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EFFECTS OF SALINITY ON GROWTH OF SEVERAL AQUATIC MACROPHYTES[1]

WILLIAM T. HALLER,
University of Florida, Gainesville, Florida 32611

D. L. SUTTON, AND W. C. BARLOWE
University of Florida and U.S. Department of Agriculture, Agricultural Research Center, Fort Lauderdale, Florida 33314

Abstract. Growth rates of 10 aquatic macrophytes in various salinities under greenhouse conditions varied widely. Salt concentrations of 1.66‰ and 2.50‰ were toxic to *Pistia stratiotes* L. and *Eichornia crassipes* (Mart.) Solms, respectively. Salinities of 16.65‰ or higher were toxic to *Lemna minor* L., but growth of *Lemna* was increased by salt concentrations of 0.83‰, 1.66‰, 2.50‰, and 3.33‰ as compared to other *Lemna* plants grown in fertilized pondwater. Other species studied, *Hydrilla verticillata* Royle, *Myriophyllum spicatum* L., *Najas quadalupensis* (Spreng.) Magnus, *Vallisneria americana* Michx., *Azolla caroliniana* Willd., and *Salvinia rotundifolia* Willd., gradually declined in growth as salinity increased. Transpiration of the emersed growth form of *Myriophyllum brasiliense* Camb. decreased with increasing levels of salinity, but root growth was stimulated by salt concentrations of 0.83‰–3.33‰, presumably a response of the plant to overcome an internal water deficit resulting from the saline solutions.

Key words: *Aquatic plants; drought; estuary; niche; nutrients; salinity; salt tolerance; salt water intrusion; sodium chloride; transpiration.*

INTRODUCTION

The flat topography of Florida, along with its extensive system of irrigation and drainage canals, makes salt water intrusion a major factor in aquatic plant survival in coastal areas, particularly during prolonged periods of inadequate rainfall. The objectives of these experiments were to determine the salinity tolerance of the major aquatic species found along the southern coast of the United States, and to determine some effects of sublethal salt concentrations on aquatic plant growth.

Plant niche in coastal regions depends primarily on salinity tolerances in some plant species. Salt tolerances of four dune grasses on the Outer Banks of North Carolina were found to be highly correlated with salinity in the areas where each species was dominant (Seneca 1972). In contrast, salinities in the normal range of seawater had no effect on seedling growth of black mangrove, *Avicennia germinans* L. (*A. Nitida* Jacq.) on the Texas coast (McMillan 1971). Thus, plants vary in their tolerance to salinity; in species that withstand saline conditions, other factors such as water turbulence, light, nutrients, and temperature become important in determining niche.

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METHODS

Seawater was collected from the Atlantic Ocean 1 mile south of the inlet to the Port Everglades harbor at Ft. Lauderdale, Florida. The seawater (pH 6.8), which had a salinity of 33.29‰ and a conductivity of 53.8×10^3 μmhos cm^{-1} (Jacobsen and Knudsen 1940, Lyman 1969), was diluted to the desired treatment concentrations with pondwater (pH 7.3) that had a salinity of 0.17‰. The pondwater was fertilized, prior to mixing with seawater, with 3 mg NO_3, 1 mg P_2O_5, and 1 mg K_2O per liter. The pH of the final treatment solutions used in the experiments ranged from 7.22 (1.66‰) to 7.11 (19.88‰).

Pondwater was fertilized for these reasons. First, mixing two sources of water in different proportions would result in different mineral compositions; hence nutrients were added in order to reduce the chance that major elements would become limiting. This level of enrichment in pondwater was used in previous experiments, and growth was maintained over periods longer than was required for the experiments reported in this paper. The second reason for adding nutrients was that the solutions we used were most often composed of 50% or greater proportions of pondwater, and thus the nutrients in the treatment solutions were generally higher than the concentration found under natural conditions.

Plants used in these studies were collected from undisturbed populations growing in canals in the Fort Lauderdale area. Groups of the floating plants *Eichornia crassipes* (Mart.) Solms., *Pistia stratiotes* L., *Salvinia rotundifolia* Willd., *Lemna minor* L., and

TABLE 1. Growth of the submersed aquatic macrophytes *Hydrilla verticillata, Myriophyllum spicatum, Najas quadalupensis,* and *Vallisneria americana* exposed to various salinity levels for 4 wk

Salinity (S ‰)	Growth (g dry wt)[a]			
	Hydrilla	*Myriophyllum*	*Najas*	*Vallisneria*
0.17	.3638 b	.6314 c	.1936 b	.4352 b
3.33	.3991 b	.5232 bc	.1621 b	.3723 b
6.66	.2467 a	.4892 bc	.1728 b	.2552 a
10.00	—[b]	.4024 b	.0522 a	.2736 a
13.32	—[b]	.2339 a	—[b]	—[b]
16.65	—[b]	—[b]	—[b]	—[b]

[a] Each value is the mean of four replications.
[b] Plants had died and decayed during the 4-wk duration of the study.

