</td>
<td>95.0</td>
</tr>
<tr>
<td>6.4(B)</td>
<td>116.0</td>
</tr>
<tr>
<td>8.9(C)</td>
<td>98.6</td>
</tr>
<tr>
<td>10.5(D)</td>
<td>83.3</td>
</tr>
</tbody>
</table>
however, the number of spikelets was reduced from 85.3 per drum in the
control (4.1 m.mhos) to only 29.0 in alkali bulrush at 12.4 m.mhos. Seed
production was highest at the 8.2 m.mhos treatment level. The number of
seeds per spikelet was also lower in alkali bulrush as the salt concentra-
tions were increased.

Chemical analysis of the plants in the field experiment gave similar
results to those in the greenhouse plants. Sodium, potassium, calcium,
and magnesium accumulations were progressively higher as the salt treat-
ment levels were increased. Similarly chloride accumulation and osmotic
pressure of plant cell sap increased considerably at higher salt treat-
ments. In cattail, sodium and potassium in the plants increased from 5.6
and 8.8 m.e./100 gram dry weight, respectively, in the control (4.2 m.mhos)
to 92.0 and 14.0 m.e./100 gram dry weight in plants at 12.5 m.mhos in
1961 (Table 23). Calcium and magnesium similarly increased from 64.7
and 32.9 m.e./100 gram dry weight respectively in the control to 105.1
and 43.1 m.e./100 gram dry weight in the plants receiving the 12.5 m.mhos
treatment level in 1961. Cattail plants absorbed much higher concentra-
tions of these ions in 1962 when the salt treatment levels were raised
higher than in 1961. Cattail plants contained as high as 198.6 and 280.7
m.e./100 gram dry weight of sodium and calcium respectively at the 18.4
m.mhos treatment level. Cattail plants absorbed somewhat smaller
amounts of potassium at high salt concentrations than did the other
species. Magnesium increased in cattail from 32.9 m.e./100 gram dry
weight in the control plants (3.7 m.mhos level) to 41.9 m.e./100 gram
dry weight absorbed by the plants at 18.4 m.mhos in 1962. Chloride
accumulation and osmotic pressure were also comparatively lower in
summer 1961 than in 1962. The higher the salt treatment levels, the
more the chloride and osmotic pressure developed in the plant cell sap. In 1962 some of the measurements on chloride accumulation and osmotic pressure in the cattail plants could not be recorded, partly because plants had died, and partly because of the dry nature of the plants which survived at these higher levels of salt treatment. Similar results were obtained in hardstem bulrush and alkali bulrush (Table 23): the higher the salt treatment levels, the higher were the osmotic pressure and chloride accumulation in plant cell sap.

It was concluded that plants in the field experiments behaved similarly toward salinity as did the plants in the greenhouse experiments. Vegetative growth and development were greatly hampered by the salinity. The plants in the field experiment similarly accumulated higher concentrations of ions as the salt treatments were increased. They also developed high osmotic pressure at higher salt treatments. However, due to uncontrolled environmental conditions of the field experiments, there was considerably more variation in the experimental data than in the greenhouse data. Therefore, it was difficult to evaluate and interpret some of the results in the field experiments. Data from laboratory studies under controlled greenhouse conditions were much more valid and provided more conclusive information on the influence of salinity on various phases of the life cycle of the experimental plants.
DISCUSSION

Salt tolerance of cattail, hardstem bulrush, and alkali bulrush seed germination was retarded by salts in solution. The degree of delayed seed germination was in direct proportion to the osmotic pressure of the saline solution. Increased osmotic pressure of the substrate resulted in decreased uptake of water by the seeds. The seed mortality was in direct proportion to the length of the treatment and the osmotic concentration of the substrate.

Reduction in germination at increasing salt treatments was believed to be due to the higher osmotic pressure of the media. This osmotic pressure lowered the availability of water which is a physiological necessity for germination of all seeds. Some reduction in seed germination was also attributed to the toxic effect of the salts. However, the non-availability of enough water for seed germination from the substrate of high osmotic pressure was believed to be the major factor involved in reducing the seed germination. The toxic effect of the salt ions was considered less important than the osmotic pressure of the substrate, although at considerably higher salt concentrations the toxicity of ions seemed equally responsible for reduced germination.

