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Barr Report

Barr Report

with Tom Barr, Greg Watson, and the Plant Guru Team

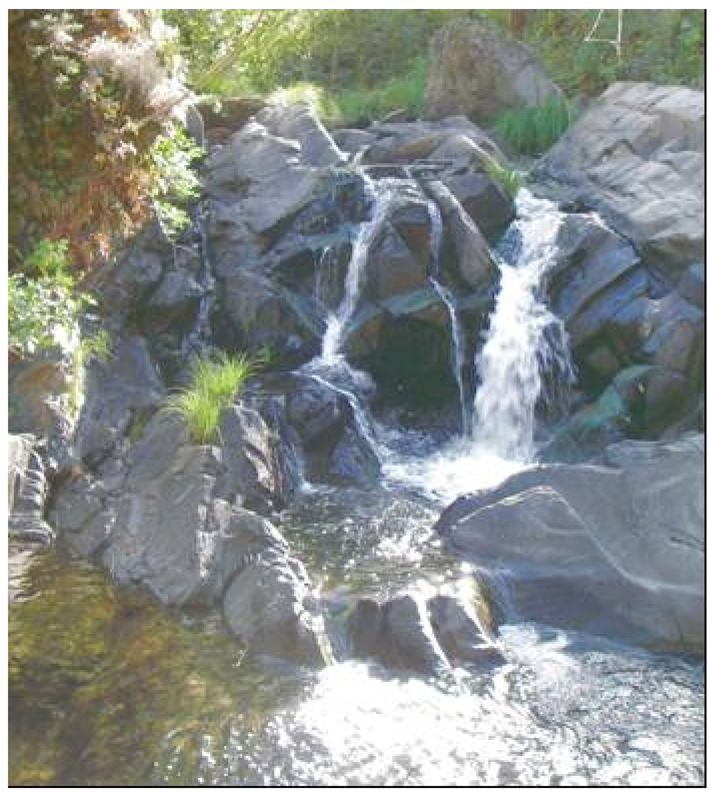
Sodium and chloride's impact on aquatic macrophytes

Special points of interest:

- Feature Article "Sodium and chloride's impact on aquatic macrophytes"
- Chloride is a required plant nutrient.
- Sodium is the sixth most abundant element on earth and is essential to all animals and some micro-organisms and plants.

Inside this issue:

We have all seen salt, sodium chloride (NaCl). We know that the sodium and chloride ions which form salt have completely different physical and chemical properties than the metal and gas from which they were formed. This difference between salt and the elemental components seems to confuse many hobbyists and well meaning folks. The component parts of ionic compounds are called "ions". Sodium chloride is an ionic compound formed when electrons from sodium atoms move to chlorine atoms (other examples include KCl etc). The sodium atom is converted into a sodium "ion" with a positive charge. The chlorine atom is converted into a chloride "ion" with a negative charge. Here are a few ideas the think about: what happens if you placed the metal sodium into water? It will react very violently and burn when exposed to water. Chlorine gas? It'll be like liquid bleach. Imagine adding these elemental compounds on your food!



A typical small waterfall in the Sierra foothills near the North Fork of the American river, California. The water coming out of the Sierra mountain range is typically extremely pure and soft from snow melt and virtually salt free.

Sodium cations are seldom confused for the sodium pure elemental metal, thus the focus will be more on chlorine. So what is the difference between a chlorine atom and a chloride anion? The chloride ion has gained an electron. The chlorine atom is very reactive for this reason. The number of electrons in a chloride ion, Cl^-, is 18, for chlorine it's 17. The chloride ion is formed when the element chlorine picks up one electron to form an anion (negatively-charged ion) Cl^-.Chlorine is very electronegative (definition: a measure of the tendency of an atom in a molecule to attract electrons to itself). In reactions to form ionic com-

Continued on page 2

Sodium and chloride's impact on aquatic macrophytes

… so what is the difference between a chlorine atom and a chloride atom? ….

The photo on the above is widgeon grass, *Ruppia maritime* is a native plant found along the entire range of both coast of the USA and AK, WI, ID and IA, reports of 4x the salinity of seawater have been reported in salt evaporation production works (Davis, 2004) for the habitat ranges and it will also grow well in hard freshwater.

