Saline Aquaponics opportunities for integrated marine aquaculture

E. Pantanella*, G. Colla

International aquaponic conference:
Aquaponics and global food security
19-21 June 2013
University of Wisconsin-Stevens Point
Presentation outline

• Introduction
  – Marine aquaculture
  – Integrated multitrophic aquaculture (IMTA)
  – Integrated aquaculture
  – Aquaponics/RAS at a glance

• Saline aquaponics/saline agriculture
  – Potentials for fish and plant integration
  – Research issues in saline plant production
  – Research experiences in saline aquaponics

• Conclusions
Leading issues in seafood production

- Fishing (capture) is a limited resource (in Italy it covers only 1/3 of the market demand)
- Marine fish is sometime preferred to freshwater
- What can I produce ↔ what can I sell?
- Development of marine aquaculture is the key, but wastewater is a resource or pollution?
- Increasing food demand: need to find new areas not vocated for agriculture to produce food (islands, desert, coastal areas) and with water with lower quality (saline)
Marine aquaculture

Cage aquaculture is apparently an easy management...

- No aeration like pond/tank
- Environmental/sea conditions
  - Moorings/streams/tides/waves
  - Ruptures
- Pollution is not properly accounted
- Competition with other water uses (tourism, navigation)
- Fouling/manintenance
- Parasites/health management/polluted water
- Escapees
Integrated marine aquaculture

Multitrophic aquaculture

Use of fish, algae and molluscs

- Management in open water
- Pollution/environmental risks (fish $\rightarrow$ env, env $\rightarrow$ fish, escapees)
- Partial reuse of nutrients
- Easy management
- Conflicts with other coastal uses
Integrated aquaculture

Open systems

- **Low nutrient** levels (below 5-10 ppm)
- Fish water and fish wastes **integrate but not substitute** common crops’ fertilization practices
- **Extensive/semi-intensive** mgt.
  - Horticulture, crops
  - Wetlands (land demanding)
  - Coastal restoration - mangroves
Integrated aquaculture

Closed systems (aquaponics)

- Full reuse of inputs and water
- Higher nutrient levels
- Higher environmental control
- Intensive management (higher productivity per acreage)
- Higher quality of productions (no residues)
- Lower health risks than open water (parasites, chemicals, pollutants)
Aquaponic system management

Continuous flow

Discontinuous flow
suitable in cold climates with warmer fish and when there are different temperature needs between plants and fish

Needs supplementary biofiltration
Aquaponics vs RAS

Recirculating Aquaculture Systems

- 10-150 gal water dumped per pound feed

Potential for dumped water to be used in **Open recirculating systems or hybrid RAS**
Open recirculating systems

Fish tank

Drum filter

Fish solid removal unit

Aerobic stage (biofiltration) $\text{NH}_4 \rightarrow \text{NO}_3$

Anaerobic stage (Denitrification) $\text{NO}_3 \rightarrow \text{N}_2$

Water line

Pump

Nutrient build-up

Dumped water 10-20% daily

Drip irrigation

Soil - Soilless

New water
Hybrid RAS

Fish tank

Drum filter

Fish solid removal unit

Aerobic stage (biofiltration) $\text{NH}_4 \rightarrow \text{NO}_3$

Anaerobic stage (Denitrification) $\text{NO}_3 \rightarrow \text{N}_2$

water line

pump

Plant trough (water reclamation)

Nutrient-free water

Dumped water 10-20% daily

Nutrient build-up
saline aquaponics
saline agriculture
Saline Aquaponics - Rationale

- Expansion of agriculture in saline or arid lands/greening the desert...
- Use of brackishwater from geothermal or from salt affected aquifers
- Development of marine aquaculture on land to avoid seawater pollution or health hazards to fish
- Use of by-products to reduce the carbon footprint in food production systems
- Shorten the distance/needs between seafish and plants’s needs...
Saline aquaponics - Fish

Marine fish are only adapted to marine conditions…

• Production at low salinity (5-7 ppt) is possible for some marine fish (e.g. European seabass).
• Asian seabass can grow with freshwater
• Seabream can grow at 10 ppt
• Marine fish are more performing in iso-osmotic conditions due to lower energy used to counterbalance the osmotic pressure
Integrated saltwater aquaculture

HORTICULTURE / CROPS

• Production of higher quality, but lower yields than freshwater
• Tailored agronomic strategies are needed (we see them later)

Cherry tomato production in Italy
Increase of salinity in irrigation water at fruiting enhances: shelflife (thicker skin), higher DM, higher taste (sugar and acidity)
Integrated saltwater aquaculture

Use of HALOPHYTES for:

- Food
- Animal feed
- Oil/fuel

- Production can be higher in saline conditions than freshwater
- Market potentials

Salinity (ppt):

| 1-5 | 5-10 | 10-15 | 15-20 | 20-25 | >25 |

Salsola spp

Salicornia
Halophytes – grain

Quinoa

• 2nd most used crop in mesoamerica (after potato and before maize)
• Grain production up to 65% of plant weight
• 2x proteins than wheat 2.5 MT/ha very rich in EA
Halophytes – grain

Eelgrass (*Zostera marina*) (gulf of California) comparable to wheat (starch 50%, 13% protein, 1% fat)

• Palmer saltgrass (*Distichlis palmeri*) is endemic to northern Gulf of California tidal marshes flooded with hypersaline (38–42 PPT) water.

