Chapter 6
Aquaponics: A Commercial Niche for Sustainable Modern Aquaculture

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Abstract Aquaponics—the combination of recirculating aquaculture system (RAS) and horticulture—has received increasing interest globally as a way to introduce a more circular economy within aqua- and horticulture and hence secure a more resource productive growth with reduced pollution to the environment. However, aquaponics production have mainly been based on small scale low-tech and labor intensive systems built by hobbyist and research units, but during the last decade larger and more complex systems based on modern RAS and hydroponics techniques have been designed and constructed. This new development has mainly been driven forward by researchers and risk taking entrepreneurs worldwide, but commercial oriented production units are emerging with participation of industry partners from both the aqua- and horticultural sectors. The biological dependence is one of the major constraints for going large-scale and commercial. De-coupled aquaponics holds the prospect of reducing or even eliminating the biological dependence, but in the same time acquire the symbiotic benefits of combining fish and plants in a circular production system.

Keywords Aquaponics · Sustainable aquaculture · Hydroponics
Organic aquaculture · Decoupled aquaponics

6.1 Introduction

The word *aquaponics* originate from the Latin and the Greek words for water (aqua and hydro), applied respectively to the words *aquaculture* (fish farming), and *hydroponics* for growing plants in water without soil used today in modern

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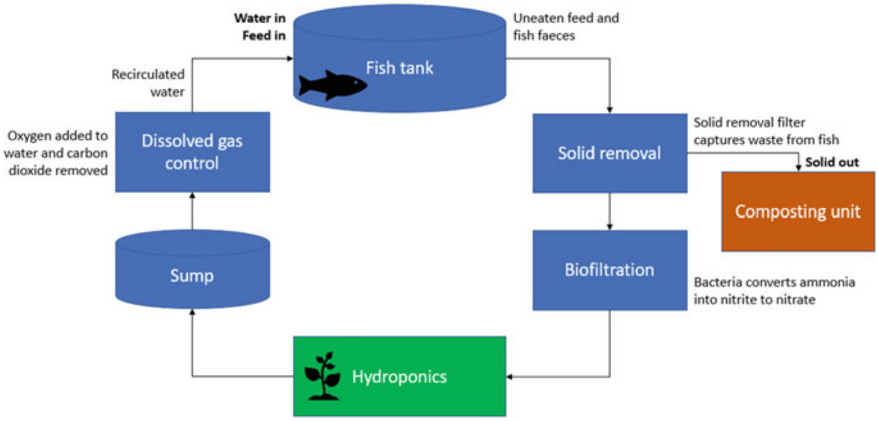

Fig. 6.1 The concept of aquaponics (Modified after Thorarinsdottir 2015)

horticulture production. Aquaponics itself represents a fusion of the two production systems combined into a singular food system producing terrestrial plants and aquatic organisms. In an aquaponics system water is kept in circulation as illustrated in Fig. 6.1.

Wastewater from the fish tanks is led to a solid removal system and further to a bio-filter, where bacteria converts ammonia to nitrate. These dissolved nutrients are circulated onwards to the horticultural part of the system where plants take up the nutrients, and hence cleanse the water before being returned to the fish. The solid removal filter captures uneaten fish and fish faeces. The solids contain a large part of the nutrients, but need to be dissolved in a composting unit or by aeration to be usable in the hydroponicsp or alternatively turned into fertilizer to be used in soil systems.

Likewise, the fish produce CO_2 valuable to the plants, and the fish tanks can obtain heat and act as a temperature buffer during night in the greenhouse saving energy costs (Körner et al. 2014). Besides these symbiotic effects, aquaponics offers to be a resource efficient closed loop food production system mimicking nature itself. Aquaponics relates to the 'cradle-to-cradle' design described in several articles (McDonough and Braungart 2002; Braungart et al. 2007; Kumar and Putnam 2008) presenting eco-effectiveness even moving beyond zero emissions and provides public goods and services when taking social, economic and environmental benefits into account.

The principles behind aquaponics—combining an aquatic feed supply to a terrestrial plant production—is not new in itself, but has been used effectively back in history by the Aztec Indians in the former valley of Mexico back in the fourteenth-century, as well as by Chinese farmers in the Pearl River Delta of South China around the same period.

6.2 The History of Aquaponics

6.2.1 The Chinampas of the Aztec

When first approaching the basin of Mexico and the Aztec capital of Tenochtitlan in 1519, Hernando Cortes and his men were amazed. They saw an astounding white city, anchored to the shores by three long causeways, floated on a glittering lake. This lake-borne city, Tenochtitlan, was the world largest at the time estimated to occupy around 3–350,000 inhabitants.

