Aquaponics—Integration of Hydroponics with Aquaculture

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By Steve Diver
NCAT Agriculture Specialist
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Updated by
Lee Rinehart, NCAT Agriculture Specialist
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Aquaponics is a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, and/or herb production. Recent advances by researchers and growers alike have turned aquaponics into a working model of sustainable food production. This publication provides an introduction to aquaponics with brief profiles of working units around the country. An extensive list of resources points the reader to print and Web-based educational materials for further technical assistance.

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Introduction

Aquaponics, also known as the integration of hydroponics with aquaculture, is gaining increased attention as a bio-integrated food production system.

Aquaponics serves as a model of sustainable food production by following certain principles:

- The waste products of one biological system serve as nutrients for a second biological system.
- The integration of fish and plants results in a polyculture that increases diversity and yields multiple products.
- Water is re-used through biological filtration and recirculation.
- Local food production provides access to healthy foods and enhances the local economy.

In aquaponics, nutrient-rich effluent from fish tanks is used to fertigate hydroponic production beds. This is good for the fish because plant roots and rhizobacteria remove nutrients from the water. These nutrients – generated from fish manure, algae, and decomposing fish feed – are contaminants that would otherwise build up to toxic levels in the fish tanks, but instead serve as liquid fertilizer to hydroponically grown plants. In turn, the hydroponic beds function as a biofilter – stripping off ammonia, nitrates, nitrites, and phosphorus – so the freshly cleansed water can then be recirculated back into the fish tanks. The nitrifying bacteria living in the gravel and in association with the plant roots play a critical role in nutrient cycling; without these microorganisms the whole system would stop functioning.



Aquaponic vegetable bed in Australia.
Photo by Joel Malcolm, Backyard Aquaponics.
www.backyardaquaponics.com

Greenhouse growers and farmers are taking note of aquaponics for several reasons:

- Hydroponic growers view fish-manured irrigation water as a source of organic fertilizer that enables plants to grow well.
- Fish farmers view hydroponics as a biofiltration method to facilitate intensive recirculating aquaculture.
- Greenhouse growers view aquaponics as a way to introduce organic hydroponic produce into the marketplace, since the only fertility input is fish feed and all of the nutrients pass through a biological process.

- Food-producing greenhouses – yielding two products from one production unit – are naturally appealing for niche marketing and green labeling.
- Aquaponics can enable the production of fresh vegetables and fish protein in arid regions and on water-limited farms, since it is a water re-use system.
- Aquaponics is a working model of sustainable food production wherein plant and animal agriculture are integrated and recycling of nutrients and water filtration are linked.
- In addition to commercial application, aquaponics has become a popular training aid on integrated bio-systems with vocational agriculture programs and high school biology classes.

Related ATTRA Publications

Aquaculture Enterprises: Considerations and Strategies

Agricultural Business Planning Templates and Resources

The technology associated with aquaponics is complex. It requires the ability to simultaneously manage the production and marketing of two different agricultural products. Until the 1980s, most attempts at integrated hydroponics and aquaculture had limited success. However, innovations since the 1980s have transformed aquaponics technology into a viable system of food production. Modern aquaponic systems can be highly successful, but they require intensive management and they have special considerations.

This publication provides an introduction to aquaponics, it profiles successful aquaponic greenhouses, and it provides extensive resources. It does not attempt to describe production methods in comprehensive technical detail, but it does provide a summary of key elements and considerations.

Aquaponics: Key Elements and Considerations

A successful aquaponics enterprise requires special training, skills, and management. The following items point to key elements and considerations to help prospective growers evaluate the integration of hydroponics with aquaculture.

Hydroponics: Hydroponics is the production of plants in a soilless medium whereby all of the nutrients supplied to the crop are dissolved in water. Liquid hydroponic systems employ the nutrient film technique (NFT), floating rafts, and noncirculating water culture. Aggregate hydroponic systems employ inert, organic, and mixed media contained in bag, trough, trench, pipe, or bench setups. Aggregate media used in these systems include perlite, vermiculite, gravel, sand, expanded clay, peat, and sawdust. Normally, hydroponic plants are fertigated (soluble fertilizers injected into irrigation water) on a periodical cycle to maintain moist roots and provide a constant supply of nutrients. These hydroponic nutrients are usually derived from synthetic commercial fertilizers, such as calcium nitrate, that are highly soluble in water. However, hydroorganics – based on soluble organic fertilizers such as fish hydrosylate – is an emerging practice. Hydroponic recipes are based on chemical formulations that deliver precise concentrations of mineral elements. The controlled delivery of nutrients, water, and environmental modifications under greenhouse conditions is a major reason why hydroponics is so successful.

Nutrients in Aquaculture Effluent: Greenhouse growers normally control the delivery of precise quantities of mineral elements to hydroponic plants. However, in aquaponics, nutrients are delivered via aquacultural effluent. Fish effluent contains sufficient levels of ammonia, nitrate, nitrite, phosphorus, potassium, and other secondary and micronutrients to produce hydroponic plants. Naturally, some plant species are better adapted to this system than others. The technical literature on aquaponics provides greater detail on hydroponic nutrient delivery; especially see papers cited in the **Bibliography** by James Rakocy, Ph.D.

Plants Adapted to Aquaponics: The selection of plant species adapted to hydroponic culture in aquaponic greenhouses is related to stocking density of fish tanks and subsequent nutrient concentration of aquacultural effluent. Lettuce, herbs, and specialty greens (spinach, chives, basil, and watercress) have low to medium nutritional requirements and are well adapted to aquaponic systems.

Plants yielding fruit (tomatoes, bell peppers, and cucumbers) have a higher nutritional demand and perform better in a heavily stocked, well established aquaponic system. Greenhouse varieties of tomatoes are better adapted to low light, high humidity conditions in greenhouses than field varieties.

Fish Species: Several warm-water and cold-water fish species are adapted to recirculating aquaculture systems, including tilapia, trout, perch, Arctic char, and bass. However, most commercial aquaponic systems in North America are based on tilapia. Tilapia is a warm-water species that grows well in a recirculating tank culture. Furthermore, tilapia is tolerant of fluctuating water conditions such as pH, temperature, oxygen, and dissolved solids. Tilapia produces a white-fleshed meat suitable to local and wholesale markets. The literature on tilapia contains extensive technical documentation and cultural procedures. Barramundi and Murray cod fish species are raised in recirculating aquaponic systems in Australia.

Water Quality Characteristics: Fish raised in recirculating tank culture require good water quality conditions. Water quality testing kits from aquacultural supply companies are fundamental. Critical water quality parameters include dissolved oxygen, carbon dioxide, ammonia, nitrate, nitrite, pH, chlorine, and other characteristics. The stocking density of fish, growth rate of fish, feeding rate and volume, and related environmental fluctuations can elicit rapid changes in water quality; constant and vigilant water quality monitoring is essential.

Biofiltration and Suspended Solids: Aquaculture effluent contains nutrients, dissolved solids, and waste byproducts. Some aquaponic systems are designed with intermediate filters and cartridges to collect suspended solids in fish effluent, and to facilitate conversion of ammonia and other waste products to forms more available to plants prior to delivery to hydroponic vegetable beds. Other systems deliver fish effluent directly to gravel-cultured hydroponic vegetable beds. The gravel functions as a "fluidized bed bioreactor," removing dissolved solids and providing habitat for nitrifying bacteria involved in nutrient conversions. The design manuals and technical documentation available in the **Resources** section can help growers decide which system is most appropriate.

