

Appendix A

Overseas Travel Report

Aquaculture



Overseas Travel Report: Inland Aquaculture Study Tour USA and Israel, October 2004



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Introduction

The Australian inland aquaculture industry (freshwater and saltwater) for fish production is still in its infancy compared to countries such as Israel and the United States of America (USA). SARDI has a new research project titled ‘Research to foster investor attraction and establishment of commercial Aquaculture Parks aligned to major saline groundwater interception schemes in South Australia’ funded by the National Action Plan for Salinity and Water (NAP) through the Centre for Natural Resource Management (CNRM). At this site to be known as the Waikerie Inland Saline Aquaculture Centre (WISAC), saline groundwater from Woolpunda, Waikerie and Qualco salt interception schemes (SIS’s) will be investigated for use in managed systems suitable for commercial aquaculture. The Woolpunda, Qualco and Waikerie SIS’s divert 30 ML/day of saline groundwater away from the River Murray to the Stockyard Plains Disposal Basin. This water has a yearly temperature of 20-24 °C with a salinity of 18-19 g/L. R&D, demonstration and training activities conducted at the WISAC will endeavour to maximise productivity from this wastewater stream through optimising retention of water temperature using the most applicable technologies identified largely by outcomes of this overseas study tour in combination with other information available. It was agreed that an audit of technology being used for inland aquaculture in these countries should be conducted before constructing a demonstration/pilot scale facility near Waikerie, SA.

The main aims for the overseas study tour were:

1. Examine the production methods and systems for culturing fish and crustaceans using fresh and brackish water in hot arid environments.
2. Examine wastewater discharge methods for land-based aquaculture.
3. Identify and conduct an audit of production systems that can be imported to Waikerie, South Australia to make best use of saline groundwater available from SIS’s.
4. Establish links and Memoranda of Understanding to foster future collaboration between SARDI and overseas organisations that will benefit both countries.

After several months of liaising with researchers and staff of commercial facilities in Israel and the USA, a 25 day itinerary (Table 1) was developed. Due to time constraints and available funds, Tim Flowers travelled to the USA on his own (5/10 – 17/10/2004), then met up with Wayne Hutchinson in Israel (18/10/2004 – 29/10/2004).

Appendix A – Overseas Travel Report.

Table 1. Itinerary for USA and Israel Overseas Technology Audit, 5th-29th October 2004.

Date	Depart	Arrive	Visit
5th Oct	Adelaide, Australia	Tucson, Arizona	
6th Oct	Tucson, Arizona		Inland Shrimp farms
7th Oct	Tucson, Arizona		Inland Shrimp farms
8th Oct	Tucson, Arizona	Phoenix, Arizona	University of Arizona
9th Oct	Rest Day		Rest Day
10th Oct	Phoenix, Arizona	Montgomery, Alabama	Travel to Inland Shrimp farms Demopolis
11th Oct	Alabama		Inland Shrimp and Catfish farms
12th Oct	Montgomery, Alabama	Raleigh, North Carolina	Auburn University
13th Oct	Raleigh, North Carolina		Hybrid Striped Bass culture
14th Oct	Raleigh, North Carolina		Southern Farm Tilapia
15th Oct	Raleigh, North Carolina	London, England	NC State Fish Barn
16th Oct	London, England	Tel Aviv, Israel	Travelling Day
17th Oct	Rest Day		Rest Day
18th Oct	Tel Aviv, Israel		Ministry of Agriculture (Tel Aviv), Saltwater MegafLOW
19th Oct	Tel Aviv, Israel		Bet Se'an Valley, Sde Trumut, Afikei Mayim
20th Oct	Tel Aviv, Israel	Elat, Israel	Mashabei Sadeh, Reem Farm
21st Oct	Elat, Israel		National Centre for Mariculture
22nd Oct	Elat, Israel		Rest Day
23rd Oct	Elat, Israel	Tel Aviv, Israel	Rest Day
24th Oct	Tel Aviv, Israel		Dor Aquaculture Research Station, Ma'agen Michael Kibbutz, Nahsholim Kibbutz
25th Oct	Tel Aviv, Israel		Maoz Haim Kibbutz, Nir David Fish Processing, Neve Etan, PRAqua Canada,
26th Oct	Tel Aviv, Israel		Ein HaMifraz, Kfar Masarik
27th Oct	Tel Aviv, Israel		Ministry of Agriculture (Tel Aviv), Tour Summary
28th Oct	Rest Day		Rest Day
29th Oct	Tel Aviv, Israel		Leave for Adelaide via London

Part 1: United States of America

Background

Arizona

In 1997 Desert Sweet Shrimp was the first shrimp farm to commence operation near Gila Bend in the Sonora Desert, western Arizona (Gong *et al*, 2004). Due to the success of Desert Sweet Shrimp, the industry rapidly developed in the Gila Bend region and by 2001 over 120 ha of land was being used for shrimp culture (Gong *et al*, 2004). The Gila Bend region was selected to grow shrimp due to the availability of saline groundwater, low cost of land, disease-free environment and excellent potential for integrated aquaculture-agriculture farming (Gong *et al*, 2004).

Pacific white shrimp, *Litopenaeus vannamei* is the only species cultured in Arizona using low salinity (<10 g/L) geothermal (25 °C) groundwater (Samocha *et al*, 2002). One crop is produced from mid-May through to mid-September. The shrimp are cultured in open ponds using mechanical aerators (Samocha *et al*, 2002) where pond temperatures can exceed 34 °C in summer (Gong *et al*, 2004). Occasionally farmers can experience mortalities during or shortly after ecdysis when shrimp reach 18-20 g due to the ionic composition of the groundwater (Gong *et al*, 2004). Research conducted by Gong *et al* (2004) identified if the diet was supplemented de-oiled lecithin, cholesterol, magnesium oxide, sodium chloride and potassium chloride, the osmoregulatory capacity of the shrimp was increased so the shrimp reached at least 25 g.

Alabama

Alabama has a long history of catfish farming commencing in the 1960's, increasing to 28,000 acres by 2002 (Boyd *et al*, 2003). Some catfish producers are now experimenting with shrimp culture. Currently there are some inland shrimp farms in Alabama located in the Blackland Prairie region in the west-central part of the state (McNevin *et al*, 2004). In 2002, four farms cultured shrimp, *L. vannamei* using saline groundwater with a salinity of 2-8 g/L (McNevin *et al*, 2004). Boyd and Thunjai (2003) reported the potassium (K) concentration of the saline water used for shrimp culture ranged between 5-13 mg/L (SD ± 2) that was less than the water used in Arizona for shrimp culture (6-29 mg/L, SD ± 8). Magnesium (Mg) concentrations in the saline groundwater are considered low too, ranging between 12-75 mg/L (SD ± 18) (Boyd and Thunjai, 2003; McNevin *et al*, 2004). K and Mg deficiencies are overcome by shrimp farmers by the addition of K-Mg sulfate compound called 'K-Mag' (IMC Global Inc., Lake Forest, Illinois, USA), which contains 18.3 % K and 11.3 % Mg (McNevin *et al*, 2004).

North Carolina

Professor Tom Losordo from North Carolina State University has extensive experience with intensive recirculation aquaculture systems used for the production of fish. He has visited Australia several times giving workshops (Losordo, 2001; Losordo, 2003). In 1989 Professor Losordo initiated the North Carolina Fish Barn project at North Carolina State University (NCSU) to demonstrate recirculating technologies for the intensive production of fish

(Losordo *et al*, 2000). A third generation Fish Barn recirculating system was upgraded in 1993 with additional investors to produce 45 tonnes pa of tilapia. This system incorporates AquaOptima double drains, drum screen filter, gravity fed biofilter, downflow oxygen contactor, and a vertical manifold water inlet to the culture tank.

Arizona Mariculture

Arizona Mariculture is located 180 miles west of Tucson near the town of Hyder approaching the Californian border. This company is the smallest producer of shrimp in west Arizona with an annual production of 25 t. There is only one species of shrimp cultured, the white shrimp, *L. vannamei*. Currently only one crop is produced each year between May and September.

Geothermal groundwater with a constant temperature of 32-34 °C and a salinity of 5 g/L is pumped from approximately 5-10 m below the ground. Nitrate levels of this water are considered high at 31 mg/L. The potassium concentration in the water is low (10 mg/L). Research has been conducted at the site to determine the K level required to be supplemented to the feed to achieve optimal growth of *L. vannamei* (Gong *et al*, 2004). This feed is produced in the USA by one of the largest feed companies 'Rangen' and is known as the 'Arizona' diet.

There is a hatchery under construction to culture *L. vannamei* post-larvae (PL) on the site. The hatchery consists of 12 x 10 KL concrete parabolic tanks to grow the PL's. Currently 7 day old PL's (PL 7's) are purchased from specific pathogen free (SPF) hatcheries in either Texas or Florida. Once the PL's enter the site, sea salt is added to a raceway to increase the salinity of the groundwater to 20 g/L. After this process the salinity is reduced over a 1 week period before the PL's are introduced to the grow out ponds (2 g/L).

The site has been located on old agricultural areas. As the land is so flat, pond walls have been constructed above the ground to create levels around the facility to allow water to be moved via gravity once pumped. Open concrete channels allow water movement between levels. Large production ponds are constructed from earth (no lined ponds) and no mechanical aeration is used. A degassing chamber has been installed at each pond for all intake water as the groundwater is super saturated with nitrogen.

Wastewater from all ponds is transferred to a lagoon. Some of this water is reused to irrigate olive trees, but the majority is left to evaporate and leach back into the ground.

