Chapter 1
Aquaponics and Global Food Challenges

Simon Goddek, Alyssa Joyce, Benz Kotzen, and Maria Dos-Santos

Abstract As the world's population grows, the demands for increased food production expand, and as the stresses on resources such as land, water and nutrients become ever greater, there is an urgent need to find alternative, sustainable and reliable methods to provide this food. The current strategies for supplying more produce are neither ecologically sound nor address the issues of the circular economy of reducing waste whilst meeting the WHO's Millennium Development Goals of eradicating hunger and poverty by 2015. Aquaponics, a technology that integrates aquaculture and hydroponics, provides part of the solution. Although aquaponics has developed considerably over recent decades, there are a number of key issues that still need to be fully addressed, including the development of energy-efficient systems with optimized nutrient recycling and suitable pathogen controls. There is also a key issue of achieving profitability, which includes effective value chains and efficient supply chain management. Legislation, licensing and policy are also keys to the success of future aquaponics, as are the issues of education and research, which are discussed across this book.

Keywords Aquaponics · Agriculture · Planetary boundaries · Food supply chain · Phosphorus

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1.1 Introduction

Food production relies on the availability of resources, such as land, freshwater, fossil energy and nutrients (Conijn et al. 2018), and current consumption or degradation of these resources exceeds their global regeneration rate (Van Vuuren et al. 2010). The concept of planetary boundaries (Fig. 1.1) aims to define the environmental limits within which humanity can safely operate with regard to scarce resources (Rockström et al. 2009). Biochemical flow boundaries that limit food supply are more stringent than climate change (Steffen et al. 2015). In addition to nutrient recycling, dietary changes and waste prevention are integrally necessary to transform current production (Conijn et al. 2018; Kahiluoto et al. 2014). Thus, a major global challenge is to shift the growth-based economic model towards a

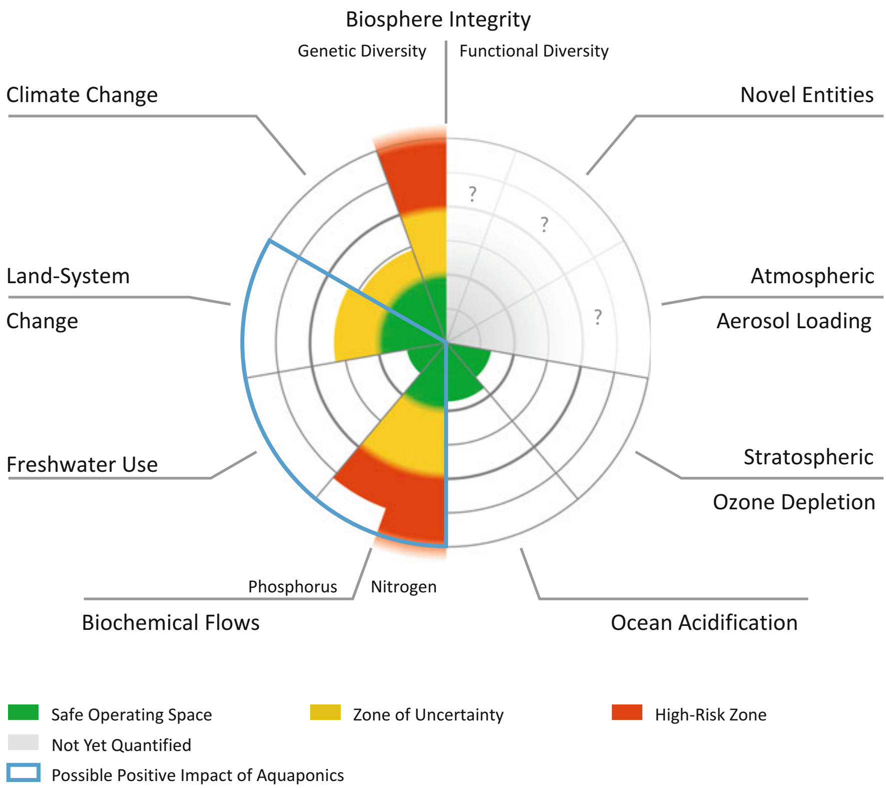

Fig. 1.1 Current status of the control variables for seven of the planetary boundaries as described by Steffen et al. (2015). The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), the red is a high-risk zone, and the grey zone boundaries are those that have not yet been quantified. The variables outlined in blue (i.e. land-system change, freshwater use and biochemical flows) indicate the planetary boundaries that aquaponics can have a positive impact on