Component Ratio: Matching the volume of fish tank water to volume of hydroponic media is known as component ratio. Early aquaponics systems were based on a ratio of 1:1, but 1:2 is now common and tank: bed ratios as high as 1:4 are employed. The variation in range depends on type of hydroponic system (gravel vs. raft), fish species, fish density, feeding rate, plant species, etc. For example, the Speraneo system described below is designed for one cubic foot of water to two cubic feet of grow bed media (pea gravel). Further, when shallow bed systems only three inches in depth are employed for the production of specialty greens such as lettuce and basil, the square footage of grow space will increase four times. Depending on the system design, the component ratio can favor greater outputs of either hydroponic produce or fish protein. A "node" is a configuration that links one fish tank to a certain number of hydroponic beds. Thus, one greenhouse may contain a multiple number of fish tanks and associated growing beds, each arranged in a separate node.

Tilapia is a warm-water species that grows well in a recirculating tank culture.

Aquaponic Systems

Profiles of several aquaponic greenhouses are highlighted below as models of commercially viable systems. Most of these operations are featured in magazine articles and conference proceedings. Some operations offer technical assistance through short courses, design manuals, and on-site tours. Please refer to articles in the **Resources** section, and the **Bibliography,** for in-depth descriptions and technical details.

The North Carolina State University System

Water consumption in an integrated aquavegeculture system amounts to 1 percent of that required in pond culture to produce equivalent tilapia yields. In the 1980s Mark McMurtry (former graduate student)

and the late Doug Sanders (professor) at North Carolina State University developed an aqua-vegeculture system based on tilapia fish tanks sunk below the greenhouse floor. Effluent from the fish tanks was trickle-irrigated onto sand-cultured hydroponic vegetable beds located at ground level. The nutrients in the irrigation water fed tomato and cucumber crops, and the sand beds and plant roots functioned as a biofilter. After draining from the beds, the water recirculated back into the fish tanks. The only fertility input to the system was fish feed (32 percent protein).

Some findings and highlights of McMurtry's research:

Biofilters (sand beds with vegetables) that are alternately flooded and drained with nutrient-laden fish tank water are called reciprocating biofilters.

- Benefits of integrating aquaculture and vegetable production are:
  1. conservation of water resources and plant nutrients
  2. intensive production of fish protein
  3. reduced operating costs relative to either system in isolation.
- Water consumption in an integrated aqua-vegeculture system amounts to 1 percent of that required in pond culture to produce equivalent tilapia yields.
- Such low-water-use symbiotic systems are applicable to the needs of arid or semi-arid regions where fish and fresh vegetables are in high demand.
- Organic vine-ripened, pesticide-free produce and "fresh-daily" fish can bring premium prices, particularly during winter months in urban areas.
- Biofilters (sand beds with vegetables) that are alternately flooded and drained with nutrient-laden fish tank water are called reciprocating biofilters.
- Reciprocating biofilters provide uniform distribution of nutrient-laden water within the filtration medium during the flood cycle, and improved aeration from atmospheric exchange during each dewatering with benefits to both nitrifying bacteria and plant roots.
- Dissolved and suspended organic materials accumulate rapidly in aquaculture systems and must be removed for efficient fish production.
- Previous integrated fish-vegetable systems removed suspended solids from the water by sedimentation in clarifiers prior to plant application. Removal of the solid wastes resulted in insufficient residual nutrients for good plant growth; acceptable fruit yields had previously only been achieved with substantial supplementation of plant nutrients.
- Aqueous nitrate concentrations in recirculating aquaculture can be adequately regulated when fish and vegetable production are linked via reciprocating biofilters.
- Tomatoes may have also assimilated nitrogen in organic amino acid forms. In 1950 Gosh and Burris (Utilization of Nitrogenous Compounds by Plants. Soil Science. Vol. 70: 187-203) found that tomatoes utilize alanine, glutamic acid, histidine, and leucine as effectively as inorganic nitrogen sources.
- Research to determine the optimum ratio of fish tank to biofilter volume on fish growth rate and water quality found that stocking density of fish and plants can vary depending on desired goal. The component ratios of the system may be manipulated to favor fish or vegetable production according to local market trends or dietary needs. Fish stocking density and feeding rates are adjusted to optimize water quality as influenced by plant growth rate.

See the **Bibliography on Aquaponics** in the appendix for a of list articles that resulted from the North Carolina research.

Aqua-vegeculture research at NCSU has been discontinued because the technology had evolved to the point where it is ready

for grower application. The Department of Horticulture and the Cooperative Extension Service at NCSU provide technical assistance to aquaponic greenhouse growers in North Carolina.

The Speraneo System

In the early 1990s, Tom and Paula Speraneo – owners of S & S Aqua Farm near West Plains, Missouri – modified the North Carolina State method by raising tilapia in a 500-gallon tank, with fish effluent linked to gravel-cultured hydroponic vegetable beds inside an attached solar greenhouse. Later, they expanded to a full-size commercial greenhouse. The Speraneo system was practical, productive, and wildly successful. It became the model for dozens of commercial aquaponic greenhouses and high school biology programs.

Sadly, Tom Speraneo died in February 2004. Tom was a true pioneer in aquaponics, and he was unfailingly generous and helpful to others. Paula Speraneo and her family continue to run the greenhouse and actively participate in aquaponics technology transfer. The following notes describe the Speraneo system and available resources.

The commercial-scale solar greenhouse at S & S Aqua Farm is 50 feet by 80 feet, oriented East-West to create a south-facing slope. It contains six 1,200 gallon fish tanks. Each tank is linked to six one-foot-deep hydroponic beds filled with river gravel. Tom referred to each tank-plus-hydroponic bed setup as a "node." This way, each node can operate independently of one another.

Some aspects of the Speraneo system were modeled after the aquaponics research at North Carolina State University, while others are modified. The Speraneos employ hydroponic vegetable beds as "fluidized bed reactors," but they use pea-grade river gravel instead of sand. Tilapia are raised in fish tanks, but the tanks are more conveniently located above ground and tilapia hybrids adapted to cooler water temperatures are grown. The reciprocating water cycle, PVC piping, and return-flow water pumping methods were designed by Tom and Paula to match their system.

For years, Purina® fish chow at 40 percent protein was the primary fertility input, supplemented with tank-cultured algae. Tilapia in the Speraneo system are raised for 7 to 12 months, then harvested at one to one-and-a-half pounds in size. Later, Tom started adding small amounts of Planters 2® rock dust on top of the gravel as a trace element supplement.

S & S Aqua Farm has grown fresh basil, tomatoes, cucumbers, mixed salad greens, and an assortment of vegetable, herb, and ornamental bedding plants in the aquaponic greenhouse. In the early 1990s, Tom and Paula were raising and selling basil for $12 a pound to gourmet restaurants about four hours away in St. Louis, Missouri. Following passage of the North American Free Trade Agreement (NAFTA), however, Mexican imports of basil resulted in a market crash to $4 per pound, so they dropped the St. Louis market. S & S Aqua Farm now grows a diverse variety of vegetable and herbs, selling locally at a farmers market combined with direct sales out of their greenhouse.

Tom once calculated the farm produces 45 to 70 pounds of produce for every pound of tilapia, an impressive yield. However, Paula explained this figure takes into account the cumulative yields of multiple vegetable crops raised during the 7- to 12-month time period required to raise fish to harvest.

The component ratio favors vegetables over fish yields in the Speraneo system.