Predation in the ponds is due to dragonfly larvae when the PL's are first introduced to the ponds. To overcome this problem, the ponds are filled just prior to the PL's being introduced to reduce the opportunity for the dragonfly larvae to establish. Bird predation is not considered an issue at the site and none of the ponds have been covered with netting.

The company has experienced problems selling the final product as the price of shrimp is continually dropping in the USA due to competition from Asian and Central American imports. Some of the shrimp at Arizona Mariculture is processed and sold into Phoenix via a supermarket chain, and some of the shrimp is held back into the season and then sold live into the Los Angeles market commanding a higher price.

Currently tilapia (*Tilapia nilotica*) have been introduced to some smaller ponds. Each of these ponds has an electric aerator to assist maintenance of dissolved oxygen levels within the pond.

Arizona Shrimp Farm

The Arizona Shrimp Farm is located 322 km west of Tucson, Arizona. The company has been operating for 3 years and is about to commence harvesting *P. vannamei* for the 2004 season. The only people employed at the company are the farm manager and a feed person. In the first season of operation, there were 9 general hands on the farm, but this has been reduced to lower operation costs.

The farm has 80 ha of pond area with this area divided into 10 x 8 ha production ponds (Figure 1). No aerators or paddlewheels are used and initial stocking densities are low (12.5 PL/m²). The farm has been constructed on land previously used to grow cotton. This year the farm is expecting to produce 110 t of shrimp to sell direct into Los Angeles. In the first year of production there were some major losses of shrimp. Anecdotal evidence suggests these losses occurred due to residual chemicals in the ground as a result of the previous cotton farming practices in the area. Some agricultural chemical spray drift from neighbouring farms may have also occurred.

Multiple bores are used at the site to extract groundwater with a salinity of 8 g/L. The water table at this location is at 12 m, and the water is pumped from 21 m. The water is known to be potassium deficient (conc unknown) and is supplemented with potash. This season 40 t of potash has been added to the incoming water at a cost of \$US50/t. The temperature of the groundwater is around 24 °C.



Figure 1. Extensive production pond (8 Ha) is used to culture shrimp at the Arizona Shrimp Farm using saline groundwater (8 g/L).



Figure 2. Grading machine for sorting *L. vannamei* at the Arizona Shrimp Farm.

Ponds are stocked with PL 14/15's that are purchased as SPF PL 12's from a hatchery in Florida. Prior to transport the PL's are pre-acclimated to 15 g/L and the salinity is reduced at the site to 8 g/L over 3 days. Enough PL's are purchased to stock one pond at a time as previously major losses have occurred when trying to stock the whole farm in one batch.

Ponds are stocked at a low density of 12.5 PL's/m² in late May/early June and harvested in early October. This year only one crop will be produced. All the ponds are earthen and no aerators or paddlewheels are used. The pond bottoms are sloping from the inflow to the discharge with water depths ranging from 0.9 m to 1.8 m. The outlet is a 1.06 m diameter pipe. When the PL's are initially stocked, the pond is approximately half filled, and as the prawns increase in size the water level in the pond is increased. Once the pond is full no additional water is added for the remainder of the growing cycle.

During the maximum growing period the water temperature is above 30 °C and there are two feeds per day to each pond. Feed trays are used to help estimate feed rations. Feed cost is \$AUS 0.74 / kg and is not bagged to reduced costs. The feed is delivered to the site in a truck and elevated into a large feed silo beside the maintenance building.

All the wastewater from the ponds is discharged out to 400 ha of land for seepage and evaporation. The discharge water is not reused for any agriculture production. Native plants have established within the wastewater channel.

Approximately 50 casual staff are employed on a seasonal basis to help during the harvest. A prawn harvesting machine has been custom built by the operator to separate the shrimp from the water. Once separated the shrimp are transferred to the processing shed that houses an automated grading machine (Figure 2) and three snap freezers. Batches of shrimp are snap

frozen to $-25.0\text{ }^{\circ}\text{C}$ within 8 hours. Shrimp (green) are sorted into five grades ranging from 46/55 to 68/77 pieces per kilogram. Shrimp are sold with either their head on or off. Higher prices are obtained for larger animals and with their heads removed.

After the harvest the ponds are left to dry. No liming occurs to sterilise the pond bottom, and chemicals are being trialed to spray on the pond bottom to reduce macroalgae and plant growth.

University of Arizona, Soil, Water & Environmental Science Research Laboratory

The University of Arizona, School of Soil, Water and Environmental Science is located in Tucson, Arizona and is managed by Dr Kevin Fitzsimmons. Unfortunately Dr. Fitzsimmons was on sabbatical in Thailand, and PhD student, Chad King, provided information on research and the facilities.

This research facility is investigating freshwater agri-aquaculture systems using ornamental fish and tilapia. All research tank systems are maintained in greenhouses. The greenhouses are covered using polycarbonate sheeting and plastic. All greenhouses are cooled using wet moisture pads at one end of the greenhouse and large extraction fans at the other end (Figure 3). During the winter they are heated using gas combustion heaters. There are no bores located at the site so all freshwater used is taken from the mains supply and discharge water is put back into the local sewer system.

Integrated agri-aquaculture systems at the facility have been used to grow basil, tomatoes and chilli peppers. Cost benefit analyses have been performed to assess the benefit of using integrated systems. Juvenile goldfish and tilapia used for experiments are cultured at the University. Small quantities of tilapia are sold live to a Tucson restaurant for around \$AUS 4.30-5.70/kg.



Figure 3. Research tank systems at the University of Arizona showing extraction fans used to cool greenhouses. (Note: Moist cooling pads have been installed at the opposite end of the greenhouse.)

Basic recirculation water treatment systems are used that incorporate rotating disc biological filters above the surface of the tank. No mechanical filters are used and excess wastes are discarded by opening a ball valve at the base of the tank.

Of most interest at this facility was research that has been conducted into the culture of *Salicornia sp.* using oceanic water. This has been undertaken using freshwater with salinity increased by addition of sea salt. *Salicornia sp.* seeds can be pressed to make vegetable oil, and young shoots can be added to salads in Europe.

Inland Saline Shrimp Farms, Demopolis, West Alabama

Alabama has six inland saline shrimp farms in the western part of the state. All the water used at the farms is pumped from the ground and is regarded as ancient water. The salinity between the farms ranges from 3-10 g/L and the potassium concentration ranges between 10-15 mg/L. All farmers supplement their pond water with potash to achieve a K concentration of 60-80 mg/L to achieve optimal growth. Most shrimp farmers are growing catfish as the primary species and experimenting with 3-4 ponds of shrimp to determine optimum production methods. Only one farm called 'Green Prairie Aqua Farms' grows shrimp exclusively using 16 ponds ranging in size from 0.6-2.1 ha (Figure 4). Average sizes of ponds across the rest of the farms range between 1.6-2.4 ha.

Shrimp ponds are stocked in May and harvested in October. For the duration of the culture cycle, pond water temperatures range between 18-34 °C. Electric paddlewheels are used to aerate the ponds. Mobile aerators connected to the back of tractors are used to supply pond aeration when there is a power blackout (Figure 5). Farmers aim to produce 4.4 t shrimp/ha with an average weight of 46-55 pieces per kilogram. Growers need to target larger average shrimp weights to achieve higher market prices.



Figure 4. Shrimp being harvested from a typical production pond at the Green Prairie Aqua Farm, Alabama.

There are a range of issues concerned with the marketing of the final product. Shrimp prices in the USA are declining due to imports from Central America and Asia. The cost of production for shrimp in West Alabama is \$6-7/kg. During harvest time local markets become saturated so alternative markets need to be found. The aquaculture extension officer has received funding over the next 2-3 years to assist local growers and aims to explore value adding options for the Alabama shrimp that highlight its local and organic status.



Figure 5. Large, mobile paddlewheels are connected to the back of tractors to provide backup aeration for shrimp and catfish farmers.

Auburn University, Alabama

I had meetings with Professor Claude Boyd and Associate Professor Allen Davis. Prof. Boyd informed me that they are attempting to establish EPA requirements in Alabama for inland aquaculture (catfish and shrimp) and the results of supplementing pond water with potash. Currently there are no regulations for discharging aquaculture effluent water in Alabama even though it could finish up back into local rivers. The catfish farming industry does not discharge large volumes of water as the water is reused in the ponds for up to seven years. The regulations for water discharged from/by aquaculture are currently under review.

Future research needs to focus on the reuse of groundwater after discharge. One option could include pumping it to holding ponds for storage before reuse. Additional pumping costs need to be considered to determine if these exceed influent well water pumping costs.

Assoc. Prof. Davis is currently involved in the culture of shrimp in low salinity groundwater. His research is focussing on the addition of K to shrimp diets. Shrimp are different to fish as they take some time to consume their food, and results suggest that the added K leaches from the feed before the shrimp can consume it and hence they do not receive any benefit from the

K supplemented food. Research has also identified that magnesium levels need to be at least 25 % of oceanic water concentrations to not affect growth.

Auburn University have a large field research facility that consists of extensive ponds for fisheries population studies and 8 x 0.1 ha (Figure 6) and 30 x 0.01 ha ponds for aquaculture research. There is a small research laboratory used for fish genetics research. The field site also contains a hatchery for culturing fish (catfish and trout) and student training. There are approximately 100 x 0.005 ha ponds for student use.



Figure 6. Extensive ponds are available for experiments at the Auburn University Aquaculture Research Station.

