Chapter 17
Insight into Risks in Aquatic Animal Health in Aquaponics

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Abstract Increased public interest in aquaponics necessitates a greater need to monitor fish health to minimize risk of infectious and non-infectious disease outbreaks which result from problematic biosecurity. Fish losses due to health and disease, as well as reporting of poor management practices and quality in produce, which could in a worst-case scenario affect human health, can lead to serious economic and reputational vulnerability for the aquaponics industry. The complexity of aquaponic systems prevents using many antimicrobial/antiparasitic agents or disinfectants to eradicate diseases or parasites. In this chapter, we provide an overview of potential hazards in terms of risks related to aquatic animal health and describe preventive approaches specific to aquaponic systems.

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17.1   Introduction

The European Food Safety Authority reported a variety of drivers and potential issues associated with new trends in food production, and aquaponics was identified as a new food production process/practice (Afonso et al. 2017). As a new food production process, aquaponics can be defined as 'the combination of animal aquaculture and plant culture, through a microbial link and in a symbiotic relationship'. In aquaponics, the basic approach is to get benefit from the complementary functions of the organisms and nutrient recovery. The aquaculture part of the system applies principles that are similar to recirculating aquaculture systems (RAS). Aquaponics has gained momentum due to its superior features compared to traditional production systems. Thus, aquaponics seems capable of maintaining ecosystems and strengthening capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters. These attributes are within reach, but as in other agri-/aquacultural production, aquaponics is not free of risks. Given the complexity of aquaponics as an environment for co-production of aquatic animals with plants, the hazards and risks may be more complicated.

The focus in this chapter is on categories of risk (i.e. animal health/disease) rather than specific risks (e.g. flectobacillosis disease). In traditional aquaculture, some of the more common types of production risks are diseases resulting from pathogens, unsuitable water quality and system failure. Snieszko (1974) reported that infectious diseases of fish occur when susceptible fish are exposed to virulent pathogens under certain environmental conditions. Thus, the interaction of pathogens, water quality and fish resistance is linked to occurrence of disease. Previous research using risk methods has studied the routes of introduction of aquatic animal pathogens in order to secure safe trade (e.g. import risk analyses) and support biosecurity (Peeler and Taylor 2011). Considering the similarity of aquaponics to RAS, it is expected that the health problems of aquatic animals in aquaponics may be identical to aquatic animals in RAS. Specifically, fluctuations in water quality may increase susceptibility of fish to pathogens (i.e. disease-causing organisms such as virus, bacteria, parasite, fungi) in RAS and cause disease outbreaks. Microorganisms in closed systems such as RAS or aquaponics are of significance in terms of maintaining fish health. Thus, Xue et al. (2017) reported the potential correlation between fish diseases and environmental bacterial populations in RAS. High pathogen density and limited medication possibilities make the system prone to disease problems. Disease or impaired health can cause catastrophic losses with decreased survival or poor feed conversion ratios. Regardless of which potential risk becomes problematic, each has the same impact: an overall decline in the production of a marketable quality product that then results in financial loss (McIntosh 2008). Diseases can be prevented only when the risks are recognized and managed before disease occurs (Nowak 2004). The severity of risks differs and will likely change depending on when each is encountered during the production cycle.

17.2 Aquaponics and Risk: A Development Perspective for Fish Health

Fish pathogens are prevalent in the aquatic environment, and fish are generally able to resist them unless overloaded by the allostatic load (Yavuzcan Yıldız and Seçer 2017). Allostasis refers to the 'stability through change' proposed by Sterling and Eyer (1988). Put simply this is the effort of fish to maintain homeostasis through changes in physiology. Allostatic load of fish in aquaponics may be a challenging factor as aquaponics is a complex system mainly in terms of the water quality and the microbial community in the system. Hence, the diseases of fish are generally species- and system-specific. Specific aquaponic diseases have not been described yet. From aquaculture, it is known that fish diseases are difficult to detect and are usually the end result of the interaction between various factors involving the environment, nutritional status of the fish, the immune robustness of the fish, existence of an infectious agent and/or poor husbandry and management practices. In order to sustain aquaponic systems, an aquatic health management approach needs to be developed considering the species cultured, the complexity of environments in aquaponics and the type of the aquaponic system management. Profitability in aquaponic production can be affected by even small percentage decreases in production, as seen in aquaculture (Subasinghe 2005).

Aquaponics is a sustainable, innovative approach for future food production systems, but this integrated system for production currently shows difficulties in moving from the experimental stage or small-scale modules to large-scale production. It could be hypothesized that the lack of economic success of this highly sustainable production system is due to major bottlenecks not scientifically addressed yet. Without a doubt, the cost-effectiveness and technical capabilities of aquaponic systems need further research to realize a scaling up of production (Junge et al. 2017). Research activity and innovations applied since the 1980s have transformed aquaponic technology into a viable system of food production, and although small-scale plants and research-structured plants are already viable, commercial-scale aquaponics are not often economically viable. The claimed advantages attributed and recognized for aquaponic systems are the following: significant reduction in the usage of water (compared to traditional soil methods of growing plants), bigger and healthier vegetables than when grown in soil, production of plants does not require artificial fertilizer and aquaponic products are free of antibiotics, pesticides and herbicides.