Cortes and his men also found the practice of a unique agricultural system. This method of farming, which still persists in limited intensity today, consists of land development through the construction of what is called *chinampas* in marshy areas and shallow lakes. The chinampa system is a network of raised fields on manmade low islands in the lakes and marshes. The method consists of piling lakebed clays and mud, aquatic plants and dry land crop silage, as well as silted muck and manures in precise layers between reed fences secured in the bottom of the lakes or marshlands. Once the ground was raised to its proper height, fast growing willow trees were planted on the edges, which prevented the erosion of the raised ground. These willow trees also provided shade and firewood, and restrained the crop-damaging pests (Aghajanian 2007).

The chinampas were between 5 and 10 m wide, up to 90 m long and around ½ m above the water level. In between the chinampa beds were canals of 1–1.3 m giving, not only life to an abundant wildlife and fish, but also providing an efficient transport system for canoes supplying labor and food.

This astonishing eco-effectiveness of combining an aquatic feed supply to a terrestrial plant production gave the chinampa agriculture a unique role in sustaining the population pressure in the Valley of Mexico during the Aztec period.

6.2.2 The Chinese Dike-Pond System

In the Pearl Delta of south China, a land-water farming system, also known as the dike-pond system, evolved during the mid-fourteenth century. The dike-pond system evolved as an important flood control measure in the delta. Water control measures were started in the lower-lying areas, where small watercourses were dammed and created to make fishponds. Ponds were dug to drain the marshes and natural ponds in order to create agricultural land, and the excavated was used to construct dykes. The fishponds were stocked with carp fry naturally occurring in the delta (Ruddle and Zhong 1988).

The first commercial crops to be grown on the dikes were Litchi and Longan followed later on by mulberry. The mulberry leaves provided an important feed for the cash crop: silkworms. Silkworm excrement was thrown into the pond, and accidentally gave way to the discovery that it could feed the fish. The mud at the bottom of the ponds was used to fertilize trees, when there was a shortage of animal manure.

Since then, several types of dike pond systems have been developed. The above example is called *the mulberry-dike-pond system*, others are called *the fruit-dike-pond system* and so on.

The pond is the heart of dike pond system. Most ponds are rectangular, 0.4–0.6 ha and 2–3 m deep. The dikes are usually 6–10 m wide and 0.5–1.0 m above the pond surface. Different species live in different water depths and have different feeding needs, which ensure full utilization of the water and pond ecology.

Pond mud contains many nutrients and can be used as fertilizer for crops on the dikes. The pond is drained two or three times a year, and mud at the bottom is retrieved up on the dikes, which then are repaired while the depth of the pond is restored.

Livestock are also part of a dike-pond system. Both small and large animals like pigs or ducks can be bred on the dykes and their manure can be thrown into the pond and thus promote growth of algae which the carp can feed on. Through photosynthesis the algae in the pond give off oxygen and produce glucose, added nutrients that benefit both fish and aquatic plants.

Fish fodder may also be cultivated on the dykes, for example Miscanthus, or fodder for animals that live on the dikes.

The idea of the dike pond system is that it is a circuit where the components are complementary, while no waste is produced, because everything is recycled and transformed. The energy input from outside is minimal and consists mainly of labor and solar energy. Solar energy has the advantage that it is renewable and free (Stenkjaer 2011).

Like in aquaponics the dike-pond system is an interrelated ecosystem that brings into full play the productive potential of humans and their environment and promotes the development of different branches of both aqua-, agri- and horticulture.

6.3 The Modern Paths of Aquaponics

In the late 1960s and beginning of the seventies ‘Limits to growth’ was a global discussion theme due to emerging and simultaneous crisis world-wide in food production, population growth, urban sprawl, pollution, energy and raw material supplies etc. Many experiments to find new and more sustainable and self-sufficient low-input solutions in production as well as consumption took place in this period, both from grass root movements as well as industry and university pioneers.

Aquaponics itself emerged from the aquaculture industry as fish farmers were exploring methods of raising fish while trying to decrease their dependence on the land, water and other resources. Traditionally, fish were raised in large ponds, or in netted pens off coastlines, but much progress has been made since then in Recirculating Aquaculture Systems (RAS) (Bradley 2014; Dalsgaard et al. 2013).

The advantage of RAS is that fish can be stocked much more densely, thus using only a fraction of the water and space to grow the same amount of fish as in pond or netting based systems. A major disadvantage with RAS is the large amount of concentrated waste water that quickly accumulates and the antibiotics needed to keep the fish healthy.

The term aquaponics is often attributed to the various works of the New Alchemy Institute and the works of Dr. Mark McMurtry at the North Carolina State University. In 1969, John and Nancy Todd and William McLarney founded the New Alchemy Institute.[1] The culmination of their efforts was the construction of a prototype Bioshelter, the “Ark”. The Ark was a solar-powered, self-sufficient, bio-shelter designed to accommodate the year-round needs of a family of four using holistic methods to provide fish, vegetables and shelter (Bradley 2014).