Hybrid Striped Bass Farming, North Carolina

Two hybrid striped bass (*Morone saxatilis* x *Morone chrysops*, HSB) farms in the eastern region of North Carolina near Greenville were visited. HSB have been farmed for nearly twenty years in the region using freshwater from the local ‘Castle Hayne’ aquifer. The two farms visited were named Castle Hayne Fisheries (CHF) and Carolina Fisheries. The groundwater is high in sulphur which is removed using degassing towers.

There are around 110 ha of ponds that produce 400-500 t of HSB between both farms, which include nursery and grow out facilities. The average pond size is around 1.2 ha, and each pond contains one 10 hp paddlewheel. Castle Hayne Fisheries uses a dissolved oxygen monitoring system and each pond has its own probe. The system controls the operation of paddlewheels when DO levels within the ponds reach unacceptable levels, and deactivates these when oxygen levels are sufficient.

The fish are harvested from the ponds using a pesculator type harvest pump (Figure 7) that uses a long Archimedes screw within a pipe to lift the fish out of the pond. Fish are crowded into a section of the pond near the fish pump. As the fish are elevated they are held in a pool

of water up to the top of the pesculator which then transfers them to the grading table. As they are being transferred from the pesculator to the grader, the fish are separated from the water, which is transferred back in to the pond. On the grading tray fish are split into three grades then moved back to the pond and held in separate floating nets. The graded fish can be transferred again using the pesculator to place them in a transport truck for sale at the live markets or relocated to another pond.

The majority of the fish produced at the farms are sold in the live fish markets in New York and Canada, with the remaining stock sold as whole fish on ice. Live fish weighing 560-680 g sell wholesale for around \$AUS 8.50-11.00/kg and chilled whole fish (340 g -1.1 kg) sell for \$AUS 7.15/kg. At Castle Hayne Fisheries the fish are purged in a 15 KL tank receiving water on a flow through system for three days before transport to market. Water is recirculated within the tank through an oxygen concentrator to maintain fish stocking densities of 80 kg/m³ (Figure 8).

There is no reuse of wastewater and all effluent water is allowed to drain into the local rivers for both farms.

Southern Farm Tilapia, North Carolina

Southern Farm Tilapia (SFT) is currently producing 230 tonnes pa of tilapia (*T. nilotica*) between two grow out sheds using intensive recirculating aquaculture systems (RAS). They are about to purchase some more grow out facilities with the aim of expanding their total fish output to 680 t pa. These RAS's are based on the North Carolina (NC) State University 'Fish Barn' design. SFT have their own hatchery that produces all the fingerlings for their company. Once the additional grow out facilities are operating, additional fingerlings will need to be purchased from an external hatchery. Tilapia are serial spawners where the females carry the live young in their mouths. SFM hold the males and females in separate tanks until they are required to spawn, then 5 males and 20 females are placed into a tank maintained at 29 °C and allowed to spawn for 7-10 days. After spawning, the females are moved into a separate tank to allow the eggs to be released or removed by a technician. The eggs are placed in an incubation container where they hatch and are released into a nursery trough. Once they absorb their yolk sac, they feed directly on a formulated pellet. The fry remain in the trough for up to 30 days where they are fed a diet containing methyltestosterone to induce all the fish to become males. Male tilapia are favoured as they do not waste energy on reproduction. After 30 days the fish are transferred to the post-nursery until they reach 100 g. The fish are graded every 7-9 days to reduce cannibalism. The tanks in the post-nursery operate on two separate recirculating systems and the fish are fed a 42 % protein, 16 % lipid diet made by Zieglers, Pennsylvania.



Figure 7. Hybrid Striped Bass are lifted from the pond using a pesculator pump to harvest/grade the fish on the land.



Figure 8. Tanks (6 x 15 KL) used to purge hybrid striped bass at stocking densities up to 80 kg/m³.

The growout shed contained 6 x 100 KL tanks which reach a maximum stocking density of 100 kg/m³. Two RAS have been constructed to support 3 tanks per system. Water temperature is maintained around 25-27 °C year round by heating the air. Each tank contains a Norwegian designed double drain system (AquaOptima) that operates by removing most of the solids in a small proportion (10 % flow) of water and directing them to a swirl separator. The swirl separator spins the water to accelerate settlement of solids that are then discharged through the bottom direct to the external sedimentation pond. Relatively clean supernatant water rises and overflows through the top outlet of the swirl separator and is directed to the drumfilter. The major proportion (90 % flow) of water removed through the double drain is sent straight to the drum filter. After being mechanically screened through the drumfilter, the water drops into a sump containing a submerged biological media filter (Figure 9). There is also capacity to divert more water from culture tanks through the biological filter multiple times when the stocking densities are high.

From the biological filter, the water is pumped through an oxygen concentrator (Figure 10) and returned to the tank. There are two inlets into each tank delivering clean oxygenated water. During the winter months, water can be passed through an inline gas heat exchanger. The fish are never graded in the grow out tanks and market size fish are 650-700 g.

All the tilapia produced by SFT are sold live to Asian markets in New York and Toronto. Fish are purged for 5-7 days before transport and the water temperature is reduced to 20 °C to slow their metabolism during transport.



Figure 9. Water can be passed through the biological filter more than once per hour when fish stocking densities are high.



Figure 10. After biological filtration, all the water passes through the oxygen concentrators before entering the fish tanks.

North Carolina State University Fish Barn

NC State University Fish Barn was constructed in 1998 to demonstrate the commercial viability of intensive recirculating freshwater fish production systems. The Fish Barn contains a nursery facility that has two rooms with a single tank in each, which also acts as a quarantine facility. Each room has its own individual RAS and husbandry equipment. The fish are held in these facilities for 6-8 weeks before being transferred to the main shed. Freshwater is pumped from a ground well 12 m down. Only 10% new water is delivered to the system daily.

Tilapia is the main species grown in the system and 1-2 g fingerlings are purchased from a hatchery in Florida. Inside the Fish Barn there are 4 x 60 KL tanks (Figure 11) supported by two RAS's. Pure oxygen is used within the system to enable stocking densities up to 100 kg/m³ to be achieved at a harvest weight. Each 60 KL tank is stocked with 7,800 fingerlings.

The air temperature within the shed is maintained at 27-28 °C using gas heating. The lights are illuminated 24 hours per day and the fish are fed 8 times/day using automatic feeders. All staff can be connected to pager systems to attend out of hour system breakdowns.

Water quality is measured daily and oxygen, water levels and flow are monitored and alarmed. Sodium bicarbonate is added to the water daily to maintain pH levels around 6.8-7.2. Alkalinity and carbon dioxide are measured daily using titration.

The RAS used at the Fish Barn are the same as the systems at SFT as they were originally designed and trialed by NC State University. Each tank has an AquaOptima (Norwegian) double drain system and swirl separator (Figure 12) to remove large solids (uneaten food and

faeces). The double drain was designed for culturing salmon raised in 12-14 °C water on a flow through system. NC State University operate their systems at 27-28 °C in a recirculation system which they find can block the double drain effluent pipes. To overcome this problem they scrub the swirl separator daily and use a high pressure hose to clean the effluent pipes from the tank. Every 3-4 days, an extended piece of 20 mm PVC pipe is used to hose the inside of the double drain.



Figure 11. 60 KL tanks are used to culture tilapia at the North Carolina State University Fish Barn.



Figure 12. AquaOptima swirl separator receives 10 % of the water flow from the double drain located in each 60 KL tank.

All water from the double drain passes through a Hydrotech drum filter before entering a moving bed biological filter that uses small media that is agitated by aeration. The ‘macaroni’ media used has a relatively high surface area ($800 \text{ m}^2/\text{m}^3$) available to support bacterial populations in the filter.

All water passes through an oxygen concentrator before it is returned to culture tanks. Liquid oxygen is used from a large bottle located outside of the fish barn. Tank inlet pipes are vertical with a series of drill holes extending to the bottom of the tank. Two return pipes are located adjacent from each other in each tank and are directed slightly toward the centre to create a circular current within the tank. This assists the movement of particles towards the centre of the double drain. Transparent water level pipes are connected at the top of the inlet pipes to give a visual indication of water flow into each tank.

Wastewater from the cleaning cycle of the drum filter and the swirl separator is concentrated to a septic system. The liquid wastewater makes its way to a settlement pond that requires pumping twice per year. Research is currently underway in this area of treating and concentrating the wastewater. The waste concentrate can be dried to make compost.

Tilapia reach market size (680 g) within 6 months and are sent to live fish markets in New York and Canada. As NC State University is a research institution they are not allowed to compete against private industry when selling fish. To overcome this problem they sell their fish for \$4.30-5.00/kg when no companies in the state of NC are selling fish.

In a separate shed the production of hybrid striped bass is being investigated. Calcium chloride is added to the HSB water to increase the hardness of the water as this is preferred by the fish but this creates cloudiness in the water. NC State University are trying to demonstrate cost effective ways to construct tanks using frames constructed from timber and then plastic lined.

Part 2: Israel

Background

Israel has a long history of land-based aquaculture compared to Australia. In 1939 the first commercially grown crop of common carp was delivered to local markets in Israel (Kissil, 1996). In 2002 Israel produced 19,200 tonnes of fish from 73 land-based aquaculture farms (Snovsky and Shapiro, 2004). Production increased by 5.7 % since 2001 due to improvements in air and feed systems, water usage and deepening of ponds (Snovsky and Shapiro, 2004). The main species produced were carp (7,748 t) and tilapia (7,819 t). In comparison, in 2001/2002 Australia produced approximately 5,000 tonnes of finfish from land-based aquaculture systems (O’Sullivan and Savage, 2003), almost four times less than Israel.