Interest in the Speraneo system resulted in more than 10,000 visitors to the small farm in Missouri, including school children, farmers, researchers, and government officials. To handle requests for assistance, the Speraneos compiled a resource packet and design manual with technical specifications to establish an S & S Aqua Farm-style aquaponic system. The resource packet includes a 10-minute video and a list of supplies. Response from growers to a practical design manual such as this was tremendous. The Speraneo system is now in use worldwide. The resource packet is available through:

Aquaponic greenhouse at S & S Aqua Farms, West Plains, Missouri. Photos by Steve Diver, NCAT.













S & S Aqua Farm
[Contact: Paula Speraneo]
8386 County Rd. 8820
West Plains, MO 65775
417-256-5124

Especially see:

Maturing Marvel (PDF/282K) by Vern Modeland, *The Growing Edge,* May-June 1998, *www.growingedge.com/magazine/back_issues/view_article.php3?AID=90535>*

The Genius of Simplicity (PDF/30K) by John Wesley Smith, *The Growing Edge*, Winter 1993-94, *www.growingedge.com/magazine/back_issues/view_article.php3?AID=50240*

Bioponics – Revolution in Food Growing: Missouri Aquafarmer Discovers Huge Benefits in Trace Elements by David Yarrow Remineralize the Earth, December 1997.

The University of the Virgin Islands System

James Rakocy, Ph.D., and associates at the University of the Virgin Islands (UVI) developed a commercial-scale aquaponic system that has run continuously for more than five years. Nile and red tilapia are raised in fish rearing tanks, and the aquacultural effluent is linked to floating raft hydroponics. Basil, lettuce, okra, and other crops have been raised successfully, with outstanding quality and yields.

The system components include: Four fish rearing tanks at 7,800 liters each, clarifiers, filter and degassing tanks, air diffusers, sump, base addition tank, pipes and pumps, and six 400-square foot hydroponic troughs totaling 2,400 sq. ft. The pH is monitored daily and maintained at 7.0 to 7.5 by alternately adding calcium hydroxide and potassium hydroxide to the base addition tank, which buffers the aquatic system and supplements calcium and potassium ions at the same time. The only other supplemental nutrient required is iron, which is added in a chelated form once every three weeks.

Tilapia are stocked at a rate of 77 fish per cubic meter for Nile tilapia, or 154 fish per cubic meter for red tilapia and cultured for 24 weeks. The production schedule is staggered so that one tank is harvested every six weeks. After harvest, the fish tank is immediately restocked. The fish are fed three times daily with a complete, floating fish pellet at 32 percent protein. Projected annual fish production is 4.16 metric tons for Nile tilapia and 4.78 metric tons for red tilapia.

In one notable experiment the UVI researchers compared the yields of a leafy herb (basil) and a fruiting vegetable (okra) grown in aquaponic vs. field production systems. Basil and okra were raised in raft hydroponics. Yields of aquaponic basil were three times greater than field-grown, while yields of aquaponic okra were 18 times greater than field-grown. Based on a market price in the U.S. Virgin Islands of $22 per kg for fresh basil with stems, researchers calculated gross income potential. The aquaponic method would result in $515 per cubic meter per year or $110,210 per system per year. This compares to field-produced basil at $172 per cubic meter per year or $36,808 per year for the same production area. When fish sales are included, the aquaponic system yields $134,245 (Rakocy, et al, 2004).

James Rakocy, Ph.D., and associates at the University of the Virgin Islands (UVI) developed a commercial-scale aquaponic system that has run continuously for more than five years.

Like McMurtry, researcher Rakocy sees integrated water reuse systems as a viable solution to sustainable food production in developing countries and arid regions – such as the Caribbean Islands – where fresh water is scarce.

To provide in-depth technical support, the UVI research team offers a week-long short course on aquaponics each year at the UVI agricultural experiment station. The UVI short course is the premier educational training program available to farmers in the world. In addition to aquaponics, UVI specializes in greenwater tank culture, a recirculating aquaculture system.

Rakocy has published extensive research reports and several Extension Service bulletins on recirculating aquaculture and aquaponics.

See the **Bibliography** in the appendix for citations to articles and papers by Rakocy.

Contact:

James Rakocy, Ph.D.
University of the Virgin Islands
Agriculture Experiment Station
RR 1, Box 10,000
Kingshill, St. Croix
U.S. Virgin Islands 00850-9781
340-692-4031
(340) 692-4035 FAX
jrakocy@uvi.edu

Aquaculture Program
www.uvi.edu/sites/uvi/Pages/AES-Aquaculture-Home.aspx?s=RE

Aquaponics
www.uvi.edu/sites/uvi/Pages/AES-Aquaculture-Aquaponic_Systems.aspx?s=RE

Especially see:

Update on Tilapia and Vegetable Production in the UVI Aquaponic System
James E. Rakocy, Donald S. Bailey, R. Charlie Shultz and Eric S. Thoman. Page 676-690. In: New Dimensions on Farmed Tilapia: Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, held September 12-16, 2004 in Manila, Philippines. Proceedings paper: 15 pages (PDF/254 K) *http://ag.arizona.edu/azaqua/ista/ista6/ista6web/pdf/676.pdf*, PDF Presentation: 49 pages (PDF/1.47 MB) *http://ag.arizona.edu/azaqua/ista/ista6/ista6web/presentation/p676.pdf*

Aquaponics: Integrated Technology for Fish and Vegetable Production in Recirculating Systems, James Rakocy, University of the Virgin Islands USDA Ministerial Conference and Expo on Agricultural Science and Technology. PowerPoint Presentation; 69 slides, *www.fas.usda.gov/icd/stconf/session2/session%202d/02-rakocy_j-2D%202nd_files/frame.htm*

The Freshwater Institute System

The Freshwater Institute in Shepherdstown, West Virginia – a program of The Conservation Fund, an environmental non-profit organization – specializes in aquaculture research and education. Fresh spring water is an abundant resource in the Appalachian region. However, protection of spring water quality as it relates to aquaculture effluent is viewed as a vital component of this technology.

Trials at the Freshwater Institute's greenhouses showed that nitrogen, phosphorus, and other nutrients in aquaculture effluent can be effectively removed by plants grown in NFT hydroponics or constructed wetland systems.

For years, the institute has specialized in cold-water recirculating aquaculture systems raising trout and arctic char. The institute helps Appalachian farmers set up two types of aquaculture systems: (a) an indoor, high-tech recirculating tank method and (b) an outdoor, low-tech recirculating tank method. Treatment of aquaculture effluent prior to its return to the natural stream flow led to collaborative research with USDA-ARS scientists in Kearneysville, West Virginia, on integrated hydroponic-fish culture systems. Trials at the institute's greenhouses showed that nitrogen, phosphorus, and other nutrients in aquaculture effluent can be effectively removed by plants grown in NFT hydroponics or constructed wetland systems.

In the mid-1990s, the institute implemented an aquaponic demonstration program based on a Speraneo-style gravel-cultured system. Tilapia is raised as a warm-water fish species. Hydroponic crops include basil, lettuce, and wetland plants.

To provide technical assistance to farmers and high school biology teachers, the institute published a series of publications on recirculating aquaculture and aquaponics. *The Freshwater Institute Natural Gas Powered Aquaponic System – Design Manual* is a 37-page manual published by the institute in 1997. Included are diagrams and photos, details on greenhouse layout and aquaponic production, parts list with suppliers and cost, estimated operating expense, and further informational resources.