balanced eco-economic paradigm that replaces infinite growth with sustainable development (Manelli 2016). In order to maintain a balanced paradigm, innovative and more ecologically sound cropping systems are required, such that trade-offs between immediate human needs can be balanced whilst maintaining the capacity of the biosphere to provide the required goods and services (Ehrlich and Harte 2015).

In this context, aquaponics has been identified as a farming approach that, through nutrient and waste recycling, can aid in addressing both planetary boundaries (Fig. 1.1) and sustainable development goals, particularly for arid regions or areas with nonarable soils (Goddek and Körner 2019; Appelbaum and Kotzen 2016; Kotzen and Appelbaum 2010). Aquaponics is also proposed as a solution for using marginal lands in urban areas for food production closer to markets. At one time largely a backyard technology (Bernstein 2011), aquaponics is now growing rapidly into industrial-scale production as technical improvements in design and practice allow for significantly increased output capacities and production efficiencies. One such area of evolution is in the field of coupled vs. decoupled aquaponics systems. Traditional designs for one-loop aquaponics systems comprise both aquaculture and hydroponics units between which water recirculates. In such traditional systems, it is necessary to make compromises to the conditions of both subsystems in terms of pH, temperature and nutrient concentrations (Goddek et al. 2015; Kloas et al. 2015) (see Chap. 7). A decoupled aquaponics system, however, can reduce the need for trade-offs by separating the components, thus allowing the conditions in each subsystem to be optimized. Utilization of sludge digesters is another key way of maximizing efficiency through the reuse of solid wastes (Emerenciano et al. 2017; Goddek et al. 2018; Monsees et al. 2015). Although many of the largest facilities worldwide are still in arid regions (i.e. Arabian Peninsula, Australia and sub-Saharan Africa), this technology is also being adopted elsewhere as design advances have increasingly made aquaponics not just a water-saving enterprise but also an efficient energy and nutrient recycling system.

1.2 Supply and Demand

The 2030 Agenda for Sustainable Development emphasizes the need to tackle global challenges, ranging from climate change to poverty, with sustainable food production a high priority (Brandi 2017; UN 2017). As reflected in the UN's Sustainable Development Goal 2 (UN 2017), one of the greatest challenges facing the world is how to ensure that a growing global population, projected to rise to around 10 billion by 2050, will be able to meet its nutritional needs. To feed an additional two billion people by 2050, food production will need to increase by 50% globally (FAO 2017). Whilst more food will need to be produced, there is a shrinking rural labour force because of increasing urbanization (dos Santos 2016). The global rural population has diminished from 66.4% to 46.1% in the period from 1960 to 2015 (FAO 2017). Whilst, in 2017, urban populations represented more than 54% of the total world population, nearly all future growth of the world's population will occur in urban areas, such that by 2050, 66% of the global population will live in cities (UN 2014). This increasing urbanization of cities is accompanied by a simultaneously growing network of infrastructure systems, including transportation networks.

To ensure global food security, total food production will need to increase by more than 70% in the coming decades to meet the Millennium Development Goals (FAO 2009), which include the 'eradication of extreme poverty and hunger' and also 'ensuring environmental sustainability'. At the same time, food production will inevitably face other challenges, such as climate change, pollution, loss of biodiversity, loss of pollinators and degradation of arable lands. These conditions require the adoption of rapid technological advances, more efficient and sustainable production methods and also more efficient and sustainable food supply chains, given that approximately a billion people are already chronically malnourished, whilst agricultural systems continue to degrade land, water and biodiversity at a global scale (Foley et al. 2011; Godfray et al. 2010).