"… Seachem is very good about educating the hobbyist. There are many scams and water purification schemes that are using hysteria and confusion to profit off the unwitting public. These myths should be aggressively corrected so they are not perpetuated endlessly on the internet.."

pounds, non-metals generally gain electrons. Strong affinity for these electrons is what makes chlorine so dangerous to biological systems. It will strip other atoms of their electrons, but once chloride gains an electron, it no longer has this property.
Some equate chloride and chlorine. There are those who feel their mission in life is to rewrite all our chemistry texts according to their own principles--the most important of which is that you don't do any background research. Many individuals and some environmental groups have what could be termed "chlorine hysteria"—they seem unable to ascertain the important chemical difference between chlorine and chloride. Don't feel bad, very few hobbyist know either. Further discussion can be found in a general inorganic text book on chemistry and in terms of aquariums here at SeaChem's web site:

http://www.seachem.com/support/Articles/Art_Science.html

The chloride ion has gained an electron. The chlorine atom has 17 electrons and is very reactive. The chloride atom has 18 electrons and is an essential nutrient commonly found on our dinner tables in the form of Salt (NaCl),

SeaChem is very good about educating the hobbyists and are an excellent contact for various chemistry whacky water issues that do not seem right. There are many scams and water purification schemes that are using such hysteria and confusion to make profit off the unwitting public, these myths should be aggressively corrected so that they do not perpetuate endlessly on the web and breed a new cohort of hobbyists who while well meaning, often get caught up in such myths and repeat them, wasting their time, money and further continuing the myth to the next generation of hobbyists. Educating new hobbyists is critical to the success of this hobby. Salt is one of the least understood topics in the aquarium plant hobby, therefore the goal of this article is to elucidate more in depth discussion of the available research, general concepts of NaCl and aquatic freshwater macrophytes.

Continued on page 3

Sodium and chloride's impact on aquatic macrophytes

Pelican Lake, Point Reyes national seashore, near Alamere Falls, Marin County, California. Several native aquatic plant species are found here. The ocean can be seen near the outflow and is mostly obscured by endless fog.

Chloride

Chlorine, bleach, any strong oxidizer (e.g. ozone, peroxide, potassium permanganate etc) will kill algae, bacteria cells, fish and plant tissue at high enough concentrations. Chloride is a different matter. It is a required plant nutrient. Plant roots readily absorb chloride. Although the amount of chloride required by plants for photosynthesis is met by extremely small concentrations, high rates of chloride have notably positive effects on soil/root relations, such as inhibiting the conversion of nitrate to ammonia, enhancing manganese availability, and increasing beneficial microorganisms. Chloride is an essential nutrient for plant growth and metabolism. The roles of chloride in plant nutrition could be divided into "essential" roles and "helpful" roles. The essential role of chloride in plant metabolism involves photosynthesis. Chloride is essential for the functioning of chloroplasts. Grown in the total absence of chloride, plant tissues cannot photosynthesize. Increased salinity has an inverse relationship with stomatal conductance and net photosynthetic rate (Curtis and Läuchli, 1986; Lopez et al., 2002), leading to reduced photo-assimilation and dry matter production (Rozeff, 1995; Lingle and Weigand, 1997). The "helpful" role of chloride in plant metabolism involves the maintenance of turgor in the plant. Plants maintain a positive turgor pressure by the accumulation of salutes, primarily in the central vacuole of the plant cell. These solutes can include non-ionic substances like sugars, or ionic substances like K^+, malate$^-$, and Cl^-. A comprehensive review of chloride in crop nutrition was published by Fixen (1993).

"Chloride is a required plant nutrient. The roles of chloride in plant nutrition could be divided into "essential" and "helpful" roles. Chloride plays an essential role in photosynthesis through the functioning of chloroplasts.

Continued on page 4

"… one of Chloride's major roles is to serve as a charge balancing ion to the vast number of cations present in plant cells ..."

Sodium and chloride's impact on aquatic macrophytes

A *Caulerpa* runner in Ohio Key, Florida. A macroalgae that lives in saltwater and some tidepools that can become more salty than normal seawater during evaporation.

Chloride affects physiological processes, such as osmoregulation, organic and amino acid synthesis, which also have direct effects on nutrient cycling and root exudation. Inasmuch as all these factors directly or indirectly influence the plant's ability to withstand stress and resist disease, sodium chloride may function through many mechanisms that are not mutually exclusive from each other. The majority of reports demonstrating disease suppression with NaCl fertilization have been made on monocots such as asparagus, barley, coconut, and date palm. However, dicots like beets and celery also have shown considerable benefit from NaCl. In acids soil, NaCl inhibits conversion of NH_4-N to NO_3-N presumably due to its inhibitory effect on species of *Nitrosomonas* bacteria. These are the same bacteria found in aquatic systems. Maintaining nitrogen as NH_4 can lower soil pH, change microbial populations, and alter host nutrition. In the case of marine sediments, this may play a significant role in the types of nitrogen typically available to the roots. In addition, acid soils treated with NaCl show an immediate release of soluble manganese ions. Manganese has been implicated in disease suppression probably through its effect on increasing host resistance. Since NaCl can also suppress disease and increase manganese levels in alkaline soils as well as in acid soils, it is obvious that mechanisms other than nitrification and chemical reduction of manganese must be operating.

