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Australian Government
Department of Education, Employment
and Workplace Relations

COMMERCIAL INTEGRATED FARMING OF AQUACULTURE AND HORTICULTURE

Andrew S de Dezsery MSc

International ISS Institute/DEEWR Trades Fellowship

Fellowship supported by the Department of Education, Employment and Workplace Relations, Australian Government

International
Specialised
Skills
Institute

ISS Institute
Suite 101
685 Burke Road
Camberwell Vic
AUSTRALIA 3124

Telephone

03 9882 0055

Facsimile

03 9882 9866

Email

officemanager@issinstitute.org.au

Web

www.issinstitute.org.au

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ISS Institute
101/685 Burke Road
Camberwell 3124
AUSTRALIA

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Executive Summary

The Fellow visited aquaponic commercial farms and related research facilities in the United States and Canada to examine the latest advances in production methodologies.

There is growing interest worldwide in commercial aquaponic farming as the integration of aquaculture and horticulture allows greater productivity and more efficient resource use. The speed and extent of its growth is limited, however, by deficiencies in technical know-how in dealing with the myriad of biological, physiochemical and hydrodynamic interactions in aquaponic systems.

Inland aquaculture development and town planning regulations are still in conflict in many regions across Australia. The establishment of management zones, designations of marine park areas and stringent licensing for mariculture activities is impacting on the capacity of the industry to grow. Peri-urbanisation is encroaching on fringe rural communities and general farming is being pushed further out. One solution would be to allow farms that use highly productive integrated farming practices (IFP) to operate on a small footprint in urban and semi-urban regions with minimal environmental impact.

If integrated inland aquaponic farming is to survive and prosper, existing and prospective industry participants will need to have access to appropriate training and professional development support. Although formal training in Recirculating Aquaculture Systems (RAS) has been available for well over a decade, current training is insufficient to cover the increasingly complex technical and scientific requirements needed to operate successful IFP operations. Only a handful of professional, commercially trained and specialised industry educators are available to perform this task.

Notwithstanding these challenges, Australia's status as an environmentally friendly producer of aquatic food provides the domestic aquaculture sector with a significant comparative advantage in export markets. Quality assurance accreditation policies and international standards have been developed by the industry. Industry training is also well underway to ensure accreditation standards for aquaculture exports are maintained. Growth of the Australian aquaculture industry has been assisted by organisations such as the Cooperative Research Centres (CRC) and Fisheries Research and Development Corporation (FRDC) who have funded numerous collaborative research and development projects.

The Fellow has been active in sharing the findings flowing from the Fellowship experience. He has been invited to make a presentation at a forthcoming major international conference on urban aquaponics development to be held in Australia. The Fellow has already conducted presentations to the South Australian Murray-Darling Basin Natural Resources Management Board. Further presentations are being considered for the Riviera region of South Australia and Victoria.

This report concludes with a number of practical recommendations for government, industry associations, and the education and training sector, that will help grow and consolidate a vibrant and sustainable sector of the food industry in Australia.

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Abbreviations and Acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
CDCS	Crop Diversification Centre South
CRC	Cooperative Research Centres
CSA	Consumer Supported Agriculture
DAC	Development and Assessment Corporation
DC	Direct Current
DEEWR	Department of Employment, Education and Workplace Relations
FRDC	Fisheries Research and Development Corporation
GM	Genetic Modified
HACCP	Hazard Analysis Critical Control Point
HID	High Intensity Discharge
IAASA	Inland Aquaculture Association of South Australia
IAS	Inland Aquaculture Systems
IFP	Integrated Farming Practices
IPM	Integrated Pest Management
ISSI	International Specialised Skills Institute
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
NFT	Nutrient Film Technique
NOSB	National Organic Standards Board
O_3	Ozone
PAR	Photosynthetic active radiation
PIFS	Precision Integrated Farming Systems
PV	Photovoltaic
RAS	Recirculating Aquaculture Systems

Abbreviations and Acronyms

SA MDB NRM	South Australian Murray-Darling Basin Natural Resources Management Board
SPF	Specific Pathogen Free
SWOT	Strengths, Weakness, Opportunities, Threats
TAFE	Technical and Further Education
USA	United States of America
USDA	United States Department of Agriculture
UV	Ultra Violet
UVI	University of the Virgin Islands

Definitions

1000 PAR

1000 micromole per m^2 per second Photosynthetic Active Radiation

Ammonification

This is the bacterial assimilation of by-products from metabolic activity, which are converted into a nitrate compound.

Anaerobic mineralisation

A complete breakdown of waste into soluble mineral compounds. Anaerobic bacteria. Bacteria that requires no oxygen to grow: anaerobic is a technical word that literally means 'without air'.

Beneficial bacteria

An example of a beneficial bacteria is Yakult, a probiotic fermented bacterium taken for the health of the human digestive system.

Clarifiers

A mechanical device used to settle solid waste

Catadromous protandrous hermaphrodite

A fish born in salt water that becomes an adolescent male in freshwater and then changes to a female when back in salt water.

Colloidal polymer flocculant

An electrolyte polymer used in a solution to floc together suspended particles.

Cylindro-conical

A cylinder object with a tapered end.

Denitrification

Bacterial assimilation of by-products from metabolic activity, which are converted into a nitrogen compound

Design

Design is problem setting and problem solving.

Design is a fundamental economic and business tool. It is embedded in every aspect of commerce and industry and adds high value to any service or product—in business, government, education and training, and the community in general.

Reference: 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.

Definitions

Ento-protein™

Is an advanced dietary nutritional product made from insects grown on agricultural waste, and products including distillers' dried grains from ethanol plants.

Innovation

Creating and meeting new needs with new technical and design styles. (New realities of lifestyle).

Reference: 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.

Ozonation

The use of Ozone (O_3) to break down organic compounds by way of oxidisation.

Oxidisation

The breakdown of compounds using oxygen as the catalyst.

Skill deficiency

A skill deficiency is where a demand for labour has not been recognised and training is unavailable in Australian education institutions. This arises where skills are acquired on-the-job, gleaned from published material or from working and/or studying overseas.

Reference: 'Directory of Opportunities. Specialised Courses with Italy. Part 1: Veneto Region', ISS Institute, 1991.

There may be individuals or individual firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the intellectual property to themselves. Over time these individuals retire and pass away. Firms likewise come and go.

Sustainability

The ISS Institute follows the United Nations for Non-Governmental Organisations' definition on sustainability: *"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

Reference: http://www.unngosustainability.org/CSD_Definitions%20SD.htm

Acknowledgements

Andrew de Dezsery would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide him throughout the Fellowship programme.

Awarding Body – International Specialised Skills Institute (ISS Institute)

The International Specialised Skills Institute Inc is an independent, national organisation that for over two decades has worked with Australian governments, industry and education institutions to enable individuals to gain enhanced skills and experience in traditional trades, professions and leading-edge technologies.

At the heart of the Institute are our Fellows. Under the **Overseas Applied Research Fellowship Programme** the Fellows travel overseas. Upon their return, they pass on what they have learnt by:

1. Preparing detailed reports to government departments, industry and education institutions.
2. Recommending improvements to accredited educational courses.
3. Offering training activities including workshops, conferences and forums.

Over 180 Australians have received Fellowships, across many industry sectors.

Recognised experts from overseas also conduct training activities and events. To date, 22 leaders in their field have shared their expertise in Australia.

According to Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010':

> Australia requires a highly skilled population to maintain and improve our economic position in the face of increasing global competition, and to have the skills to adapt to the introduction of new technology and rapid change.
>
> International and Australian research indicates we need a deeper level of skills than currently exists in the Australian labour market to lift productivity. We need a workforce in which more people have skills, but also multiple and higher level skills and qualifications. Deepening skills across all occupations is crucial to achieving long-term productivity growth. It also reflects the recent trend for jobs to become more complex and the consequent increased demand for higher level skills. This trend is projected to continue regardless of whether we experience strong or weak economic growth in the future. Future environmental challenges will also create demand for more sustainability related skills across a range of industries and occupations.[1]

In this context, the Institute works with Fellows, industry and government to identify specific skills in Australia that require enhancing, where accredited courses are not available through Australian higher education institutions or other Registered Training Organisations. The Fellows' overseas experience sees them broadening and deepening their own professional practice, which they then share with their peers, industry and government upon their return. This is the focus of the Institute's work.

For further information on our Fellows and our work see www.issinstitute.org.au.

[1] Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010', pp. 1-2 http://www.skillsaustralia.gov.au/PDFs_RTFs/WWF_strategy.pdf

Acknowledgements

Fellowship Supporter

This Fellowship has been sponsored by the Department of Education, Employment and Workplace Relations (DEEWR).

DEEWR provides national leadership and works in collaboration with the States and Territories, industry, other agencies and the community in support of the Government's objectives. DEEWR aims to touch the lives of all Australians in a positive way, working towards a vision of creating a productive and inclusive Australia. Andrew de Dezsery would like to thank them for providing funding support for this Fellowship.