Please note the institute no longer provides direct technical assistance to farmers on aquaponics. Instead, it has made some of their publications on recirculating aquaculture and aquaponics available online. Contact The Freshwater Institute for information on obtaining design manuals and other publications not available as Web downloads.

The Freshwater Institute
1098 Turner Road
Shepherdstown, WV 25443-4228
Phone (304) 876-2815
www.freshwaterinstitute.org

Selected Publications from The Freshwater Institute:

- Suggested Management Guidelines for An Integrated Recycle Aquaculture – Hydroponic System
- The Freshwater Institute Natural Gas Powered Aquaponic System – Design Manual
- 880 Gallon Recycle Aquaculture System Installation Guide
- Linking Hydroponics to a 880 Gallon Recycle Fish Rearing System
- Operators Manual for 880 – Recycle System

The Cabbage Hill Farm System

Cabbage Hill Farm is a non-profit organization located about 30 miles north of New York City. The foundation is dedicated to the preservation of rare breeds of farm animals, sustainable agriculture and local food systems, and aquaponic greenhouse production.

Cabbage Hill Farm designed and continues to operate a simple recirculating aquaponic system. Cabbage Hill Farm promotes education on aquaponics and hosts greenhouse interns. Tours are available.

Tilapia fish and leaf lettuce are the main products of the Cabbage Hill Farm system, though basil and watercress are also grown in smaller quantities. In addition to hydroponics, water passes through a constructed reed bed outside the greenhouse for additional nutrient removal.

Cabbage Hill Farm
115 Crow Hill Road
Mount Kisco, NY 10549
914-241-2658
914-241-8264 FAX
www.cabbagehillfarm.org

The New Alchemy Institute

The New Alchemy Institute in East Falmouth, Massachusetts, conducted research on integrated aquaculture systems during the 1970s and 1980s. Although the institute closed in 1991, New Alchemy publications on greenhouse production and aquaponics provide historical insight to the emerging bioshelter (ecosystem greenhouses) concept and are still a valuable resource for technical information. The Green Center, formed by a group of former New Alchemists, is again making these publications available for sale. The website has a section featuring for-sale articles on aquaculture and bioshelters (integrated systems). A selection of past articles is available online.

Contact:

The Green Center
28 Common Way, Hatchville, MA 02536
www.thegreencenter.net

Especially see:

An Integrated Fish Culture Hydroponic Vegetable Production System (PDF/6.57 MB) by Ronald D. Zweig, *Aquaculture Magazine*, May-June 1986. *www.thegreencenter.net*
Listed under the heading: New Alchemy Institute Publications Online

Summary of Fish Culture Techniques in Solar Aquatic Ponds (PDF/815K) by John Wolfe and Ron Zweig. *Journal of The New Alchemists,* 1977. *www.thegreencenter.net*
Listed under the heading: New Alchemy Institute Publications Online

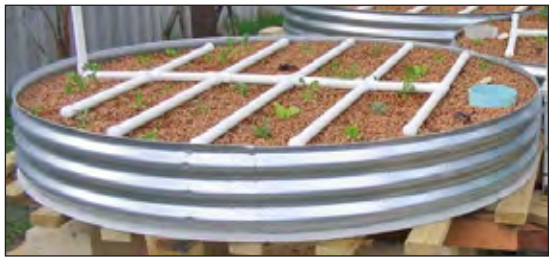
Miscellaneous Systems

Instead of locating the fish and vegetable components in separate containers inside a greenhouse, fish production can be located in outdoor tanks or adjacent buildings. The effluent simply needs to be delivered to hydroponic vegetable beds.

In warm climates, hydroponic vegetable beds may be located outside. As an example, the Center for Regenerative Studies at California State Polytechnic University-Pomona implemented an outdoor integrated bio-system that links: (a) a pond containing treated sewage wastewater stocked with tilapia and carp; (b) water hyacinth – an aquatic plant

In warm climates, hydroponic vegetable beds may be located outside.









Backyard Aquaponics in Western Australia. Photos by Joel Malcolm, Backyard Aquaponics. (with permission) *www.backyard aquaponics.com*





very efficient at sucking up nutrients – covering 50 percent of the water surface area; the plant biomass generated by water hyacinth is used as feedstock for compost heaps; (c) nearby vegetable gardens irrigated with nutrient-laden pond water.

In addition to locating the fish and vegetable components in separate containers, fish and plants can be placed in the same container to function as a polyculture. For example, plants sit on top of floating polystyrene panels with their roots hanging down into the water that fish swim around in. Models include the Rakocy system, solar-algae ponds (see literature by Zweig and Kleinholz), and the solar-aquatic ponds, or Living Machines, made popular by John Todd at Ocean Arks International.

In Australia, barramundi *(Lates calcarifer)* and Murray cod *(Maccullochella peelii peelii)* fish species have been adapted to recirculating aquaculture and aquaponics systems. The stocking densities for these fish species is higher than tilapia, which in turn results in greater hydroponic surface under production. Several references are provided on these fish species and aquaponic systems in the **Resources** and **Bibliography** sections.

Organic Aquaculture

Organic production of crops and livestock in the United States is regulated by the Department of Agriculture's National Organic Program, or NOP. The NOP is an organic certification and marketing program that ensures foods and food products labeled as "organic" meet universal standards and guidelines for organic production. Production inputs used in organic production – such as feed and fertilizers – must be of natural origin and free of synthetic materials. A farm plan, documentation of inputs and production methods, and farm inspection are required to obtain "certified organic" status. This process allows farm products to be labeled and sold as organic.

Organic trout, tilapia, salmon and other fish species are raised in Europe, Australia, and Israel using production standards developed by international organic certification agencies (for more information see The IFOAM *Norms for Organic Production and Processing,* Version 2005 and updated in 2009 at *www.ifoam.org/about_ifoam/standards/norms/norm_documents_library/Norms_ENG_V4_20090113.pdf*). However, organic aquaculture was not clearly defined in the NOP and the lack of organic aquaculture guidelines has hampered the growth of a domestic organic aquaculture industry in the United States.

The ATTRA publication *Aquaculture Enterprises: Considerations and Strategies* contains a section on organic aquaculture. It states that accredited organic certifying agencies can certify organic aquaculture operations, but the products are not allowed to carry the USDA organic label.

Organic certifying agencies can certify organic aquaculture operations, but the products are not allowed to carry the USDA organic label.

In fact, Quality Certification Services in Florida has certified three organic aquaculture operations in the U.S. and abroad under a private label. AquaRanch (*www.aquaranch.com/index.html)* an aquaponic greenhouse in Illinois, set a precedent for the aquaponics industry by obtaining organic certification for its hydroponic produce through Indiana Certified Organic. Meanwhile, AquaRanch markets its greenhouse-raised tilapia as "naturally grown."

To address the issue of organic aquaculture, the National Organic Standards Board (NOSB) established an Aquatic Animals Task Force in June 2000. In 2003, a second group – The National Organic Aquaculture Working Group (NOAWG), comprised of 80 aquaculture professionals and related stakeholders – formed to provide further guidance and clarification to the NOSB. The interim final report published by NOAWG in January 2006 provides proposed recommendations on organic aquaculture to NOSB, accessible at *www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5062436&acct=nopgeninfo.*

To provide access to the large volume of documents, reports, and organic production standards surrounding the issue of organic aquaculture, the National Agricultural Library published an 80-page bibliography, *Organic Aquaculture,* through the Alternative Farming Systems Information Center.