Similar results on the reduced ability of seeds to absorb enough water required for germination were reported by various investigators: Magistad (1945), Ayers and Hayward (1948), and Ayers (1952). The toxic effect of salts on the germination and development of embryo was observed by Uhvits (1946). She stated that the percentage of defective seedlings on sodium chloride substrate was greater than in the control. Mulwani
et al. (1939), however, pointed out that small concentrations of sodium chloride stimulated germination. When this was exceeded the seeds were injured.

Slight pH variation had an insignificant effect on seed germination in salt substrate. However, light and temperature seemed to play important roles in seed germination of these plants in saline media. Cattail seeds preferred illumination for germination in the greenhouse conditions, although hardstem bulrush and alkali bulrush germinated best in the dark. This is in agreement with the germination of these plants in the field. Cattail seeds normally germinate while free floating on the marginal water of a marsh. Hardstem bulrush and alkali bulrush seeds germinate through the muddy soil of the marsh.

Isely (1944) reported favorable results on hardstem bulrush seed germination in the darkness. Ahi and Powers (1938) and Ogasa (1939) related temperature as a dominant factor in seed germination of some other plants under saline conditions. Uhvits (1946) found that an increase of 5 F in the mean greenhouse temperature reduced the percentage germination at all levels of salt treatments, the difference being more pronounced at higher salt levels.

Greenhouse experiments on seed storage conditions before the germination in salt substrate indicated that dry storage was good for cattail. Better viability and quick germination was obtained in hardstem bulrush and alkali bulrush seeds when stored wet in the soil or in water just above freezing. These conditions correspond to the natural storage of these seeds in the field. Cattail seeds remain in the spikes for a considerably longer time. Most of the hardstem bulrush and alkali bulrush seeds fall much earlier and remain dormant in the wet soil of a
marsh. After the dormant winter season, seeds of these plants germinate in the following spring.

Stanley et al. (1939) reported that moisture during storage increased germination percentage in hardstem bulrush. Isely (1944) observed that scirpus seeds frozen in ice over a long period of time showed a better seedling production than did those stored in water. Muenscher (1936) recommended water storage at temperatures just above freezing to ensure good germination in most of the aquatic plants.

The most salt affected stage was during seed germination in all the experimental plants. The tolerance of these plants seem to increase with maturity. Tender seedlings were considerably more sensitive to salinity than in the later stages of their growth period.

Grillot (1954) while reviewing work on development of growing plants referred to the investigations of Pantanelli (1937) who claimed that resistance to salinity increases with the age of the plant. On passing from the vegetative to the seed production stages there is a marked and probably sudden increase in its salt tolerance. Russell (1952) stated that salinity tolerance may be low in the seedlings stage and high when the plant is well established.

Vegetative growths of plants such as height, weight, stem diameter, and root elongation decreased considerably in cattail, hardstem bulrush, and alkali bulrush as the salt treatments were increased. Salinity inhibited floral development and reduced quality and quantity of seed production. Low salinity of about 90 m.e./l, however, increased seed production in alkali bulrush. Plants receiving higher salt concentrations reached maturity much earlier than the normal plants. Severity of symptoms such as chlorosis and tip burn were in direct proportion to the
salt concentration of the substrate. Plants accumulated increasing amounts of various ions from the substrate of high salt treatments. Osmotic pressure developed considerably higher in plant cell sap than in the normal plants. Plants absorbed smaller amounts of water from the substrate of higher osmotic concentrations.

Similar reduction in vegetative growth and development of plants grown in salinized media was reported by various investigators: Lilleland (1945), Ayers et al. (1952), Cooper and Gorton (1950), Garner et al. (1930), Hawyard and Long (1943).

Reduction in yield and size of fruit on salt substrate was observed by Bernstein and Ayers (1951), Kapp (1947), Wadleigh et al. (1952), Magistad and Reitemeier (1943), Brown et al. (1953), Brown and Voth (1955).

Accumulation of sodium in plants from substrate of high concentrations was investigated by Wallace et al. (1948), Collander (1941), Chapman (1949), and Ratner (1935). Potassium accumulation in plants was reported by Russell (1952), and Walsh and Clark (1942). Calcium absorption was investigated by Wadleigh and Gauch (1944), Wadleigh et al. (1951), Lehr (1942), Gauch and Wadleigh (1942). Accumulation and injury by magnesium was reported by Wadleigh and Gauch (1944), Gauch (1940) and others. Toxicity of chloride ion was reported by many workers: Eaton (1942), Hayward and Long (1941), Magistad (1945), Harper (1946), Wadleigh and Ayers (1945), Heller et al. (1940), Doughty and Stalwick (1940), Gertrand et al. (1959), and Hayward et al. (1946).

