

# Salicornia Production by Produced Water

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## PRODUCED WATER

- ▶ Produced water is a by-product of oil and gas recovery operations
- ▶ World average water to oil ratio (WOR) = 2 : 3
- ▶ TDS = 12000 mg/L to 160000 mg/L (1.2% - 16%).
- ▶ Sodium adsorption ratio (SAR) = 5 - >32
- ▶ Oil and Grease = 25 mg/L to 5000 mg/L (0.0025 - 0.5%)
- ▶ Typically found inorganics in produced waters include zinc, lead, manganese, iron, and barium.



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## MANAGING PRODUCED WATER

- ▶ Deep Well Injection
- ▶ Enhanced Oil Recover
- ▶ Water Treatment including:
  - Reverse osmosis systems (very costly)
  - Wetlands (sustainable and practical)



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## WET LANDS VS DEEP WELL INJECTION

- ▶ Energy consumption to treat produced water:
  - Wetland treatment = 0.06 kWh per m<sup>3</sup>
  - Deep well injection = 3.6 - 5.5 kWh/m<sup>3</sup>
- ▶ Saving of 98.3 - 98.9 %
- ▶ Reduction in CO<sub>2</sub> emissions
- ▶ Wetlands also provide a valuable habitat for migratory bird



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## NIMR REEDBED WATER TREATMENT PROJECT

- ▶ The NIMR oilfield requires 250,000 m<sup>3</sup>/d of water to be managed
- ▶ One of the largest constructed wetland systems to manage more than **45,000 m<sup>3</sup>/day**
- ▶ System consists of a passive oil-water separator
  - ▶ **234 ha** of surface flow wetlands and
  - ▶ **300 ha** of evaporation ponds
- ▶ During 2012, **120 ha** were added to wetland to increase the treatment capacity of the plant to **95,000 m<sup>3</sup>/day**.

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## NIMR REEDBED WATER TREATMENT PROJECT

- ▶ Project is able to recover as much as **>200 bbl/d** of oil from the produced water
- ▶ The oil content in the produced water reduced from **400 mg/L** to **<0.5 mg/L**
- ▶ Reduced the energy footprint by **80%**
- ▶ Expected salt production of **0.21 million m<sup>3</sup>/year**
- ▶ The wetlands provided a habitat for migratory birds of **100 bird species**

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## DOES WETLAND PROVIDED FULL SOLUTION TO PRODUCED WATER PROBLEM?

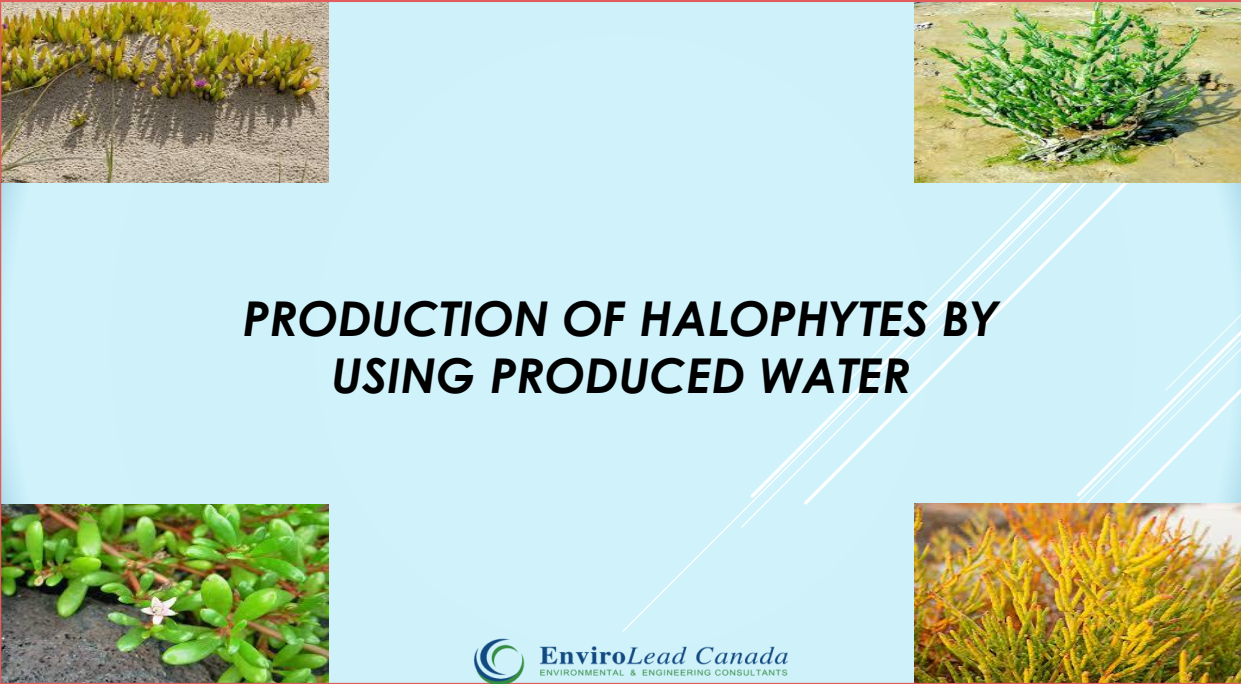
- ▶ No! ... Why:
  - ▶ **Wetland treated the hydrocarbons but not the salinity leaving behind highly saline water**
    - ▶ Incoming water salinity = 6180 mg/L
    - ▶ Outgoing water salinity = 10460 mg/L
    - ▶ **59% higher than the untreated water**
  - ▶ For which evaporation ponds are used to evaporate the water.

