Halophytes and Their potential Use for Phytoextraction of Metals

By Rachael DeTar
What is a Halophyte?

- A Halophyte is a plant that can complete its life cycle in a substrate that is 1% sodium chloride (Stuart 2012). A plant that cannot tolerate this much salt is called a glycophyte.

- This type of plant is endemic to both arid soils with high salt content and saline coastal soils and waters (Stuart 2012, Manousaki and Kalogerakis 2011).
How do Halophytes handle High Salt Environments?

- There are two methods by which halophytes handle high salt concentrations.
  
  ~Avoidance- Plants simply don't allow salt into cells in the first place, or excrete it before it can to harm. Many halophytes have specialized salt glands in their leaves that move salt from the symplast onto the leaf surface. (Stuart 2012).

  ~Tolerance/Accumulation- plants can continue to metabolize and function in spite of high salt levels in cells, which is likely related to biochemical pathways that prevent oxidative and osmotic stress, and assist in safe storage of salts (Manousaki and Kalogerakis 2011). For use in phytoremediation, salt accumulators have been the focus of most studies. These species have great potential for the phytoextraction of metals.

- It is postulated that halophytes may accumulate salt for several reasons- one may be to maintain low water potential in cells (Stuart 2012). Another reason is that halophytes may be less selective about which ions they take up compared to glycophytes- they even can use Na in place of K for certain cell functions (Broadly et al 1999).
Halophytes have potential for use in Metal Extraction

- Many Halophytes often have high metal tolerance that is strongly linked to traits for salt tolerance.
- Some halophytes are also accumulators, and even hyper-accumulators of certain metals.
- Halophytes can grow in saline soils where glycophytes would die. This is important because often landfills and other toxic sites are contaminated with both metals and salts (Pastor and Hernandaz 2012).
Halophytes have Metal Tolerance due to Salt Tolerance Mechanisms

- There is overlap between the systems halophytes use for salt tolerance, and those that they use for metal tolerance. These systems include:

  ~ Antioxidant systems that are more effective at detoxifying reactive oxygen species (ROS) than those in non-accumulators (Shalata and Tal 1998).
  
  ~The production of osmoprotectants like proline to maintain water balance and scavenge free radicals (Thomas et al 1998, Manousaki and Kalgerakis 2011).

  ~Excretion from specialized salt glands onto the leaf surface. This process also occurs with certain inorganic pollutants other than NaCl (Manousaki and Kalgerakis 2011).
Antioxidants

- There are several antioxidants that are used to scavenge free radicals that are created as a result of both metal stress and salt stress.
  - Catalayse (CAT) - converts hydrogen peroxide to water and gaseous oxygen
  - Super-oxide dismutase (SOD) - scavenges singlet oxygen
  - Peroxidase - also detoxifies hydrogen peroxide and other ROS
- Halophytes like S. Branchiata up-regulate the activity of these enzymes in response to metals like Cd and Ni (Sharma et al. 2010).
Halophyte Antioxidant Systems tend to be More efficient Than those in Glycophytes

The antioxidant systems in some salt accumulator species are superior to closely related, non-accumulator species. Even within a species, salt tolerant genotypes have more efficient antioxidant systems than salt sensitive genotypes.

~Salt accumulators tend to have higher levels of activity for SOD, CAT, Peroxidase and other antioxidant enzymes.

~They may also have enzymes similar to those in their non-accumulator relatives, but often these enzymes slightly differ in structure or co-factors.

~Salt accumulators tend to have lower levels of damage to their lipid membrane from ROS when under abiotic stress.

( Olmos et al 1994, Shalata and Tal 1998)

This is important because these systems can better scavenge free radicals resulting from the red-ox properties of heavy metals, or abiotic stress in general!
Osmoprotectants

- In response to increased salt and metal concentrations in the soil, Halophytes synthesize high amounts of the osmoprotectant proline compared to glycophytes.

- Proline is an amino acid which aids in alleviating drought stress through signaling stomata to close.

- It also prevents oxidative stress by scavenging free radicals, and acts as a chelator to bind metals. (Sharma and Dietz 2006).
Osmoprotectants cont'd

- In a study with copper, a ten fold increase in copper lead to a fifteen fold increase in the concentration of proline the leaves of halophyte *M. crystallinum* (Thomas et al 1998). However, the greatest increase in proline occurred when the plants were salt stressed.