Sodium is not known to benefit many physiological systems in plants. Chloride, on the other hand, is essential for photosynthesis and is the only inorganic anion that is not structurally bound to metabolites (K+ is similar but a cation). One of its major roles is to serve as a charge-balancing ion to the vast number of cations present in plant cells. When a cell absorbs chloride, it accumulates in the cell vacuole and lowers the cell water potential below that of the medium surrounding the cell. Water then flows into the cell and increases hydrostatic cell pressure so it maintains a pressure that exceeds the force exerted by the plasmalemma. The cells remain turgid and are able to grow even when drought conditions prevail. This was first investigated in England in the 1970's

Continued on page 5

Sodium and chloride's impact on aquatic macrophytes

when applications of NaCl increased the water capacity of the sugar beet leaves and improved growth of the plant during periods of soil moisture deficits. Similar reports of NaCl suppressing disease while reducing osmotic potentials have been made on pearl millet affected by downy mildew, wheat affected by take-all disease, and asparagus affected by *Fusarium*. Other reports have shown similar effects using KCl to suppress disease. Changes in osmotic potential affect the water cycling of plants and the exudation of carbon substrates by plant roots. These substrates serve as a food base for microbes that live on and around the root. In 1980, the possible role that beneficial *Pseudomonas* species might play in disease suppression on chloride-treated wheat plants was recognized. Studies with KCl on celery confirmed that root exudates were being altered. When asparagus plants were treated with NaCl, an increase in the beneficial *Pseudomonas* species was noted (Elmer 2003). Thus, treating salt-tolerant plants with NaCl causes a root-mediated effect on the microbial community. The major influence of NaCl fertilization on plant disease appears to be reduction of cell osmotic potential, increased manganese uptake, and enhancement of beneficial microbes via altered root exudation. Soil pH may have a governing effect on whether manganese uptake is mediated chemically or microbiologically. In acid soils (<6.6), NaCl suppresses nitrification, whereas in neutral to alkaline soils, NaCl may enhance manganese availability by altering the nutritional composition of the root exudates that, in turn, favors microbes that possess the manganese reduction trait. These mechanisms would seemingly have far-reaching effects on both foliar and root diseases. These same processes also occur in wetland sediments and marine sediments.

Plant? Marco algae? Coral? Pink Riccia? This is a beautiful red alga, *Neogoniolithon*. Ohio Key, Florida, USA.

The final resolution of NaCl's effect on plant disease, however, may require the use of genetic manipulations of chloride-sensitive plants. For example, NaCl-tolerant and -sensitive lines of *Arabidopsis* are available. Specific genes that affect sodium and chloride accumulations and partitioning in the plants could be used in studies designed to test water potential effects in the absence of manganese fluctuations and vice versa. Furthermore, transfer of particular genes that confer tolerance to NaCl into salt-sensitive plants may allow salt applications to be useful in managing these crops when stress conditions prevail. A better understanding of rates and timing of NaCl supplementation for plants at critical periods of development or pathogenesis will help agriculturalists better target NaCl nutrition, thus reducing demand on alterna-

Continued on page 6

Sodium and chloride's impact on aquatic macrophytes

tive control strategies, such as fungicides and fumigants. Many asparagus, beet, and coconut growers around the world have already adopted NaCl into their management programs. A great deal of research is now being done in this area for crop stress responses and ways to improve the crop's ability to withstand increases in salinity due to irrigation and poor soils. These stresses often enhance a pathogen's ability to attack the plants. Such stresses to aquatic plants also can allow small algae epiphytes to attach to the plants, and often cause the plants to leach out nutrients (allowing the algae epiphytes to have a good nutrient source).

Photosynthesis

A direct role for Cl in photosynthesis has been the subject of several investigations since Warburg and Luttegens (1944) first demonstrated that the water splitting system of photosystem II (PSII) required Cl. A number of studies have been conducted on isolated chloroplasts from spinach and sugar beet plants. Chloride has been postulated to act as a bridging ligand between Mn atoms during the transfer of electrons from water to PSII (Critchley, 1985), or as a structural component of the associated (extrinsic) polypeptides (Coleman et al., 1987). The importance of Cl in PSII *in vivo* has been criticized by Terry (1977). He found sugar beet growth was reduced when Cl concentrations in the leaf blades fell below 700 ppm. However, PSII was not affected even when the leaf Cl concentration fell to 35 ppm (A concentration at which severe deficiency symptoms would be expected in any species). Note: this is for internal concentrations, not external water column concentrations of Cl.