The principal factor depressing plant growth in salinized media was correlated with the decrease in available water due to high osmotic pressure of the substrate. Water absorption by the plants was reduced.
as the osmotic pressure of the substrate was increased. Enough water is a prerequisite for plant life in cell turgidity and exposure of leaves to the sunlight for photosynthesis. Water is also required for cell elongation and thereby plant growth. Decreased water absorption by plants seems to have resulted in lowered meristematic activity of the growth region of the plant and maturation of cells of smaller size. Lowered meristematic activity of the growing tip of the plants resulted in reduced height of plants at higher salt concentrations. Lowered meristematic activity of the root tip induced by salinity resulted in sparse growth of roots of the plants. Smaller diameter of stems was attributed to the reduction in the amount of vascular tissue at the high levels of salt concentrations. Reduced availability of water is also reported to plasmolyse and deform plant cells.

Decrease in growth of plants in saline media may also be due to harmful effects of specific ions. However, the ion injury is somewhat less important than the inhibition resulting from high osmotic pressure. The increased accumulation of toxic ions especially sodium, magnesium, and chloride seemed to have burnt and killed the cells which were represented by chlorosis and especially tip burn. These dead portions of the plants may be connected with lowered content of chlorophyl per unit of leaf surface and a weakened photosynthetic activity.

High salt concentrations of media may also inhibit availability of nutrients to the plant which again decreases plant growth.

Similar statements were made by other investigators giving reasons how the growth of plant is reduced by salinity. Decreased water absorption by plant from substrate of high osmotic concentration was reported by Hayward and Spurr (1943). Osmotic pressure rather than specific ion
effect was attributed by Eaton (1941) as the primary factor involved in plant growth depression. Hayward and Long (1943) investigated total concentration regardless of any salt as a major factor in the resultant general growth depression.

Interference of salinity in meristematic activity was pointed out by: Hayward and Long (1941, 1943), Hayward and Blair (1942), Gauch and Wadleigh (1942) stated that in high osmotic concentration of NaCl and CaCl₂, there was a marked difference in total absorption and distribution of basic nutrients N-K-P. Toxicity of specific ion was reported by Heller et al. (1940), Cooper and Gorton (1950), Lilleland et al. (1945) and others.

Baslavskaja (1936) reported that large doses of chloride decreased the total sum of carbohydrates in the leaves. This was connected to lower photosynthesis in the leaves. Gauch and Eaton (1942), however, observed accumulation of carbohydrate with salt accumulation indicating that salts interfered with utilization of carbohydrates in cellular elaboration rather than with photosynthetic activity.

Cattail, hardstem bulrush, and alkali bulrush responded differentially towards salinity. Gertrand et al. (1959) reported that different species of plants had distinct differences in protoplasmic salt resistance. Magistad et al. (1943) stated that crops do not behave alike in their reaction to the combined effects of salt and climate.

Magistad (1945) listed many reasons why reduction in water uptake decreases plant growth. These include salting out of cellular protein, shrinkage of cell contents from the cell wall, irreversibility of hydration of cell contents and interference with ion accumulation. U.S.D.A., plant physiologist R. H. Nieman (1960) believes that salinity slows the
growth, though its effect on cell division which in turn may be linked to the supply of genetic material. Salinity, by slowing down reproduction of DNA and cell division retards leaf growth. Higher osmotic pressure in cells of plants grown on saline culture may adversely effect some key enzyme systems.

From the above discussion it is evident that the mechanism by which the plant growth is reduced by lowered availability of water from salinized media is not clearly understood. However, influence of salinity and resultant reduced growth of plants is well established. The results obtained by other investigators of the effects of salt on decreased vegetative and reproductive growth, accumulation of ions, development of characteristic symptoms and increased osmotic pressure in the plant cell sap is in agreement with the results of this study. But for differences in species specificity, marsh plants responded towards salinity in a way similar to other common agricultural plants.

Salinity in the marshes has increased with rapid development and accelerated demand of water by agriculture and industry. It is believed that increased demand for water will endanger the valuable fish and wildlife resources. It is, therefore, necessary to work out quality and quantity of water requirements for management of marshes to help in securing adequate water for marshlands.