At the same time in the 1970s, research on using plants as a natural filter within fish farm systems began, most notably by Dr. James Rakocy at the University of the Virgin Islands (UVI) (Rakocy et al. 2007). In the late nineties they developed the still much applied *UVI- system*, which is described further below.

During the mid-1980s, Mark McMurtry and Professor Doug Sanders at North Carolina State University developed an aqua-vegeculture system based on Tilapia fish tanks sunken 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 plants and sand beds served as a bio-filter. After draining from the beds, the water recirculated back into the fish tanks. The only fertility input to the system was fish feed (32% protein) (Diver 2000).

The first larger scale commercial aquaponics facility, Bioshelters in Amherst, MA, was established in the mid-1980s. Then in the early 1990s, Missouri farmers Tom and Paula Speraneo inspired by Mark McMurtry, introduced their *Bioponics* concept. They grew herbs and vegetables in ‘ebb and flow gravel grow beds’ irrigated by the nutrient rich water from a 2200 L tank in which they raised Tilapia (Bradley 2014).

While gravel grow beds had been used for decades by hydroponics growers, the Speraneos were the first to make effective use of them in Aquaponics—remembering prior to this, sand was the main growing medium used in emerging aquaponics systems. Their system was practical and has been widely duplicated, and many present day DIY (Do-It-Yourself) aquaponics owes its origin to the Speraneos. They wrote a ‘how-to manual’ that became a springboard for many home based or school educational systems built throughout the world.

However, the Speraneos system of substituting sand for gravel in ebb and flow beds only works well if the system is fitted with dedicated mechanical and biological filtration. If not, the system will bear the risk of an eventual ‘collapse’, due

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[1] The New Alchemy Institute evolved in 1991 to the Green Center Inc., which is a non-profit educational institute, and the custodian and distributor of publications of New Alchemy’s ecological research conducted from 1971 to 1991. www.thegreencenter.net.

to the accumulation of organic matter using up oxygen in the system needed for the fish and furthermore reduced aeration of media bacteria and the plant root zone.

By 1997, Rakocy and his colleagues developed the use of deep-water culture hydroponic grow beds in a large-scale aquaponics system.

The UVI system has been the inspiring layout of several minor commercial systems in the US, Canada and Europe, and also applied by university researchers due to its proven reliability over several decades. The University of Virgin Islands has also been active in aquaponics research for more than thirty years and has a globally recognized aquaponics education program. The system developed at UVI is a raft hydroponic system and the aquaculture part focus is on Tilapia production (Rakocy et al. 1997, 2007).

A continuous operation was run at UVI for 2.5 years (1995–1997) with red Tilapia and leaf lettuce production (Rakocy et al. 1997, 2007). The system (Fig. 6.2) was based on four fish rearing tanks, each with 7.8 m^3 water volume (total 31.2 m^3), two cylindro-conical clarifiers (3.8 m^3 each), four rectangular filter tanks (0.7 m^3 each) containing orchard netting, six hydroponic tanks (11.5 m^3 each) and a sump (0.6 m^3). The hydroponic tanks were 30.5 m long by 1.2 m wide by 0.4 m deep and had a combined surface area of 214 m^2. Thus, the surface area to fish tank volume was 6.85 m^2/m^3. The water volume was 110 m^3. A 0.5 hp in-line pump moved water at an average rate of 378 L/min from the sump to the fish rearing tanks (mean retention time of water 1.5 h), from which effluent flowed with gravity through the system. Air diffusers were used both in fish and hydroponic tanks through air stones supplied by air from a 1.5 hp blower for fish and 1 hp blower for plants (Rakocy et al. 2007).

The daily fish feed input averaged 12 kg equivalent to 56 g/m^2 plant growing area. The waste water from the fish was only supplemented with potassium (K), calcium (Ca) and iron (Fe) to provide sufficient amounts of the essential nutrients for normal plant growth. These additions were equivalent to 16.1 g KOH, 3.3 g CaO, 13.7 g $Ca(OH)^2$ (more economical than CaO) and 6.0 g iron chelate (10%) per kg of fish feed. The annual production of tilapia was 3096 kg and the lettuce production was projected to 1694 cases (appr. 11 tons), or appr. 3.5 tons lettuce per ton Tilapia produced and the land use was 0.04 ha, which can be considered being a small-scale system (Rakocy et al. 1997).

6.3.1 Current Status

At present, the interest in aquaponics is increasing globally (Goddek et al. 2015). In Europe several strong collaboration networks have been established e.g. the COST FA1305 Aquaponics hub running from 2014–18 with 26 participating countries. Several ongoing projects in semi-commercial scale aquaponics and research units are delivering results to support upscaling of aquaponics systems capable of contributing to a new integrated and sustainable food production methodology (Thorarinsdottir 2015).