Organic Aquaculture: AFSIC Notes #5 by Stephanie Boehmer, Mary Gold, Stephanie Hauser, Bill Thomas, and Ann Young. Alternative Farming Systems Information Center, National Agricultural Library, USDA. *www.nal.usda.gov/afsic/AFSIC_pubs/afnotes5.htm*

Evaluating an Aquaponic Enterprise

Due to the highly technical nature of aquaponics and the expense associated with greenhouse production, prospective growers are advised to thoroughly investigate production methods and market potential.

Aquaponics is one method of hydroponics, and hydroponics is one method of greenhouse production.

For general information and supplies associated with greenhouse vegetable production, see the ATTRA resource list Greenhouse and Hydroponic Vegetable Production Resources on the Internet. Complementary ATTRA publications include *Organic Greenhouse Vegetable Production* and *Integrated Pest Management for Greenhouse Crops.*

Building and equipping a commercial-sized aquaponic greenhouse can cost $10,000 to $30,000, depending on the system design and choice of components. Due to the highly technical nature of aquaponics and the expense associated with greenhouse production, prospective growers are advised to thoroughly investigate production methods and market potential. A sequence of considerations and learning opportunities geared to evaluating an aquaponic greenhouse enterprise are listed below.

1. Aquaponic greenhouses yield two food products. To evaluate greenhouse profitability, obtain typical yields and market prices for hydroponic vegetables and fish, and investigate local and regional markets and related point of sales. Retail sales directly out of your greenhouse or roadside stand might be an ideal situation, but this will depend on your location.

2. Aquaponics is one method of hydroponics, and hydroponics is one method of greenhouse production. Consider lower-cost and simpler alternatives. Bag culture of greenhouse vegetables – raising plants in polyethylene grow bags filled with compost-based potting mixes – is a simple and productive way to get started in greenhouse vegetable production. You may quickly find that your biggest challenge is weekly marketing of fresh produce rather than successful production of vegetables. This includes labor to harvest vegetables, grading and packing with brand name labels, post-harvest handling methods to maintain superior quality, and quick delivery of perishable produce to established markets.

3. Read technical and popular literature on recirculating aquaculture and aquaponics to become familiar with production methods, yields, and market prices for fresh fish and hydroponic vegetables. The **Web Resources** listed below provide quick access to reading material, diagrams and images, and related details. The **Bibliography** in the appendix provides access to in-depth research and technical data.

4. Visit an aquaponic greenhouse to gain first-hand observations. Take lots of pictures to document the system components and how they relate to one another. Keep in mind that aquaponic growers are busy people with a considerable investment in time and resources to establish their businesses.

5. Attend a short course. There are three prominent aquaponic short courses in North America, offered by University of the Virgin Islands, (University of the Virgin Islands, No date) Aquaculture International (Aquaculture International, No date) in North Carolina, and Growing Power (Growing Power, No date) in Wisconsin. Cornell University co-hosts a recirculating aquaculture short course in association with The Freshwater Institute (Cornell University, No date). In addition, Nelson and Pade, Inc. has a list of training courses on their website accessible at *www.aquaponics.com/infoCourses.htm.*

6. Obtain one or two aquaponic training manuals to acquire detailed technical specifications. The book *Aquaponic Food Production: raising fish and plants for food and profit*; the *Desktop Aquaponics Booklet*;

and the *Introduction to Aquaponics* DVD from Nelson and Pade, Inc. are good starting points. When you are ready to explore a commercial system, the design manuals from S&S Aqua Farm in Missouri and Joel Malcolm's Backyard Aquaponics in Western Australia contain in-depth technical specifications, illustrations, and parts lists (S&S Aqua Farm, Joel Malcolm, no dates). The **Web Resources** section lists additional training manuals and technical documentation.

7. Hire an agricultural consultant to acquire expert advice and consultation, and to shorten the time and risk involved getting started. A few consultants with expertise in aquaponics are listed in the **Agriculture Consultants** section below.
8. Participate on the Aquaponics E-mail Discussion Group. E-mail discussion lists have become the modern town square. This is where practitioners, scientists, specialists, and business people all share resources, supplies, and production methods. The e-mail list is hosted by Paula Speraneo with S&S Aqua Farms. The archives are publicly accessible, and serve as a treasure trove of technical information and farmer-to-farmer exchange.
9. Lastly, avoid the "inventor's urge" to reinvent the wheel. Successful aquaponic greenhouse operators have already figured out the system components and methods of production, based on years of research and experience. Pick one of the existing models and duplicate it insofar as possible. The old saying, "Get the engine running first, then adjust the carburetor," can be aptly applied to aquaponic start-up greenhouses.

References

1. Rakocy, James E., Donald S. Bailey, R. Charlie Shultz and Eric S. Thoman. 2004. Update on tilapia and vegetable production in the UVI aquaponic system. p. 676-690. In: New Dimensions on Farmed Tilapia: Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Held September 12-16, 2004 in Manila, Philippines.
2. University of the Virgin Islands – International Aquaponics and Tilapia Aquaculture *www.uvi.edu/sites/uvi/Pages/AES-Aquaculture-International_Aquaponics.aspx?s=RE*
3. Aquaculture International – Short Course on Aquaponics *www.aquacultureinternational.org*
4. Growing Power – Short Course on Aquaponics *www.growingpower.org*
5. Cornell University – Short Course on Recirculating Aquaculture *www.bee.cornell.edu/cals/bee/outreach/aquaculture/short-course/index.cfm*
6. S&S Aqua Farm – Design Manual *www.jaggartech.com/snsaqua*
7. Joel Malcolm – Backyard Aquaponics Design Manual Western Australia *joel@backyardaquaponics.com*, *www.backyardaquaponics.com*

Resources

E-mail Discussion Lists for Aquaponics - Hydroponics - Aquaculture

Aquaponic E-Mail List

Paula Speraneo of S&S Aqua Farm in Missouri hosts the Aquaponics E-Mail list on the Internet. The Aquaponics List is a prominent source of technology transfer and resource sharing on all aspects of aquaponics: hydroponics, aquaculture, fish species, supplies, practical solutions, and resources. The e-mail archives are a key source of information.

To subscribe, send an email request to:
snsaquasys@townsqr.com
To view Web e-mail archives, go to:
Aquaponics List – Before 2002
www.i55mall.com/aquaponics

Hydroponics and Aquaculture E-Mail List
A number of e-mail lists on hydroponics and aquaculture are scattered among the Internet hosting sites like YahooGroups.com, MSN.com, and Topica.com.