Salt tolerance ranges of these plants to achieve a minimum of 50 percent germination and plant survival can be inferred from greenhouse and field studies (Table 25). During the seed germination period the salinity in a marsh should not exceed more than 7.0 m.mhos for cattail and hardstem bulrush, and 9.0 m.mhos for alkali bulrush. During the growth and development of young plants, the salt concentration in a
Table 25. Salt tolerance range needed to achieve 50 percent germination and survival of aquatic plants

<table>
<thead>
<tr>
<th>Stage</th>
<th>m.mhos per cm at 25 C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cattail</td>
</tr>
<tr>
<td>Seed</td>
<td>5-7</td>
</tr>
<tr>
<td>Young plants</td>
<td>5-7</td>
</tr>
<tr>
<td>Mature plants</td>
<td>8-10</td>
</tr>
</tbody>
</table>
marsh should not be more than 7.0, 8.0, and 12.0 m.mhos for cattail, hardstem bulrush, and alkali bulrush respectively. Salinity in a marsh when plants have reached mature stage should be maintained below 10.0, 15.0, and 18.0 m.mhos for cattail, hardstem bulrush, and alkali bulrush respectively.

As a comparison with the above figures from greenhouse and field experiments some of the conductance measurements taken in Utah marshes are given in Table 26. The salinity in the marshes is comparatively low during the months of May-June but increases from June to the middle of September. Seeds of these plants germinate during April-May. The month of June may be regarded as the growth period of young plants. These plants attain full growth in July-August.

During the years of normal moisture and average use of water by agriculture and industry, the salinity in the marshes of the state of Utah seem within the salt tolerance range of seed germination, growth, and seed production of experimental plants. As the salinity in the marshes increases from the month of June onward to September, the salt tolerance of these plants also increases with age.

However, salinity in the marshes changes considerably from year to year. Salinity as high as 51.5 m.mhos was reported at the outlet of Bear River Refuge in August 1959 by Christiansen and Tsai (1961). The highest reported conductance at the same outlet was only 6.5 in 1960 and 20.0 in 1961. These higher conductance readings are beyond the salt tolerance for vegetative growth and seed production of the experimental plants. Salinity as high as 12.0 m.mhos was observed in the south area of the Public Shooting Ground Refuge in May 1961. This period coincides with the germination stage of these plants. Such a high concentration is
Table 26. Average conductance measurements of water in Utah Bird Refuges in 1961\(^a\)

<table>
<thead>
<tr>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ogden Bay</td>
<td>-</td>
<td>1.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.7</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Farmington Bay</td>
<td>-</td>
<td>4.6</td>
<td>5.2</td>
<td>5.4</td>
<td>5.4</td>
<td>5.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Bear River</td>
<td>3.4</td>
<td>3.9</td>
<td>6.0</td>
<td>8.7</td>
<td>14.5</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>Public Shooting Grounds</td>
<td>4.7</td>
<td>4.5</td>
<td>5.9</td>
<td>9.4</td>
<td>10.8</td>
<td>4.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

\(^a\)The data are compiled from the progress report part V on water requirements for waterfowl areas near the Great Salt Lake by Christiansen and Tsai, November 1961, Utah State University, Logan, Utah.
virtually intolerable for seed germination requirements for plants of this study.
RECOMMENDATIONS

It is obvious from the experimental results that salinity not only interfered in seed germination but also vegetative growth and development and seed production of all the plants were substantially reduced. Since most of the results of this study were based on controlled experiments under greenhouse conditions, salinity tolerance of these plants need more experimentation under field conditions. The following recommendations for further investigations are made to help understand the role of salinity in the growth and reproduction of aquatic plants:

1. It is recommended that salt tolerance of cattail, hardstem bulrush, and alkali bulrush be studied under various environmental conditions and their interactions with salinity observed.

2. Salt resistance of rhizomes and underground stems of these plants which remain dormant in winter should be investigated.

3. Several other important marsh plants such as Wigeon grass (Ruppia maritima), horned pondweed (Zannichellia palustris), musk-grass (Chara spp.), salt grass (Distichlis stricta), and algae (Cladophora spp.) should be intensively studied to determine their salt tolerances.

4. The application of salt and salinity levels in the control of undesirable and less resistant plants such as cattail should be further investigated.

5. The influence of salinity on the reproductive phase of important marsh plants and its effect on yield and quality of seed production by subsequent generations of the plants needs intensive investigation.