Supporters

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- Joel Malcolm, Director, Backyard Aquaponics
- Adrian Mathews, Director, Barra Fresh Pty Ltd
- Rosemary McKenzie-Ferguson, Manager, Work Injured Resource Connection SA
- Robin Moseby, Secretary, Inland Aquaculture Association of South Australia (IAASA)
- Jeremy Nelson, Regional Land and Water Management Planning Coordinator, South Australian Murray-Darling Basin Natural Resources Management Board (SA MDB NRM)
- Gavin Smith, Manager, 1Aquaponics
- Gavin Smith, Manager, Barra Fresh Pty Ltd
- George Verrasi, General Manager, Hydro R Us Pty Ltd
- Ron Watts, General Manager, Northern Area Business Enterprise Centre (SA)
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In Canada

Montreal

- Dr Karl Ehrlich, Vice President, IET-Aquaresearch Ltd
- Marc Laberge, Director, Technologies Aquaponics ML Inc

Calgary

- Dr Nicholas Savidov, Leader-Greenhouse Crops, Crop Diversification Centre South (CDCS)

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Florida

- Ricardo Arias, International Division Manager, Aquatic Eco-Systems Inc
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- Jane Davis, Aquarium Curator, Disney Animal Programs, Epcot (Experimental Community of Tomorrow) Walt Disney World
- Dr Raymond Wheeler, Leader – Advanced Life Support Program, National Aeronautics and Space Administration (NASA)

Illinois

- Myles Harston, Director, AquaRanch

Virgin Islands

- Dr James Rakocy, Director, Research Professor of Aquaculture, University of the Virgin Islands

Wisconsin

- Dr Robert Morrow, Principal Scientist, Orbital Technologies Corporation
- Rebecca Nelson, Consultant, Nelson and Pade, Inc.

Australian Organisations Impacted by the Fellowship

Government

- Agri-Food Skills Council Australia
- Commonwealth Scientific and Industrial Research Organisation
- Commonwealth, State and Territory Occupational Health and Safety Commissions
- Department of Agriculture Fisheries and Forestry
- Department of Education, Employment and Workplace Relations
- Department of Water, Land & Biodiversity Conservation
- FarmReady
- Horticultural Skills Australia
- Horticulture Australia Limited
- Metropolitan, regional and rural Councils
- Primary Industries and Resources South Australia
- Rural Skills Australia
- South Australian Murray-Darling Basin Natural Resources Management Board (SA MDB NRM)
- Work Cover agencies

Acknowledgements

Professional Associations

- Inland Aquaculture Association of South Australia
- National Aquaculture Associations
- National Horticulture Associations
- Primary Industry Farming Groups
- Relevant Industry Groups

Education and Training

- Agriculture and Horticulture Training Council
- E-learning Providers
- Registered Training Organisations Australia wide
- Schools
- TAFE Australia wide
- Universities

Community

- Community houses/gardens
- Community Resource and Education Centres
- Shop front food suppliers

About the Fellow

Name: Andrew S de Dezsery

Employment

- Operations Manager, Omega Fish Products

Qualifications

- Graduate Diploma of Aquaculture, Deakin University, 1994
- Master of Science, Aquaculture, Deakin University, 1996
- Certified Seafood Industry Trainer and Assessor

Memberships

- Inland Aquaculture Association of South Australia
- Revival Fellowship of Australia

Andrew de Dezsery was born in Adelaide, South Australia in 1964.

In 1989 the Fellow became involved in aquaculture and later in the experimental potting of the Blue swimmer crab in Gulf St Vincent. He subsequently took a position with Fish Protech Pty Ltd, which had developed Australia's first aquaculture park using new recirculating aquaculture system (RAS) technologies from overseas.

The Fellow's passion for aquaculture led to the purchase of land north of Adelaide to develop his own business, Aquaculture Advantage. He subsequently established a consultancy business, was closely associated with the development of the Barramundi industry in Southern Australia, and managed a research and developmental recirculation system hatchery.

Between 1996 and 2006 the Fellow was a specialist lecturer in aquaculture engineering and RAS at the Flinders University in South Australia. During that time he also helped establish the Inland Aquaculture Association of South Australia (IAASA).

The Fellow currently operates a pilot commercial integrated farming research facility in association with Gavin Smith, Manager of Barra Fresh Pty Ltd.

Aims of the Fellowship Programme

The aim of the Fellowship was to obtain world-best-practice information from key USA and Canadian research institutions and industry on integrated aquaponic farming practices, full value adding of wastes, improving sustainability through alternative protein diets and organic certification processes.

The Fellow identified the following detailed objectives:

- Become familiar with multi-disciplined competencies in a wider range of polyculture techniques outside of aquaculture and associated food production issues.
- Achieve a better understanding of the current challenges in integrated farming practices (IFP) in aquaponics.
- Identify skill sets not being used in the Australian aquaponics sector.
- Have a better understanding of issues relating to developments in the aquaponic and aquaculture industry of North America, particularly with respect to recent advances in industry certification protocols.
- Identify all significant advances in the use of IFP and associated industry practices in the USA and Canada and determine how those advances can be integrated into the Australian industry.
- Enhance international professional networks.
- Develop models to integrate Australian RAS and hydroponic practices with latest overseas IFP technologies.
- Identify pathways for future formal training and possible pathways to incorporate IFP education into school systems.
- Use the knowledge gained to advise relevant stakeholders about the advantages of incorporating IFP into their businesses.

The Australian Context

The Australian aquaculture industry has developed primarily along our coastal fringes alongside established fishing towns and various allied industries. The progressive diversification of commercial fishing from wild capture activities to aquaculture farming and feed lotting has attracted an increasing investment in aquaculture.

At the 1998 The Australian Bureau of Agricultural and Resource Economics (ABARE) Outlook Conference, the Chair of the Australian Aquaculture Forum predicted that:

"Australian aquaculture will expand from a AU$400 million a year industry to a AU$1.4 billion industry by the year 2005." [2]

The Chair also identified a number of challenges that would confront the Australian aquaculture industry in the decade ahead, such as environmental and planning regulations, access to suitable sites, and business establishment costs.

The decade since the 1998 ABARE Outlook Conference has seen the Australian aquaculture industry grow, albeit erratically. It experienced a decline of some 30 per cent between 2001 and 2005, but had recovered sufficiently by 2006–07 to be a AU$799.6 million industry, still well short of the growth prediction made a decade earlier.[3]

At this same conference Paula Holland, Principal Research Economist of ABARE pointed out that one of the many challenges that Australian aquaculture face is access to suitable sites. Holland was of the view that planning systems would need to be flexible and able to accommodate all forms of aquaculture.[4]

The challenges Australian aquaculture faced in 1998 still remain. Inland aquaculture development and town planning regulations are still in conflict. The establishment of management zones, designations of marine park areas and stringent licensing for mariculture activities is impacting on the capacity of the industry to grow. Peri-urbanisation is encroaching on fringe rural communities and general farming is being pushed further out. One solution would be to allow farms that use highly productive IFP with minimal waste outputs, to operate on a small footprint in urban and semi-urban regions.

Notwithstanding these challenges, Australia's status as an environmentally friendly producer of aquatic food provides the domestic aquaculture sector with a significant comparative advantage in export markets. Quality assurance accreditation policies and international standards are being developed by the industry. Industry training is also well underway to ensure accreditation standards for aquaculture exports are maintained. Growth of the Australian aquaculture industry has been assisted by organisations such as the Cooperative Research Centres (CRC) and the Fisheries Research and Development Corporation (FRDC) who have funded numerous collaborative research and development projects.

In 2007–08 the value of South Australia's Southern Bluefin tuna harvest was AU$186.7 million.[5] Over two thousand people are employed directly and indirectly in this sector alone.[6]

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[2] Outlook 98: Commodity Markets and Resource Management: National Agricultural and Resource Outlook Conference Proceedings. (ABARE), Canberra ACT, 1998, vol 1, pp. 274–277

[3] http://www.abareconomics.com/publications_html/conference/archive/cp98_15.pdf

[4] ibid

[5] http://www.sardi.sa.gov.au/sbt/the_industry

[6] http://www.heraldsun.com.au/business/tipping-the-apple-cart/story-e6frfh4f-1111116124988

The Australian Context

The recent closing of the lifecycle of the Southern Bluefin tuna by the Clean Seas Company in South Australia holds out the prospect of additional job opportunities. Other marine species have also been identified as suitable for farming.

However, the development of aquaculture facilities in marine management and coastal zones will become increasingly few and far between. Enhanced production systems such as RAS and associated new technologies will increasingly be the means by which inland aquaponic farming is developed and sustained. Whilst coastal farming delivers large volumes of fresh marine fish and other seafood, inland integrated farming practices can also produce edible vegetables, fruits and other protein products through value adding farm waste.

A significant issue confronting inland farming is salinity. A decade ago the use of inland saline water from interception schemes was advocated as a means of encouraging greater investment in inland aquaculture production. A pilot inland saline aquaculture site was even established at Waikerie in South Australia. Regrettably, this pilot project has not released the research outcomes that would assist potential inland aquaponic farming investors to make informed decisions.

By way of contrast, there is greater investor optimism in integrated inland freshwater aquaculture farming. Many small-scale backyard hobbyists are active in freshwater integrated farming. Fish produce nitrogenous waste nutrients that edible plants strip out as part of their growth cycle.

Water used in RAS fish farming releases all backwash effluent into existing or purpose-built evaporation ponds rather than into waterways. The nutrient bioremediation that can be utilised by reusing this water significantly reduces the impact on the natural ecosystem. Purpose grown fish grow-out in RAS farms together with hydroponic and bioremediation components for nutrient stripping and water use minimisation are now the benchmark for a sustainable inland aquaculture industry.