Aquaculture and Aquaponic Trade Magazines, Organizations, and Journals

Aquaponics Journal
Nelson and Pade, Inc.
PO Box 761
Montello, WI 53949, USA
phone 608-297-8708
Toll-free Fax: 866-815-9734
info@aquaponics.com
www.aquaponicsjournal.com
Aquaponics Journal *is the quarterly journal from Nelson and Pade, Inc. It has become a prominent source for articles, reports, news, and supplies for the aquaponics industry. Back issues are a valuable resource, available in print or as e-files.*

The Growing Edge Magazine
New Moon Publishing
P.O. Box 1027
Corvallis, OR 97339-1027
800-888-6785; 541-757-8477
541-757-0028 Fax
www.growingedge.com
The Growing Edge *is a bi-monthly trade magazine on high-tech gardening systems like hydroponics, bioponics, aquaponics, and ecologically based pest management. Past articles are an important source of technical information on aquaponics, bioponics, and organic hydroponics.*

Practical Hydroponics & Greenhouses
P.O. Box 225
Narrabeen, NSW 2101 Australia
Phone: +61 (02) 9905 9933
Fax: +61 (02) 9905 9030
info@hydroponics.com.au
www.hydroponics.com.au
Practical Hydroponics & Greenhouses *is a bimonthly magazine dedicated to soilless culture and greenhouse production. Articles profile soilless culture and greenhouse enterprises from around the world. It also reports on new products, research and development, and industry news. Back issues are a valuable resource. The award-winning magazine is now online as an exact digital copy of the print edition, using DjVu technology.*

Grower Talks
www.ballpublishing.com

Ball Publishing
622 Town Road
P.O. Box 1660
West Chicago, IL 60186
Tel: (630) 231-3675
Toll Free (888) 888-0013
Fax: (630) 231-5254
email: info@ballpublishing.com

Greenhouse Grower
www.greenhousegrower.com

Greenhouse Product News
www.gpnmag.com

Scranton Gillette Communications, Inc.
3030 W. Salt Creek Lane, Suite 201
Arlington Heights, Illinois 60005-5025 USA
847-391-1000
847-390-0408

World Aquaculture
www.was.org/main/summaryasp?page=magazine
Carol Mendoza, Director
WAS Home Office
143 J. M. Parker Coliseum
Louisiana State University
Baton Rouge, LA 70803 (USA)
1-225-578-3137
FAX: 1-225-578-3493
carolm@was.org

Aquafeed.com
http://aquafeed.com
editor@aquafeed.com

Austasia Aquaculture
www.austasiaaquaculture.com.au
Unit 2, Level 2, Bellerive Quay,
31 Cambridge Rd, Bellerive
Tasmania, Australia
701803 6245 0064

Aquanews Archives
http://pdacrsp.oregonstate.edu/aquanews/archive.html

Aquaculture articles. *Permaculture Activist* #52 (magazine). Summer 2004. *www.permacultureactivist.net*

Aquaculture Collaborative Research Support Program, Oregon State University.
http://pdacrsp.oregonstate.edu

NOAA Aquaculture Program
http://aquaculture.noaa.gov

Aquaculture Network Information Center (AquaNIC)
www.aquanic.org

Ecotao's Aquaculture Links
www.ecotao.com/holism/agric/aqua.htm

American Fisheries Society Online Journals
http://afs.allenpress.com/perlserv/?request=get-archive

Scientific Journals on Aquaculture (Elsevier journal)
www.sciencedirect.com/science/journal/00448486

Aquacultural Engineering (Elsevier journal)
www.sciencedirect.com/science/journal/01448609

Aquaculture International (Springer journal)
www.springerlink.com/content/1573-143X/?p=d6dfe772b59245f287cad843d6809276&pi=107

Aquaculture Research (Blackwell journal)
www.wiley.com/bw/journal.asp?ref=1355-557X

Aquaponic Books and Videos

Nelson and Pade, Inc., publisher of Aquaponics Journal, offers booklets, DVDs, videos, and educational curricula on aquaponics, hydroponics, and aquaculture. See their Web page for details. Contact:

Nelson and Pade, Inc.
PO Box 761
Montello, Wisconsin
53949 USA
608-297-8708
866-815-9734 FAX
Pinfo@aquaponics.com
www.aquaponics.com

Rebecca L. Nelson and John S. Pade. 2008. Aquaponic Food Production: raising fish and plants for food and profit. *www.aquaponics.com/ShopAFPBook.htm*

Integrated agriculture-aquaculture: A primer. FAO/IIRR/WorldFish Center 2001. *www.fao.org/docrep/005/y1187e/y1187e00.htm*

Hutchinson, Laurence. 2005. Ecological Aquaculture: A Sustainable Solution. Hampshire, England: Permanent Publications. *www.amazon.com/Ecological-Aquaculture-Sustainable-Laurence-Hutchinson/dp/1856230325*

Van Gorder, Steven D. 2000. Small Scale Aquaculture: A hobbyist's guide to growing fish in greenhouses, recirculating systems, cages, and flowing water. Breinigsville, PA: Alternative Aquaculture Association, Inc. *www.altaqua.com*

The Aquaponics Guidebook
http://accesstoaquaponics.com/book.html

Agricultural Consultants for Integrated Hydroponics and Aquaculture

AquaRanch Industries, LLC
[Contact: Myles Harston]
404 D. East Lincoln St.
P.O. Box 658
Flanagan, IL 61740
815-796-2978
(815)796-4485 FAX
kat@aquaranch.com
www.aquaranch.com

Fisheries Technology Associates, Inc.
[Contact: Bill Manci]
506 Wabash Street
Fort Collins, CO 80522-3245
970-225-0150
info@ftai.com
www.ftai.com

Global Aquatics USA, Inc.
505 Aldino Stepney Rd.
Aberdeen, MD 21001
443-243-8840
410-734-7473 FAX
aquatic@iximd.com
www.growfish.com

Gordon Creaser
4886-115 Garfield Street
Sumas, Wa 98295 USA
Phone: (407) 421-9816
www.gordoncreaser.com

Mark R. McMurtry
PMB 267
1627 W. Main St.
Bozeman, MT 59715-4011
(406) 585-8000
mcmurtry@avicom.net

Nelson and Pade, Inc.
PO Box 761
Montello, Wisconsin
53949 USA
608-297-8708
866-815-9734 FAX
kat@aquaponics.com
www.aquaponics.com

S&S Aqua Farms
[Contact: Paula Speraneo]

407 Pennsylvania Ave
West Plains, MO 65775
417-256-5124
snsaquasys@townsqr.com
www.jaggartech.com/snsaqua

Aquaculture Associations

Aquacultural Engineering Society
www.aesweb.org

American Tilapia Association
http://ag.arizona.edu/azaqua/ata.html

The Alternative Aquaculture Association
www.altaqua.com

Directory of Aquaculture Associations
Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/publicat/govagen/nal/associat.htm

Texas Aquaculture Association
www.texasaquaculture.org

Miami Aqua-culture, Inc.
www.miami-aquaculture.com

Aquaculture Directories and Resource Collections

National Agricultural Library – Alternative Farming Systems Information Center

The Alternative Farming Systems Information Center (AFSIC) at the National Agricultural Library, a program of USDA-ARS, provides extensive aquaculture resource listings. Organic Aquaculture (AFSIC Notes No. 5), published in January 2005, is an important new publication from AFSIC that addresses the potential of organic aquacultural products; it also contains a section on recirculating aquaculture.

Aquaculture Resources

http://afsic.nal.usda.gov/nal_display/index.php?info_center=2&tax_level=2&tax_subject=295&level3_id=0&level4_id=0&level5_id=0&topic_id=1410&&placement_default=0

Organic Aquaculture

- Aquaculture-Related Internet Sites and Documents
- Directory of Aquaculture Related Associations and Trade Organizations
- Directory of State Aquaculture Coordinators and Contacts
- Automated Searches on General Aquaculture Topics

AFSIC, NAL, USDA-ARS
10301 Baltimore Ave., Room 132
Beltsville, MD 20705-2351
301-504-6559
301-504-6927 Fax
afsic@nal.usda.gov
http://afsic.nal.usda.gov/nal_display/index.php?tax_level=1&info_center=2

Other Aquaculture Resources

Aquaculture Network Information Center (AquaNIC)
http://aquanic.org

AquaNIC is the gateway to the world's electronic resources for aquaculture information. Especially see the extensive resource listing on recirculating aquaculture systems, and the complete listing of publications from the Regional Aquaculture Centers.