Recent studies show that current trends in agricultural yield improvements will not be sufficient to meet projected global food demand by 2050, and these further suggest that an expansion of agricultural areas will be necessary (Bajželj et al. 2014). However, the widespread degradation of land in conjunction with other environmental problems appears to make this impossible. Agricultural land currently covers more than one-third of the world's land area, yet less than a third of it is arable (approximately 10%) (World Bank 2018). Over the last three decades, the availability of agricultural land has been slowly decreasing, as evidenced by more than 50% decrease from 1970 to 2013. The effects of the loss of arable land cannot be remedied by converting natural areas into farmland as this very often results in erosion as well as habitat loss. Ploughing results in the loss of topsoil through wind and water erosion, resulting in reduced soil fertility, increased fertilizer use and then eventually to land degradation. Soil losses from land can then end up in ponds, dams, lakes and rivers, causing damage to these habitats.

In short, the global population is rapidly growing, urbanizing and becoming wealthier. Consequently, dietary patterns are also changing, thus creating greater demands for greenhouse gas (GHG) intensive foods, such as meat and dairy products, with correspondingly greater land and resource requirements (Garnett 2011). But whilst global consumption is growing, the world's available resources, i.e. land, water and minerals, remain finite (Garnett 2011). When looking at the full life-cycle analysis of different food products, however, both Weber and Matthews (2008) and Engelhaupt (2008) suggest that dietary shifts can be a more effective means of lowering an average household's food-related climate footprint than 'buying local'. Therefore, instead of looking at the reduction of supply chains, it has been argued that a dietary shift away from meat and dairy products towards nutrition-oriented agriculture can be more effective in reducing energy and footprints (Engelhaupt 2008; Garnett 2011).

The complexity of demand-supply imbalances is compounded by deteriorating environmental conditions, which makes food production increasingly difficult and/or unpredictable in many regions of the world. Agricultural practices cannot only undermine planetary boundaries (Fig. 1.1) but also aggravate the persistence and propagation of zoonotic diseases and other health risks (Garnett 2011). All these factors result in the global food system losing its resilience and becoming increasingly unstable (Suweis et al. 2015).

The ambitious 2015 deadline of the WHO's Millennium Development Goals (MDGs) to eradicate hunger and poverty, to improve health and to ensure environmental sustainability has now passed, and it has become clear that providing nutritious food for the undernourished as well as for affluent populations is not a simple task. In summary, changes in climate, loss of land and diminution in land quality, increasingly complex food chains, urban growth, pollution and other adverse environmental conditions dictate that there is an urgent need to not only find new ways of growing nutritious food economically but also locate food production facilities closer to consumers. Delivering on the MDGs will require changes in practice, such as reducing waste, carbon and ecological footprints, and aquaponics is one of the solutions that has the potential to deliver on these goals.