- Proline accumulates in metal stressed plant cells even when they are turgid, underscoring their additional role as an antioxidant/ chelator (Sharma and Dietz 2006).
Excretion and Accumulation

- The halophyte *Tamarix aphylla* aka the mangrove tree excretes metals like Cd, Li, Mg, and Ca onto the leaf surface from its salt glands along with Na-Cl. (Hagemeyer and Waisel 1988)

- Even in soils with high concentrations of Cd (16 ppm), the concentration of Cd in mangroves remains below toxic levels, suggesting that excretion may play a role in Cd tolerance (Manousaki et al. 2008)

- However, excretion does not appear to expel large amounts of metals (<5% of metals taken up)
Excretion- a Bane or a Boon?

- If metals can be removed from the leaf surface, the plants would not have to be clipped or harvested, thus optimizing plant growth and potentially decreasing the costs and time requirements for the phytoremediation project (Manousaki and Kalogerakis 2011).

- The downside of metal excretion is that if the plants are not treated to remove the pollutant from the leaf surface, the pollutant may wash back into the soil. Wildlife and humans may also be more likely to be exposed to the pollutant after excretion.
Halophytes that can Accumulate Metals

- *Sesuvium portulacastrum* is a halophyte with relatively high biomass that can tolerate and accumulate high levels of lead.

- This plant can accumulate 3400ug per g of dry weight. B.Juncea only accumulates 2200 ug/g dry weight!

- This halophyte may be a better all purpose phytoextractor for lead than B.Juncea.

(Zaier et al 2010)
Halophytes that can Accumulate Metals

- *M. Crystallinum* can accumulate as much as 3500 ppm of Copper in its tissue, making it a copper hyper accumulator (Thomas et al. 2008).

- However, it does not have very high biomass.
Halophytes that can Accumulate Metals

- *Atriplex Halimus* typically accumulates low concentrations of Pb and Cd, but has high biomass, making it a viable candidate for use in phytoextraction in arid, saline soils (Manousaki and Kalergarakis 2009).
Halophytes that can Accumulate Metals

- *Salicornia Maritimia* is not a metal hyper-accumulator, but is can accumulate reasonable levels of Cu and Zinc, and tolerate both moist or dry saline soils (Milic et al 2012)
When are Halophytes more useful than Glycophytes for Metal Phytoextraction?

- The primary advantage of halophytes is simply that they can grow and accumulate metals in saline, arid, or waterlogged soils that many glycophyte metal accumulators cannot tolerate (Manousaki and Kalogerakis 2011, Sharma et al).

- Some evidence suggests that certain halophytes may be more effective accumulators than glycophytes like *B. Juncea* or *Arabidopsis* even in non-saline soils (Jaier et al 2010, Jorden et al 2002).
Other Advantages

- Halophytes in the genus Salicornia produce oil that can be used in bio-fuel production, allowing the possibility to re-purpose plants used for phytoextraction (Christianson).
- Obviously, salt accumulating halophytes can also extract salt while extracting metals from the soil.
Disadvantages

- Halophytes can have low biomass compared to many glycophytes (Zaier et al 2010).
- Depending on the species, some halophytes accumulate the majority metals in their roots, making it difficult to harvest metal laden plant parts (Milic et al 2012).
- Uptake and accumulation of metals can decrease in the presence of high concentrations of Na-Cl (Lefevre et al 2009).
- On the other hand, many halophytes are most productive at above average salt concentrations, so many may not be a good choice for use on non-saline soil (Stuart 2012).
Conclusions

- Halophytes have metal tolerance mechanisms that are tied to salt tolerance. The genes for these mechanisms should be investigated, and possibly used in genetic modification projects to create a better metal accumulator.

- Some halophytes can accumulate or excrete metals, making them good candidates for phytoremediation in saline soils.

- Studies suggest that some halophytes like *S. portulacastrum* are generally better metal accumulators than *B. Juncea*. These species should be tested in the field to see if they are ideal for widespread use.
Questions

- What osmoprotectant is commonly used by halophytes to tolerate high salt and metal concentrations? (Think osmotic and free radical stress)

- True or false- All halophytes are metal hyper-accumulators.


Question Answers

• What is osmoprotectant is commonly used by halophytes to tolerate high salt and metal concentrations? (Think osmotic and free radical stress)
  ~Proline

• True or false- All halophytes are metal hyper-accumulators.
  ~False