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## WHAT TO DO WITH HIGH SALINITY PRODUCED WATER?

- ▶ Water is life and its value is tremendous in desert areas of the World
- ▶ It is “Blue Gold” if oil is “Black Gold”
- ▶ There are other uses of this water including
- ▶ Aquaculture and
- ▶ Production of halophytic plants (hydroponics or soil based production)

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## PRODUCTION OF HALOPHYTES BY USING PRODUCED WATER

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# HALLOPHYTS

Plants that naturally possess the traits needed to grow and reproduce on saline soils at 200 milli moles are termed as halophytes.

Plant Order: Caryophyllales



21.4 % halophytic spp



Family: *Amaranthaceae*



Genus: *Salicornia*



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# SALICORNIA

**Salicornia consists of highly salt tolerant annuals without salt glands/salt bladders (Flowers et al., 2010).**

**Salicornia has been "selectively developed" since early 1980's in Mexico's Sonora state, on the edge of the Gulf of California.**



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## SALICORNIA

- Worldwide, there are  $130 \times 10^6$  ha of land ( $0.5 \times 10^6$  miles<sup>2</sup>) = land under conventional irrigation today, which can be brought under Salicornia cultivation.
- Salicornia crops had been grown successfully in trial plots in the United Arab Emirates, Egypt and Kuwait, as well as in Jubail, Saudi Arabia.



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## SALICORNIA

In Behar Project of Saudi Arabia about 100 tons of Salicornia crop was used as forage for dairy herds, and exploring the possibility of air-shipping the crunchy green tips of Salicornia to wholesalers.

Historically, Salicornia was known for its digestive and anti-flatulent properties. It also contains diuretic and depurative properties and is rich in I, P, Ca, Si, Zn, Mn and vitamins A, C and D.



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## SALICORNIA RESPONSE TO SALINITY

- In low salinity, the cell electro potential of *Salicornia* root cells were found to respond to inhibitors in a fashion similar to that observed in glycophytes
- In high salinity, root cell membrane potential appears to be insensitive to bathing salinity and *m-chlorocarbonylcyanide phenylhydrazone* induces membrane hyperpolarization
- $\text{Cl}^-$  and  $\text{Na}^+$  are apparently accumulated at the expense of metabolic energy by *Salicornia* roots



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## SALICORNIA GROWTH IN SALINE WATER

The halophytic species of the *Amaranthaceae* family have generally the highest  $\text{Na}^+ : \text{K}^+$  ratios, which are detrimental to most other species.

*Salicornia dolichostachya* possesses a mechanism to specifically absorb  $\text{K}^+$  in the presence of high external  $\text{Na}^+$  levels.

*Salicornia dolichostachya* showed optimum growth at 300 mM NaCl in the root medium.



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## SALT TOLERANCE OF SALICORNIA

Plant Species	Salt Concentration (mM) at which germination reduced from 75 to 100%
<i>Salicornia brachystachya</i>	240
<i>Salicornia bigelovii</i>	1000
<i>Salicornia brachiata</i>	600
<i>Salicornia dolistachya</i>	240
<i>Salicornia europaea</i>	850
<i>Salicornia herbacea</i>	1700
<i>Salicornia pacifica</i>	860
<i>Salicornia patula</i>	340
<i>Salicornia persica</i>	>500
<i>Salicornia rubra</i>	1000
<i>Salicornia virginica</i>	600

Khan and Gull, 2006

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## SALICORNIA PRODUCTION USING NIMR TREATED WATER

- Salinity of NIMR wetland project = 10140 mg/L which is = approximately 1 % salts or 174 mM.
- Seawater in the world's oceans has a salinity of about 35000 mg/L, or 3.5% (599 mM).
- Optimum growth of salicornia is achieved at 300 mM or 17529 mg/L or 1.75% salts.
- The above mentioned concentrations clearly show that the NIMR project treated water can successfully be used for salicornia production.