1.3 Scientific and Technological Challenges in Aquaponics

Whilst aquaponics is seen to be one of the key food production technologies which 'could change our lives' (van Woensel et al. 2015), in terms of sustainable and efficient food production, aquaponics can be streamlined and become even more efficient. One of the key problems in conventional aquaponics systems is that the nutrients in the effluent produced by fish are different than the optimal nutrient solution for plants. Decoupled aquaponics systems (DAPS), which use water from the fish but do not return the water to the fish after the plants, can improve on traditional designs by introducing mineralization components and sludge bioreactors containing microbes that convert organic matter into bioavailable forms of key minerals, especially phosphorus, magnesium, iron, manganese and sulphur that are deficient in typical fish effluent. Contrary to mineralization components in one-loop systems, the bioreactor effluent in DAPS is only fed to the plant component instead of being diluted in the whole system. Thus, decoupled systems that utilize sludge digesters make it possible to optimize the recycling of organic wastes from fish as nutrients for plant growth (Goddek 2017; Goddek et al. 2018). The wastes in such systems mainly comprise fish sludge (i.e. faeces and uneaten feed that is not in solution) and thus cannot be delivered directly in a hydroponics system. Bioreactors (see Chap. 10) are therefore an important component that can turn otherwise unusable sludge into hydroponic fertilizers or reuse organic wastes such as stems and roots from the plant production component into biogas for heat and electricity generation or DAPS designs that also provide independently controlled water cycling for each unit, thus allowing separation of the systems (RAS, hydroponic and digesters) as required for the control of nutrient flows. Water moves between components in an energy and nutrient conserving loop, so that nutrient loads and flows in each subsystem can be monitored and regulated to better match downstream requirements. For instance, phosphorous (P) is an essential but exhaustible fossil resource that is mined for fertilizer, but world supplies are currently being depleted at an alarming rate. Using digesters in decoupled aquaponics systems allows microbes to convert the phosphorus in fish waste into orthophosphates that can be utilized by plants, with high recovery rates (Goddek et al. 2016, 2018).

Although decoupled systems are very effective at reclaiming nutrients, with near-zero nutrient loss, the scale of production in each of the units is important given that nutrient flows from one part of the system need to be matched with the downstream production potential of other components. Modelling software and Supervisory Control and Data Acquisition (SCADAS) data acquisition systems therefore become important to analyse and report the flow, dimensions, mass balances and tolerances of each unit, making it possible to predict physical and economic parameters (e.g. nutrient loads, optimal fish-plant pairings, flow rates and costs to maintain specific environmental parameters). In Chap. 11, we will look in more detail at systems theory as applied to aquaponics systems and demonstrate how modelling can resolve some of the issues of scale, whilst innovative technological solutions can increase efficiency and hence profitability of such systems. Scaling is important not only to predict the economic viability but also to predict production outputs based on available nutrient ratios.

Another important issue, which requires further development, is the use and reuse of energy. Aquaponics systems are energy and infrastructure intensive. Depending on received solar radiation, the use of solar PV, solar thermal heat sources and (solar) desalination may still not be economically feasible but could all be potentially integrated into aquaponics systems. In Chap. 12, we present information about innovative technical and operational possibilities that have the capacity to overcome the inherent limitations of such systems, including exciting new opportunities for implementing aquaponics systems in arid areas.

In Chap. 2, we also discuss in more detail the range of environmental challenges that aquaponics can help address. Pathogen control, for instance, is very important, and contained RAS systems have a number of environmental advantages for fish production, and one of the advantages of decoupled aquaponics systems is the ability to circulate water between the components and to utilize independent controls wherein it is easier to detect, isolate and decontaminate individual units when there are pathogen threats. Probiotics that are beneficial in fish culture also appear beneficial for plant production and can increase production efficiency when circulated within a closed system (Sirakov et al. 2016). Such challenges are further explored in Chap. 5, where we discuss in more detail how innovation in aquaponics can result in (a) increased space utilization efficiency (less cost and materials, maximizing land use); (b) reduced input resources, e.g. fishmeal, and reduced negative outputs, e.g. waste discharge; and (c) reduced use of antibiotics and pesticides in self-contained systems.

There are still several aquaponic topic areas that require more research in order to exploit the full potential of these systems. From a scientific perspective, topics such as nitrogen cycling (Chap. 9), aerobic and anaerobic remineralization (Chap. 10), water and nutrient efficiency (Chap. 8), optimized aquaponic fish diets (Chap. 13) and plant pathogens and control strategies (Chap. 14) are all high priorities.

In summary, the following scientific and technological challenges need to be addressed:

1. *Nutrients*: As we have discussed, systems utilizing sludge digesters make it possible to optimize the recycling of organic waste from fish into nutrients for plant growth, such designs allow for optimized reclamation and recycling of nutrients to create a near-zero nutrient loss from the system.
2. *Water*: The reuse of nutrient-depleted water from greenhouses can also be optimized for reuse back in the fish component utilizing condensers.
3. *Energy*: Solar-powered designs also improve energy savings, particularly if preheated water from solar heaters in the greenhouses can be recirculated back to fish tanks for reuse.