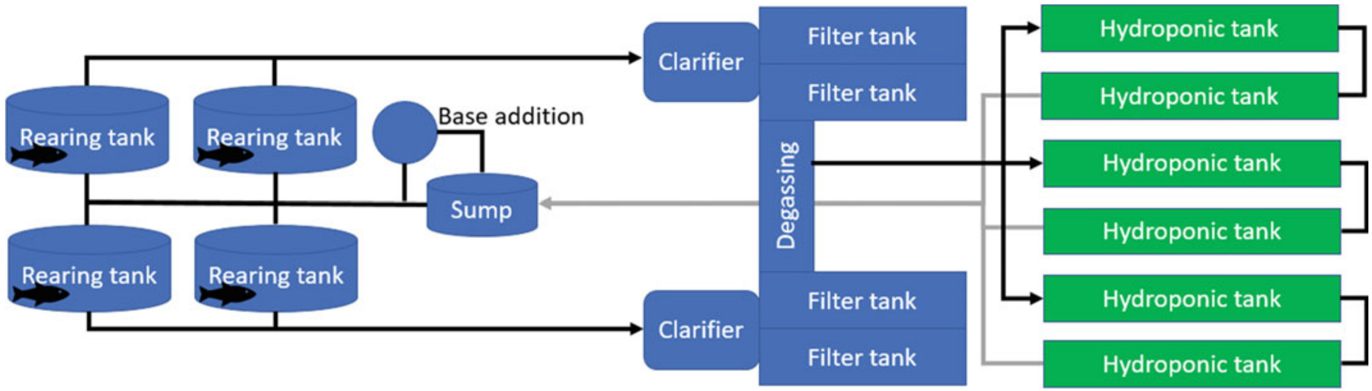

Fig. 6.2 UVI aquaponics system diagram (Modified after Rakocy et al. 1997)

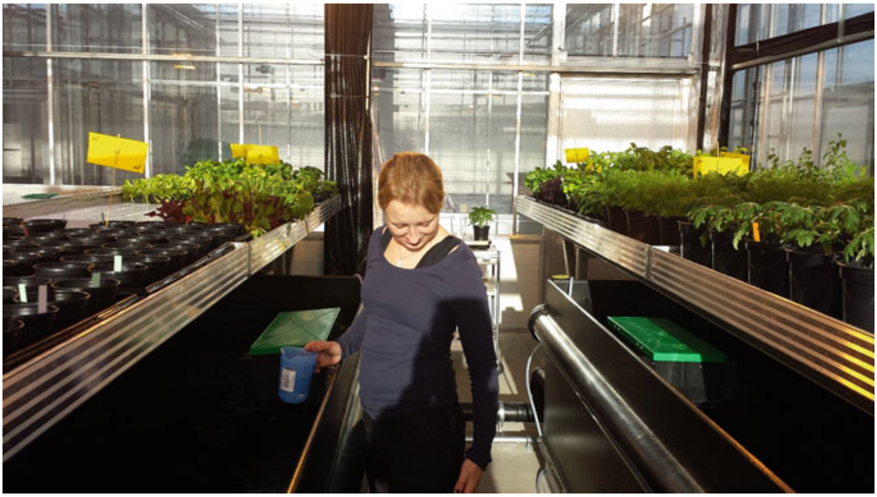

Fig. 6.3 IGFF aquaponics pilot unit, Denmark (Photo, Paul Rye Kledal/IGFF)

The renewed growing interest in aquaponics can also be seen by the incorporation of technological improvements and productivity gains made within modern RAS driven by high capital costs and increasing technical complexity putting large demands on RAS system management and productivity (Dalsgaard et al. 2013) and hydroponics over the last two decades (Stickney and Granvil 2012; Resh 2013). In RAS this goes in regards to drum-filters, bio-filters, low-energy pumps, low-cost measurement equipment, data logging, broad range of fish feed etc. In horticulture recent developments have resulted in improved fertilizer, grow media, hydroponic pipe optimization, accessible bio-pest management, IT climate control etc.

In general the *UVI-system* is still the foundation for the renewed interest in aquaponics, which is understandable. It is reliable and have been tested over two decades, but new innovations are made on other areas.

IGFF[2] in Denmark has developed a decoupled aquaponics unit of 70 m^2 (Fig. 6.3). The IGFF unit consists of six plant tables arranged in three pairs of 1.45 × 7.50 m on the top of three rectangular fish tanks (3 × 1 × 0.8 m) with a usable volume of 2 m^3 each. Moveable plant tables produce horticulture products in pots with compost to open up for the prospect of getting an organic certification for the aquaponics system. Soil is used because to obtain an organic certification requires plants to be grown in various specified types of soil. Silver Tilapia, Red Tilapia and Pike perch have been tested as fish species and various plants such as lettuce, basil, tomatoes and peppers have been grown successfully on the plant

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[2] www.igff.dk.