If integrated inland aquaponic farming is to survive and grow, existing and prospective industry participants will need to have access to ongoing training and professional development support. Although formal training in RAS has been available for well over a decade, the available training modules are insufficient to cover the increasingly complex technical and scientific requirements needed to operate successful RAS operations. Only a handful of professional, commercially trained and specialised industry educators are available to perform this task. The Fellow developed a training and development model in 1999 specifically for the RAS sector, but limited funding and insufficient industry interest prevented it being taken any further.

Developing and maintaining integrated farming practice skill sets requires a holistic approach that integrates and adapts other industry practices and skills to aquaponic farming. Many new industries fail due to poor cash flow. Aquaculture is no different. Integration can improve cash flow. For example, in early February 2010 the average farm gate price of farmed Barramundi in the Melbourne live trade market was $14.50 kg (production time: 6–9 months), organically produced lettuce at a farm gate price was $1.10 per unit (production 31–42 days) and rabbit live to the processor at a farm gate price was $6.20 kg (production 42–49 days). These figures show how integrating these systems can improve cash flow. Moreover, all these products can be produced by utilising water in a hydraulic loop that enables wastes to be used to create high value products.

The Australian Context

Globalisation and changing climatic conditions provide unique growth opportunities for integrated farming in Australia. However, it is imperative that the industry be built up methodically. The involvement of key industry groups is crucial to ensuring a coordinated approach is applied to developing the industry. If this can be achieved, IFP will be a significant player in propelling Australia into a new and exciting era of efficient and diverse food production.

Agro-economists concur that urban farming can create jobs. Even without this type of local food production, the food industry creates far more revenue in both production and delivery to point of sale than for every retail dollar spent on food.

When one looks at average fresh vegetable products purchased in Australia, they may have travelled up to two thousand kilometres, with a portion of the produce spoiling en route despite the fact that it was bioengineered to withstand the rigours of transport. In the Fellow's local supermarket, hydroponic lettuce produce is imported from NSW to SA when two of the largest hydroponic lettuce growers in the region are only three minutes away from the store.

Food that reaches the shelf seems fresh enough only because of the refrigeration used in transit. This adds great expense and a huge carbon footprint to each item. In addition, many of the beneficial vitamins and minerals, that would still be present if the food had been grown in the local area organically, would have dissipated.

Add to this the water footprint to grow the produce, package the goods and deliver the goods, and the costs involved in food production mount up. And this is even before labour costs associated with the field-to-plate journey are factored in. If food is big business, then more efficient profit could be made if food were grown closer to the source of demand, minimising wastage of resources and reducing overall consumer cost.

Many developed countries are importing both canned food and other food stuffs simply to minimise agricultural land use close to urban centres. According to the Australian Horticultural Corporation, their Future Focus report predicts imported vegetables will rise by 463,000 tonnes up to 680,780 tonnes in Australia by 2020. Food imports alone from 2002–2007 were already AU$7.2 billion. Seafood imports alone were AU$1.15 billion in the same period.[7]

As consumers demand year-round produce and productive land on the perimeter of our cities becomes increasingly valuable, agricultural enterprises in increasingly drought-affected areas are becoming less reliable and productive. Addressing housing and its affordability, as well as urban sprawl, is now the priority for State and Local Governments and planning agencies.

The continued removal of native vegetation to accommodate urban expansion will create other problems that could impact on climate change, food bio-security, storm water runoff and even community health. The mono-crop paradigm, therefore, needs to shift to an integrated ecosystem-based farming paradigm to facilitate sustainability. It is also quite likely that with the continuing drought conditions drying out major food producing regions coupled with an ever global population expansion, Australia may have to double farm outputs using only two-thirds of today's available water as fresh water volumes decrease.

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[7] ibid

The Australian Context

Further declines in the availability of freshwater resources are difficult to quantify going into the future, but it is likely that competing demands for freshwater resources will continue to create problems between supplying agricultural requirements and attempting to cater for escalating urban demands.

Aquaculture food production has already intensified through the technologies of RAS so that farming can be done anywhere. If not properly operated, these systems can be heavy water users and polluters where fish are stocked at up to 100 kg per cubic metre.

A better use of these available waste production resources could allow higher yields. Rakocy et al showed the water footprint of producing AU$100 worth of cotton was 470,000 litres of water compared to only 173 litres of water for an integrated production of AU$100 worth of fish and basil.[8] Australian farmers have moved away from the holistic approach of integrated farming for various reasons but it is this precision integrated farming approach that minimises risk, disease and vastly increases productivity.

Such production systems can be brought into urban areas where soils, climate or size are not necessarily the major site selection criteria. This is a massive shift from traditional agriculture and suggests that a portion of total food production going into the future will be developed through newer and more centrally located production systems.

Such production systems will create greater efficiencies through their proximity to processing, packaging and consumption, in turn, achieving levels of production density and resource use efficiency that will be hallmarks of the industry approach. Further to this, restricted space or poor land suitability for the housing of these production systems in the urban environment could be further mitigated by avoiding the use of land all together—instead utilising the rooftops within most capital cities now offering acres of available space.

SWOT Analysis

Strengths

- Production of multiple agri-products from single input nutrient sources through waste-stream value adding.
- Efficient use and partitioning of nutrient resources enabling total nutrient resource conservation.
- Diversity of products produced using a single re-circulated water source on a single footprint for the production of animal and vegetables. One drop of water equals two bio-diverse crops.
- Water sustainability through waste re-use in closed hydraulic systems.
- Establishment of nature-mimicking systems with all the added benefits of complex ecologies equating to lowered pests, supply of organic macromolecules and tannins.
- Diversity of species from various climates within one country.
- Ability to produce fresh food via protected agriculture, Light Emitting Diode (LED) technology in small spaces.

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[8] http://www.aquaponicsjournal.com/articleMiserlyWaterUse.htm

- Ability of high-density technologies to be urban located at the places where food is consumed; therefore, lowering the food miles distances to markets and their significant transport costs and carbon footprint.
- Merging of existing intensive farming practices with other animal or vegetable produce, creating new markets and employment.
- Only existing technology and infrastructure is required and these can be automated.
- Australia is seen as a clean, green and healthy.

Weaknesses

- Environmental disasters.
- Lack of global intellectual human resources.
- Lack of global practical human resources.
- Lack of fishmeal and adequate alternatives suitable for farmed fish species to create certified organic based meal.
- Lack of education to the public of technological availability and the product perception respectively.
- Distance from some markets.
- Product oversupply in current monoculture farming practices.

Opportunities

- Use of urban locations for production.
- Public perception and interest in chemical spray-free food production.
- 'Greening' of urban environments through food production allows a double advantage of food and passive environmental enhancement.
- Global markets are currently under supplied in high-grade and chemical-free animal and vegetable products.
- Adoption of simplified, low-tech systems by removing the technological complexity.
- Lower waste by recycling and end-waste product utilised in other industries.
- Water re-use for zero waste.
- Local and regional employment.
- Increase market penetration.
- New technology development.
- Improved husbandry practices of animals, minimising disease.

Threats

- Disease, pests.
- Ignorance of the production approach where organic soil certifiers do not understand aquatic production systems.
- False start syndrome, where the industry develops too quickly and bad advice is given, therefore causing high failure rates which, in turn, negatively impact on the perception of the industry.

- Lack of education facilities and willingness to aspire to best practice.
- Lack of capital and necessary infrastructure.
- Environmental legislation not foreseen today.
- Importation of cheaper canned goods versus better quality, local, fresh foods from aquaponics, due to a lack of consumer education.

Identifying the Skills Deficiencies

Integration and Commercialisation Methodologies

Skill Deficiencies

1. What is the current best practice and can it be improved for Australia?
2. Can new methods be used and what additional skills may be required?
3. Can all Australian species be farmed this way and if not, how?
4. What skills are required to seamlessly integrate current operational farms?
5. What is the best way to implement them?

Action

- Attend the aquaponic course at the University of the Virgin Islands and other research centres in North America.
- Evaluate successful production and integration techniques.

Sustainable Protein Feeds

Skill Deficiencies

6. Can sustainable protein feeds be developed in Australia using current technologies?
7. What processes are required?
8. How can these methodologies be obtained?

Action

- Visit key feed processors or farmers producing and using sustainable feeds.
- Evaluate the potential for knowledge transfer to Australia.

Education and Skills Development

Skill Deficiencies

9. World-best-practice aquaponics curricula and training programmes
10. Can these be adapted for use in Australia?

Action

- Interview key aquaponics education personnel.
- Evaluate current curricula used for IFP.
- Evaluate business models of successful aquaponics farms.

The International Experience

The Fellow visited universities, government facilities and private sector commercial operations in the United States and Canada.

US Virgin Islands, USA

The University of the Virgin Islands (UVI), St Croix

Contact: Professor Jim Rakocy, Director of the UVI Aquaculture Program

The Fellow attended the 11th International Aquaponics and Tilapia Aquaculture short course held at the University of the Virgin Islands (UVI). Professor Rakocy, Director of the UVI Aquaculture Program, led the course, which was comprised of a series of presentations on water quality, fish production and horticulture. The formal presentations were then complemented by a series of practical sessions with particular emphasis on the aquaculture species, tilapia.