The ability to recycle water, nutrients and energy makes aquaponics a potentially unique solution to a number of environmental issues facing conventional agriculture. This is discussed in Chap. 2.

1.4 Economic and Social Challenges

From an economic perspective, there are a number of limitations inherent in aquaponics systems that make specific commercial designs more or less viable (Goddek et al. 2015; Vermeulen and Kamstra 2013). One of the key issues is that stand-alone, independent hydroponics and aquaculture systems are more productive than traditional one-loop aquaponics systems (Graber and Junge 2009), as they do not require trade-offs between the fish and plant components. Traditional, classic single-loop aquaponics requires a compromise between the fish and plant components when attempting to optimize water quality and nutrient levels that inherently differ for the two parts (e.g. desired pH ranges and nutrient requirements and concentrations). In traditional aquaponics systems, savings in fertilizer requirements for plants do not make up for the harvest shortfalls caused by suboptimal conditions in the respective subsystems (Delaide et al. 2016).

Optimizing growth conditions for both plants (Delaide et al. 2016; Goddek and Vermeulen 2018) and fish is the biggest challenge to profitability, and current results indicate that this can be better achieved in multi-loop decoupled aquaponics systems because they are based on independent recirculating loops that involve (1) fish, (2) plants and (3) bioreactors (anaerobic or aerobic) for sludge digestion and a unidirectional water (nutrient) flow, which can improve macro- and micro-nutrient recovery and bioavailability, as well as optimization of water consumption (Goddek and Keesman 2018). Current studies show that this type of system allows for the maintenance of specific microorganism populations within each compartment for better disease management, and they are more economically efficient in so much as the systems not only reduce waste outflow but also reutilize otherwise unusable sludge, converting it to valuable outputs (e.g. biogas and fertilizer).

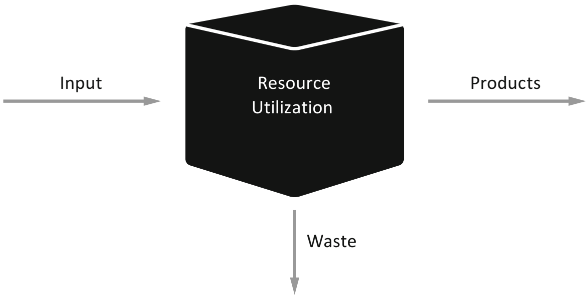

Fig. 1.2 An aquaponics system seen as a black box scheme. We do not get to see inside the box, but we know the inputs, the outputs (i.e. fish and plants) and the waste

Independent, RAS systems and hydroponics units also have a wide range of operational challenges that are discussed in detail in Chaps. 3 and 4. Increasingly, technological advances have allowed for higher productivity ratios (Fig. 1.2), which can be defined as a fraction of the system's outputs (i.e. fish and plants) over the system's input (i.e. fish feed and/or additional fertilization, energy input for lighting, heating and pumping CO_2 dosing and biocontrols).

When considering the many challenges that aquaponics encounters, production problems can be broadly broken down into three specific themes: (1) system productivity, (2) effective value chains and (3) efficient supply chain management.

System Productivity Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs. Traditional small-scale aquaponics systems were designed primarily to address environmental considerations such as water discharge, water inputs and nutrient recycling, but the focus in recent years has increasingly shifted towards economic feasibility in order to increase productivity for large-scale farming applications. However, this will require the productivity of aquaponics systems to be able to compete economically with independent, state-of-the-art hydroponics and aquaculture systems. If the concept of aquaponics is to be successfully applied at a large scale, the reuse of nutrients and energy must be optimized, but end markets must also be considered.