Tonoplast proton-pumping ATPase

Chloride has been implicated as being important in the function of several enzymes. The proton-pumping ATPase at the tonoplast has been show to be stimulated by Cl (Churchill and Sze, 1984). This pump is important in pH regulation of the cytoplasm and ion uptake (various nutrients). This topic has been review by Marschner (1995).

Osmotic regulation

Chloride has long been known to be important it in osmotic adjustment (Arnold, 1955). The ability of Cl to move rapidly across cell membranes and its biochemical inertness are two importance properties which make it well suited to serve as a key osmotic solute in plants (Maas, 1986). Chloride serves in this capacity at relatively low energetic cost to the plant (Sanders, 1984). If Cl is in short supply, plants may use more energy-costly organic salts for turgor control. The process of osmotic adjustment occurs when solutes such as Cl accumulate within a cell (or cell component), causing the water potential to decreases below the external potential. The resulting water potential gradient causes water to enter the cell and the plasmalemma to expand against the rigid cell water. This results in an increase in cell turgidity.
The importance of Cl osmoregulatory function on plant growth depends on its concentration in the plants. Marschner (1995) noted that at plant Cl concentrations of 0.2% (dry wt. basis), a concentration in close proximity to reported critical levels in several crops, there was insufficient Cl in the plant for it to be of great importance in the osmoregulatory function of the bulk plant tissue, unless it was partitioned preferentially into certain tissues (e.g. extension zones) or cells (e.g. guard cells). Not until plant concentrations are in the range of 1.7 to 5.3% (dry wt. basis) or 50 to 150 mM (fresh wt. basis) does Cl represent the dominant inorganic ion in the vacuoles of the entire plant. It should be noted that aquatic plants do not show wilting due to loss of turgor like terrestrial plants.

Stomatal Regulation

In selected plant species Cl plays an essential role in stomatal regulation. Opening and closing of the stomata is controlled by fluxes of K and accompanying anions such as malate and Cl. If chloroplasts in the guard cells lack the capability of producing malate, such as they do in *Allium cepa*, Cl becomes essential for stomatal functioning (Schnabl, 1980). In coconut a close correlation exists between K and Cl fluxes during stomatal opening. In Cl deficient plants stomatal opening is delayed by about 3 hr. Impairment of stomatal regulation is considered to an important factor in growth reduction of Cl deficient coconut plants (von Uexjull, 1985; Braconnier and d'Auzac, 1990).

Continued on page 7

Sodium and chloride's impact on aquatic macrophytes

Deficiency symptoms:

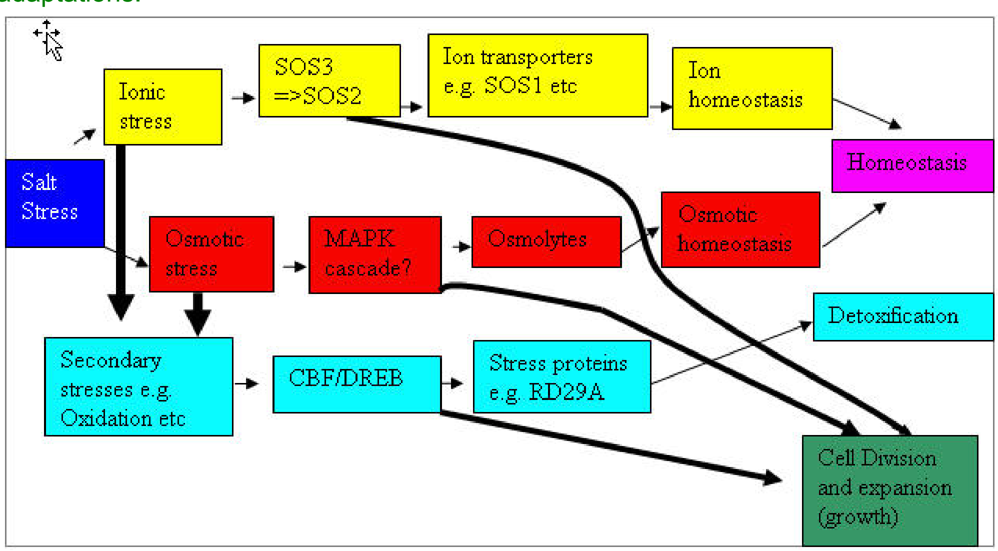
Reduction in plant biomass, wilting or curling of leaves, localized area of tissue necrosis, and abnormal root growth (extensive branching, stubby or thicken appearance) are common symptoms observed in Cl deficient plants grown in water culture. The question arises as to what role Cl plays in plant nutrition such that in its absence growth is reduced. Currently, not much is known about the physiologic role of Cl in plant nutrition. Several roles in plant metabolism have been proposed, but not all are universally accepted. In addition, many of these functions may not explain the observed symptoms of Cl deficiency in plants grown in water culture, pot experiments, or in the field. Levels less than 140 ppm are safe for most plants. Chloride sensitive plants may experience tip or marginal leaf burn at concentrations above 20 ppm. Plants with chlorine deficiencies will be pale and suffer wilting. Excesses will cause burning of tips and margins, and bronzing and abscission of the leaves.