Warm yearly temperatures and availability of brackish water unsuitable for agriculture provided ideal conditions for the culture of common carp in open ponds. Over time pond culture has intensified due to the efficient use of fertilisers, introduction of aeration systems, formulation of efficient pelleted diets for fish culture and the development of covered ponds to regulate water temperatures (Kissil, 1996). A variety of fish have been cultured in Israel including: carp, tilapia, grey mullet, rainbow trout, hybrid striped bass and ornamental fish (Kissil, 1996).

In recent years scientists at the Israel Oceanographic and Limnological Research, National Centre for Mariculture, have conducted extensive research on the culture of seawater fish, and using secondary species such as seaweeds and bivalves to remove the nutrients from fish effluent water (Cohen and Neori, 1991; Neori *et al*, 1989; Neori *et al*, 1991; Shpigel and Blaylock, 1991; Shpigel *et al*, 1993).

Saltwater Megaflow, Hadera

The ‘Megaflow’ RAS at Hadera incorporates the principal design features of high water flow and low head movement between and within culture raceway tanks and water treatment components. The aim of this design is to simplify the mechanisation, reduce construction costs and minimise energy use in an intensive RAS. This is achieved by using multiple airlift pumps to move high volumes of water at low head pressure with water not lifted more than 20 cm within the system. The primary water treatment principle of the Megaflow system is to separate the flow required to achieve ammonia treatment (1-2 x tank volume per hour) from that required for to supply fish oxygen and degas the carbon dioxide (10-20 x tank volume per hour). Mechanical filtration is achieved using a submerged upflow filter bed of the same ‘macaroni’ type media that is also used as a fluidised biological filter. The airlifts operating in the Megaflow system provide high water flow and re-oxygenation rates to allow dissolved oxygen levels to be maintained above 80 % saturation with typical stocking densities up to 50-80 kg/m³ without the need for use of pure oxygen. Ongoing system developments are concentrating on improving oxygen transfer and carbon dioxide removal efficiency of air lifts and reducing construction and operating costs through careful selection of building materials and energy conservation.

The Megaflow RAS at Hadera was one of the first systems built in 2001. The system was being used to produce sea bream (*Sparus auratus*) using seawater from the discharge of a

power station one hour north of Tel Aviv. The system was housed inside a greenhouse fitted with rollup sides to allow airflow to cool the inside air temperature (Figure 13) during summer. The roof material is made of a green plastic membrane that inhibits the growth of microalgae within the culture water. An additional shade screen is attached on top of this plastic roof during the summer months to further reduce microalgae growth and inside air temperature.

The water in the culture tanks is recirculated through water treatment sections 1-2 times/hour. This system was capable of producing 5 tonnes of fish in the 2 x 50 m³ of water available. Fish are stocked in the system at 2 g and are harvested within 9 months at 400-600 g. Six airlift pumps are used within each 50 m³ system to uplift water from the fluidised bead filter and move it to the culture tanks (Figure 14). The tank bottom slopes toward one end where the ‘water planer’ is located to separate bottom water flow containing fish faeces and uneaten food. After the ‘water planer’, the water passes through the mechanical filter, ‘macaroni’ bead filter and then back into the tanks. The annual operating temperature for the system is 26-29 °C and higher water exchanges are performed during the summer to keep tank temperatures down. Dissolved oxygen is monitored by a probe located near the end of the raceway and this is connected to a computer which logs all the data. This data can be accessed remotely by dialling up on the internet.



Figure 13. A saltwater ‘Megaflow’ system used to culture sea bream housed inside a green plastic lined greenhouse.



Figure 14. Large airlifts (150 KL/hr) aerate and move water within the raceway sections of the Megaflow system.

Bet She'an Valley

The Bet She'an Valley in the north-eastern region is the location of much of Israel's aquaculture production. Tilapia and carp are the major aquaculture species and these are farmed in a pond system that has been developed to utilise water reservoirs or brackish water sources (>1500-2000 ppm TDS) that cannot be used for irrigation.

Current Israeli government policy is to reduce the volume of good quality water used for aquaculture and encourage intensification using RAS. As part of this policy, a program to install 5 demonstration RAS systems of approximately 100 t pa production capacity. These systems will be jointly funded by the operator and the government (50-80%) in return for most of the existing water allocation being forfeited.

Sde Trumut

An early Megaflow system is used to produce 40 t pa of hybrid striped bass at stocking densities up to 20 kg/m³. This system comprised 20 x 70 m³ concrete raceways (approx 15 m x 4 m x 1.5 m deep, Figure 16) supported by two water treatment systems each with submerged solids removal section and moving bed biological filter. Both systems utilised the "macaroni" type plastic media. Water flow and aeration in the system was generated by the one 2 hp paddle wheel at the start of each raceway. Megaflow airlifts were used to transfer water into the mechanical/biological treatment sections from a channel that collected water from each raceway. Water was also returned to tanks through a concrete channel.

On this site a demonstration, scale version of a recent design for the Megaflow system was operating but not stocked (Figure 17). A new greenhouse covering was also being trialed that

was constructed of an internal and external layer of white plastic film with an internal layer of Dacron mat to provide insulation (Figure 17). When completed that structure will have partially rigid walls, roll up sides and a permanent light attenuating roof cover. The white internal colour provides good light dispersal to avoid the need for lighting while allowing a shaded environment for fish culture. Fish culture sections of the system consisted of 2 x 50 KL D-ended wrap around tanks with a centrally located solids filter, moving bed filter and return airlifts. A new design of airlift was installed in the culture tanks to improve oxygen transfer efficiency.



Figure 15. Megaflow designer Roly Haddas and son Rory (Yitzhak Simon behind Roly) standing inside the harvesting channel of a 100 t system at Sde Trumut.



Figure 16. An early design of Megaflow (40 t capacity) was used to culture hybrid striped bass at Sde Trumut at stocking densities of 20 kg/m³.



Figure 17. A new greenhouse cover being trialed at Sde Trumut.

At this location a 100 t Megaflow production unit was in the early stage of construction (Figure 15). The facility was one of the government RAS development projects and contained a demonstration (2 x 50 KL raceways) Megaflow nursery production system (Figure 17). This commercial production system used pre-cast stressed concrete sections to form culture raceways, water treatment sections and channels. All wet surfaces are covered with a 900µm plastic film glued to the concrete to provide an impervious membrane. The system incorporates a central return drainage channel and peripheral return water supply channels. These channels also allow fish to be transferred between tanks and harvested. Each side of the system comprises 14 m x 7 m x 1.2 m deep D-ended culture raceways. Megaflow airlifts, water plane (separator), solids filter and moving bed filter were not installed but sumps and pits to house these units had been constructed.

Sde Eliyahu

In the late 1980's the Sde Eliyahu kibbutz installed a system of 9 x 300 m³ octagonal concrete tanks that are used to culture red tilapia on a flow through system that exchanges approximately 10-15 % per hour. Two times per day an external standpipe is removed to drop about 50 % of the volume and provide an extra flushing of settled solids. All tank standpipes drain to a 300 mm diameter pipe located around the top of a common concrete pit that is large enough to accommodate a truck to load fish destined for market.

In 1992 an American designed RAS was constructed and used to culture red tilapia and carp (Figure 18). The system is housed in a multi-span greenhouse structure with sides that can be opened during summer and closed in winter. Stocking density in the system can achieve 50 kg/m³ and despite being designed to achieve 100t pa, production of only 65 t pa has been achieved. The total volume of the system is 350 m³ with fish cultured in 10 wide raceways (approximately 15 m long x 2.5 m wide x 1.2 m deep) and 10 smaller raceways (approximately 15 m long x 1.2 m wide x 1.2 m deep). This system turns over the total volume once per hour and incorporates a drum filter for mechanical filtration, 2 trickling bed biological filters using rigid media and 2 x 5 m high oxygenation cones. The system used 4 large pumps and is regarded by the operator as an energy efficient design. The system was the first attempt to incorporate RAS into commercial aquaculture in Israel and no further units of this type have been built.



Figure 18. An American RAS system was constructed at Kibbutz Sde Eliyahu that was used to culture red tilapia and carp at stocking densities up to 50 kg/m³.

Mashabei Sadeh

Mashabei Sadeh Kibbutz is part of the Ramat Negev Desert Agro-Research Centre, which is located 30 km south of Be'er Sheva in the central desert region of Israel. A 600 m deep well has been drilled at the site which delivers 5 g/L saline water with a temperature of 38 °C. Extensive agricultural research has been conducted at the site for the past 20 years growing greenhouse vegetables, open field vegetables, flowers and fruits. Attempts have been made to establish a water user chain at the site to incorporate agriculture and aquaculture. The Kibbutz owners see this as being essential to attracting outside investors.

At Mashabei Sadeh they have unsuccessfully tried to culture *Litopenaeus vannamei* using groundwater. Shrimp larvae were sourced from the USA and stocked into tanks. They suspect low potassium levels in the water were the problem.

Fish are produced at the site are in 12 x 300 KL tanks (Figure 19) each containing 1 x 1 hp paddlewheel. All the tanks are positioned inside two greenhouses with roll up walls and are lined with Palgreen™ to prevent microalgae developing within the culture water. The main fish that are grown at the site are tilapia and carp *sp.* Over the past three years prices for tilapia and carp *sp.* have reduced, so researchers are now also experimenting with the culture of hybrid striped bass, red drum and barramundi. An automated feeding system has been installed that uses high pressure air to blow feed through a single 40 mm pipe. Where there is a tank, a section of pipe drops directing the designated quantity of food into the water. After the feed has been dispensed, the section closes so food can be delivered to the next tank.