Fish and horticulture production area (0.05 ha)

Tilapia ready for harvest

The UVI system comprises four fish rearing tanks (7.8 cubic metres each), two cylindro-conical clarifiers (3.8 cubic metres each), four filter tanks (0.7 cubic metres each), one degassing tank (0.7 cubic metres), six hydroponic tanks (11.3 cubic metres each), one sump (0.6 cubic metres) and one base addition tank (0.2 cubic metres). The total water volume and hydroponic tank growing areas are 110 cubic metres and 214 square metres respectively. The total area occupied by the UVI system is 0.05 hectares. Produce from this commercial system is sold point of sale through their general store at the UVI campus.

Discussing water chemistry and plant nutrition

Clarifier waste © UVI

Solids waste after dewatering

As plant nutrients in aquaponics are obtained from food fed to fish, ten of the 13 essential nutrients required for plant growth are delivered through fish waste. The UVI short course taught the necessary skills to recognise system failure, in particular the nutrient deficiencies of iron (Fe), calcium (Ca) and potassium (K), as well as the pathways blocking nutrient uptake, such as pH swings. The course also provided new insights into the use of base chemicals, such as calcium hydroxide ($CaHo_2$) and potassium hydroxide (KOH), to rapidly stabilise deficiencies whilst simultaneously levelling off pH swings within the system.

Solid waste settlement and bioremediation

Lettuce ready for market

Harvesting lettuce

The International Experience

Inspecting good root growth and hygiene

Rice grown in aquaponics

Okra grown in aquaponics

The course provided an opportunity for the Fellow to present research findings from the commercial pilot farm he operates in South Australia. The Fellow's research showed that hydroponic production requires a much higher nutrient level and water usage to obtain the same results as aquaponic production.[9] These findings, which are similar to the UVI research findings show that aquaponics can be both environmentally sound and commercially viable in a dry region such as South Australia.[10]

The sessions stressed the key interlocking mechanisms of aquaculture and horticulture. In fact, a number of course participants, who had attended principally for the practical work sessions with tilapia, realised the commercial potential of integrated systems that utilise efficient waste management techniques.

The produce grown on site is processed and sold at the UVI produce store. It was surprising to note that of the numerous locals who were spoken to by the Fellow, many were not aware of the store or its availability to supply fresh, local produce.

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9 Resh, H.M 1989, *Hydroponic Food Production, A Definitive Guidebook of Soilless Food Growing Methods.* Woodbrdge Press Publishing Co., Santa Barbara, CA.

10 UVI water analysis results tabulated and shown in class comparative to water analysis from the hydroponic industry

The socioeconomic climate of St Croix, in particular its close to the university, may be a contributing factor to this interesting phenomenon. The marketing of this type of village farming opportunity is, therefore, important to the success of not only feeding a community but also staying in business.

The UVI International Aquaponics and Tilapia Aquaculture short course provided the following insights:

- Protein quantities in the fish feed dictate fish to plant ratios.
- Fish waste provides most of the nutrients plants require.
- Hydroponic subsystems act as a living biological filter.
- Plants convert waste nutrients into valuable by-products.
- Plant production biologically polishes water for extended use and minimises discharge to the environment.
- Concentrated solids discharge can be further de-watered and composted for the production of high quality silage.
- In contrast to individual systems, integrated farming requires less water quality monitoring.
- Profitability is increased because of free nutrients, organically grown vegetable matter, less water requirements, shared infrastructure and operating costs, less regulatory water quality monitoring requirements and the elimination of separate biological filters.

Furthermore, the Fellow's participation in this course provided an invaluable opportunity to expand his professional networks.

Boca Raton, Florida, USA

Neptune Industries Inc

Contact: Sal Cherch, Chief Operating Officer

Neptune Industries is a seafood and aquaculture company established in 1998. At the time of the Fellow's visit the company was experiencing some financial difficulties. Nevertheless, the visit enabled the Fellow to learn about their work in developing pelletised fish feed. Neptune Industries' Ento-Protein™ is an advanced dietary nutritional product made from insects grown on agricultural waste and products including distillers' dried grains from ethanol plants. The Soldier Fly, an endemic insect found in the USA, has a protein ratio of 45 per cent found in its larvae. The Black Soldier Fly is a species also found in the Australian subtropics. As most meal component ratios in fish feed is between 28 and 50 per cent, using this insect could deliver the required protein for Australia's diverse fish species.

Black Soldier Fly Larvae

Black Soldier Fly

The International Experience

Bulk waste feedstuffs for insect production are expensive to purchase and store. Protecting these feedstuffs from heat damage and drawing them down efficiently is critical. By developing efficient certifiable organic methodologies and protocols for the processing of incoming feedlots, Cherch is of the view that a certified organic production capability for the aquaculture industry will be achieved.

According to Cherch only one commercial facility for insect protein exists in the northern hemisphere, thereby, providing Neptune with the opportunity to expand its insect meal business. Because the Australian aquaculture industry currently relies on imported fishmeal, adoption of the technologies being developed by Neptune Industries could help to slow and hopefully reverse the reliance on baitfish and the rising cost of fish production. These new methods also offer the potential to reduce landfill organic waste.

The Fellow was also briefed on the company's innovative Aqua-Sphere floating fish tank. The Aqua-Sphere is a solid-walled polypropylene fish tank similar to those used in aquaculture. It floats in a lake or dam and can be connected to other Aqua-Sphere tanks or work platforms. If used at sea, hinges allow it to flex with ocean currents and waves. According to Cherch, their single 10-metre diameter model can produce up to 43 metric tonnes of fish per year.

The Aqua-Sphere operates using airlifts to replace water to the tank whilst solid fish waste and uneaten food that has accumulated on the tank bottom is removed for filtering. Two waste streams from the filter are available: solid and nutrient-rich water. When operating in a freshwater environment, the nutrient-rich water waste stream can be used in an aquaponic configuration to host high quality vegetable crops.

Floating Aqua-Sphere © Neptune Ind

The Aqua-Sphere can also isolate a fish crop and any associated metabolic waste from the outside environment. Waste collected from the Aqua-Sphere can be used for algae production for biodiesel feedstock or utilised in its raw state for methane gas production. As the Aqua-Sphere's airlift system requires only 1500 watts, power can be sourced from methane gas turbines or Photovoltaic (PV) cells.

Neptune Industries Ento-Protein demonstration facility established in January 2010 will produce commercial quantities for shipment to a variety of feed mills, universities and labs. This facility will be used to develop protocols, test equipment options and research market demand. This information will be used by Neptune Industries to design and build in 2011, the first full-fledged USA commercial production site.

The Aqua-Sphere operates using airlifts to replace water to the tank whilst solid fish waste and any uneaten food that has accumulated in the bottom are removed for filtering.

The company is currently finalising the design of a new 15-metre diameter production tank (10 metre deep). Funding has now been secured through partnerships and joint venture agreements. The company is confident Australia could be an important participant in their future development plans. This holds out the possibility of Neptune Industries' Ento-Protein technology transfer to the Australian aquaculture industry.

National Aeronautics and Space Administration (NASA), Kennedy Space Centre

Contact: Dr Raymond Wheeler, Leader for Advanced Life Support Program.

Dr Wheeler briefed the Fellow on LED technology. NASA developed LED technology for the space programme.

Plant growing chamber © ORBITEC

NASA researchers have used LEDs and other High Intensity Discharge (HID) lighting systems to grow closed-system hydroponic crops including potatoes, sweet potatoes, soybean, lettuce, spinach, radishes, wheat, onion and herbs. Their research has focused on optimising plant growth to generate food, oxygen, and clean water for life support on space missions. LED arrays have already been used on several missions to provide high quality light for research on zero gravitational impact on plant growth and in-flight fresh food production as a means of supplementing astronauts' pre-packaged diets in future long haul space missions. LEDs are particularly suitable for such research activities because of their solid-state construction, excellent electrical efficiency, and long operating life.

Varying combinations of LEDs in closed-environment indoor aquaponics and hydroponic systems optimise photosynthesis and morphological development. Additional advantages include superior electrical efficiency, longer operating life and the absence of mercury. NASA research points to LEDs as an efficient, cost-effective means of producing aquaponic and hydroponic sourced food in harsh climatic conditions.

Apopka, Florida, USA

Aquatic Eco-Systems Inc (AES)

Contact: Ricardo Arias, International Division Manager

Aquatic Eco-Systems Inc. (AES) was initially established in 1978 as a lake improvement company specialising in aeration and de-stratification. The company now manufactures and supplies equipment for aquaponic production and is recognised as the world's largest equipment supplier.

Aquatic Eco Systems Headquarters

Most aquaponic production in the USA is monocropping and equipment is manufactured specific to that sector of the industry. Only a few farms in the USA operate multi-species or integrated facilities. According to Arias the commercial aquaponic industry in the USA is limited to a few farms. Consequently, the company is a bespoke supplier with no immediate plans to produce off-the-shelf, commercial aquaponic equipment. Therefore, any potential development of a corporate commercial sector for aquaponics in the USA is currently stalled.

Portion of the packing and manufacturing area

Orlando, Florida, USA

Walt Disney World Experimental Prototype Communities of Tomorrow (Epcot)

Contact: Jane Davis Aquarium Curator, Disney Animal Programs

The Walt Disney World Experimental Prototype Communities of Tomorrow Theme Park located at the 300-acre Epcot Centre offers visitors of all ages an extraordinary range of visual and interactive experiences that are both entertaining and educational.