Deficiency: Wilted chlorotic leaves become bronze in color. Roots become stunted and thickened near tips.
Toxicity: Burning of leaf tip or margins. Bronzing, yellowing and leaf splitting. Reduced leaf size and lower growth rate.

*Note, such deficiency symptoms are general and overlap with many other nutrient symptoms. Thus keep in mind the many possible options and try to rule them out step wise.

Rice is a common very well studied agricultural crop and is also an aquatic macrophyte. It feed more people than any other grain crop in the world. Salt resistant rice showed less accumulation of Na, Cl, Zn and proline (often a cell wall component) and more K+ than the salt sensitive strains when exposed to 0, 20, 30, 40 or 50 m*M* NaCl. PO4 transport was reduced in salt sensitive species (Zhu 2001). The oldest leaves accumulated more Na, Cl and decreased K+ in the salt resistant types. Plant biotypes do tend to have varying degrees of salt resistant cultivars and some aquatic macrophytes also appear to possess such adaptations.

Figure 1. This is a generalize response flow chart showing how plants maintain their growth and maintenance when salt stress is added. Adapted from Lutts *et al*, (1996) there are two main types, ionic and osmotic, the pathways have various enzymes that help the plant maintain the salt content, reduce and block salt from entering inside the plant. Some enzymes are signaling (MAPK etc), telling the plant what is in the environment and how to response to it rapidly.



Continued on page 8

Sodium and chloride's impact on aquatic macrophytes

What about aquatic macrophytes? Abiotic stresses are known to act as a catalyst in producing free radical reactions resulting in oxidative stress in various plants where reactive oxygen species (ROS) such as superoxide radical (O_2-), hydroxyl radical (·OH), hydrogen peroxide (H_2O_2) and alkoxyl radical (RO·) are produced (Scandalios, 1993; Zhang and Kirkham, 1994; Hernandez et al., 1994; Gallego et al., 1996; Weckx and Clijsters, 1997; Loggini et al., 1999; Panda and Patra, 2000; Bakardjieva et al., 2000; Hernandez et al., 2000. The toxic superoxide radical has a half life of less than one second and is usually rapidly dismutated by superoxide dismutase (SOD) to H_2O_2, a product which is relatively stable and can be detoxified by catalase (CAT) and peroxidases (Grant and Loake, 2000). Increased SOD activity is known to confer oxidative stress tolerance (Bowler et al., 1992; Slooten et al., 1995). If the production rate of the superoxide radical under abiotic stress exceeds SOD activity, then oxidative damage results (Casano et al., 1997). This is also true for humans as well; often health reports suggest antioxidants are helpful to long term health. If someone does not have enough, damage tom issues can occur. In *Hydrilla*, NaCl-salinity increased SOD activity while water stress decreased it. The SOD in *Hydrilla* also showed excellent stability at higher temperatures (45C). I've found *Hydrilla* in salt springs Florida, Cl- ranges are about 1300ppm, quite high by any standard for a freshwater plant, also found were *Potamogeton* (Now *Stucknia*), and *Vallisernia americana.*

Sodium

What happens if you place sodium metal into water!