Reem Farm

Reem Farm is a 350-400 t pa fish farm located in the Negev desert, 50 km south of Be'er Sheva. Hybrid striped bass and barramundi are cultured in a 32,000 m³ recirculating aquaculture system. The facility has been operating for eight years and uses 'fossil' water (salinity 3 g/L) pumped from 700 m below the ground.

Large concrete raceways are used to culture the fish (Figure 20). Each raceway contains 4 x 2 hp paddlewheels and 2 x 1 hp aerators. A similar automatic feeder to the one observed at Mashabei Sadeh is used to manage feeding. All raceways are maintained inside large greenhouse lined with Palgreen™ walls and roof with roll up sides to assist with cooling in summer. Currently the system is stocked at 15 kg/m³, but the farm manager aims to gradually increase this level.

A pesculator type pump is used to harvest the fish as it is quiet and gentle on the fish. The farm has its own processing facility where 5 t of fish can be chilled from 25 °C to 4 °C within 1 hour. The fish are then packed on ice and sold whole.

All the wastewater at the facility is used to irrigate 100 ha of olives.



Figure 19. 300 KL tanks used to culture fish at kibbutz Mashabei Sadeh in the Negev Desert.



Figure 20. Concrete raceways are used to produce 350-400 t of barramundi and hybrid striped bass at Reem Farm in the Negev Desert.

Israel Oceanographic & Limnological Research, National Centre for Mariculture, Elat

The Israel Oceanographic and Limnological Research (IOLR), National Centre for Mariculture (NCM) has conducted considerable research on integrated aquaculture systems over many years. Dr. Muki Shpigel and Dr. Amir Neori discussed the concepts of seaweed culture to remove and utilise nutrients from marine aquaculture wastewater. The culture of *Ulva sp.* (Figure 21), *Gracilaria sp.* and *Enteromorpha sp.* has been achieved and researchers are also experimenting with the culture of *Salicornia sp.* (samphire).

Currently the NCM has invested in construction of a 100 t Megaflow RAS adjacent to the Elat site. This system will be used to culture marine fish such as sea bream and sea bass. The Megaflow system is in the early stages of construction with a number of tank wall sections erected.

Due to the variability of saline groundwater between Elat and the Dead Sea, research has been conducted to acclimate marine fish (ie. sea bream) to grow in water with a salinity of 5-15 g/L. Experiments have been conducted at the NCM comparing the growth of 200 mg sea bream in 35 g/L and 5 g/L saline water. The high growth rate of these small fish allows a result to be achieved within 3 weeks. Sea bream have been transferred from 40 g/L to 25 g/L to 5 g/L within 7-10 days.



Figure 21. Ulva sp. tank (100 KL) at the National Centre for Mariculture in Elat, to remove the nutrients from aquaculture wastewater.

Dor Aquaculture Research Station

The Dor research station is near Hadera, 45 km north of Tel Aviv. Here we were updated on the research undertaken at the facility by Igal Magen and Ofer Sachs. Both of these people work for the State of Israel, Ministry of Agriculture and Rural Development, Department of Fisheries and Aquaculture.

Research conducted at this station includes:

- Designing and trialing carp vaccines for commercial use. A vaccine for carp has been used successfully by the industry to increase production after severe losses due to a herpes like virus that has recently decimated the industry, reducing production by 80 %.
- A tilapia broodstock enhancement program is in its second year. Tilapia are being carefully selected to increased growth, survive low temperatures and develop a resistance to *Streptococcus sp.*
- When tilapia are kept over the winter in external ponds, they can develop fungus on their bodies after handling. To overcome this problem the fish are treated in malachite green. Malachite green is about to be banned from aquaculture use, so an alternative remedy is required by industry. Currently screening of alternative therapeutants is being conducted to assess alternatives to overcome this problem.
- The use of ozone to treat the water of live holding facilities to extend the shelf life of fish from 10 to 30 days at 22 °C. In this system the fish are exposed to ozone at a concentration of 6 mg/L for one hour a day.

- A protocol has been developed to produce sterile female carp which grow faster than male and fertile female carp.

Facility Summary

The Dor Research Station has 80 ponds ranging in size from 350 m³ to 2 ha that are maintained by 10 technical staff. Water supply is from freshwater bores located on the site and all the water from the ponds flows into a large storage dam. Water recirculates around the facility at a rate of 600 m³/hr, and is passed through a 200 µm primary filter to prevent fertilised fish eggs from being transferred into other ponds. The majority of the ponds are left empty over the winter to dry and sterilise.

Additional to the ponds there are two greenhouses (12.5 m x 40 m) used as nursery facilities. Inside each of these greenhouses there are 12 x 40 m³ circular tanks receiving new water from the bores on a flow through system. All the effluent water is discharged to the sedimentation pond receiving water from all the production ponds. One greenhouse contains a computer controlled automatic feeder that has been observed on other facilities. The other greenhouse ponds are fed using 2 belt feeders per tank.

There is a freshwater hatchery on the site that is currently not in operation.

They maintain and hold 4-5 strains of carp species as broodstock. A new greenhouse has been constructed to hold broodstock for genetics projects. This facility houses 16 x 1 m³ and 4 x 5 m³ tanks. Half of these tanks are temperature controlled and all effluent water goes to a separate area to receive chlorination.

Ma'agen Michael Kibbutz

This kibbutz contains freshwater recirculating raceways to produce 400 tonnes of koi carp per annum that are exported for stocking of ornamental ponds. There is also a freshwater and seawater hatchery, and a brackish water growout facility used to produce sea bass, red drum, tilapia and grey mullet.

Grow out

When the farm commenced operation it began culturing tilapia, but has since switched to hybrid striped bass production and more recently switched to production of sea bass and red drum. There are 20 bores located around the site to supply water. Sea bass are cultured in semi-intensive ponds (300 KL) using new well water and red drum are cultured in 'reused' green water pumped from the storage ponds (3 x 3 ha) that are stocked with a low density of tilapia and grey mullet. There are 9 ponds for sea bass and 11 for red drum. Water flow rate in the intensive production ponds is 70-80 m³/hr which includes recirculated and new water. Both of these ponds use mechanical paddlewheels and liquid oxygen on demand (Figure 22).

There are a total of 130 ha of ponds (including effluent settlement) used to produce edible fish on the farm. This year the farm hopes to produce 110-120 tonnes of sea bass and 280 tonnes of red drum with a stocking density of 20-25 kg/m³. A further 1000 tonnes of tilapia and grey mullet are expected to be produced from the effluent water.

All sea bass and red drum effluent water passes through a central drain and each pond receives 10 % of new well water per hour. 2000-3000 tilapia are kept in each pond to help

control microalgal populations and feed on organic wastes. All ponds are exposed to ambient weather conditions with minimum yearly water temperatures in winter reaching 9-10 °C.

The growout facility is operated by 5 technical staff with at least one on site at all times.

Aeration and feeding to each pond is automated and controlled by a central computer system. There is an Oxyguard dissolved oxygen probe in each pond which determines how many paddlewheels operate in each pond or if the oxygen concentrator switches on via minimum and maximum oxygen levels. No feeding is done by hand, everything is automated with the fish behaviour observed to help determine any changes in appetite.

All fish are sold locally. Sea Bass sell for \$AUS10/kg and red drum sell for \$AUS5.6/kg.



Figure 22. Sea bass and red drum are cultured in 0.1 ha semi-intensive ponds at Ma'agen Michael.

Hatchery Production

A pipeline extends 350 m from the sea to pump saltwater to a hatchery built from shipping containers. This hatchery produces 3 million fish for sale to local growers of sea bass, sea bream, barramundi and grey mullet.

There is also a freshwater hatchery used to produce ornamental koi carp for stocking within their own farm.

Nahsholim Kibbutz

Nahsholim Kibbutz is only a small farm producing 30 tonnes pa of sea bream and hybrid striped bass. This is only one of three farms producing sea bream in the northern part of

Israel. The location of the site allows 12-14 g/L saline water to be pumped from 22 m beneath the ground. 4 bores extract a total of 90 m³/hr and the water has a constant temperature of 23 °C.

The fish production is situated on the top of a hill to allow effluent water to flow by gravity down to the sedimentation ponds (Figure 23). Fish production is conducted in 4 x 100 m³ ponds each equipped with one paddlewheel and 4 x 300 m³ ponds each equipped with two paddlewheels. Feeding is done using belt feeders. All fish production ponds are covered with nets to prevent bird predation.

A total of 20 ha of ponds have been allocated for the treatment of wastewater. Tilapia and grey mullet are cultured in these wastewater ponds with a total annual production of 120 tonnes. Due to the constant year round water temperature, a niche market has been developed for the over wintering of tilapia for other growers. This year 600,000 tilapia will be maintained over the winter and on sold to farms in spring when they will be 40-100 g.

Maoz Haim Kibbutz

At the Maoz Haim kibbutz approximately 100 ha of freshwater ponds are used to produce a mixed range of fish species including: tilapia (black and red), carp *sp.*, grey mullet and red drum. These species can all be grown in the same pond. The farm produces around 1800 tonnes per annum, with all produce sold to the local market. There is a freshwater spring on the site that can supply 300 m³/hr. The farm is efficient with their water management and reuse as much water as possible. Any effluent water is discharged into the Jordan River. The majority of water loss at the site is through evaporation, and a small percentage seeps back into the ground.