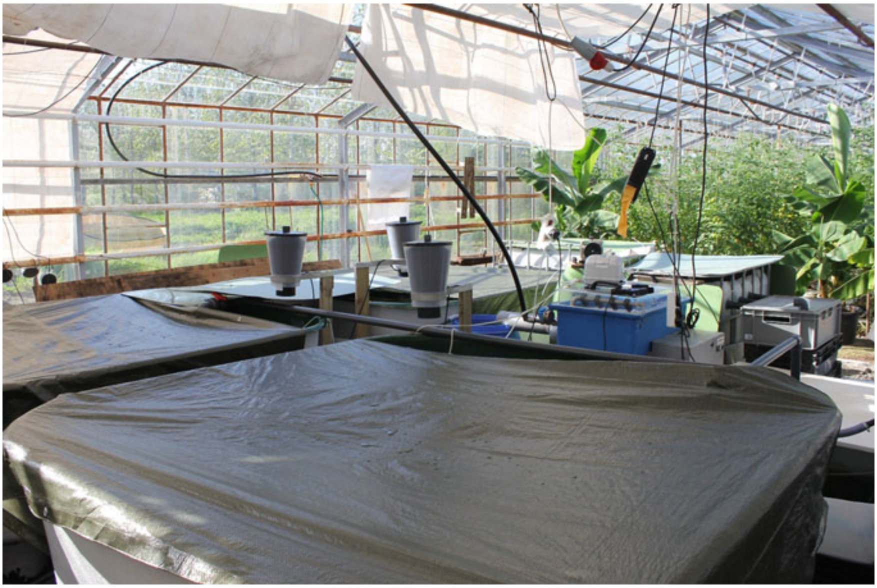

Fig. 6.4 The semi-commercial pilot unit of Svinna-verkfraedi Ltd. in Iceland (Photo, Ragnheidur Thorarinsdottir)

tables. Water to the plants is supplied by the ‘flood and ebb’ principle, and the plant tables are placed above the tanks to provide shade as well as optimize ‘economies of space’ in the greenhouse.

In Iceland Svinna-verkfraedi Ltd. (www.svinna.is) has constructed a semi-commercial pilot unit in a greenhouse farm in South Iceland, see Fig. 6.4. The design is based on decoupling the RAS and the plant system to obtain optimum growing conditions for both the aquaculture and plant production parts. The RAS unit consists of three 4 m^3 fish tanks, a drum filter, a bio-filter and a sump tank. A sedimentation tank and second sump tank is used for collecting water from the drum filter for plant irrigation and the water is not recirculated to the RAS again. During the first development phase a relatively small 50 m^2 hydroponics unit has been included in the circulation to stabilize the dissolved nitrogen level in the RAS.

NER-Breen in Hondarribia, Basque Country is developing a 6000 m^2 commercial aquaponics based on the development by the innovation company Breen.[3] The farm is being constructed and is designed partly as a decoupled farm. However, parts of the plants are used to control the dissolved nutrient level in the RAS. The farm is under construction, see Fig. 6.5 and the plan is to start production in 2016.

Other interesting steps are planned for decoupling the aquaculture and the plant production units as for example suggested by Aqua4C fish farm in Kruishoutem Belgium. The plan is to use residual energy from an adjacent tomato farm for the

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[3] www.breen.es.

Fig. 6.5 The Breen aquaponics plant of 6000 m^2 planning to be starting production in 2016 (Photo, Ragnheidur Thorarinsdottir)

fish farm and to link the water systems together as well so the rainwater collected in the greenhouses could be used for the aquaculture before it is used for tomatoes (Hortidaily.com 2015).

Another interesting development is the new urban aquaponics farm in St. Paul Minnesota designed and constructed by the RAS company Pentair plc in collaboration with Urban Organics LCC (Pump Industry Analyst 2015). The companies are setting up an 87,000 ft^2 indoor aquaponics facility with the potential to produce 275,000 lbs. of fresh salmonid and 400,000 lbs. of leafy greens.

6.4 Aquaponics and Economic Organization Typology

Overall the type of aquaponics production systems prevailing today can roughly be divided according to its choice of economic organization. In Fig. 6.6, the aquaponics systems are divided whether they are operating in the *non-market area*, pure *market oriented* or a *hybrid* (a mix of the two others). The type of economic organization will to a large extend also determine the choice and level of technology, capital and labor input.

The *non-market* oriented aquaponics system will typically have a low input of technology and capital, but require a higher level of labor on surveillance and maintenance in relation to production output. Homemade or various types of DIY systems as well as small educational kits will normally belong to this group. Likewise, research units on universities will also belong to this category.