TABLE 2. Growth of the floating aquatic macrophytes *Lemna minor, Eichornia crassipes,* and *Pistia stratiotes* exposed for 4 wk to various salinity levels

Salinity (S ‰)	Growth (g dry wt)[a]		
	Lemna	*Eichornia*	*Pistia*
0.17	3.36 a	11.64 c	7.51 c
0.83	3.83 cd	12.48 c	3.59 b
1.66	3.91 d	9.84 b	1.95 a
2.50	3.83 cd	7.19 a	—[b]
3.33	3.64 bc	—[b]	—[b]
4.16	3.47 ab	—[b]	—[b]
5.00	3.44 ab	—[b]	—[b]

[a] Each value is the mean of four replications except *Lemna,* which was replicated eight times.
[b] Plants had died and decayed during the 4-wk duration of the study.

Azolla caroliniana Willd. were selected for uniformity. Approximately 7.5, 4.7, 2.0, 1.0, and 2.0 g dry weight of each species, respectively, were placed in separate 11.4-liter containers with the salt solutions. The containers were placed in a screened shadehouse. The combination of shade, high humidity, and the rapid covering of the water surface by plant growth resulted in low evapotranspiration, generally less than 1 liter per week. Nevertheless, water levels in the containers were maintained by weekly additions of distilled water. Plants were observed visually until the end of 4 wk, at which time they were harvested and the dry weights determined.

Apical sections of the submersed plants *Hydrilla verticillata* Royle, *Myriophyllum spicatum* L., *Vallisneria americana* Michx., and *Najas quadalupensis* (Spreng.) Magnus weighing approximately 0.25, 0.25, 0.25, and 0.05 g dry weight, respectively, were planted in 5-cm plastic pots filled with a 1:1 v/v mixture of sand and muck. Three pots of each species were placed in 3.785-liter glass jars containing treatment solutions. The top of the jars were covered with clear polyethylene and placed in a growth room that maintained a 14-hr day of 1600 lumens. Room temperature was maintained at 20°C.

The emersed growth form of *Myriophyllum brasiliense* Camb. was cultured as described previously by Sutton and Bingham (1969). Plants weighing approximately 1.0 g dry weight were placed one each in 0.95-liter glass jars wrapped with aluminum foil and containing water at various salinity levels. These jars were placed in a greenhouse and plants were harvested after 4 wk. Weekly water losses were measured, and distilled water was added to restore the original volume.

Treatments were set up in a randomized complete block design. After completion of analysis of variance, treatment means were compared for significance with Duncan's multiple range test. Values within a column in the tables followed by the same letter are not significantly different at the 5% level.

RESULTS

Symptoms of salinity stress on the larger floating plants (*Eichornia* and *Pistia*) and emergent *Myriophyllum* were similar to symptoms described for terrestrial plants (Gauch 1972). Leaf margins became chlorotic; the leaves twisted and finally became necrotic in toxic concentrations. Toxicity symptoms first appeared on the older leaves and progressed to younger, more immature foliage. Frequency of occurrence and severity of symptoms were dependent on salt concentrations. The smaller floating species (*Lemna, Azolla,* and *Salvinia*) became chlorotic and, in toxic solutions, sank to the bottom of the containers. Submersed species at toxic salinity levels did not exhibit any of these characteristic symptoms but rather remained dark green as if preserved, and after 2 to 3 wk decayed and sank.

The submersed species *Hydrilla* and *Vallisneria* failed to grow in salt solutions of 6.66‰ (Table 1). *Najas* and *Myriophyllum spicatum* were more tolerant, with toxicity occurring in salinities around 10.00‰ and 13.32‰, respectively.

The floating macrophytes *Eichornia* and *Pistia* were affected by much lower salinities than were the submersed species (Table 2). Growth of *Lemna* was increased by salinities of 0.83‰, 1.66‰, 2.50‰, and

TABLE 3. Growth of the floating aquatic macrophytes *Lemna minor, Azolla caroliniana,* and *Salvinia rotundifolia* exposed to various salinity levels for 4 wk

Salinity (S ‰)	Growth (g dry wt)[a]		
	Lemna	*Azolla*	*Salvinia*
0.17	3.48 d	7.01 d	5.79 d
3.33	3.58 d	4.14 c	6.03 d
6.66	3.41 d	2.96 b	3.36 c
10.00	2.28 c	2.72 b	2.92 b
13.32	1.35 b	1.69 a	2.50 a
16.65	0.83 a	1.46 a	2.25 a

[a] Each value is the mean of four replications.