• Flour similar to wheat but 8.7% protein vs 13.7%. Proteins well balanced in ammino acids)
Halophytes - grain

- **Pearl millet** (*Pennistum typhoides*) tolerates irrigation of EC of 27-37 dS/m. (up 20 PPT) It can provide 1.6 MT/ha and 6.5 MT/ha as fodder

- **Seashore mallow** (*Kosteletzkya virginica*) can reach 1.5 MT/ha with water at 2.5% salt (25 PPT). It is high in protein (32%) and oil (22%)
Halophytes – leaf/fodder

*Kochia scoparia*
- Seeds are eaten as a food garnish called **tonburi**. Its texture is similar to caviar, it is called "field caviar" and "mountain caviar"
- used in traditional Chinese medicine.
- useful forage for livestock

*Sea fennel (Chrithmum maritimum)*
- Has a number of uses in the culinary field. Asparagus flavour. Contain about thirty essential oils, such as gamma terpins
Halophytes – leaf/fodder

- *Atriplex triangularis* (similar to spinach)

- Common purslane (*Portulaca oleracea*)
Halophytes – leaf/fodder

- *Salsola spp*
- Seabeet (chard) *Beta maritima*
- *Salicornia spp*
- *Mesembryanthemum spp*
- *Atriplex spp.*
Algae for food

May need a different management (example hybrid RAS + sterilization)

- Spirulina
  - rich vegetable protein (60~63% 3~4 times higher than meat)
  - multi Vitamins
  - Wide range of minerals
  - 5x more Vit A than carrots

- Clorella

- Nori Japanese seaweed for sushi
Research issues in saline plants
Salinity problems in plants

- Direct sodium toxicity at root and plant level
- Reduced growth due to increased difficulties to take up water/nutrients (→ osmotic pressure)
- Higher water stress
Strategies for salt management

Higher salinity $\rightarrow$ higher osmotic pressure
$\rightarrow$ Higher effort to drink $\rightarrow$ Less liquid taken

Any drinker cannot replace all the water lost unless we..

1) modulate the environmental conditions so that the drinker needs less water to compensate evaporation (less sweat) or can “lean the straw” to drink a bit more
2) Give concentrated liquid to let the drinker have the same amount of nutrients
3) Treat the drinker with anti stress factors
4) Change the drinker with one more tolerant to stress
(1) modulate the environmental conditions

- Shadow/temp/humidity control to reduce evapotranspiration and/or to avoid the closing of stomata in leaves
- Change salts balances to more tolerant ones suitable for both fish and plants
- Watering strategies (flushing)
Advances in plant research/management

(3) Uses of anti-stress factors

- Vitamins
  - Antioxidants
  - Stress inhibitors/plant hormone inducers
- Methilene blue*
  *methylene blue enhances mitochondrial function
(4) Use of resistant plants

• Use of resistant species/varieties
• Use of salt resistant roots and adopt the grafting technology:
  • Plant from a commercial variety
  • Root from a resistant variety
Plant grafting

- Grafting used for
  - tomato
  - eggplant
  - pepper
  - cucumber
  - melon
  - watermelon
- Cross species is possible
- In Europe at least 20% of plants are grafted
- Grafting used mostly to overcome soil borne diseases (geodisinfectant – methil bromide) or favor nutrient absorption from soil
Plant grafting for salt resistance

Grafting bypasses the need to develop complex geneting selection programmes to transfer the resistance traits to a commercial varieties

- Present research mostly use GMO rootstocks, specifically targeted for salt resistance
- Trials in literature for tomato fruiting at 75 mmol NaCl (1.3 ppt)
- But... why not using wild varieties already available in nature?
Saline aquaponics research

Eureka aquaponic experimental center
Research rationale

• Assess the production and quality of salt tolerant plants (halophytes) under low-medium-high salinity (10 → 20 ppt) and different nitrogen concentrations

• Assess production and quality of traditional horticultural plants under low salinity levels (3.5 – 7.0 ppt)
  – Tomato
  – Basil
  – Peppermint
  – Water spinach
  – Salsola kali
  – Sea beet (Swiss chard)
Salsola spp