Effective Value Chains The value chains (added value) of agricultural products mainly arise from the processing of the produce such as the harvested vegetables, fruits and fish. For example, the selling price for pesto (i.e. red and green) can be more than ten times higher than that of the tomatoes, basil, olive oil and pine nuts. In addition, most processed food products have a longer shelf life, thus reducing spoilage. Evidently, fresh produce is important because nutritional values are mostly higher than those in the processed foods. However, producing fresh and high-quality produce is a real challenge and therefore a luxury in many regions of the world. Losses of nutrients during storage of fruit and vegetables are substantial if they are not canned or frozen quickly (Barrett 2007; Rickman et al. 2007). Therefore, for large-scale systems, food processing should at least be considered to balance out any fluctuations between supply and demand and reduce food waste. With respect to food waste reduction, vegetables that do not meet fresh produce standards, but are still of marketable quality, should be processed in order to reduce postharvest losses.

Although such criteria apply to all agricultural and fisheries products, value adding can substantially increase the profitability of the aquaponics farm, especially if products can reach niche markets.

Efficient Supply Chain Management In countries with well-developed transportation and refrigeration networks, fruit and vegetables can be imported from all around the world to meet consumer demands for fresh produce. But as mentioned previously, high-quality and fresh produce is a scarce commodity in many parts of the world, and the long-distance movement of goods – i.e. supply chain management – to meet high-end consumer demand is often criticized and justifiably so. Most urban dwellers around the world rely on the transport of foods over long distances to meet daily needs (Grewal and Grewal 2012). One of the major criticisms is thus the reliance on fossil fuels required to transport products over large distances (Barrett 2007). The issue of food miles directs focus on the distance that food is transported from the time of production to purchase by the end consumer (Mundler and Criner 2016). However, in terms of CO_2 emissions per tonne/km (tkm), one food mile for rail transportation (13.9 g CO_2/tkm) is not equal to one food mile of truck/road transportation, as truck transportation has more than 15 times greater environmental impact (McKinnon 2007). Therefore, transportation distance is not necessarily the only consideration, as the ecological footprint of vegetables grown on farms in rural areas is potentially less than the inputs required to grow food in greenhouses closer to urban centres.

Food miles are thus only a part of the picture. Food is transported long distances, but the greenhouse gas emissions associated with food production are dominated by the production phase (i.e. the impact of energy for heating, cooling and lighting) (Engelhaupt 2008; Weber and Matthews 2008). For example, Carlsson (1997) showed that tomatoes imported from Spain to Sweden in winter have a much lower carbon footprint than those locally grown in Sweden, since energy inputs to greenhouses in Sweden far outweigh the carbon footprint of transportation from Spain. When sourcing food, the transport of goods is not the only factor to take into consideration, as the freshness of products determines their nutritive value, taste and general appeal to consumers. By growing fresh food locally, many scholars agree that urban farming could help secure the supply of high-quality produce for urban populations of the future whilst also reducing food miles (Bon et al. 2010; dos Santos 2016; Hui 2011). Both areas will be discussed in more detail in Sect. 1.5.

From a consumer's perspective, urban aquaponics thus has advantages because of its environmental benefits due to short supply chains and since it meets consumer preferences for high-quality locally produced fresh food (Miličić et al. 2017). However, despite these advantages, there are a number of socio-economic concerns: The major issue involves urban property prices, as land is expensive and often considered too valuable for food production. Thus, purchasing urban land most likely makes it impossible to achieve a feasible expected return of investment. However, in shrinking cities, where populations are decreasing, unused space could be used for agricultural purpose (Bontje and Latten 2005; Schilling and Logan 2008) as is the case in Detroit in the United States (Mogk et al. 2010).

Additionally, there is a major issue of urban planning controls, where in many cities urban land is not designated for agricultural food production and aquaponics is seen to be a part of agriculture. Thus, in some cities aquaponic farming is not allowed. The time is ripe to engage with urban planners who need to be convinced of the benefits of urban farms, which are highly productive and produce fresh, healthy, local food in the midst of urban and suburban development.