The high tonnage of fish produced at this farm is achieved by culturing the fish in 10-15 ha ponds. Each of these ponds contains 20-30 paddlewheels (Figure 24) and multiple zones where outlets from feed pipes are located. Feeding is automated using a computer located in the office and a floating feed is used to assist in the feed management. Due to the high inputs of feed and aeration to each pond, stocking densities of 25 t/ha (2.5 kg/m³) are obtained.

The whole production cycle of hatchery, nursery and grow out is undertaken at the farm. The nursery phase aims to produce 100 g fish, before they are transferred to the growout where they will not be graded until harvest.



Figure 23. At Kibbutz Nahsholim fish are cultured on top of a hill to allow wastewater to gravity down the hill to the sedimentation/treatment ponds.

The large ponds take 10 days to drain. Fish are harvested when they reach a target weight around 400-800 g. The fish are harvested by using feed to attract them to an area where underneath is a net spread between 4 poles. Once the fish are above the net, hydraulic winches lift the net and trap the fish. A person then paddles a board out to the net and disconnects the centre forming a sock that is connected to a pesculator pump. The remainder of the net is stretched out to provide the fish with some space and water is pumped over them to maintain aeration. The pesculator transfers the fish to a grading table (Figure 25) that separates the water from the fish and then the fish into 8 different sizes. Large fish bins containing water are positioned below each grading chute to catch the fish. Some clove oil is placed inside the bins to help relax the fish when they are transferred to other ponds or purging tanks. The fish are purged for 48 hours before sale. This method of harvesting is extremely efficient and can remove 30-50 tonnes per day.



Figure 24. 10-15 ha ponds are used to culture a mixture of species at Kibbutz Maoz Haim using 20-30 paddlewheels per pond to achieve stocking densities of 25 t/ha (2.5 kg/m³).



Figure 25. A pesculator pump is used to transfer fish on to a grading table that is capable of splitting the fish into 8 different size categories direct to transfer bins.

Nir David Fish Processing

The Nir David fish processing facility at Bet She'an in the Jordan valley processes 3000 t of fish per annum from the Maoz Haim and Neve Etan fish farms only.

The fish sent to the facility are the species that are commanding the best price for a given week. Live fish are delivered to the processing plant in a tractor pulled trailer tank. When the fish arrive they are placed into a 2-4 °C water bath and left for 1 hour to allow their core body temperature to drop. Once chilled, they first pass through a rotating bar screen to remove small, growth stunted fish then on to a conveyer belt where a person hand sorts fish into different sizes and species and removes any deformed fish (Figure 26). The graded fish pass through a chute into a plastic tub. The tub is filled with the specific grade or species until the weight reaches 15 kg. The filled tub is then moved to an area where it is covered in ice and stacked on a pallet. Once the pallet is full, it is stored in a coolroom before transport to the market.



Figure 26. Fish are hand sorted into individual species for packing into 15 kg boxes.

Neve Etan

The Neve Etan fish farm in the Jordan Valley produces around 1200 tonnes per annum of species including: tilapia, carp *sp.*, grey mullet and red drum. Most of the fish are produced in ponds but some are produced in above ground tanks (8 x 500 m³ and 4 x 300 m³, Figure 27).

The effluent from the tank facility flows into a storage dam (1000 m³) where solids settlement occurs. Water is pumped up to an elevated holding dam (5000 m³) that acts like a biofilter. The tanks have 2 x paddlewheels that create a fast circular current which could be seen from above. A feed silo is used to supply two ponds. All ponds were covered in bird netting to prevent predation.



Figure 27. 500 m³ and 300 m³ tanks are used to culture fish at Kibbutz Neve Etan.

PRAqua Canada

This facility contains an intensive recirculation system, designed to produce 100 tonnes of tilapia per annum. The components for this system were sent direct from Canada. Currently this system is in its fourth year of operation and the system has been operating since 2000. Its first year of operation produced 97 tonnes of Nile tilapia, but in their second year they were hit severely by a *Streptococcus sp.* and at the same time the price of tilapia dropped drastically. A decision was made to farm hybrid striped bass instead. Currently the farm is producing mainly HSB, but there is a small amount of tilapia and koi production. The farm also rents out tanks to other companies for over wintering of broodstock and tilapia. These tilapia are sold as advanced fingerlings up to 150 g which take around 100-150 days to produce. The system allows market size tilapia to be sold in the off-season (winter), when prices are higher as outdoor pond facilities have no product for market. The farm is now operated to make a profit, not for maximum production with careful consideration as to what species they must grow each year and how to take advantage of market supply fluctuations to optimise price for products.

The PRAqua System is arranged as four recirculating systems. Two systems are comprised of 8 x 3 m³ and two with 4 x 45 m³ tanks. The water in each tank is circulated 3 times/hour and undergoes filtration through a 60 µm drum filter. Each of the 45 m³ tanks have their own biofilters positioned above the tank, and all tanks within the system have their influent water oxygen saturated in a chamber using liquid oxygen. The 8 x 3 m³ systems have only one biofilter for each system. The biofilters consisted of fluidised microbeads of polystyrene (2-4 mm diameter) to provide very high surface area to volume ratio. The advantage of having the four systems is to allow different temperatures to be maintained to suit different species. HSB prefer 23-24 °C, tilapia 26-27 °C, and ornamental koi 29-30 °C.

There is a backup generator on the site. In the event of a power blackout, an oxygen diffuser must be manually placed into each tank to maintain dissolved oxygen levels. There is a 15-20 minute window where the oncall person must attend any problems before any fish die.

To save costs during construction, no automatic feeding system was installed so all feeding is done by hand and demand feeders have been installed on each tank.

The fish are harvested by removing the centre standpipe which is 300 mm in diameter. The fish pass through this outlet and collect in a 60 m³ concrete purging tank. This allows a truck to park next to the tank and collect the fish for live transport to market.

The farm manager of the facility recommended some improvements/changes for the facility if he had the opportunity to build it again. These included:

- Increase production to 200 tonnes pa. To produce tilapia in the current market he believes you need to produce a minimum of 500 tonnes pa to be economically viable.
- Separate equipment such as biofilters, pumps, etc, and place them in a plant room to remove the noise within the facility.
- Combine the biofilters for the 45 m³ tanks, but have them in 4 sections to allow cleaning.
- Improve CO₂ degassing within the system. Currently CO₂ levels build up within the facility that can cause staff to feel dizzy.
- When purchasing overseas systems, source as much of the equipment as possible from local suppliers to access the warranty and service support.

Ein HaMifraz

Ein HaMifraz is part of a kibbutz in the northern region of Israel near the town of Haifa. The production methods at this farm vary between pond culture, semi-intensive tank culture and intensive culture using a recirculating aquaculture system. The total production from these methods yields 700 t per annum. When the farm commenced operation, they would pump water from a near by river called the Na'aman during the winter when flows were high. Due to the presence of this freshwater source, numerous aquaculture facilities developed in the region. Over time due to increased pressures on the river through aquaculture and irrigation, the supply and quality of the river water has greatly decreased.

At Ein HaMifraz, river water taken during winter requires three months retention to remove sediments before it can be used to culture fish. To maintain production a bore has been sunk down to 110 m that delivers water at 350 m³/hr that has a salinity of 12 g/L. The water at the farm must be monitored regularly to maintain optimal salinities for culturing different species of fish. Tilapia will grow in saline water up to 18 g/L, but the salinity for carp must be kept below 5 g/L. During one summer when there was a drought, the salinity in one pond increased to oceanic concentrations (35 g/L). There is a total of 60 ha of ponds at the farm that are used to culture silver/grass carp, grey mullet, tilapia, red drum, sea bass and sea bream. A management decision at the farm has decided to culture only one species/pond at any one time. There is a hatchery at the site that is only used to culture carp *sp.* and tilapia, with the rest of the stock sourced from external hatcheries.

The majority of the production takes place in ponds, but some fish are grown in large tanks (300-500 m³) either open or enclosed within greenhouses. Using these tanks sea bass and sea bream received new bore water from the salinised well in 300 m³ tanks, where the water is exchanged 4-5 times/day. Paddlewheels are used for aeration, and the maximum stocking densities achieved are around 18-20 kg/m³. The effluent from these ponds is transferred to a sedimentation pond. The sediment water contains microalgae (green water) that is moved to 4 x 500 m³ tanks to culture tilapia or red drum (18-20 kg/m³). The effluent water from these tanks is transferred to a large sedimentation pond which acts as a large scale biofilter. This water is then pumped back to the tilapia and red drum ponds for reuse.

Two years ago the farm purchased an intensive recirculation system from HESY with the aim of producing 100 t of fish, and to investigate alternative production methods for fish culture in Israel. The HESY system was chosen after travelling the world investigating the available production systems at the time. This was the second closed system constructed in Israel. A benefit of purchasing a HESY system is that a warranty is provided for the performance and it is a 'turn key' project.

A shed was constructed with an insulated roof and the walls contain greenhouse plastic that can be rolled up. Within the shed there were three separate systems built to grow fish. Two systems of 10 x 15 m³ and a nursery system containing 2 x 10 m³ and 2 x 3.7 m³. By having three separate systems fish can be grown at different salinities and temperatures to provide more production and marketing flexibility.