- *Salsola* spp is widespread in the world
  - In Italy and Japan is a high-value salad
  - In the Middle East is a native plant that can be used as fodder
- Species used *S. soda* (Italy) *S. kali* and *S. Komarovii* in north Europe or Japan
- In Italy it is worth 2€/kg at wholesale markets up to 4.5 €/kg for off-season retail markets
**Salsola spp**

- Great historical importance → ashes from *Salsola soda* are very rich in sodium carbonate (soda ash, up to 30% in weight) used in the glass industry.
- Widely used worldwide, also as fodder (alternative feed for animals in drylands).
- Salsola is halophyte but optimal growth can be achieved within certain salinity levels.
**Salsola spp**

*Salsola soda* tested at:
1st crop: 5 vs 10 ppt
2nd crop: 10 vs 20 ppt
3rd crop: 10 vs 30 ppt
Average NO3 concentrations 25 mg L⁻¹ (1st crop) 40 mg L⁻¹ (2nd and 3rd crop)
Salsola spp

- Best growth from aquaponics at 10ppt (outperforming hydroponics), but still good growth at 20ppt (similar to hydroponics)

10 USD (wholesale)
22.7 USD (retail)
per m2 every 28 days!
Salicornia spp.

Raw

processed

extracted

By-products

Feed (as kelp substitute in sea urchins’ diets)

Biofuel - seeds
(Salicornia bigelovii)

Animal feed
(seed meal)
Salicornia

- Grows in marshlands by the sea
- Resistant to high salinity.
- Used as food, feed and biodiesel (seeds)
- Plant tested at 9 (LS) and 18 ppt (HS) on both sand beds or floating systems
Faster growth from sand sub-systems

Stunted growth visible in both sub-systems

Low salinity

high salinity

45 DAT
Crop growth

Yellowish leaves in floating sub-system

Aquaponics LS

Accelerated plant maturity

Aquaponics HS

66 Days after transplant

Sand: growth pace increases. Floating: yellowish leaves
Salicornia

- Growth is optimal above 50 mg L\(^{-1}\) of nitrogen in aquaponic water.
- Higher salinity reduces the growth pace

Mullet-tilapia polyculture
FCR: 1.6 (LS), 1.9 (HS).
SGR: 1.02 (LS), 0.75 (HS)
Salicornia nutritional quality

- **Floating sub-systems**: higher CP and ash but lower fiber & fat than sand systems
- **Aquaponic sand systems** showed no differences in CP and fat between LS and HS, but LS had higher fiber content and lower ash
- **Hydroponic sand systems** showed lowest CP values due to accelerated plant maturity, but fat levels were similar to aquaponics

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crude Protein (%)</th>
<th>Crude Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salicornia HS float</td>
<td>21.4 ± 1.4 c</td>
<td>1.7 ± 0.1 a</td>
</tr>
<tr>
<td>Salicornia HS sand</td>
<td>15.7 ± 0.8 b</td>
<td>3.2 ± 0.6 b</td>
</tr>
<tr>
<td>Salicornia LS float</td>
<td>20.2 ± 1.0 c</td>
<td>1.7 ± 0.0 a</td>
</tr>
<tr>
<td>Salicornia LS sand</td>
<td>16.4 ± 1.3 b</td>
<td>3.9 ± 0.3 b</td>
</tr>
<tr>
<td>Hydroponics LS sand</td>
<td>10.7 ± 0.3 a</td>
<td>3.2 ± 0.8 b</td>
</tr>
</tbody>
</table>

Significance: ***
Seabeet (chard)

- Salt in water enhances plant taste
- Salt in leaves may also enhance the shelf life
Seabeet (chard)

- 1st test at 20ppt (32dS m\(^{-1}\)), 10ppt (20dS m\(^{-1}\)) with N at 90-110 ppm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yields (kg m(^{-2}))</th>
<th>% dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st crop</td>
<td></td>
</tr>
<tr>
<td>aquaponics 20 ppt</td>
<td>0.3 ± 0.0 a</td>
<td>8.5 ± 0.2 c</td>
</tr>
<tr>
<td>aquaponics 10 ppt</td>
<td>2.6 ± 0.2 b</td>
<td>6.8 ± 0.2 b</td>
</tr>
<tr>
<td>hydroponics</td>
<td>6.1 ± 1.3 c</td>
<td>5.7 ± 0.5 a</td>
</tr>
</tbody>
</table>

Significance: ***
Seabeet (chard)

2 Tests @ 7ppt (14.5dS m$^{-1}$) and 3.5 ppt (8.5dS m$^{-1}$)

- 2nd crop $\rightarrow$ At higher salinity yields are low with 20 ppm of Nitrogen