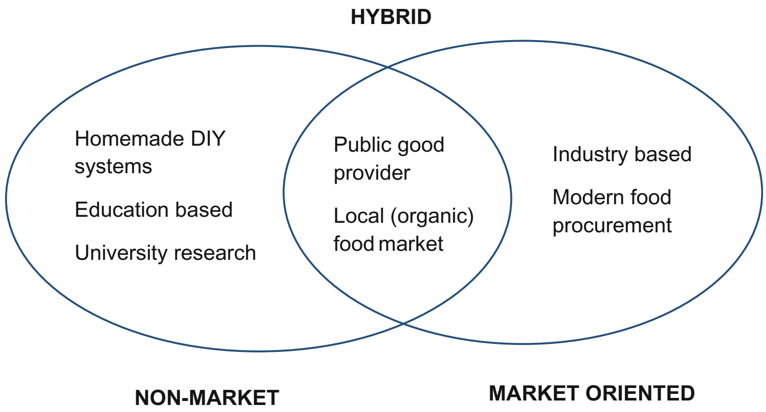

Fig. 6.6 Type of aquaponics system according to its economic organization

The pure *market oriented* aquaponics system will normally require a high input of technology and capital in relation to production output, but labor cost in comparison will be relatively low. Markets will be modern food procurement systems targeting grocers, restaurants and supermarkets.

Market oriented aquaponics systems will still be very small in terms of production output, and in comparison with present day specialized RAS or horticultural systems. However, with the societal demand for universities to take more part in 'blue-green' bio-circular innovations, and the advent of commercial oriented aquaponics systems, we foresee both a growing and closer cooperation between research entities and the infant aquaponics industry. This type of research would be welcome, because a major part of the aquaponics research done at universities are limited in its value for commercial oriented entrepreneurs targeting larger scale risk markets. A more 'dynamic' and 'hands-on' research approach in close cooperation with producers focusing on a variety of fish:plant relations, and their potential production flexibility to cope with fluctuating markets, would be an important research step to support a growth in the market oriented aquaponics industry.

Hybrids will often be an economic organization chosen when a certain scale of food production is being provided to a neighborhood or a community—for example an urban farm. The food system is in the same time also providing various types of social and/or environmental goods to the community in terms of job creation, social inclusion and environmental education. Typically, a public or a non-profit entity will support such an economic organization in return, hence making it a hybrid between a pure market and non-market economic organization.

However, despite the many technological improvements in both RAS and hydroponics being incorporated into aquaponics, one of the major constraints for aquaponics production to move into a larger market-oriented scale, is the higher economic risk associated compared to a specialized RAS or horticulture production. The reason for this is firstly the biological dependency built in the system.

Secondly, the knowledge complexity rises exponential since a producer needs to be specialized, in not only fish and plants, but also understand their interaction with the life cycle of bacteria in bio-filters.

The biological dependency as a risk factor is constantly present with most aquaponics systems operating today. If the plant production declines due to diseases or a pest attack, its ability to function as an efficient cleansing bio-filter is reduced dramatically, and will affect the fish production negatively. Similarly, if the fish production fails because of disease or problems with the bacteria in the mechanical bio-filter, the quality and output of the plant production will be reduced significantly due to fertilizer deficiencies. Therefore, the larger a production, the more technology and capital inputs are required, and the larger economic risk will be the consequence if a system failure occurs.

For aquaponics production to move into larger scale commercial markets the circular dependency in the system has to be decoupled in such a way, that both the biological and economical risks are minimized to a degree where the symbiotic benefits are much greater.

6.5 Future Developments and Research Foci

6.5.1 Decoupled Aquaponics

In today's aquaponics systems the water circulates from fish to plants and via bio-filtering back to the fish as originally shown in Fig. 6.1. The water quality is specifically managed to fit the requirements of the fish species being cultured, and suitable plants are normally chosen to fit the fish environment. It is not always guaranteed that the fish preferences are completely aligned with the optimum requirements of the plants. This calls for compromising of the plant's needs, and as a result they may not achieve their full growth capacity, hence reducing a full optimization of the production and its investments. Likewise, the biological dependency built in aquaponics is a major risk factor hindering large-scale market orientation.

Focus is therefore oriented towards dividing the water flow into two independent subsystems that can occasionally communicate whenever plants need a boost in nutrients or the fish require reclaimed water from plants to dilute the wastes accumulating in the fish sub-unit. This solution, which is referred to as a "decoupled" system (Fig. 6.7) would not only better secure optimal environmental conditions for both the plant and fish production units, but also eliminate the biological dependency in aquaponics hence minimize the economic risk substantially.