The Fellow was given unique access to senior staff involved with The Land and The Seas pavilions.

Backstage view of the unique hydroponic complex

The Fellow with tilapia

The Land pavilion has several large greenhouses covering 25,000 square metres and takes visitors on a journey through the history of agriculture, arriving at today's technological breakthroughs, such as plant cloning, and high-yield indoor plant growing techniques, such as hydroponics and integrated aquaculture.

The Land Eco-tour

Sweet potatoes grown above ground hydroponically

Epcot restaurants and cafes utilise all the produce grown on site. The Behind the Seeds tour showed the technologies involved in growing vegetables. Examples of the innovative technologies included Brussels sprouts growing on a conveyor belt system, a tomato tree that produces over 30,000 cherry tomatoes in a twelve-month period, cotton grown in sand using drip irrigation, lemon trees producing nine pound fruit, hydroponic sweet potatoes grown above ground and a cassabanana melon that produces a different fruity fragrance as the fruit develops and matures.

Integrated aquaculture of tilapia and lettuce

Sturgeon aqua cell display for aquaculture

The tomato tree seed was sourced from China. It produces high yields from a single vine. The Manager of Agricultural Science, Yong Huang, explained how genetic modification is not always necessary to deliver higher productivity. Whilst this specific tomato plant is unique to Epcot and is not available elsewhere in the USA, a smaller variety called the Trip-L-Crop or Italian Tree Tomato is available commercially. The Fellow noted with interest the advantage in trimming vines to one stem and training them in this tree-like fashion. Hydroponic tomato bushes in Australia could be cultivated and trained in this way to deliver increased productivity. On the other hand, the Fellow was of the view that Epcot's methodology for Brussels sprouts production is not commercially viable.

Huang has developed many other high-yield bearing fruits and plants. He showed the Fellow the methodology involved in successfully growing sweet potato above ground through constantly lifting the tuber out of the soil so that when each node touches the soil it produces another tuber. This process can then be repeated.

Tomato tree produced over 30,000 berries

Hanging conveyor belts of Brussels sprouts

Epcot's Integrated Pest Management (IPM) system was developed at their entomology research station. Insect colonies of predatory mites, wasps and beetles are reared and released into their greenhouse crops to destroy thrips, aphids and whitefly. Such chemical-free pest control methods are very effective in an enclosed greenhouse environment where harmful pests can be eradicated without them being replaced. Epcot also boasts state-of-the-art research facilities and provides paid professional internships for college graduates to further their study and research.


Biological pest control research station, Epcot

Dade City, Florida, USA

Morning Star Fishermen

Contact: Hans Geissler, Director

Morning Star Fishermen is a not-for-profit education and training organisation. Its mission is to alleviate world hunger by training people to use aquaponics to feed themselves and their communities. Established by Hans Geissler nearly 20 years ago, Morning Star Fishermen builds self-sustaining aquaponic systems and trains farmers at its facility in Florida as well as on location in underdeveloped countries. It houses around forty tanks at its Florida headquarters and has built more than 100 aquaponic systems throughout the Caribbean and Latin America. According to Geissler the aquaponic systems established under the auspices of Morning Star Fishermen now feed thousands of people.

Logo and mission statement

Hydroponic tanks showing plants

Employee feeding tilapia outside

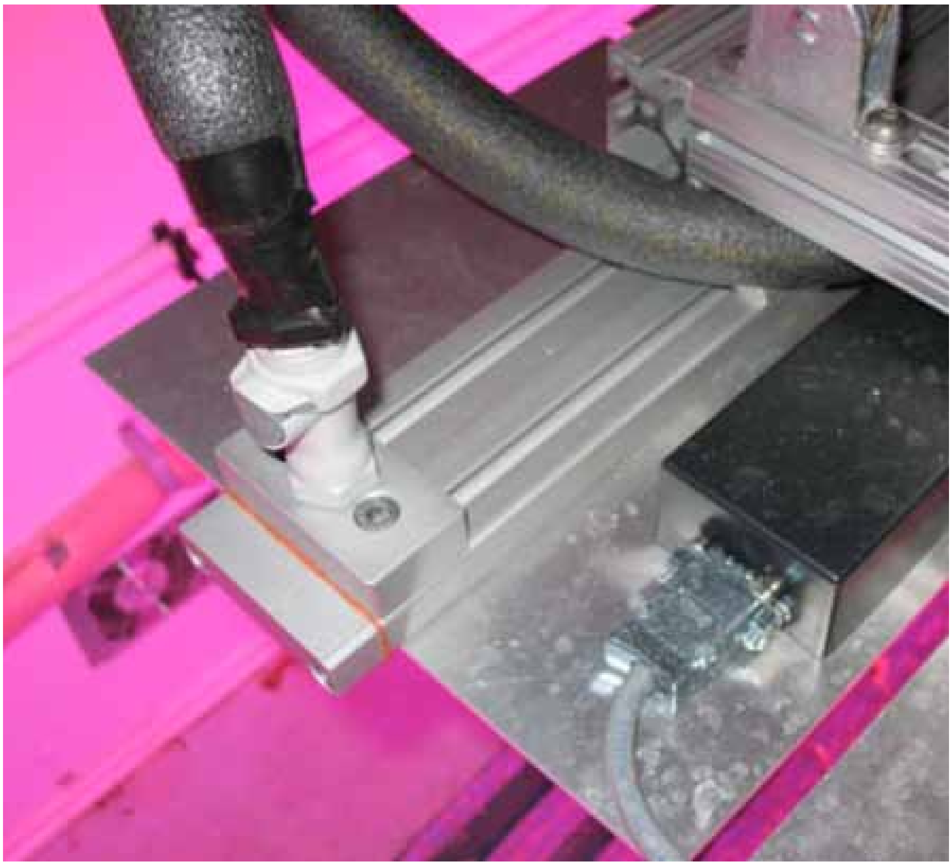
Fish tanks in the classroom

Madison, Wisconsin, USA

Orbital Technologies Corporation (ORBITEC)

Contact: Dr Robert Morrow, Principal Scientist

Orbital Technologies Corporation (ORBITEC) is a leading high-technology development company. Discussions with Dr Morrow and his staff centred on the manufacture and use of LEDs for aquaponic applications, controlled environment production of medicinal and pharmaceutical plants, and outdoor supplemental lighting.



Water cooling jacket © ORBITEC

ORBITEC has trialled LEDs in controlled environments. The trials have provided valuable information that will assist in further developing LED array design and manufacture. LEDs are a solid-state construction with no burning filament. However, large-scale LED arrays develop a heat sink that can result in diode failure and excessive heat build-up in the room and over the surface of the plants. Newer versions of such arrays are fan and water cooled to dissipate heat.

The use of red, blue and orange wavelengths eliminate excessive white light, thereby reducing the energy needed to power plant growth lamps. However, white light is still required to check for plant disease.

ORBITEC's research panel array costs approximately US$20,000 per unit. Four arrays are required for each room. Recent advances in LED technologies have decreased production costs significantly and increased the potential use of assimilation lighting in greenhouse production systems. Factors such as plant shape, plant population and row widths will affect leaf distribution and subsequent shading.

Dr Morrow discussed with the Fellow the feasibility of developing a flexible LED array that could be placed in crop locations where assimilation light could normally not penetrate in order to increase leaf photosynthesis through Photosynthetic active radiation (PAR). Further advances in indoor and supplemental lighting technologies that produce greater than 1000 PAR at the canopy surface would generate a 24-hour growth cycle and consequently higher yield crops.

Plant production under red and blue array © ORBITEC

Low-wattage, high-intensity LEDs can deliver up to 50,000 hours of light and can be powered by photovoltaic cells. For this reason NASA is considering using these lighting systems for on-board food production for future long-term manned space missions.

The Fellow purchased a small commercial LED array from the USA. The array has been trialled in his South Australian research facility in a controlled indoor aquarium aquaponic system. Improved lighting efficiencies and crop growth rates were shown in desktop trial using lettuce. Additional field trials are being conducted throughout 2010 and the results of these trials will be published.

Montello, Wisconsin, USA

Nelson and Pade Inc

Contact: Rebecca Nelson and John Pade, Consultants

Rebecca Nelson and John Pade are the publishers of The Aquaponics Journal. Issues covered in The Aquaponics Journal include articles relating to fish, water, pumps, electricity and plants.

Nelson and Pade also provide consultancy services, training programmes and demonstrations of aquaponics systems. According to Nelson there are probably between 800 and 1,200 aquaponics systems in use in American homes and at least another 1,000 systems of varying sizes located in school science classes.

Tours and short courses are held at their greenhouse training facility in Portage. The Fellow observed some of their turnkey systems and had detailed discussions on the latest aquaponic industry issues in the USA and Australia. These discussions highlighted both the challenges and opportunities in setting up and running a commercial aquaponics industry. These include:

- Start-up costs (over and above the cost of aquaponics hardware) can be a disincentive to prospective industry participants.
- Because many farmers' markets in the USA move indoors during winter and soil farmers cannot grow their crops, food is imported from interstate or overseas. In harsh climatic conditions controlled agriculture is a viable food production method. Fresh, local, aquaponics produce at a premium retail price in farmers' markets enables smaller aquaponics farms to become more efficient and compete with imported products on price.
- Because aquaculture production of catfish in the USA is not currently a viable commercial proposition, aquaculturists are looking to use their ponds to grow other crops besides fish.
- Hydroponic greenhouses have high operating costs. Fertiliser is expensive and unstable, whereas, the cost of fish feed is reasonably stable. John Pade is of the opinion that if hydroponic farmers better understood the cost advantages of organic solutions for their fertiliser requirements, then more hydroponic farmers would consider integrating their farms with aquaponics. It is also apparent that people moving into aquaponics in the USA do not have any aquaculture background. This may be due to a perception that fish farming requires significantly more technical expertise than passive horticulture production.
- Population growth and urban expansion in the USA will lead to further changes to—and restrictions in—land use across what were once rural and semi-rural areas. Over time, consumer demand for locally produced food in preference to imports will open up opportunities for the establishment of integrated urban aquaponic farms to meet consumer demand.