The HESY system removes water and wastes (incl. dead fish) from the centre of the tank through a surface skimmer box at the side of each tank. This allows mortalities to be easily removed. All the effluent water then passes through a 30 µm screen drumfilter positioned inside a concrete sump. The sump also contains a paddlewheel that provides aeration and degassing to remove CO₂ (Figure 28) that is removed from the inside of the facility by opening up the walls. After mechanical filtration and degassing, the water passes through a biological trickle filter comprised of bioblock. There are fans above the biofilters drawing air through the media (Figure 28). After biological filtration, the water is super saturated with liquid O₂, and is then passed back to the tanks. 5 m³/hr of new water from the bore enters the system, and the system holds around 400 m³ of water (incl. biofilters). Currently there is a mixture of species cultured, including tilapia (Figure 29), HSB and sea bream. Only two staff are required to operate the 100 t system.



Figure 28. A paddlewheel has been added to the Hesy filtration system to assist in CO₂ degassing. Fans are positioned above the biological filters to help push air through them.

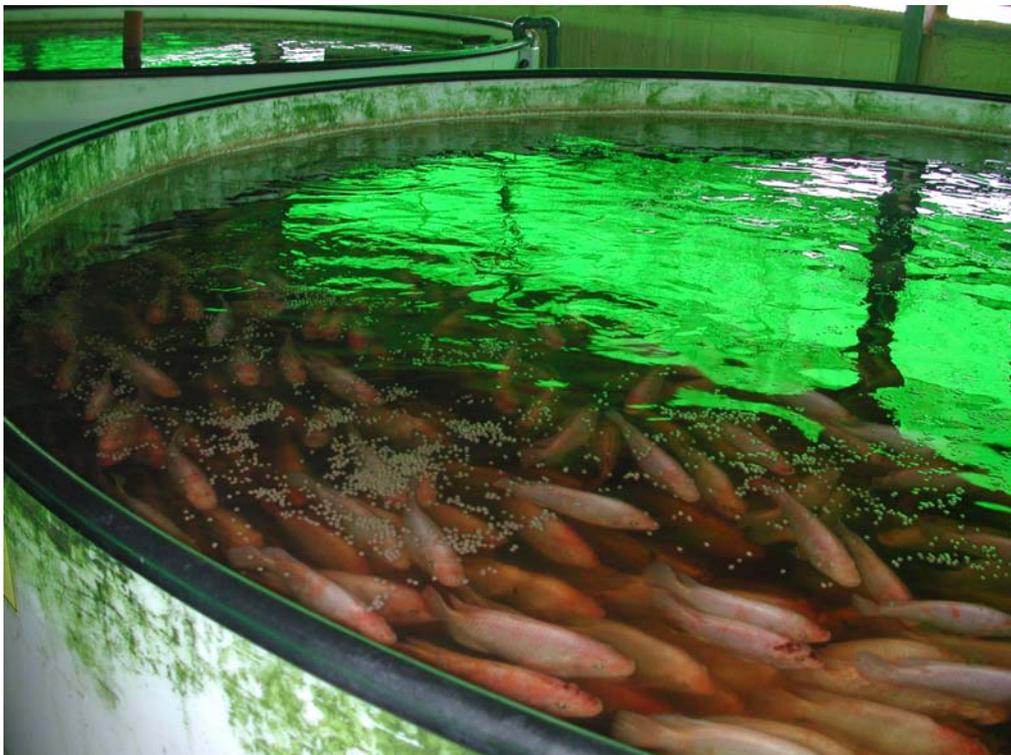


Figure 29. Red tilapia are fed a floating pellet to assist in feed management within the HESY system.

Fish are harvested from the system in a similar way to the PRAqua Canadian system where the centre standpipe is removed to allow the fish to swim through to a purging tank (Figure 30). Here the fish can be graded into 4 sizes using a grader and vacuum pump.

Daily water quality monitoring is performed manually to assess the biological and mechanical performance of the system. Once a week the fish are checked by a veterinarian for parasites.



Figure 30. Market size fish are transferred to a holding tank for purging, before being vacuum pumped through a grader ready for transport to market.

Kfar Masarik

Kfar Masarik is another kibbutz located near Haifa in northern Israel. Aquaculture operations at this kibbutz produce 300-400 t of fish per annum using 10 x 5.5 ha ponds. A mixture of species are grown including tilapia, grey mullet, red drum and grass/silver carp. Tilapia are over wintered inside greenhouses to try and increase sale price during this period.

At the time of inspection an underground water catchment system was being constructed to intercept the rising watertable. To do this a 2.5 m trench was being dug using a backhoe. The trench was then dug to 5 m using a large trench digger that could lay both agricultural drainage pipe with coarse gravel around it (Figure 31). Additional gravel is placed over the pipe using an excavator and backhoe. This method of drainage pipe laying is the cheapest way and they can lay 300 m of pipe per day. A system of these subsurface drains was being constructed to bring water to central locations from where it could be pumped for aquaculture use.

350-500 m³ tanks are used for nursery production and over wintering of fish. Some inflated greenhouses were imported from the USA twelve years ago. Problems have occurred with

these systems because during winter outside cold air is pumped into the greenhouses that cools inside air temperatures and thus water temperatures.

At Kfar Masarik they use large ponds to produce their fish. These ponds have 2-3 m deep walls so an earthen balcony/platform is constructed at one end of the pond (Figure 32) to provide a working area close to the pond water to allow the access of machinery and harvesting equipment. A vacuum pump is used for harvesting the fish from the pond. Water and fish are moved onto a grading table where they can separate into nine different sizes.

A cooperative has been established between farms in the region for selling tilapia over the winter. They have agreed to a price and will keep a constant supply of fish entering the market during this period.

All the wastewater from the site was used for irrigation.



Figure 31. Agricultural drainage pipe is positioned 5 m below the ground using a large trench digger to catch underground water for aquacultural use.



Figure 32. Ponds with high walls require a 'balcony' at one end to allow a safe working area for machinery and harvesting equipment.

Highlights from Overseas Technology Review

This overseas technology audit was conducted to assist in the development of a R&D, pilot scale demonstration facility at Waikerie aligned to Woolpunda/Waikerie/Qualco SIS's. This saline groundwater has an annual temperature range of 20-24 °C and a flow rate of 30,000 KL/day. One of the aims of the project is to identify aquaculture systems that capitalise on these attributes (constant temperature and flow) and maximise the production potential of this resource in order to stimulate an aquaculture industry aligned to these SIS's.

During this overseas trip, various methods for culturing fish and shrimp (prawn) were inspected. In Israel, fish production systems observed included open pond culture, semi-intensive tank/raceway culture (250-500 KL), intensive tank culture systems (HESY and PRAqua) and low head medium-intensive culture systems (Megaflow). In the USA there are inland shrimp culture production ponds in Arizona and Alabama and in North Carolina fish are cultured in medium density ponds and intensive recirculation systems.

Due to the age of the inland aquaculture history of the USA and Israel, we have been able to observe how technology has evolved over time. This will allow informed decisions to be made to assist the advancement of the industry in South Australia. After reviewing the production techniques and system designs in the USA and Israel, the following points have been highlighted which must be considered when attempting to develop an inland saline aquaculture industry in the SA Riverland:

1. Recirculating aquaculture systems allow a greater control of environmental parameters to promote year round production.
2. The Israel government has identified a need for offering incentives/subsidies to promote facilities to change from high water use pond systems to low water use systems (medium/high intensive RAS).
3. Keep production systems relatively simple to lower initial setup costs and reduce the chance of mechanical malfunction.
4. Careful consideration must be given when choosing an intensive recirculating aquaculture system. There are many 'horror' stories of people who have purchased systems that don't produce what the designer/engineer/consultant suggests.
5. Treatment methods for effluent discharged from brackish and marine water aquaculture systems are still in the early stages of development. Alternative measures, such as growing salt tolerant plants like *Salicornia sp.* require further examination as alternatives to using macroalgae.
6. Brackish water pond culture in arid environments in the summer months can result in increases in salinity to oceanic strengths and higher. A similar problem has been observed in early attempts to culture prawns in SA (Pt Broughton).
7. Any greenhouses built must have roll up sides to allow summer cooling, and the roof must be either insulated or green in colour to prevent microalgae from developing in the culture water.
8. In the USA there is a large market for live fish sold to the Asian community, which allows aquaculturalists to sell their products for premium prices. Any similar market in Australia is likely to be much smaller.

9. People wishing to establish aquaculture ventures must have sound business plans before construction and realise that production facilities will probably have to culture a minimum of 100 tonnes pa to be economically viable (species dependant).

Review of USA and Israel Production Systems

Table 2 provides a summary of the culture systems observed in the USA and Israel. Using the stocking densities provided and the percent water exchange per day, the production per tank/pond and water use per day was determined. Taking into consideration the total water flow entering the Stockyard Plains Disposal Basin a day (30,000 KL), it was calculated that medium (Megaflow) and high (RAS, USA) density culture systems are capable of producing significantly more fish than semi-flow through tanks (250-500 KL) and open pond systems. A summary of the advantages and disadvantages of each type of system has been detailed (Table 3).

Pond Culture

The SPDB is capable of producing 750 t pa of fish in 60 x 1 ha ponds exposed to ambient conditions (Table 2). Pond culture is not recommended for the SPDB water due a number of reasons. Firstly the initial cost of lining and constructing the ponds is expensive because earthen ponds cannot be used, as pond water will leach back into the ground deteriorating the quality of the land. Secondly, the Riverland climate is extreme with high summer air temperatures (> 40 °C) and low winter air temperatures (< 0 °C). High temperatures create high evaporation rates that can increase the salinity of the ponds. At one facility in Israel using brackish water, the salinity increased to oceanic strength within one summer when there was a drought. Winter ambient pond temperatures in SA are low (7-8 °C), and if only 10 % water exchange is occurring per day, water temperatures will be too low for fish growth. Also, considerable money must be invested in netting the ponds to prevent bird predation.