TABLE 4. Effect of salinity on the growth and transpiration of *Myriophyllum brasiliense*

Salinity range[a] (S ‰)	Growth (g dry wt)[b]			Transpiration (ml)
	Shoot	Root	Total	
0.17–0.20	1.2276 c	.2969 ab	1.5076 cd	628 d
0.83–0.96	1.1762 bc	.4313 c	1.6272 d	575 cd
1.66–1.88	1.1238 bc	.4319 c	1.5550 d	510 c
2.50–2.83	1.0396 bc	.4388 c	1.4785 bcd	503 c
3.33–3.68	0.9412 abc	.3832 c	1.3244 bc	405 b
4.16–4.56	0.8997 ab	.3667 bc	1.2753 b	377 b
5.00–5.39	0.6877 a	.2803 a	0.9680 a	294 a

[a] The salinity range is a result of measuring the transpiration weekly, and then replenishing the loss with distilled water.
[b] Each value is the mean of 10 replications.

3.33‰; however, growth gradually decreased at levels above 6.66‰ (Table 3). Dry weight of *Azolla* and *Salvinia* gradually decreased with increasing salinities.

Enclosing *Myriophyllum brasiliense* roots in a foil-covered jar made it possible to measure effects of salt concentrations on growth and transpiration at nontoxic salinities (Table 4). Total transpiration over the 4-wk period gradually decreased with increasing salinities, although growth of plant was not reduced except in the three higher salinities. Root growth was stimulated in salt concentrations of 0.83‰, 1.66‰, 2.50‰, and 3.33‰, which correspond to the concentrations that increased growth of *Lemna* (Table 2). In a separate experiment the salt concentration toxic to *Myriophyllum brasiliense* was found to be between 10.00‰ and 13.32‰.

DISCUSSION

Data in this paper deal with the effect of salinity on plants that have been transferred directly from their natural environment into saline solutions. There is some evidence that when plants are gradually subjected to increasing salt concentrations, they can survive higher salinities (Slayter 1961). It is difficult to determine the exact salinity level that is toxic to a plant, because preconditioning of the plant and possibly environmental and physiological factors alter the levels of toxicity to some degree. Consequently, these data offer a reference point, and toxic levels are probably within small ranges of the concentrations reported.

Increased growth of *Lemna* in salt concentrations of 0.83‰ to 3.33‰ suggests that comparatively high levels of sodium or chloride, or both, are required for maximum production. The importance of these elements in plant growth has become known only recently. When different plant species were placed in a sodium-enriched media, some plants failed to grow, some grew only slightly, and others exhibited a large increase in growth (Evans and Sorger 1966). Recently it has been demonstrated that sodium is required by all plants possessing the C_4 dicarboxylic acid pathway for metabolism of carbon dioxide (Brownell and Crossland 1972). Chloride is required for the photoreduction of oxygen in chloroplasts, and is an essential element in higher plants (Bollard and Butler 1966).

The decreases in transpiration and total dry weight of *Myriophyllum brasiliense* are typical responses of most plants when subjected to increasing salinities (Eaton 1942). These data concur with the theory developed for terrestrial plants, that as salinities of the substrate increase, plant metabolism is gradually affected until toxic salt concentrations are reached. Increased root growth in slightly saline solutions was probably a response of *M. brasiliense* to overcome a water deficit by increasing the root surface area.

The aquatic plants studied can be roughly divided into three groups according to salinity tolerance. The larger floating species *Eichornia* and *Pistia* were most susceptible to low levels of salinity (2.50‰). With the exception of *Myriophyllum* species, the submersed plants were the next most susceptible to increasing salinities. Concentrations toxic to this group were between 5‰ and 10‰. Salinities toxic to smaller floating species and *Myriophyllum* species ranged between 10.0‰ and 16.6‰. This grouping indicates that morphology of aquatic plants may be a factor in determining salt tolerances.

A comparison of these data to growth of aquatic macrophytes along coastlines is difficult because of the lack of this type of information. Penfound and Earle (1948) reported that *Eichornia* will not tolerate more than faintly brackish waters, and, when found near brackish waters, they are confined to the protected shorelines of inflowing freshwater streams.

Crystal River, located on the Gulf Coast of Florida, rises from a series of large springs and has a 10-km run to the Gulf of Mexico. *Hydrilla* and *Myriophyllum spicatum* are the dominant species at the head of the river. *Hydrilla* disappears in the lower portion of the river, and *Myriophyllum spicatum* becomes the dominant submersed species. The degree of salinity is apparently the reason for the demarcation between these two well-established plants, and salt tolerance is the major factor in the selection of plants surviving in the lower parts of the river.

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