Training facility at Montello

Rebecca Nelson (right) at the Farmers' Market

Aquaponic system fish and lettuce

The International Experience

School aquaponic introduction system

John Pade with cucmbers in foreground

Herbs grown in rafting system

Flanagan, Illinois, USA

AquaRanch

Contact: Myles Harston, Director

AquaRanch has been in operation since 2004 and is one of the largest commercial aquaponics facilities in the USA, Myles Harston is recognised as an aquaponics industry leader.

AquaRanch Headquarters

Myles Harston with herb crops

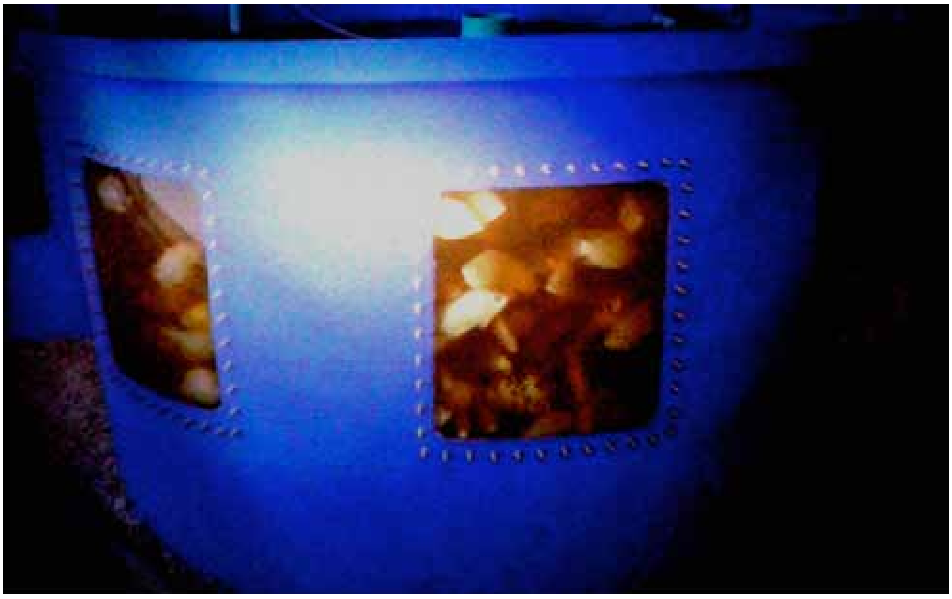
The AquaRanch facility has twelve 4.8 cubic metre fish tanks. Water runs through a proprietary clarifier and mineralises the solids anaerobically to release the minerals into the water. After the water leaves the clarifier it flows through 30-metre-long grow beds before returning to the fish tanks. Water flows through these beds and the plants rest in holes cut into floating foam rafts allowing the plant roots to hang down into the water and strip out passing nutrients. Depending on the species, stocking rate, feeding and water management, the most efficient fish to plant ratio is 4 litres of aquaculture water to every 270 square centimetres of planting area.

Fish production tanks

As with any water-based system, evaporation and respiration with plant uptake occurs. However, only one per cent of water volume is replaced daily at this facility compared to stand-alone aquaculture facilities that use 20–25 per cent daily to dilute and flush any toxic metabolites. Rainwater collected from the greenhouse roof provides most of AquaRanch's water replacement requirements.

AquaRanch produces tilapia from egg to harvest. The fish are grown out in 48 weeks. AquaRanch does not use sex reverse hormones of methyl-Testosterone to produce a faster growing (26 weeks) male fish, nor are they exposed to heavy metals or any other environmental toxins or growth enhancers.

In-house processing, filleting, and packaging add significant commercial value to the AquaRanch business model. AquaRanch fillets retail for US$28 per kilogram. This is twice the price of tilapia fillets sold in the American 'Big Box' stores. The AquaRanch brand is recognised as high quality produce.



Tilapia ready for harvest

Value adding: fish filleted and packed

AquaRanch also grows certified organic produce including lettuce, kale, chard, and herbs such as basil. Herbs are also used to make Sweet Basil Vinaigrette, which is sold wholesale to restaurants and natural food stores. Produce is also sold at local and regional Farmers' markets under the AquaRanch label. A State-funded food safety course has enabled a Hazard Analysis Critical Control Point (HACCP) system to be developed with a nominated restaurant used as the certifying kitchen for AquaRanch's manufactured items.

Lettuce and basil production

An example of value adding: basil Vinaigrette

A range of start-up challenges confronted AquaRanch, including:

- Sourcing finance.
- Obtaining organic certification.
- Integrating hydrodynamics into the system to ensure water was moving fast enough to prevent bio-fouling and anaerobic conditions.
- Installing larger energy-efficient pumps for its closed re-circulating systems.
- Achieving power cost efficiencies through the use of fuels such as biodiesel and alcohol.

AquaRanch has subsequently generated additional revenue streams through the provision of aquaponics courses and facility tours where visitors get to see and taste the produce. The success of AquaRanch has led to their production systems being used into schools across the USA as a science education tool.

North Hatley, Quebec, Canada

IET-Aquaresearch Ltd

Contact: Dr Karl Ehrlich, Vice President

IET-Aquaresearch is one of the world's leading manufacturers and suppliers of bioremediation products. Their early success with aquaponics and aquaculture trials has led to IET-Aquaresearch's biological remediation products now being marketed and sold worldwide.

Discussions with Dr Ehrlich centred on beneficial natural bacteria and its role in IFP systems. Selected bacteria are used to break down metabolites produced from fish production. Other beneficial bacterium is often destroyed through stringent aquaculture hygiene protocols such as Ultra Violet (UV) sterilisation and ozonation. The currently unknown bacteria needs to be better understood so that it can also be utilised to deliver even greater efficiencies in aquaponic mineralisation.

Bottled products for bioremediation

Dr Ehrlich explaining bacterial stages

The visit to this facility reinforced to the Fellow the benefit of using nitrifying and denitrifying bacteria to break down pollution wastes such as grease, biodegrading hydrocarbon spills and aquaculture waste. Beneficial microbes are able to digest sludge, reduce soluble phosphorous, facilitate oxygenation and clarify water and ecosystem immunity and biodiversity without creating noxious or toxic odours.

Australia does not utilise such organic bioremediation tools. In most cases their production and use is primarily for septic waste treatment. These IET products are sold only in liquid form and the importance of living organisms carrying a 'live bacteria' label creates significant difficulties for many foreign customs control authorities. Border control protocols for such products need to be harmonised internationally. Nevertheless, the Fellow has obtained import permits for these bioremediation products, which have proved highly successful for aquatic system conditioning.

Quarantine production area

Bench top production system for bacteria

Sainte Agathe des Mont, Quebec, Canada

Technologies Aquaponics ML Inc

Contact: Marc Laberge, Director

Technologies Aquaponics is located in the industrial precinct of Sainte Agathe des Mont. The company's single production aquaponic tank produces over five thousand Boston lettuce and two hundred smoked fillets of Rainbow Trout each week.

Technologies Aquaponics was the first commercial aquaponic facility in Canada. It was also the first facility the Fellow visited that did not grow tilapia. The unique design of the system delivers a smaller footprint compared to USA facilities. This is achieved through the use of rectangular, instead of cylindro-conical, fish tanks. Rectangular tanks facilitate more dynamic river water flow conditions and these are more suited for the production of salmonid trout.

Office and the fish/plant production housing

Concrete skeleton of production area

The International Experience

The plant production area is based on the aquaponic raft system designed and used in the USA. However, that is where similarities end. The entire production area is in concrete. Fish raceways are attached at one end of the main basin where 30,000 heads of Boston lettuce float on styrofoam trays. About 4,000 trout ranging in size from 30–450 millimetres are introduced as fingerlings and then grown in the raceways, harvested and processed on site. An in-house employed food technologist value adds the processed trout which is maple-smoked, vacuum packed and shipped to local restaurants for around CAD$32 per kilogram. Boston lettuce is produced on site from seed and is sold to retail outlets as chemical-free produce for around CA$16 per case of 24.

Seedlings of Boston lettuce

Water is replaced from the municipal town supply at two litres a minute. The flow is constant. Cycled water in the system is filtered mechanically, passively UV sterilised, and then sent to the shallow artificial pond where the lettuces act as a filter. The water is then mineralised through gravel, rejuvenated with oxygen and returned to the trout raceways. No chemicals are used at any stage. The process delivers a genuine clean and green product.