Semi-flow Through Tanks

Semi-flow through tanks (250-500 KL), require 100 % of their tank volume exchanged per day to achieve relatively low stocking densities (20 kg/m³). An example of this was seen at Ma'agen Michael in Israel where sea bass and red drum were cultured. Only 10 % of the daily water was new water from the well, with the remaining 90 % pumped from the sedimentation ponds. If this type of production method was transferred to the SPDB, 600 t of fish could be produced (Table 2) if you didn't reuse the culture water from a sedimentation pond. If large sedimentation ponds were used at the SPDB, and 90 % of the water was reused then the yearly production would significantly increase to 3000 t. The reuse of sedimentation water at the SPDB is a concern due to the cold winters of the Riverland. Reuse of water exposed to ambient conditions will drop in temperature that in turn will affect fish growth.

There is an advantage to reusing high volumes of water at the SPDB. During the year the salt interception pipes connected to the SPDB must be shut down for routine maintenance. Cleaning can take up to one week that is repeated multiple times per year, so the reuse of water is critical for a facility to survive during this period.

Medium Intensive Recirculating Aquaculture Systems

In Israel a medium intensive RAS called Megaflow has been designed to culture fish at stocking densities of 50 kg/m³. This is a low head system that uses only airlifts to move water around the system. These systems are relatively water efficient requiring only 10 % exchange per day, and the temperature in the system can be controlled by water exchanges in the summer and winter and the use of greenhouse structures to house the system. If this type of system was adopted at the SPDB, 15,000 t of fish could be produced yearly (Table 2). An advantage of this system is that it requires only a small storage capacity to keep the system operating when the salt interception scheme is shutdown for routine maintenance. Unfortunately this system has not been trialled with Australian species, so the performance of the system is unknown. If the recommended 15,000 t of fish are produced, marketing issues will occur if the product cannot be sold.

High Intensive Recirculating Aquaculture Systems

High density RAS's are water efficient like the Megaflow system enabling large quantities of fish to be produced. The difference between the Megaflow and high density RAS (eg. NC State University) is that the high density system uses liquid oxygen and expensive solid removal components to achieve stocking densities up to 100 kg/m³. High density RAS operated with water from the SPDB are capable of producing 30,000 t of fish pa (Table 2). These systems maximise the production of fish per litre of culture water using minimal labour to make them the most productive systems currently available on the market. Due to the technical complicity of the design, the price of fish production is significantly higher than all the other systems previously mentioned. Backup facilities must be on site as there is very little time available to react to a system shutdown. The high density RAS has a similar advantage to the Megaflow system where water storage facilities only need to be small to maintain the full production of the system when the salt interception pipelines are shut down for routine maintenance.

Table 2. Review of Israel and USA fish production systems and the costs benefits utilising saline groundwater from the Woolpunda/Waikerie salt interception schemes.

System Type	Semi-Intensive Tanks Israel	Megaflow Israel	Ponds Israel	Intensive Recirc. USA	Ponds USA
<i>Manufacturer</i>	Haogenplast	Kora Megaflow	n/a	NC State Uni	n/a
<i>Species</i>	carp <i>sp.</i> , tilapia, sea bream, sea bass, barramundi, red drum	sea bream, hybrid striped bass, tilapia	carp <i>sp.</i> , tilapia, sea bass, grey mullet, red rum	tilapia, barramundi	hybrid striped bass, catfish
<i>Tank type</i>	hexagonal tanks	continuous raceway	earthen pond	tanks	earthen pond
<i>Size</i>	100 - 500 KL	100 KL	1 - 15 Ha	60 KL	1 Ha
<i>Max. SD (kg/KL)</i>	20	50	2.5	100	2.5
<i>Water type</i>	fw & sw	fw & sw	fw & brackish	fw	fw
<i>Temperature control</i>	greenhouse or ambient	greenhouse	ambient	insulated building	ambient
<i>Tank/pond volume (KL)</i>	100	100	5,000	60	5,000
<i>Water exchange/day (%)</i>	100 ^a	10	0-5	10	0-5
<i>Water Use per day (KL)</i>	100	10	500	6	500
<i>Production (t) pa^b</i>	2	5	12.5	6	12.5

Production Capacity Using Waikerie/ Woolpunda SIS Flow

Total Flow (KL/day) 30,000

<i>Total tanks/ponds</i>	300	3000	60	5000	60
<i>Total Production (t) pa</i>	600	15000	750	30000	750
<i>Value @ \$8.00/kg (\$Million)</i>	4.8	120	6	240	6

^a % new water added daily (assumes additional supply of recycled water 300-400 %/day).

^b Assumes the fish take 12 months to reach market size.

Table 3. Considerations for transfer of overseas production systems to use water from SIS’s in SA.

System	Advantages	Disadvantages
Low - Intensive Open Ponds (USA & Israel)	<ul style="list-style-type: none"> • Simple operation that can readily utilise all the water available • Low construction and operating costs 	<ul style="list-style-type: none"> • Sludge removal • Expensive to plastic line ponds • Loss of heat in winter • Evaporation loss in summer • Low production potential from water available • Bird Predation
Semi – Intensive Tanks 100 – 500 KL (Israel)	<ul style="list-style-type: none"> • Relatively simple operation • Able to manage wastes 	<ul style="list-style-type: none"> • Does not maximise production from available water resource • Requires supplemental oxygen • Sedimentation ponds required to allow water reuse to increase production
Medium – Intensive Recirculation Megaflow (Israel)	<ul style="list-style-type: none"> • Robust system with few complexities • Provides high productivity from available water • Low cost and energy requirements • Able to manage wastes • Minimum water storage required for operation during salt interception scheme shutdown 	<ul style="list-style-type: none"> • System unproven in Australia with local species • Market needs to be large to accommodate potential production
High – Intensity Recirculation (USA)	<ul style="list-style-type: none"> • Maximises production/litre of water • Minimal labour required • Able to manage wastes • Minimum water storage required for operation during salt interception scheme shutdown 	<ul style="list-style-type: none"> • Market needs to be large to accommodate potential production • High operating/maintenance costs • Minimal time to react to system shutdown

Recommendations to Establish an Inland Saline Aquaculture Industry in SA

Visiting aquaculture facilities in the USA and Israel allowed comparisons to be made between the available production systems (Tables 2 and 3) and understand the evolution of the inland aquaculture industry in these countries. Taking into consideration the positive attributes of the intercepted saline groundwater from the Woolpunda and Waikerie SIS's (ie. elevated water temperature, available volume and supply advantages), it was concluded that the Israeli designed 'Megaflow' system is worth importing to South Australia to demonstrate its capabilities at Waikerie. A medium intensive culture system needs to be examined further for expanding the inland saline aquaculture industry in South Australia. The review of the potential production figures and approximate dollar amounts (Table 2) suggest medium and high density recirculating production systems must be transferred to the Riverland region aligned to salt interception schemes. We consider the medium intensive production system to be more favourable over the high intensive system due to its simplicity and reliance on the positive attributes that SIS water has.

Medium Intensive Recirculation System Design

The design of the 'Megaflow' system is mechanically very simple where a series of airlift pumps are used to move water through a raceway tank. After the water exits the tank it passes through an upflow biofilter and then through a fluidised 'macaroni' media biological filter. The 'Megaflow' system will be located inside a greenhouse to enhanced winter temperatures and have the capabilities to reduce inside summer temperatures. The water within the system will not require heating because it will be controlled through the volume of water used from the salt interception pipeline. The amount of exchange will be varied depending on the change in water temperature within the system. It is anticipated that the water temperature during the winter will decrease and during the summer will increase.

Application to Salt Interception Schemes

After careful consideration, it has been decided that any aquaculture facility aligned to a salt interception scheme must have the capacity to reuse water. A major problem with using saline groundwater from salt interception schemes is there are periods when the scheme must be shutdown for routine maintenance. There are also times when a SIS pipe can be broken by someone digging in the vicinity. This will prompt an immediate closer of a pipeline until the pipe can be repaired. To manage the risk of pipeline closures, aquaculture production systems need to be water efficient to reduce the backup storage capacity of a facility. If a flow through system was operated, then an enormous storage dam would be required at the site. This dam would be expensive to build and difficult to maintain the elevated temperature of the water.

All system components and culture units must be in lined ponds or tanks to allow no infiltration of saline groundwater into surrounding land, aquifers or waterways.

Future Research Collaborations

It is apparent that Israel and South Australia share many similar issues that affect aquaculture (and agriculture). Throughout the study visit a number of potential areas of collaboration have been highlighted and Dr Hillel Gordin (Director of Mariculture Division, Ministry of Agriculture and Rural Development, Department of Fisheries and Aquaculture) has reconfirmed his commitment to an Israel – South Australia aquaculture research fund, with each party investing. As this would entail considerable time to promote it was agreed that cooperation should start as ongoing information exchange, visits, student placements and sending researchers to conferences in each country. Initial collaborative projects in the following areas could have mutual benefits:

- Improving the performance of recirculating systems for intensive inland aquaculture in saline water.
- Optimisation of production and water reuse from lined saline aquaculture pond systems.
- The integration of additional species and the production of downstream products to increase income from inland saline aquaculture systems.

This collaboration will be initiated as a memorandum of understanding (MOU) that will state the willingness of each party to commit to this approach, and will be signed off by both countries in December 2004 if both parties can agree.

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