6. The development of salt-resistant strains of plants suitable for artificial propagation in saline marshes also needs detailed investigation.
SUMMARY AND CONCLUSIONS

The water resources of the state of Utah are rapidly being developed for agriculture and industry. Much research has been conducted to determine the water requirements of agricultural crops, but relatively little is known about quality and quantity of water needed for good growth of important marsh plants. Experiments were, therefore, conducted in the greenhouse at Utah State University and in the field at Ogden Bay Bird Refuge to determine the quality of water needed to maintain the salinity below the lethal level for desirable plants.

Water culture and sand culture methods were followed in the greenhouse and in the field respectively. Cattail, hardstem bulrush, and alkali bulrush were selected as the experimental plants. Calcium chloride and sodium chloride in the ratio of 1:2 were used as the salts. All treatments including the control plants received the same base nutrient solution. The unit of salt measurement of the substrate was milliequivalent per liter in the greenhouse and conductance for the sand culture method in the field.

The effects of various salt concentrations on seed germination were recorded. The influence of various salt concentrations on growth and development of tender seedlings (15 days old), of young plants (30 days old), and on the vegetative growth, seed production, and salt accumulation of mature plants (60 days old) were studied.

The osmotic pressure developed in the plant cell sap was determined by freezing point depression method. The chloride accumulation in the plant cell sap was assessed by Convey Gell method. Sodium and potassium
in the plants were determined by flame photometer. Calcium and magnesium in the plants were measured by EDTA titration method.

The following conclusions were drawn from the greenhouse and field experiments on salinity tolerance studies:

1. Seed germination of cattail, hardstem bulrush, and alkali bulrush progressively decreased as the salt concentrations of the substrate were increased.

2. No seeds of cattail germinated at or above 180 m.e./l treatment level with an 8-day period. While in hardstem bulrush and alkali bulrush no seeds germinated at or above 240 m.e./l level within the same period. Thus cattail seeds were somewhat less resistant to salinity than hardstem bulrush and alkali bulrush seeds.

3. The rate of seed germination was delayed considerably at higher salt concentrations and was directly in proportion to the salt concentrations of the substrate.

4. Reduced seed germination was believed to be due to decreased absorption of water by the seeds from the substrate of high osmotic concentration.

5. The injury of seeds by salinity was in direct proportion to the salt concentrations and the length of treatments.

6. Unsuitable environmental conditions of light, temperature, and pH further reduced the seed germination beyond that caused by salinity alone.

7. Tender seedlings and young plants of all species were less tolerant to salts than mature plants.

8. Root growth of young plants was reduced significantly at higher salt concentrations. Further reduction was noted in plants that were
non-aerated.

9. Young cattail plants were practically intolerant to salt concentration of 120 m.e./l, while fair growth of young alkali bulrush was attained at the same level. Young hardstem bulrush plants were judged to be median salt tolerant.

10. Vegetative growths such as height, diameter, leaf growth, fresh and dry weight of adult plants were severely reduced at higher salt treatments.

11. Cattail and hardstem bulrush did not flower in the greenhouse. Although flowering of the alkali bulrush was significantly reduced at the higher salinity levels, salinity around 90 m.e./l during the reproductive phase of the cycle seemed to have stimulated more seed production.

12. Salinity around 180 m.e./l seemed to have started flowering earlier and for shorter duration which brought earlier maturity in plants. Plants at higher salt treatments soon withered while control plants remained green for a considerably longer time after flowering.

13. Plants grown in salinized media developed characteristic symptoms such as dwarfness, yellowing of leaves, chlorosis and tip burn. Symptoms appeared earlier and the severity of symptoms was in direct proportion to the salt concentrations.

14. None of the adult cattail plants survived at the 220 m.e./l treatment as against 17 and 59 percent survival in hardstem bulrush and alkali bulrush at the same level. Thus, adult alkali bulrush plants were the most and cattail the least salt tolerant plants. While adult hardstem bulrush plants were median in salt tolerance.

15. Mortality rate increased and survival period decreased as the salt concentrations were raised.
16. Accumulation of sodium, potassium, calcium, and magnesium in the plants increased as the concentrations of salts in the substrate were increased. However, alkali bulrush, which was rated the most salt tolerant of the three species, eliminated magnesium, absorbed lower amounts of sodium and higher amounts of potassium. Cattail which was least tolerant behaved opposite to alkali bulrush in the absorption of ions.

17. Osmotic pressure and chloride accumulation in plant cell sap increased at significantly higher rates as the salinity of the substrate was increased.

18. Results of the greenhouse and field experiments were quite comparable, although there was considerably more variation in the field data than the plants in the controlled greenhouse experiments.
LITERATURE CITED


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