Part of the fish packaging room

Array of pumps in parallel

The International Experience

Marc Laberge at Technologies Aquaponics where they produce 5,000 head lettuce a week

Boston lettuce

Fish tanks in background producing 200 fillets a week

Laberge's company is also actively involved in the local community. Technologies Aquaponics employs a number of part time workers including four intellectually impaired adults. He also supports local schools by providing work experience opportunities for underachieving students.

Some of the issues Laberge encountered were:

- The design structure could not be changed once the concrete was poured, therefore, engineering was difficult without design models on which to base calculations.
- Government and private funding were difficult to secure because of the lack of available commercial models
- Most systems have only been used to grow tropical fish, such as tilapia, and little research with cold-water aquaponics was available.
- Hydrodynamics and flows were best achieved by using multiple pumps rather than the 'one pump' rule.
- Water quality issues were overcome by trial and error and Laberge did not elaborate but emphasised this is the real key to a successful aquaponic system.

Brooks, Alberta, Canada

Crop Diversification Centre South (CDCS)

Contact: Dr Nicholas Savidov, Leader-Greenhouse Crops

The Fellow spent a number of days with Dr Nicholas Savidov and his staff discussing integrated farming theory and practices. Dr Savidov, Patricia Cote, Nabeel Mohammed and Aquaponic Project Manager, Dan Watson, willingly shared with the Fellow their experiences and research findings.

The original UVI model used at CDCS has undergone a number of iterations. The new model currently in use delivers excellent water efficiencies and nutrient assimilation.

A variety of plants, fruit, and vegetables have been grown on site including, tulips, cut and edible flowers, eggplant, okra, cantaloupes, tomatoes, cucumbers and herbs. At the time of the Fellow's visit, Genovese large leaf sweet basil was in commercial production. This herb produces a single cut harvest in approximately five weeks. The process requires the seedling to spend two weeks in the nursery after germination and a further three weeks in the main growing trough. All production from seed to the market is done at the facility. The local Farmers' Market is used to test consumer acceptance of CDCS produce. CDCS also farms the tropical tilapia fish.

Vacuum seeder – seeds one tray a minute

Basil seedling in organic coco peat

Sprouted seeds for weekly crop

Dr Savidov explaining water hydrodynamics

The Fellow's visit to CDCS also coincided with the construction of a CAD$18 million, 1.5-acre commercial research facility comprising multiple greenhouses. This facility will be the most technically advanced of its kind in North America.

Framework for CA$18 million R&D unit

The International Experience

The time at CDSC provided invaluable new insights into aquaponic farming.

As the CDSC aquaponic system reaches optimum operating levels, accelerated plant production depletes nutrient levels. As a consequence either more fish are required or heavier feeding regimens need to be administered. Aquaponic systems are not sterile environments. They require natural bacterial predators. When a system is balanced, both plant and fish pathogens are suppressed. Aquaculturists generally kill these bacterial predators by UV Sterilisers and ozone generators to minimise general bacterial levels.

Utilising solid wastes and mineralising the by-products in situ increases water efficiencies. Mineralised wastes are more readily taken up at a pH of 6.

Pythium is a spore-producing plant pathogen that causes root rot. It becomes more prevalent in higher temperatures. If infection is detected, Pythium can be filtered out using micron filters.

The ration of nitrogen to potassium should be 1.5:1. Most aquaculture systems run at 15:1 or higher because of the protein content and ammonification. Aquaponic systems create a balance more amenable for plant production.

CDSC has introduced denitrification within the system as a side stream. Waste is dewatered using a Colloidal polymer flocculant and the water remains in the system.

Solids waste digestion

Basil and fish production area

The waste stream is then transferred to a geotextile filter containing aquatic microworms. The worms break down the solids and release valuable trace elements that would normally be bound to organic particles and lost during back-washing of solids. The total recovery of wastes and water are unique to aquaponic systems and provide the models for technology uptake in the dry integrated farming regions, such as South Australia.

Other CDCS modifications included the horticulture production basin run across the bed rather than down the length of raceway tanks. This bed is approximately 7 x 10 metres and utilises space more efficiently than narrow long raceways.

Knowledge Transfer: Applying the Outcomes

Integration of Aquaculture and Hydroponics

The integration of aquaculture and horticulture in the USA and Canada is targeted at the water consuming industry. Aquaponic production combining fish and horticulture is the most efficient means of operation.

Long channel raft culture developed at UVI is the principal technology of choice in the USA and Canada. The only facility visited that uses a different system was Epcot. This is known as the Nutrient Film Technique (NFT). The Fellow also uses this system and believes it delivers better water savings and higher product yields.

The average raft culture system in commercial aquaponics use has a 110 cubic metre water holding capacity that can produce around 12 tonnes of food per year. Per acre, this extrapolates to around 90,000 kilograms of food production.

Not only are integrated aquaponic footprints more efficient compared to field crops, but plants grown in aquaponic systems tend to grow more rapidly, have ample water and nutrients, and enjoy a competitive weed-free environment. Consequently, aquaponic systems are small and cost efficient.

Both UVI and the CDCS have trialled numerous vine and bush plants. CDCS alone has successfully trialled around 60 different types of plants.

A hybrid combination of raft and NFT will conserve more water per unit of plant production. This is particularly beneficial in dry climates. As many hydroponic farmers in Australia already possess the skills of this NFT technology, appropriate financial incentives would give farmers a chance to be rewarded for taking care of the environment and providing consumers safe, healthy foods.

The Fellow noted that the main fish species used for organic nutrient production is the tilapia. In Australia, native fish such as the Barramundi can have complex lifecycles. As a Catadromous protandrous hermaphrodite, the barramundi requires exceptional skill and expertise to spawn and produce a recruitable juvenile. Tilapia, on the other hand, they are reasonably fecund, spawn readily, mouth brood their young and can be chemically sex-reversed to produce all-male fast growing cohorts that can command high prices.

With some modification, a variety of Australian aquaculture species may be used in aquaponic production. Some will require different tank depths, shape and hydrodynamics. However, it is the protein efficiency and content of the feeds used in production that will dictate the production efficacies of integration into aquaponics. Protein requirements for Australian species are almost one third higher than omnivorous species such as tilapia. This provides higher nutrient recovery for plant and horticulture production. Based on UVI data, Australian carnivorous native species require 40–55 grams of high protein fish feed per square metre for horticulture in a raft production system, whereas 60–100 grams are required for tilapia in the same system using low protein feeds.

Micro-aquaculture of beneficial bacteria is the key to minimising ammonia toxicity in fish, and establishing long-term colonies of antagonistic bacteria that will out-compete pathogens and boost the plant immune systems. However, a limiting factor in the growth of large commercial operations is developing the skills to formulate the right team of microbes to fully maximise waste from protein assimilation.

Knowledge Transfer: Applying the Outcomes

As with marine aquaculture, it was not until marine algal species were identified and their production methods honed for green water culture, that the rapid onset of multi-marine species production and development took place. Consequently, more work needs to be done in understanding interactive beneficial bacteria for aquaponics. The Fellow has obtained microbes under permit from IET Aqua-research and is establishing their use for facilities currently having difficulties arising from their biological waste building up.

Sustainable Protein Feeds

Approximately 30 million tonnes of Industrial fish such as anchovies, sardines, anchovetta, herring, capelin and other short-life species are used to produce fishmeal for aquaculture each year.[11] Both fishmeal and omega fatty acid oils are used extensively for the production of aquaculture diets, as well as for terrestrial animals. The demand for fishmeal will continue to increase. Australian researchers are working to develop genetically modified (GM) soybean to produce the Omega 3 and Omega 6 long-chain fatty acids required in human diets.

These GM feed additives also have the potential to reduce meal requirements in pelletised fish diets. Whilst such protein supplements hold out the prospect of reducing the use of fishmeal in commercial aquaculture diets, the use of GM feeds is not the complete answer to aquaculture dietary needs. Naylor et al. has highlighted the negative consequences for marine ecosystems that would result from the extinction of baitfish fisheries.[12] Alternative protein profiles have also been used, including lupins, wheat, corn, soybean, barley protein and terrestrial animal protein meals such as chicken and chicken feather meal. However, new development of the extraction of proteins from insects is now a priority for global research scientists.

Black Soldier Fly larvae have a high protein content of 45 per cent and an essential fat content of 38 per cent. It should be noted, however, that this fat content is not the highly desirable unsaturated fatty Omega 3 acids found in fishmeal profiles of oceanic species. Current insect-sourced protein diets are more suited for chicken and pig production. A more complete and balanced profile for fish nutrition remains to be developed. A number of unknowns remain: the correct storage methods for feedstuffs; the optimum time frames for utilising feedstuffs without increasing heating temperatures, as required for prolific larvae production; and feedstuff cost variables that may impact on the overall financial feasibility of the production process. Neptune Industries in the USA have been active in exploring the commercialisation of Ento-Protein feedstock. The company commissioned a new facility for stage one Ento-Protein production in January 2010.

In the USA new tax rebates are available based on the previous year's feed consumption by fish farms. There is also some government funded research taking place. Developing substitute feeds, such as Ento-Protein to alleviate, the rising cost of fishmeal-based production whilst simultaneously enhancing its claim of being an environmentally sustainable industry that produces 100 per cent natural produce is a priority objective of the industry in the USA.

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[11] Pike, IH and Barlow, SM 2003, *Impact of fish farming on fish stocks International Aquafeed Directory and Buyers' Guide* 2003, pp. 24–29.