Recirculating Aquaculture Systems – Index, Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/systems/recycle/documents/recirculatingoklahoma.pdf

Regional Aquaculture Center Publications – Index, Aquaculture Network Information Center (AquaNIC)
http://aquanic.org/publicat/usda_rac/fact.htm

Environmentally Friendly Aquaculture Digital Library
National Sea Grant Library
http://nsgd.gso.uri.edu/aquadig.html

The National Sea Grant Library (NSGL) contains a complete collection of Sea Grant funded work. The NSGL maintains a bibliographical database containing over 36,000 records that can be searched by author-keyword or browsed by topic. Selected items include proceedings from recirculating aquaculture conferences and related documents. The Environmentally Friendly Aquaculture Digital Library is a topic-oriented portal to NSGL, organized by subject category.

Aquaponic Resources on the Web

Selected Publications from Southern Regional Aquaculture Center (SRAC)

Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture
SRAC Publication No. 454 (PDF/314K)
http://srac.tamu.edu/tmppdfs/504545-SRAC454.pdf?CFID=504545&CFTOKEN=21206104&jsessionid=90308c91b4fe7d1ee6e016a4c5e6e4a61c51

Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations SRAC Publication No. 451 (PDF/142K)
http://srac.tamu.edu/tmppdfs/504545-451fs.pdf?CFID=504545&CFTOKEN=21206104&jsessionid=90308c91b4fe7d1ee6e016a4c5e6e4a61c51

Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems SRAC Publication No. 452 (PDF/115K)
http://srac.tamu.edu/tmppdfs/504545-452fs.pdf?CFID=504545&CFTOKEN=21206104&jsessionid=90308c91b4fe7d1ee6e016a4c5e6e4a61c51

Recirculating Aquaculture Tank Production Systems: Component Options
SRAC Publication No. 453 (PDF/378K)
http://srac.tamu.edu/tmppdfs/504545-453fs.pdf?CFID=504545&CFTOKEN=21206104&jsessionid=90308c91b4fe7d1ee6e016a4c5e6e4a61c51

Tank Culture of Tilapia
SRAC Publication No. 282 (PDF/49K)
http://srac.tamu.edu/tmppdfs/504545-282fs.pdf?CFID=504545&CFTOKEN=21206104&jsessionid=90308c91b4fe7d1ee6e016a4c5e6e4a61c51

Selected Aquaponic Training Materials and Design Manuals

S&S Aqua Farm
www.jaggartech.com/snsaqua
Design manual with specifications

Backyard Aquaponics
http://www.backyardaquaponics.com
Design manual with specifications

A Prototype Recirculating Aquaculture-Hydroponic System (PDF/94K)
By Donald Johnson and George Wardlow
University of Arkansas, Department of Agricultural and Extension Education
AgriScience Project
www.uark.edu/depts/aeedhp/agscience/aquart2.pdf
A 10-page reprint article, originally published in Journal of Agricultural Mechanization (1997). It describes a low cost (less than $600) recirculating aquaculture-hydroponic system suitable for use in laboratory settings, including a materials list with approximate cost of materials to set up a 350-gallon aquaponic unit.

The Freshwater Institute Publications Index, Shepherdstown, West Virginia
www.freshwaterinstitute.org/publications

- Suggested Management Guidelines for An Integrated Recycle Aquaculture – Hydroponic System
- The Freshwater Institute Natural Gas Powered Aquaponic System - Design Manual
- 880 Gallon Recycle Aquaculture System Installation Guide
- Linking Hydroponics to an 880 Gallon Recycle Fish Rearing System
- Operators Manual for 880 - Recycle System

Aquaculture on Cat Beach
www.rainbowfish.se/english/f89.htm
www.rainbowfish.se/bilder/education_short.doc
A 10-page booklet with directions on establishing a small aquaponic system, including a parts list. The HTML version contains additional photos that illustrate system components and greenhouse production.

Barrel-Ponic (aka Aquaponics in a Barrel) (PDF/3.09MB) by Travis W. Hughey
www.aces.edu/dept/fisheries/education/documents/barrel-ponics.pdf

General Aquaponic Resources on the Web

The Essence of Aquaponics – Index to Aquaponics Mail Group Topics
www.rainbowfish.se/mailgroup/index.html
The Essence of Aquaponics website of Pekka Nygard and Stefan Goës in Sweden provides an index to key topics (aquaponics, fish, fish feed, plants, plant nutrition, water, biofilters, greenhouses, maintenance, economics, links, literature) posted on the Aquaponics Mail Group (see e-mail resources above).

Aquaponics Library
http://aquaponicslibrary.20megsfree.com/Index.htm

Enhancing Student Interests in the Agricultural Sciences through Aquaponics (PDF/725K) by G.W. Wardlow and D.M. Johnson
University of Arkansas, Department of Agricultural and Extension Education.
www.uark.edu/depts/aeedhp/agscience/aquart.pdf

Free Articles on Hydroponics, Practical Hydroponics and Greenhouses
http://hydroponics.com.au/php/viewforum.php?f=3

Aquaponics Proves Profitable in Australia, Aquaponics Journal, First Quarter, 2002.
www.aquaponicsjournal.com/articleaustralia.htm

Integrated Systems of Agriculture and Aquaculture
Aquaculture in the Classroom,
University of Arizona
http://ag.arizona.edu/azaqua/extension/Classroom/Aquaponics.htm

Aquaponics Pty Ltd
www.aquaponics.com.au/index.htm

Aquaponics Combine Fish, Tomatoes, and Ingenuity
University of Illinois Extension
http://web.extension.uiuc.edu/smallfarm/pdf/oursare/aquaponics.pdf

Hydroponics Integration with Aquaculture (powerpoint)
www.texasaquaculture.org/Presentations/Masser%20Aquaponics.pdf

Aquaculture Resources on the Web

Greenhouse Tilapia Production in Louisiana
Louisiana State University
www.lsuagcenter.com/en/communications/publications/Publications+Catalog/Environment/Aquaculture++Fisheries/Greenhouse+Tilapia+Production+in+Louisiana.htm

Recirculating Aquaculture Systems -- Teacher's Resource Website. Auburn University
www.aces.edu/dept/fisheries/education/recirculatingaquaculture.php

The Urban Aquaculture Manual by Jonathan Woods
www.webofcreation.org/BuildingGrounds/aqua/TOC.html

NorthernAquaFarms.com
www.northernaquafarms.com

National Oceanic and Atmospheric Administration Aquaculture Program
http://aquaculture.noaa.gov

Florida Division of Aquaculture
www.floridaaquaculture.com

West Virginia University Extension Service Aquaculture
www.wvu.edu/~agexten/aquaculture

Aquaculture Budgets

Aquaculture Enterprise Budget Spreadsheets. Auburn University Marine Extension & Research Center.
www.aces.edu/dept/fisheries/aquaculture/budgets.php

The Extension specialists at Auburn have developed four Excel spreadsheets and are available as a free download from their website. The budgets include

- *Channel catfish pond farm*
- *Hybrid striped bass pond farm*
- *Rainbow trout raceway farm*
- *Water recirculating fish farm*

Aquaculture Budgets, Universities of Illinois and Indiana Sea Grant
www.agecon.purdue.edu/AQUABUSINESS/budgets.html

Aquaculture Publications

Southern Regional Aquaculture Center Publications.
http://srac.tamu.edu

The Southern Regional Aquaculture Center has an online library of very helpful publications on all aspects of aquaculture, from pond and cage construction to species and disease to marketing and promotion.