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## SALINE WATER COMPOSITION

Salinity	Sea Water	Produced Water NIMR	Optimum Salicornia Growth	Brackish Groundwater
ppm	35,000	10140	17529	3000
%	3.5	1	1.75	0.3
mM/L	599	174	300	51.48



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## SALICORNIA PRODUCTION SYSTEMS



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# AQUACULTURE

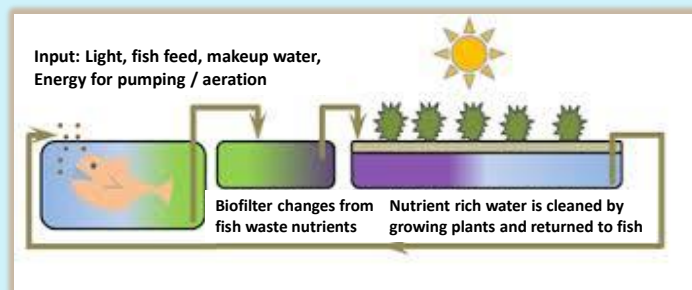
- ▶ The term aquaculture refers to the cultivation of both marine and freshwater fish species
- ▶ A rich protein food source for humans
- ▶ Aquaponics – Integration of Aquaculture with Hydroponics
- ▶ Enrichment of produced water with nutrients needed for plant production i.e. production of salt tolerant (halophytic) plants



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## SMALL SCALE SALICORNIA PRODUCTION THROUGH AQUAPONICS

**Aquaponics = Aqua culture + hydroponics**



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## SMALL SCALE SALICORNIA PRODUCTION

Green House Production

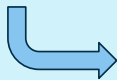


Bigger Green House



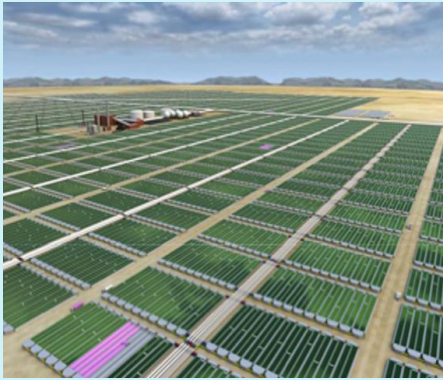
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## SALICORNIA BY DRIP IRRIGATION



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## LARGE SCALE SALICORNIA PRODUCTION



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## HYDROPONIC SALICORNIA



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# LARGE SCALE SALICORNIA PRODUCTION

Somalia



Eritrea



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## NUTRITIONAL VALUE OF SALICORNIA

**Glycolipids**

**Phospholipids**

Monogalactosyldiacylglycerol (MGDG)

Phosphatidylcholine (PC)

Sulfoquinovosyldiacylglycerol (SQDG)

Phosphatidylethanolamine (PE)

The slide features four chemical structures of lipids found in Salicornia. The top-left structure is Monogalactosyldiacylglycerol (MGDG), showing a glycerol backbone with two fatty acid chains (R1 and R2) and a galactose sugar. The top-right structure is Phosphatidylcholine (PC), showing a glycerol backbone with two fatty acid chains (R1 and R2) and a choline head group. The bottom-left structure is Sulfoquinovosyldiacylglycerol (SQDG), showing a glycerol backbone with two fatty acid chains (R1 and R2) and a sulfated quinic acid head group. The bottom-right structure is Phosphatidylethanolamine (PE), showing a glycerol backbone with two fatty acid chains (R1 and R2) and an ethanolamine head group. The EnviroLead Canada logo is at the bottom center.

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## SALICORNIA COMPOSITION

Crude protein	Ether	Crude fiber	Gross energy	Oil Content	Protein
g kg <sup>-1</sup>			MJ kg <sup>-1</sup>	%	
340	64.5	36.0	19.4	26-33	33

*Attia F. M . Et al 1997*



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## SALICORNIA VS OTHER OILSEED CROPS

Salicornia	Cotton seed	Soybean
Fatty Acids %		
26-33	15- 24	17-21
Salicornia fatty acid composition		
polyunsaturated fatty acids	Oleic acid (Omega 3)	Linoleic acid (Omega 3)
19.98	12-17	76-80

*Elsebaie et al 2013*



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## MARKETING OF SALICORNIA PRODUCTS




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## SALICORNIA RECIPES



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## SALICORNIA RECIPES



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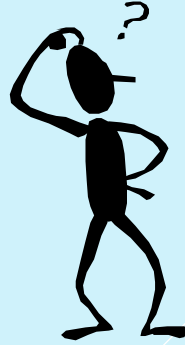
## SALICORNIA MARKETING



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# Questions

No question is a silly question



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Done



# Thank You



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