[12] Naylor, RL et al. 2000, *Effect of aquaculture on world fish supplies*, Nature 405, pp. 1017–1024

Knowledge Transfer: Applying the Outcomes

In the Australian context, the Fellow is seeking relevant permits to import Ento-Protein from Neptune for protein sparing trials and laboratory verification.

The United States Department of Agriculture (USDA) has stringent organic certification processes. Organic certification is obtainable through the USDA via protocols used for the certification of poultry. Integrated farming activities such as aquaponics need to have a stand-alone organic certification protocol that will underpin their status to potential investors as an industry with genuine organic credentials.

There is ongoing debate worldwide as to what dictates organically grown produce. AquaRanch in Illinois was the first certified aquaponics facility in the USA. The company had organic certifiers assess their property. Certification was given on the following basis:

1. As fish are not E. coli carriers and AquaRanch's well water is used solely within the fully enclosed property; E. coli contaminants were not a potential risk in the food production.
2. The facility is within a contained building and the fish production water and vegetables do not have contact with the nutrient water, due to a physical barrier between plant and water.
3. Certified organic seeds used on the site are started in net pots with a certified organic coco peat core and waste worm castings.
4. In aquaponics beneficial microbial interaction that creates nutrients occurs naturally in both water and soil at a faster rate.
5. Records of all processes on site are stringently kept and HACCP traceable.

USA-certified organic soil growers were opposed initially to AquaRanch receiving organic status. It was seen as a threat to the traditional organic movement. After years of seeing quality produce emanating from AquaRanch, organic soil growers have now accepted aquaponics as a parallel sector of organic farming that constitutes no threat to their existing markets and revenue.

Australia has its own organic certification protocols. Qualified organic certifiers could help develop the necessary certification protocol requirements for the industry. However, existing skill shortages in Ento-Protein production needs to be addressed first.

To assist in achieving the longer-term goal of aquaponic industry organic certification, the Fellow is seeking to encourage university entomology departments to advance research and development in feeds, particularly in relation to the potential use of insects in organic pelletised feed production. The Fellow is also speaking with certified organic farmers in South Australia to discuss the benefits of this type of farming.

Education and Developing a Critical Mass in Aquaponics

Rebecca Nelson and John Pade showed the Fellow how a quarter-acre aquaponic system can supply 600–800 head of lettuce a week all year round in a closed, controlled greenhouse. When their produce is shown at the Portage Farmers' Market customers are amazed with the growing process and are willing to sample it. Some have even been inspired to learn more about this production method with a view to setting up aquaponic growing beds at home.

Knowledge Transfer: Applying the Outcomes

Rebecca Nelson and John Pade have inspired the Fellow since his return from the USA to approach a number of local Farmers' Markets to set up an aquaponics produce stall. One of the fastest growing farming activities in the USA is supplying and selling produce direct to Farmers' Markets and Consumer Supported Agriculture (CSA) concerns. Nelson and Pade predict that smaller commercial farming ventures will expand rapidly throughout the USA. Australia is also having a spate of Farmers' Market start-ups based on these USA models.

AquaRanch, as well as Nelson and Pade, have also been active in encouraging schools to teach integrated sciences using aquaponics. Their efforts have been highly successful.

The Aquaponics Journal, established by Nelson and Pade, is now in its tenth year of production and provides helpful information to both novices and professionals. The internet has also facilitated worldwide information sharing.[13]

Although some USA training curricula is available locally, as a qualified commercial aquaculturist and certified curriculum educator, the Fellow is of the view that its current content can be improved to enhance Australian technical and formal education courses.

Value Adding

Fresh produce observed at the locations visited in the USA and Canada was not as consistent in quality compared to Australia. One reason for this disparity is that between 30 and 40 per cent of food consumed in the USA is imported.

There is a growing awareness in the USA of the concept of 'food miles'. Local food production is declining due to climatic extremes that impact on year-round food production. Farms in the Midwest are shrinking in size due to escalating running costs and many farms have shifted to growing corn for biofuel instead of food.

Farmers remaining on the land are now looking for more efficient processes to value add to their end product. Aquaponics is gaining in popularity with USA farmers looking for small commercial ventures to supplement their incomes. Farmers have discovered that when comparisons are made between the cost of fish feed calculated and the cost of fertiliser, the additional available organic wastes from aquaponics can add significant value to their production inputs. In Wisconsin a dairy farm uses cow manure to produce methane gas to heat and power its aquaponic facility.

Other value-adding developments are occurring at a rapid rate. AquaRanch is producing vinaigrette made from their certified organically grown basil. They sell the vinaigrette and packaged, boneless, fish fillets at the local farmers' market. Aquaponiques Technologies in Canada also value adds their produce by selling hot smoked trout fillets.

Year-round produce must be available locally and be price competitive. Seasonal price variations for foods such as fancy lettuce can quickly be priced out of the market if seasonal price rises are too high. As AquaRanch explained, it is better business to change the appearance of its product, by packaging it as a pre-packed salad with AquaRanch vinaigrette dressing, than trying to compete against imported raw produce.

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[13] Examples of Australian websites are: www.1Aquaponics.com.au and www.BackyardAquaponics.com.au

Knowledge Transfer: Applying the Outcomes

There is also value-adding potential in aquaponic production of solid organic fish waste for fodder production. At the UVI, dewatered solids wastes from the fish production were dried and applied to tertiary crops. This process can provide bagged fertiliser for fish farmers to sell to horticulture farmers. It also enables the fish farmer to claw back the cost of feeding their fish, whilst simultaneously value adding to their operation with organic aquaponic crops.

Fodder crops are also now becoming more popular in countries and regions where drought conditions prevail. Aquaponics affords the opportunity to produce grass tonnage for cattle, sheep and rabbits. Many USA farmers still sow crops and harvest to their silos in order to feed their cattle during winter. The cost of tilling, seeding, harvesting, storage and spoilage far outweighs the cost of feed produced using indoor aquaponics. New lighting techniques utilising LED technologies allow low wattage 12–48 volt DC systems to be arrayed indoors for this type of production.

Specific Knowledge Transfer Initiatives

The Fellow has been active in sharing the findings arising from the Fellowship with commercial primary producers, education professionals, town planners and urban developers.

A major international conference on urban aquaponics development will be held in Australia in the near future. The Fellow has been invited to make a presentation to this prestigious international conference.

The Fellow has conducted presentations to the South Australian Murray-Darling Basin Natural Resources Management Board. Further presentations are being considered for the Riviera region of South Australia and Victoria.

An Aquaponics 101 course developed by the Fellow in 2001 has now been modified with the new findings arising from the Fellowship. This course was conducted in Adelaide in October 2009 and again in February 2010. The course is aimed initially at cooperative small-scale acreage farmers.

The Fellow will also be running public information sessions at the Adelaide Royal Agricultural and Horticultural Show in September 2010.

Media activities undertaken by the Fellow concerning the Fellowship and broader issues associated with the Fellow's involvement in aquaponics industry include:

- The International Aquaponics Journal[14]
- Austasia Aquaculture magazine
- The Bunyip, SA
- The Plains Producer newspaper, SA
- ABC Television, Land Line
- ABC Radio National
- FIVEaa radio Adelaide

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[14] http://www.aquaponicsjournal.com/BacktIssue53.htm

Recommendations

Government

It is imperative that the Australian Government becomes more proactive in developing strategies to offset the decline in conventional agriculture with more efficient and integrated production systems. Such strategies need to encourage integrated farming practices.

Recommendations:

- That all spheres of government actively participate in policy working groups to develop industry management guidelines for integrated farming. Guidelines need to cover set criteria for achieving best management practices in the aquaponics industry.
- That the Australian Government provides green production rebates for the introduction of Green Production Rebates for primary producers who invest in technologies for the purpose of integrating their production methods with other production systems to minimise their impact on water resource and the environment.
- That the Australian Government funds an aquaponics best management practices pilot programme.
- Evaluate the establishment of a Cooperative Research Centre (CRC) for the Aquaculture and Aquaponics industries to undertake research on the biological and technical requirements necessary to increase the uptake of these farming systems.
- That State and Local Governments undertake a top-to-bottom re-evaluation of their existing planning laws and regulations with a view to providing greater incentives for people to establish small and micro-footprint aquaponics operations in urban areas.

Industry

Recommendation:

- The establishment of an Aquaculture advisory group that will work through key sector issues and consult with other established industry groups in the pursuit of the development of aquaculture and aquaponic industry benchmarks, based on the implementation of best management practices.

Professional Associations

Recommendation:

- That a newly established Aquaculture Industry Advisory Group works directly with other key horticultural industry groups to establish a framework for ongoing collaboration in developing and embedding aquaculture and aquaponics best management practices.

Education and Training

Recommendations:

- Establish regional aquapoinics and aquaculture demonstration sites as education models.
- That a nationally accredited course for aquaculture and aquaponics integrated sciences be established through the Australian Quality Training Framework.
- That bridging modules be developed through the SFI04 Seafood Industry Training Package, the AGF07 Agri-Food Training Package and the RTE03 Rural Production Training Package until an independent course is developed and accredited.

Recommendations

Community

Recommendation:

- That green roofing and wall landscaping be included into new building design codes, particularly in public malls, shopping centres and public amenities.

ISS Institute

Recommendation:

- That the ISS Institute bring together other Fellows with appropriate and relevant skill sets to present workshops and seminars to promote the development of integrated farming practices in Australia.

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