The processing of sludge from the aquaponics system has recently received increased interest. Not only is prompt removal from the system helping to maintain healthier and more resilient systems for fish, but also it improves the productivity by better capitalizing of by-products through their reintroduction into the production

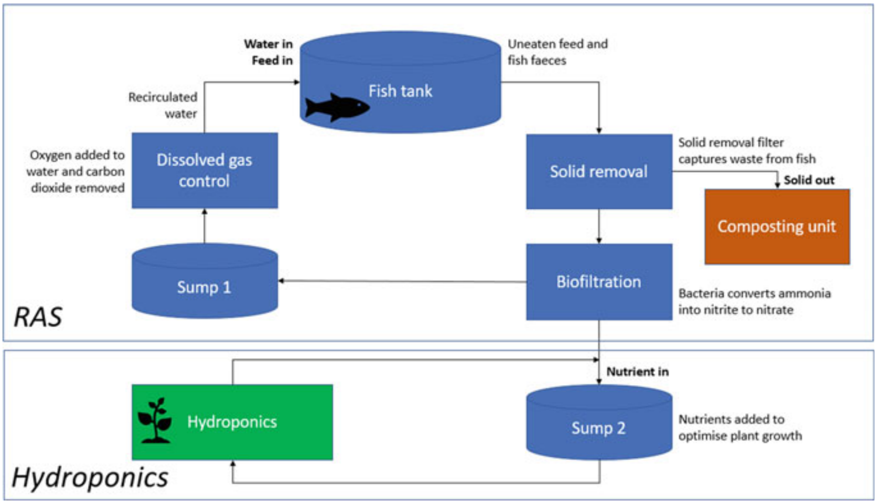

Fig. 6.7 The principles of a decoupled aquaponics system (Thorarinsdottir 2015)

system. Several ideas are being tested aiming for zero waste solutions, using the sludge as e.g. feed for crayfish, farming of worms and/or black soldier flies, or making fertilizer through aerobic or anaerobic digestion.

6.5.2 *Aquaponics and Urban Farming*

It is important that cities reclaim foods that were once characteristic of their community because these foods instill a sense of place, strengthening the communal bonds between the residents. In addition, these foods can generate jobs and revenue for the community (Yang 2012).

Likewise, there has been a fast growing interest in urban farming in both developing as well as developed countries since the world food crisis of 2007 (FAO 2010; de Zeeuw et al. 2011). The vulnerability and dependency of food for the world urban community, already reaching 60%, and a reliance based on a very concentrated food system, made it clear for a growing number of city councils as well as a varied range of non-governmental organizations (NGO's), that change in the food system from 'farm to fork' had to change (http://www.urbanagricultureeurope.la.rwth-aachen.de/)

Aquaponics is becoming very popular among these various urban farm initiatives around the world. This is especially true for community building in areas of unemployment, food security issues and social problems related to inclusiveness; other factors include educational awareness through giving a simple overview of the complexity of nature and recycling. Hence, aquaponics production will typically be organized as a *non-market* or *hybrid* economic organization.

Aquaponics related to urban farming are still based on small production units (Sommerville et al. 2014) due to first and foremost the requirement of a large plant area when more simple technology systems are in use. The potential introduction of more modern bio-filters or decoupled production systems opens up for larger scale industrial based aquaponics. However, the closer you move an urban farm from the peri-urban zone to the inner city center the more space becomes a physical issue as well as a constraint for establishing a financially viable food business. The latter is also true with regards to space becoming a scarce resource in competition with other economic sectors the closer one gets to the city core. Therefore the ‘empty’ or ‘free’ roof spaces of a city has gained increased focus for potential areas of food production, but requires often an expensive change in the present building construction to carry an urban (aquaponics) roof-top farm.

6.5.3 Aquaponics and Organic Certification

Organic certification appears to be a natural step for an aquaponics producer since the whole system is based on a holistic thinking in terms of recycling, lowering the resource intake and securing zero pollution. However, the present organic regulatory regime does *not* have any standards or regulations for certifying organic aquaponics. The RAS technology is even *forbidden* under the present organic regulation, which seems to be more of an economic protection to the extensive open pond systems prevalent in organic fish production rather than having anything to do with fish welfare or the aquatic environment.

It is only possible to have an aquaponics production system completely certified organic if a *non-holistic* approach is made, meaning a certification towards the organic fish- and horticulture regulation is made separately. Firstly, the plants must be grown in soil. Secondly, the fish produced must be fed with organic certified fish feed, and thirdly the fish can only be produced in a RAS system if the fish are sold as fingerlings for further growth in open-air pond systems certified organic. However, if aquaponic produce gains markets and moves into larger scale production systems, it seems indisputably; that the organic farm movement will need to revise its present regulation focusing on specific technologies rather than having a more principle based approach allowing for new resource productive and holistic production systems such as aquaponics.

The present regulatory framework for organic fish and horticultural production in the EU is regulated by the Council Regulation (EC) No. 834/2007 whereas more detailed rules are regulated by the Commission Regulations (EC) No. 889/2008, and (EC) no. 710/2009.

6.5.3.1 Horticultural Produce

For organic horticultural production current Commission Regulation (2008), implementing Council Regulation (2007), contains only one element specific to greenhouse production:

art. 4 which bans hydroponic production and allows organic cultivation only in soil.