Sodium is the sixth most abundant element on earth. Sodium is often associated with chloride; common table salt is mostly sodium chloride. Sodium is used extensively in industrial processes, food processing, and in some water softening devices. Sodium is represented in the Periodic Table of Elements as **Na**. All waters contain sodium, it is essential to all animals and some microorganisms and plants. Generally, sodium is not considered a limiting factor for freshwater plants, unless sodium concentrations reach upper levels where freshwater plants cannot survive. Plants that are salt tolerant, and Na tolerant tend to have very good gate keeping in their roots and leaves, this process keeps the salt out, and the freshwater in. As sodium concentrations increase in a water body, there can be a continuous transition from freshwater organisms to those adapted to brackish water and then ultimately to marine (saltwater) or hyper saline organisms (brine shrimps etc). In Florida lakes, sodium concentrations which ranged from 1 to over 1100 mg/L. More than 75% of these water bodies had sodium concentrations less than 13 mg/L. The higher concentrations of sodium are found in lakes located near the coast and in lakes where the groundwater entering the lakes has been in contact with natural salt deposits. Salt Springs is a natural deep water salt spring in Florida with Chloride concentrations at 1300ppm and has abundant aquatic plant life (*Potamogeton*, *Hydrilla* and *Vallisernia* mainly, although there is some *Hydrocotyle* and *Typha*). This spring is salty to the taste and has the distorted look when mixing with the freshwater. If sodium predominates in the solution calcium and magnesium may be affected (osmotic antagonism). Salt tolerant plants adopt many strategies that range from morpho-anatomical to physiological and biochemical in nature (Cheeseman, 1988; Zhu, 2001). The physiological ones include the exclusion of ions into physiologically less active parts (Schachtman and Munns, 1992), better selectivity of K^+ over Na^+ (Wilson et al., 2000), and synthesis of compatible osmotica for osmo-protection (Sakemoto and Murata, 2002). Plant tolerance to salinity may be more related to the Na^+:K^+ ratio in the cell than the absolute Na^+ concentration (Benzyl and Reuveni, 1994; Qian et al., 2001). Tolerant plants adjust osmotically by the synthesis of highly water soluble compatible osmotica (e.g. glycinebetaine, free proline, and low molecular weight sugars) and maintain turgor. Ionic imbalance occurs in the cells due to excessive accumulation of Na+ and Cl- and reduces uptake of other mineral nutrients, such as K+, Ca2+, and Mn2+ (Lutts et al., 1999). External supplied Ca+2 has been shown to ameliorate the adverse effect of salinity in plants, presumably by facilitating higher K+/Na+ selectivity (Hasegawe et al., 2000).

Continued on page 9

Sodium and chloride's impact on aquatic macrophytes

"Oh? You think you have a pruning issue in your tank?"

Excess sodium can be dangerous to plant metabolism and affects development and growth, unless it can be excluded, excreted or stored out of harms way. Exclusion/excretion can be a viable strategy for unicellular plants/algae if these cells can compensate for the osmotic potential generated by high sodium externally. This is not a viable strategy for multicellular land plants. What are their options? Exclusion can be successful if the plant internal osmotic potential is constitutively low or can be adjusted rapidly but sodium will inevitably enter the plant when the stress persists long term. A better option seems to be sodium inclusion because sodium can be used as an osmoticum. In this scenario, the path of sodium through the plant must conform certain rules: low sodium in the cytosol (although how low sodium must be seems to be species-specific), a sodium gradient from root to shoot and an effective storage capacity for NaCl.