Northeastern Regional Aquaculture Center (NRAC)
www.nrac.umd.edu

NRAC is a principal public forum for the advancement and dissemination of science and technology needed by Northeastern aquacultural producers and support industries. Publications are located here www.nrac.umd.edu/publications/factSheets.cfm.

ALabama Education in aquatic sciences, Aquaculture, Recreational fisheries and Natural resource conservation (ALEARN)
www.aces.edu/dept/fisheries

Mississippi State University Aquaculture Publications
http://msucares.com/aquaculture

University of Arkansas Aquaculture/Fisheries Center Publications
www.uaex.edu/aqfi/extension/publications/factsheet

National Ag Law Center – Aquaculture
http://nationalaglawcenter.org/readingrooms/aquaculture

Water Engineering

Bocek, Alex. Water Harvesting and Aquaculture for Rural Development. Auburn University: International Center for Aquaculture and Aquatic Environments.
www.ag.auburn.edu/fish/international//waterharvestingpubs.php

Alberta Agriculture. 2002. Spring Development, Agdex 716 (A15). Technical Services Division. *http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex4595*

USDA. 1984. National Engineering Handbook - Part 650, Engineering Field Handbook, Chapter 12, Springs

and Wells. *http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17550.wba*

Aquaculture and Aquaponic Farms

Sweet Water Organics.
http://sweetwater-organic.com/blog
Sweet Water Organics will be the first major commercial upgrading of MacArthur genius Will Allen's aquaculture methodologies, i.e. a three-tiered, aquaponic, bio-intensive fish-vegetable garden. Sweet Water will be the anchor project in the transformation of a massive industrial building in an "industrial slum" into a showcase of the potential of living technologies and high-value added urban agriculture. Sweet Water's sustainable aquaculture system harvests urban waste streams, e.g. wood chips, cardboard, veggie residues, coffee grounds, and brewers mash, along vermiculture lines, yielding the richest possible soil. This soil in hundreds of potted plants on the simulated wetland tiers is key to the transformation of fish wastes into natural nitrate for plant growth and water filtration.

Eli Rogosa. Organic Aquaponics.
www.growseed.org/growingpower.html
Photographic tour of a Growing Power aquaponic system.

Bioshelters.
www.bioshelters.com
Bioshelters is a recirculating aquaponics facility located in Amherst, Massachusetts. Our entire system is contained in a large solar-heated greenhouse called a Bioshelter. Solar structures create the least expensive and best natural environment for plants, animals and people. To learn more about our greenhouse system please follow the link below. Because the fish, plant and human systems are linked, no pesticides can be used on our produce.

Backyard Aquafarms
http://backyardaquafarms.com

Community Supported Fisheries

Much like community supported agriculture, community supported fisheries are cooperatives of family fishermen who market their catch directly to customers usually through a subscription mechanism, whereby customers receive a certain amount of product per week (a share) for a yearly share price. Four innovative projects are listed below:

Port Clyde Fresh Catch CSF
www.portclydefreshcatch.com

DukeFish, a Durham-based community-supported fishery. Duke University's student chapter of the American Fishery Society
www.walking-fish.org

Carteret Catch, Project Green Leaf, Carteret County, NC
http://greenleaf.uncg.edu/carteretcatch/Index3.html
Information for fishermen and consumers. *http://greenleaf.uncg.edu/carteretcatch/CommSuppFish1.html*

Catch a Piece of Maine, Lobster Community Supported Fishery
www.catchapieceofmaine.com

Aquacultural and Maricultural Business Development

Aquacopia
www.aquacopia.com

Aquaculture Investment: Lowering the Risks, Western Regional Aquaculture Center
http://aqua.ucdavis.edu/DatabaseRoot/pdf/WRAC-103.PDF

Regional Aquaculture Centers sponsored by the Extension Service

Northeastern Regional Aquaculture Center (NRAC)
www.nrac.umd.edu

North Central Regional Aquaculture Center (NCRAC)
www.ncrac.org

Southern Regional Aquaculture Center (SRAC)
www.msstate.edu/dept/srac

Western Regional Aquaculture Center (WRAC)
www.fish.washington.edu/wrac

Center for Tropical and Subtropical Aquaculture
www.ctsa.org

Aquaculture Network Information Center
www.aquanic.org

Integrated Bio-Systems on the Web

Integrated Biosystems, Paul Harris, The University of Adelaide
www.adelaide.edu.au/biogas/website/integratedbiosys.pdf

World Fish Center
www.worldfishcenter.org/wfcms/HQ/Default.aspx

Ecological Engineering (Elsevier journal)
www.sciencedirect.com/science/journal/09258574
Ecological engineering has been defined as the design of ecosystems for the mutual benefit of humans and nature.

Specific topics covered in the journal include: ecotechnology; synthetic ecology; bioengineering; sustainable agroecology; habitat reconstruction; restoration ecology; ecosystem conservation; ecosystem rehabilitation; stream and river restoration; wetland restoration and construction; reclamation ecology; non-renewable resource conservation.

Wastewater-fed Aquaculture in Temperate Climates - Nutrient recycling with Daphnia and Fish (PDF/97K), 4th International Conference on Ecological Engineering for Wastewater Treatment, June 1999, Aas, Norway
www.hortikultur.ch/pub/files/15.pdf

Appendix I: Bibliography on Aquaponics

The following bibliography contains selected literature citations on aquaponics and integrated hydroponics-aquaculture published in trade magazines and scientific journals. Collectively, these articles provide an instant library on aquaponics. They are provided here as an important time saver to those seeking technical and popular information on this topic. University libraries carry scientific journals (e.g., Aquaculture International, Aquacultural Engineering) and trade magazines (Aquaculture, Greenhouse Management and Production), and they offer on-site photocopying services to library visitors. Inter-Library Loan is a service available through most local libraries, and can provide photocopies of articles for a small fee.

Please note The Growing Edge, Aquaponics Journal, and Practical Hydroponics & Greenhouses are the most relevant trade magazines for aquaponics, recirculating aquaculture, hydroponics, and related topics, including farmer profiles. However, they are relatively new and less widely distributed in university libraries. For a complete list of articles and back issues available through these trade magazines, see the publisher's websites:

The Growing Edge
www.growingedge.com/magazine/compindex.html

Aquaponics Journal
www.aquaponicsjournal.com/BackIssues.htm

Practical Hydroponics & Greenhouses
www.hydroponics.com.au

North Carolina State University

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Appendix II: Dissertations

Dissertations (PhD) and theses (Masters degree) on integrated aquaculture-hydroponic systems can provide critical access to research data and literature reviews. For example, the Speraneos in Missouri and Gordon Watkins in Arkansas used Mark McMurtry's dissertation from North Carolina State University as a guide in the design of their systems. The UMI ProQuest Digital Dissertations database (see below) provides public Web access to titles and abstracts, via keyword and author search. Print copies are available for sale. Land-grant university libraries – through fee-based subscription– provide full-text access to recent documents via the ProQuest Dissertations and Theses database. Selected titles on aquaponic systems are listed below. The thesis by Carla MacQuarrie contains a detailed description of an aquaponics facility, including parts and pumping equipment, for example. There are numerous other titles in hydroponics, aquaculture, recirculating aquaculture, tilapia, tank culture, and wastewater effluent for those who wish to explore further. Contact:

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Notes

Notes

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