Since most aquaponics production systems are based on a soilless hydroponic technology, the plants produced under such a system cannot be certified as organic. This leaves with the only option to adopt culturing practices applying soil through decoupled aquaponics/RAS wastewater.

6.5.3.2 Aquacultural Produce

For organic aquaculture the production is regulated by Commission Regulations of (2008) and (2009). In parr. 11. Commission Regulation (2009) recirculating systems are clearly prohibited in organic aquaculture, except for the specific production in hatcheries and nurseries making and selling fingerlings for further growth in open-air pond systems.

Parr. 11.
Recent technical development has led to increasing use of closed recirculation systems for aquaculture production, such systems depend on external input and high energy but permit reduction of waste discharges and prevention of escapes. Due to the principle that organic production should be as close as possible to Nature, the use of such systems should not be allowed for organic production until further knowledge is available. Exceptional use should be possible only for the specific production situation of hatcheries and nurseries.

Since recirculating technology is at the core of the aquaponics production system it is at present not possible to get a complete organic certification on an aquaponics system, if all of the finishing produce is to be sold for the consumer market.

6.5.3.3 Future of Organic Aquaponics

The crux for aquaponics producers to get an organic certification in the future lies in the acceptance of the recirculating technology within organic regulation itself, as well as presenting aquaponics as an ideal closed loop, non-pollute and holistic food production system.

Short-term strategies in this regard could be to:

(1) View aquaponics as a farm based on a necessary harmony and biomass ratio between husbandry (the fish), and a soil-based horticultural production as the field turning waste into valuable resources and providing a food production with no discharges to the environment.
(2) Work towards a specific regulation on aquaponics. This would imply allowing recirculating technology such as RAS, and an intensification of the fish production. Fish intensification is already regulated by the organic regulation, but is based on an extensive open-air pond system and the question of discharge of fish manure to the aquatic environment.

Paragraph 24 in the Commission Regulation (2009) opens up for an interpretation that such steps for a revision in the organic rules could be allowed. Especially the last four lines in Parr. 24 implies that national initiatives could be taken with the aim of improving the common EU regulation on organic aquaculture. This would require a more dedicated willingness in the organic movement to commence a process in this direction, but unfortunately this dedication and willingness does not seem to exist at present.

Parr. 24
Organic aquaculture is a relatively new field of organic production compared to organic agriculture, where long experience exists at the farm level. Given consumers' growing interest in organic aquaculture products further growth in the conversion of aquaculture units to organic production is likely. This will soon lead to increased experience and technical knowledge. Moreover, planned research is expected to result in new knowledge in particular on containment systems, the need of non- organic feed ingredients, or stocking densities for certain species. New knowledge and technical development, which would lead to an improvement in organic aquaculture, should be reflected in the production rules. Therefore provision should be made to review the present legislation with a view to modifying it where appropriate.

6.6 Perspectives

Aquaponics is rapidly moving into new development phases and presenting industrial and commercial potential. The UVI-production system is still prevalent, but the technological innovations made in both the industrial aqua- and horticulture sectors within the last two decades has led to the emergence of new approaches.

De-coupled aquaponics holds the prospect of reducing or even eliminating the biological dependence, but at the same time acquires the symbiotic benefits of combining fish and plants in a circular production system. A more dynamic and hands-on relevant research targeting de-coupled aquaponics would be very valuable for the development of a *generation 2* within the aquaponics industry.

The large amounts of CO_2 produced from both the aqua- and horticulture sector could become a serious growth constraint for these sectors. Use of CO_2 produced by the fish in an aquaponics system by plants placed in a closed greenhouse environments could therefore provide a huge potential for the 'blue and green' sectors in the future.

Sufficient phosphorus production will also be a major concern in the near future. In current recirculating aquaculture systems and aquaponics setups, 30–65% of the phosphorus added to the system via fish feed is lost in the form of fish sludge that is filtered out by mechanical filtration. Since phosphorus is a major component of agricultural fertilizer, the development of phosphorus recycling production systems in aquaponics would be an important contribution for future food production.

With the emergence of a *generation 2* de-coupled aquaponics system, the next constraint required to be addressed within aquaponics would be the huge plant area required to maintain a sustainable fish production both economically and environmentally. A viable commercial and technological development in bio-gassing the sludge from the fish manure would be a major breakthrough for introducing large industrial scale aquaponics. A viable bio-gassing of the fish manure would mean a tremendous reduction in the required plant area to uphold the land-based aquaculture production systems known today. It would see the emergence of a *generation 3* within aquaponics presented as a flexible environmental production module that could be applied to almost any existing aqua- or horticultural production of today.

If the major constraints listed above are addressed and viable solutions found, the aquaponics industry holds the prospect of being an important niche within the aquaculture sector itself just as the organic sector is within agriculture today.

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