17.2.1 Risk Analysis Overview

Risk is defined as 'uncertainty about and severity of the consequences of an activity' (Aven 2016), and the risk picture reflects (i) probabilities/frequencies of hazards/threats, (ii) expected losses given the occurrence of such a hazard/threat and (iii)
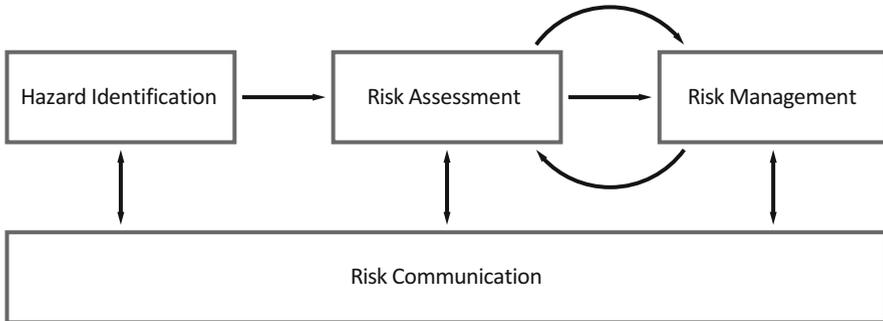
Fig. 17.1 Risk analysis (OIE 2017)

factors that could create large deviations between expected outcomes and the actual outcomes (uncertainties, vulnerabilities). Risk analysis offers tools to judge risk and assist in decision-making (Ahl et al. 1993; MacDiarmid 1997). Risk analysis is based on systematic use of the available information for decision-making, using the components of hazard identification, risk assessment, risk management and risk communication as indicated by World Organisation of Animal Health (OIE) (Fig. 17.1). This framework is commonly used for pathogen risk analysis (Peeler et al. 2007).

Risk analysis in food production, including aquaponics, can be applied to many cases, such as food security, invasive species, production profitability, trade and investment, and for consumer preference for safe, high-quality products (Bondad-Reantaso et al. 2005; Copp et al. 2016). The benefits of applying risk analysis in aquaculture became more clearly linked to this sector's sustainability, profitability and efficiency, and this approach can also be effective for the aquaponics sector. Therefore, disease introduction and potential transmission of pathogens can be evaluated in the context of risk to aquatic animal health (Peeler et al. 2007). Various international agreements, conventions and protocols cover human, animal and plant health, aquaculture, wild fisheries and the general environment in the field of risk. The most comprehensive and broad agreements and protocols are the World Trade Organization's (WTO) Sanitary and Phytosanitary Agreement, United Nations Environmental Program's (UNEP) Convention on Biological Diversity and the supplementary agreement Cartagena Protocol on Biosafety and the Codex Alimentarius (Mackenzie et al. 2003; Rivera-Torres 2003).

A key challenge regarding the field of risk relates to our depth of knowledge. Risk decisions are related situations characterized by large uncertainties (Aven 2016). Specifically, animal health risk analysis depends on knowledge gained from studies of epidemiology and statistics. Oidtmann et al. (2013) point out that the main constraint in developing risk-based surveillance (RBS) designs in the aquatic context is the lack of published data to advance the design of RBS. Thus, to increase robust

Table 17.1 Composite research needs for aquatic animal health in aquaponics

Research area	Research need
Basic research	Understanding the aquatic animal health and welfare concept in aquaponics in terms of the species of aquatic organisms and the system used
	Understanding the stress/stressor concept for aquatic organisms in aquaponics by the species and the system used
	Understanding the allostatic load for aquatic organisms and the emergence of diseases
	Understanding the welfare concept in aquaponics
	Characterizing the critical water quality parameters against aquatic animal health
	Understanding the sensitivity of aquatic organisms to the aquaponic environment
	Revealing the microbial profile for the different systems of the aquaponics
Health indicators	Developing and validating health indicators for aquatic animals raised in the aquaponic systems
Database development	Field data on the health/disease of aquatic animals in the aquaponics
	Field data on the microbial profile including pathogens

knowledge of risks in aquaponics, studies that both increase scientific data and reduce specific weaknesses and uncertain fields in aquaponics operations are needed. Some research areas that require more data for risk analysis in aquaponic systems are presented below (Table 17.1).

In terms of risk analysis for aquatic animal diseases or health in aquaponic systems, the OIE Aquatic Animal Health Code (the Aquatic Code) can be considered because the Aquatic Code sets out standards for the improvement of aquatic animal health and welfare of farmed fish worldwide and for safe international trade of aquatic animals and their products. This Code also includes use of antimicrobial agents in aquatic animals (OIE 2017).