1.5 The Future of Aquaponics

Technology has enabled agricultural productivity to grow exponentially in the last century, thus also supporting significant population growth. However, these changes also potentially undermine the capacity of ecosystems to sustain food production, to maintain freshwater and forest resources and to help regulate climate and air quality (Foley et al. 2005).

One of the most pressing challenges in innovative food production, and thus in aquaponics, is to address regulatory issues constraining the expansion of integrated technologies. A wide range of different agencies have jurisdiction over water, animal health, environmental protection and food safety, and their regulations are in some cases contradictory or are ill-suited for complex integrated systems (Joly et al. 2015). Regulations and legislation are currently one of the most confusing areas for producers and would-be entrepreneurs. Growers and investors need standards and guidelines for obtaining permits, loans and tax exemptions, yet the confusing overlap of responsibilities among regulatory agencies highlights the urgent need for better harmonization and consistent definitions. Regulatory frameworks are frequently confusing, and farm licensing as well as consumer certification remains problematic in many countries. The FAO (in 2015), the WHO (in 2017) and the EU (in 2016) all recently began harmonizing provisions for animal health/well-being and food safety within aquaponics systems and for export-import trade of aquaponic products. For instance, several countries involved in aquaponics are lobbying for explicit wording within the *Codex Alimentarius*, and a key focus within the EU, determined by the EU sponsored COST Action FA1305, the ‘EU Aquaponics Hub’, is currently on defining aquaponics as a clear and distinct entity. At present, regulations define production for both aquaculture and hydroponics, but have no provisions for merging of the two. This situation often creates excessive bureaucracy for producers who are required to license two separate operations or whose national legislation does not allow for co-culturing (Joly et al. 2015). The EU Aquaponics Hub, which has supported this publication (COST FA1305), defines aquaponics as ‘a production system of aquatic organisms and plants where the majority (> 50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms’ (see Chap. 7).

Consumer certification schemes also remain a difficult area for aquaponics producers in many parts of the world. For instance, in the United States and Australia, aquaponic products can be certified as organic, but not within the European Union.

From an economic perspective, aquaponics is in theory capable of increasing the overall value of fish farming or conventional hydroponics whilst also closing the food-water-energy cycle within a circular bio-based economy. In order to make small-scale aquaponics systems economically viable, aquaponics farmers generally have to operate in niche markets to obtain higher prices for products, so certification thus becomes very important.

The most pressing issues are whether aquaponics can become acceptable at the policy level. Food safety is a high priority for gaining public support, and although there is a much lowered pathogen risk in closed systems, thus implying less need for antimicrobials and pesticides, managing potential risks – or moreover managing perceptions of those risks, especially as they may affect food safety – is a high priority for government authorities and investors alike (Miličić et al. 2017). One concern that is often raised is the fear of pathogen transfer in sludge from fish to plants, but this is not substantiated in the literature (Chap. 6). As such, there is a need to allay any remaining food safety and biosecurity concerns through careful research and, where concerns may exist, to ascertain how it may be possible to manage these problems through improved system designs and/or regulatory frameworks.

Aquaponics is an emerging food production technology which has the ability to condense and compress production into spaces and places that would not normally be used for growing food. This not only means that it is exceptionally relevant in urban areas, where aquaponics can be placed on underutilized and unused places such as flat roofs, development sites, abandoned factories, housing estates and schools, but it provides a means both in the developed and developing world for people to take back part of the food production process by providing fresh local food to the market (van Gorcum et al. 2019). The integration of aquaponics with vertical farming and living wall technologies will, in time, most likely improve productivity by reducing the overall farming footprint with reduced land take and intensification.

The intense production methods in aquaponics rely on the knowledge of a combination of key factors which are highly suitable for use in teaching STEM (science, technology, engineering and maths) subjects in schools. Aquaponics provides the teacher and student with opportunities to explore the realm of complex systems, their design and management and a host of other subject areas, including environmental sciences, water chemistry, biology and animal welfare. Aquaponics is also being used in prisons/correctional facilities, such as at the San Francisco County Jail, to help inmates gain skills and experience in aquaculture and horticulture that they can use on their release. In the domestic context, there is a growing trend to design countertop systems that can grow herbs as well as small systems that can be located in offices, where exotic fish provide a calming effect, whilst plants, as part of living walls, similarly provide an aesthetic backdrop and clean the air.