- 3rd crop $\rightarrow$ at higher salinity yields get closer to other treatments with 80 ppm of Nitrogen

<table>
<thead>
<tr>
<th></th>
<th>2nd crop</th>
<th>3rd crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>aquaponics 7.0 ppt</td>
<td>1.1 ± 0.1 a</td>
<td>1.7 ± 0.3</td>
</tr>
<tr>
<td>aquaponics 3.5 ppt</td>
<td>3.5 ± 0.7 b</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td>hydroponics</td>
<td>4.1 ± 1.7 b</td>
<td>2.9 ± 1.1</td>
</tr>
</tbody>
</table>

Significance
- *  
- **3**

<table>
<thead>
<tr>
<th></th>
<th>2nd crop</th>
<th>3rd crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>aquaponics 7.0 ppt</td>
<td>8.1 ± 0.2 b</td>
<td>7.8 ± 0.3 b</td>
</tr>
<tr>
<td>aquaponics 3.5 ppt</td>
<td>5.8 ± 0.4 a</td>
<td>6.5 ± 0.3 a</td>
</tr>
<tr>
<td>hydroponics</td>
<td>6.1 ± 0.4 a</td>
<td>6.4 ± 0.6 a</td>
</tr>
</tbody>
</table>

Significance
- *  
- ns
Sweet basil

- Salinity (3.5ppt and 7.0 ppt) does not cause toxicity problems, but reduces yields.
- Quality enhancement (LS ratio) observed with salinity

Strategies adopted

- Climatic control
- Higher density (up to 3 times → 120-150 plants m\(^{-2}\))
- Plant conditioning
## Sweet basil

Plant conditioning (training the plant to cope stress)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant weight (g plant$^{-1}$)</th>
<th>L/S ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquap 0, norm</td>
<td>39.9 ± 3.9 a</td>
<td>2.0 ± 0.1 a</td>
</tr>
<tr>
<td>Aquap 0, cond</td>
<td>57.0 ± 13.3 b</td>
<td>1.9 ± 0.1 a</td>
</tr>
<tr>
<td>Aquap 3.5 ppt norm</td>
<td>26.3 ± 2.8 a</td>
<td>2.5 ± 0.1 b</td>
</tr>
<tr>
<td>Aquap 3.5 ppt cond</td>
<td>31.6 ± 4.5 a</td>
<td>2.3 ± 0.1 b</td>
</tr>
</tbody>
</table>

**Significance:**

- **:**
- ***:**
Sweet basil

- Saline conditions, lower yields but density can be enhanced by **3 times** → close yields to freshwater hydroponics (still **20-35%** less)… But plants give **30% more leaves**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant weight (g plant⁻¹)</th>
<th>yield (kg m⁻²)</th>
<th>L/S ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquap 7.0 ppt norm</td>
<td>5.2 ± 0.9 a</td>
<td>0.8 ± 0.1 a</td>
<td>2.7 ± 0.2 bc</td>
</tr>
<tr>
<td>Aquap 7.0 ppt cond</td>
<td>6.4 ± 1.7 a</td>
<td>1.0 ± 0.3 a</td>
<td>3.3 ± 0.8 c</td>
</tr>
<tr>
<td>Aquap 3.5 ppt norm</td>
<td>13.0 ± 1.8 a</td>
<td>2.1 ± 0.3 b</td>
<td>2.1 ± 0.1 ab</td>
</tr>
<tr>
<td>Aquap 3.5 ppt cond</td>
<td>15.4 ± 5.2 a</td>
<td>2.5 ± 0.8 bc</td>
<td>2.2 ± 0.4 ab</td>
</tr>
<tr>
<td>Hydroponics</td>
<td>57.7 ± 15.0 b</td>
<td>3.2 ± 0.8 c</td>
<td>1.7 ± 0.1 a</td>
</tr>
</tbody>
</table>

Significance

- ***
- **
- *
Strategies for fruity crops

TOMATO

• Use of self grafting or salt-resistant wild rootstocks to cope with salt
• Salinity increases % dry matter in fruits, sweetness (°brix, +10-30%), acidity and ascorbic acid (Vit C) content (+20-100%) depending on the rootstock used
• All these are quality traits expected by the industry
• Other strategies refer to climatic control and N/K/Na balances
Conclusions/remarks

• Saline aquaponics can be a viable production system in arid or salt affected zones
• Horticultural plants can be cropped in saline conditions providing that appropriate agronomic strategies are used
• Traditional aquaponic design may need to be adjusted
• Lower production but quality is enhanced
• Bringing sea fish into the coastlines or desert is possible
Thanks for your attention

edpantanella@gmail.com