Which genes are involved? It seems that HKT-like alkali ion transporters are responsible for influx(the gate keepers of the plant), and several other transporters share responsibilities in the distribution and long-distance flux of sodium: vacuolar sodium/proton antiporters, vacuolar sodium/inositol symporters, and plasma membrane sodium/proton antiporters. We know about phosphorylation- dependent changes in the presence and activity of these transporters and the existence of supportive biochemical pathways that regulate osmolyte synthesis and water channel activity. In many field studies, horticulturists and agronomists set out to test the hypothesis that N-fertilizer additions alleviate, at least to some extent, the deleterious effect of salinity on plants. Despite the lack of evidence indicating that N applied to saline soil or media above a level considered optimal under non-saline conditions improves plant growth or yield, a number of laboratory and greenhouse studies have shown that salinity can reduce N accumulation in plants (Pessarakli, 1991). Champagnol (1979), reviewed 17 publications and reported that, P, added to saline soils, increased crop growth and yield in 34 of the 37 crops studied. Similar to the effect of added N, added P did not necessarily increase crop salt tolerance. In most cases, salinity decreases the concentration of P in plant tissue (Güneş et al., 1999), but the results of some studies indicated salinity either increased or had no effect on P uptake. The role of K is vital for osmoregulation and protein synthesis, maintaining cell turgor and stimulating photosynthesis (Peoples and Koch, 1979). Higher levels of K+ in young expanding tissue are associated with salt tolerance in many plants (Gorham, 1993; Khatun and Flowers, 1995). NaCl also changes the anion concentrations in plants. A lowered supply of nitrite to growing leaves may be responsible for inhibition of growth under saline conditions (Hu and Scmidhalter, 1998). Maintaining an adequate supply of Ca2+ saline soil solutions is an important factor in controlling the severity of specific ion toxicities, particularly in crops which are susceptible to sodium and chloride injury (Maas, 1993). Salinity stress has stimulatory as well as inhibitory effects on the uptake of some micronutrients by plants. The uptake of Fe, Mn, Zn and Cu generally increases in crop plants under salinity stress (Alam, 1994). The detrimental effects of NaCl stress on the nutrition of bean plants are reflected in higher concentrations of Cl and Mn in roots and Cl, Fe and Mn in leaves and Cl and Fe in fruits (Carbonell-Barrachina et.al., 1998). Briefly, it is reasonable to believe that numerous salinity-nutrient interactions are occurring at the same time but whether they ultimately affect crop yield or quality depends upon the salinity level and composition of salts, the crop species, the nutrient in question and a number of environmental factors. These disorders may result from the effect of salinity on nutrient availability, competitive uptake, transport or partitioning with in the plant. For example salinity reduces phosphate uptake and accumulation in crops grown in soil a primarily by reducing phosphate availability. Salinity dominated by Na+ salts not only reduces Ca2+ availability but reduces its transport and mobility to growing regions of plant, affecting the quality of both vegetative and reproductive organs. Salinity can directly affect nutrient uptake as Na+ reducing K+ uptake or by Cl- reducing NO3- uptake. High concentration of Na+ and Cl- in the soil solution may depress nutrient-ion activities and produce extreme ratios of Na+/ Ca2+, Na+/ K+, Ca2+/Mg2+ and Cl-/NO3-. Salinity can cause a combination of complex interactions affecting plant metabolism or susceptibility to injury.

Continued on page 10

Sodium and chloride's impact on aquatic macrophytes

A new species Ondinea purpurea from northern Australia, photo courtesy of Dave Wilson.

Below are some relevant abstracts on research that has been done with respect to salt and aquatic macrophytes:

> *"The effects of light and salinity on Vallisneria americana (wild celery) were studied in outdoor mesocosms for an entire growing season. Morphology, production, photosynthesis, and reproductive output were monitored from sprouting of winter buds to plant senescence and subsequent winter bud formation under four salinity (0, 5, 10, and 15 psu) and three light (2%, 8%, and 28% of surface irradiance) regimes. Chlorophyll a fluorescence was used to examine photochemical efficiency and relative electron transport rate. High salinity and low light each stunted plant growth and reproduction. Production (biomass, rosette production, and leaf area index) was affected more by salinity than by light, apparently because of morphological plasticity (increased leaf length and width), increased photosynthetic efficiency, and increased chlorophyll concentrations under low light. Relative maximum electron transport rate (ETR_{max}) was highest in the 28% light treatment, indicating increased photosynthetic capacity. ETR_{max} was not related to salinity, suggesting that the detrimental effects of salinity on production were through decreased photochemical efficiency and not decreased photosynthetic capacity. Light and salinity effects were interactive for measures of production, with negative salinity effects most apparent under high light conditions, and light effects found primarily at low salinity levels. For most production and morphology parameters, high light ameliorated salinity stress to a limited degree, but only between the 0 and 5 psu regimes. Growth was generally minimal in all of the 10 and 15 psu treatments, regardless of light level. Growth was also greatly reduced at 2% and 8% light. Flowering and winter bud production was impaired at 10 and 15 psu and at 2% and 8% light. Light requirements at 5 psu may be approximately 50% higher than at 0 psu. Because of the interaction between salinity and light requirements for growth, effective management of SAV requires that growth requirements incorporate the effects of combined stressors." From French and Morrea, (2003).*