Aquaponics is a farming technology advancing rapidly from its first exploits in the last years of the twentieth century and the first decades of the twenty-first century. But it still is an 'emerging technology and science topic' (Junge et al. 2017) which is subject to a considerable amount of 'hype'. When comparing the number of aquaculture, hydroponic and aquaponic peer-reviewed papers, aquaponic

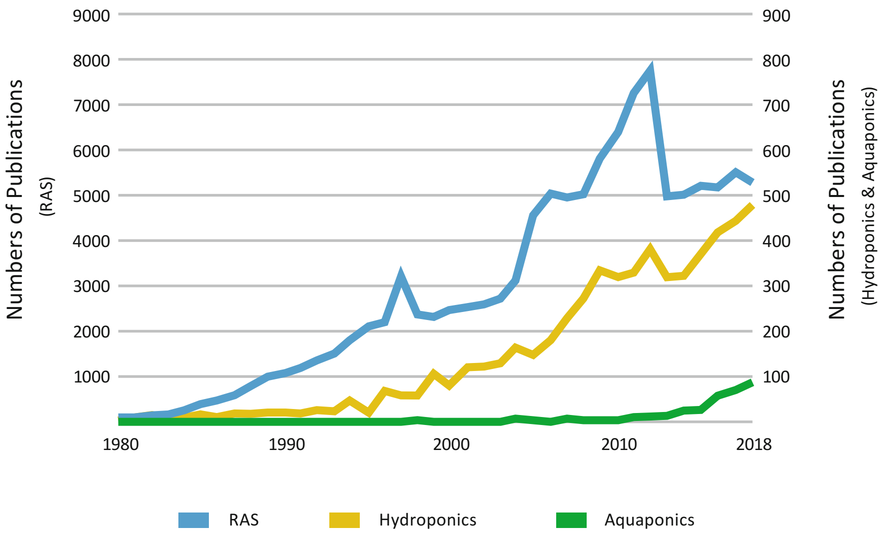

Fig. 1.3 The number of papers published on 'hydroponics', 'RAS' and 'aquaponics' from 1980 to 2018 (data were collected from the Scopus database on 30 January 2019). Please note that the scale for 'RAS' is one order of magnitude higher than that for 'hydroponics' and 'aquaponics'

papers are considerably lower (Fig. 1.3), but the numbers are rising and will continue to rise as aquaponics education, especially at university level, and general interest increases. A 'hype ratio' can be described as an indicator of the popularity of a subject in the public media relative to what is published in the academic press. This can, for example, be calculated by taking the search results in Google divided by the search results in Google Scholar. In the case of aquaponics, the hype ratio on 16 August 2016 was 1349, which is considerable when compared to the hype ratios of hydroponics (131) and recirculating aquaculture (17) (Junge et al. 2017). The sense one gets from this is that, indeed, aquaponics is an emerging technology but that there is enormous interest in the field which is likely to continue and increase over the next decades. The hype ratio, however, is likely to decline as more research is undertaken and scientific papers are published.

This book is aimed at the aquaponics researcher and practitioner, and it has been designed to discuss, explore and reveal the issues that aquaponics is addressing now and that will no doubt arise in the future. With such a broad spectrum of topics, it aims to provide a comprehensive but easily accessible overview of the rather novel scientific and commercial field of aquaponics. Apart from the production and technical side, this book has been designed to address trends in food supply and demand, as well as the various economic, environmental and social implications of this emerging technology. The book has been co-authored by numerous experts from around the world, but mostly from within the EU. Its 24 chapters cover the whole gamut of aquaponics areas and will provide a necessary textbook for all those interested in aquaponics and moving aquaponics forwards into the next decade.

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