Continued on page 11

Sodium and chloride's impact on aquatic macrophytes

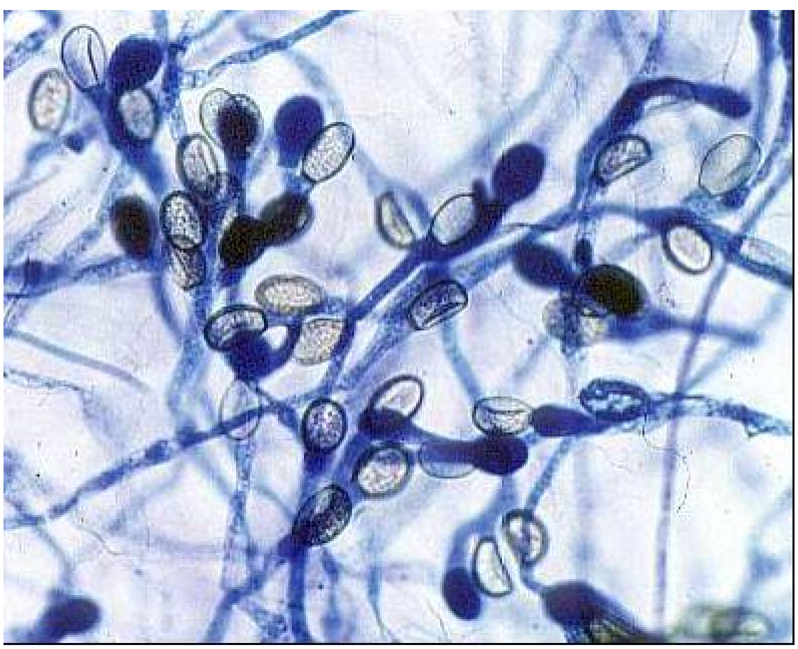
"The sublethal effects of salinity on four freshwater macrophyte species commonly found in floodplain wetlands in north-eastern Victoria (*Myriophyllurn crispaturn, Eleocharis acuta, Potamogeton tricarinatus* and *Triglochin procera*) are reported. These species taken from the same freshwater wetland showed a wide range of salt sensitivities; *P. tricarinatus* was the most sensitive followed by *M. crispatum* and then *E. acuta* and *T. procera*. A progressive depression of growth rate and plant size was observed for each species when grown at salinities greater then 1000 mg L^{-1}. The onset of these changes in growth pattern occurred earlier at the higher salinities. Both sexual and asexual reproduction was blocked in *M. crispatum* at salinities greater than 1000 mg L^{-1}, even though 52% of plants survived after 72 days growth in water of salinity 7000 mg L^{-1}." From James and Hart (1993)

Further reading:

This is an excellent older reference: Haller W. T., Sutton, D. L. , Barlow, D. C., and Effects of Salinity on Growth of Several Aquatic Macrophytes **.** *Ecology*, Vol. 55, No. 4 (Jul., 1974) , pp. 891-894

Also: Robert R. Tilley, John W. Bark, 1990, Growth of Submersed Macrophytes under Experimental Salinity and Light Conditions
Estuaries, Vol. 13, No. 3 (Sep., 1990) , pp. 311-321

Algae: Stag horn algae: *Compsopogon* appears ton have little issue with 35ppt, about that of full seawater strength (GLAZER et al, 1994). Leland et al 2001 did a good study on algae in the CA. Distribution of algae in the San Joaquin River, California, in relation to nutrient supply, salinity and other environmental factors.
What about fungi? Fungi decomposers of aquatic macrophyte litter appear well adapted to adjust their salt content internally and maintain homeostasis (Kuehn *et al*, 1998**).**



Chytrids (Chytridiomycota): These fungi are mostly aquatic, are notable for having a flagella on the cells (a flagella is a tail, somewhat like a tail on a sperm or a pollywog), and are thought to be the most primitive type of fungi.

Fungi are traditionally considered to be dominant in organic matter cycling in terrestrial environments, while bacteria correspondingly are superior in aquatic areas. However, fungi are commonly found in sea and lake water, and their importance in nutrient cycling may be higher than expected.

Most research on aquatic fungi have focused on either taxonomy or morphology, e.g. of spores, and on degradation of leaves and plant debris. Little is known about their growth physiology and ability to grow on planktonic cell remains such as dead phytoplankton cells. Presence of fungi in natural waters raise interesting questions such as (1) is occurrence of fungi in water unintended (transport into the water due to wind and rain?) (2) Do aquatic fungi form hyphae like terrestrial species and if yes, how do they cope with waves etc.? (3) Can the fungi grow on minute surfaces such as dead planktonic algae? And (4) how do the fungi survive in an environments crowed by bacteria that are expected to have a high uptake capacity for organic matter? Do aquatic macrophytes form mycorrhizal associations? Some evidence suggests that there are such associations. More research is required. Does NaCl influence fungi? Probably not.

Table 2

Sodium and chloride's impact on aquatic macrophytes

Aero-aquatic fungi in ponds - skeletonized leaf from the pond - leaf and fungi have been eaten by snails and tree-frog tadpoles. It should be noted that fungi love to go after dead leaves as a food source. Bacteria and algae also tend to do this as well.

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Sodium and chloride's impact on aquatic macrophytes

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