17.3   Hazard Identification

In risk analysis, a hazard is generally specified by describing what might go wrong and how this might happen (Ahl et al. 1993). A hazard refers not only to the magnitude of an adverse effect but also to the likelihood of the adverse effect occurring (Müller-Graf et al. 2012). Hazard identification is important for revealing the factors that may favour the establishment of a disease and/or potential pathogen threat, or otherwise detrimental for fish welfare. Biological pathogens are recognised as hazard in aquaculture by Bondad-Reantaso et al. (2008). A broad range of factors can be taken into consideration as long as they are associated with disease occurrence, i.e. they are hazards.

Table 17.2 List of potential hazards for aquatic animal health in aquaponics

	Hazard identification	Hazard specification
Abiotic	pH	Too high/too low/rapid change
	Water temperature	Too high/too low/rapid change
	Suspended solids	Too high
	Dissolved oxygen content	Too low
	Carbon dioxide content	Too high
	Ammonia content	Too high, pH dependent
	Nitrite content	Too high
	Nitrate content	Extremely high
	Metal content	Too high, pH dependent
Biotic	Stocking density	Too high/too low
	Biofouling	
Feeding	Nutrients by the fish species	Surplus/deficiency
	Feeding frequency	Inadequate/improper feeding
	Dietary toxins	
	Feed additives	Unsuitable growth promoters
Management	Aquaponic system design	Poor system design
	Fish species	Unsuitable for aquaponics
	Operational issues (water circulation, biofilter, mechanical)	
	Chemotherapeutants use	Threat for the microbial balance
	Staff hygiene	
	Biosecurity	
Welfare	Stressors	Too high
	Allostatic load	High
	Rearing conditions	Suboptimal
Diseases	Nutritional diseases	
	Environmental diseases	
	Infectious diseases	

The sustainability of aquaponics is linked with a variety of factors, including system design, fish feed and faeces features, fish welfare and elimination of pathogens from the system (Palm et al. 2014a, b). Goddek (2016) reported that aquaponic systems are characterized by a wide range of microflora as fish and biofiltration exist in the same water mass. Since a great variety of microflora exists in aquaponic practices, the occurrence of pathogens and risks for human health should also be considered in order to guarantee food safety. In terms of sustainability of aquaponic

systems, pathogen elimination to prevent losses due to diseases may be a challenging factor when aquatic animal production is intensified.

The use of chemotherapeutants in aquaculture to fight pathogens presents a number of potential hazards and risks to production systems, the environment and human health (Bondad-Reantaso and Subasinghe 2008) (Table 17.2).

To eliminate hazards, the fish rearing and plant cultivation phases should be considered separately. The biggest risks in fish rearing are related to water quality, fish density, feeding quality and quantity and disease (Yavuzcan Yildiz et al. 2017). Depending on the species of fish reared, the level of risk can increase if the species is not appropriate for the conditions of the particular system. For example, potassium is often supplemented in aquaponic systems to promote plant growth, but results in reduced performance in hybrid striped bass. Normally, freshwater and high-density culture-tolerant species are utilized in aquaponics. The most common species of fish in commercial systems are tilapia and ornamental fish. Channel catfish, largemouth bass, crappies, rainbow trout, pacu, common carp, koi carp, goldfish, Asian sea bass (or barramundi) and Murray cod are among the species that have been trialled (Rakocy et al. 2006). Tilapia, a warm-water species, highly tolerant of fluctuating water parameters (pH, temperature, oxygen and dissolved solids), is the species largely reared in most commercial aquaponic systems in North America and elsewhere. The results of a recent online survey, based on answers from 257 respondents, showed that tilapia is reared in 69% of aquaponic plants (Love et al. 2015). Tilapia presents an economic interest in some markets but not in others. In the same survey (Love et al. 2015), other species utilized were ornamental fish (43%), catfish (25%), other aquatic animals (18%), perch (16%), bluegill (15%), trout (10%) and bass (7%). One of the major weaknesses in aquaponic systems is the management of water quality to meet the requirements of the tank-reared fish, while cultivated crops are treated as the second step of the process. Fish require water with appropriate parameters for oxygen, carbon dioxide, ammonia, nitrate, nitrite, pH, chlorine and others. A high level of suspended solids can affect the health status of fish (Yavuzcan Yildiz et al. 2017), provoking damages to gill structure, such as the epithelium lifting, hyperplasia in the pillar system and reduction of epithelial volume (Au et al. 2004). Fish stocking density and feeding (feeding rate and volume, feed composition and characteristics) affect the digestion processes and metabolic activities of fish and, accordingly, the catabolites, total dissolved solids (TDS) and waste by-products (faeces and uneaten feed) in the rearing water. The basic principle on which the aquaponic system is based is the utilization of catabolites in water for plant growth. Aquaponic systems require 16 essential nutrients and all these macro- and micronutrients must be balanced for optimal plant growth. An excess of one nutrient can negatively affect the bioavailability of others (Rakocy et al. 2006). Therefore, the continuous monitoring of water parameters is essential to maintain water quality appropriate for fish and crop growth and to maximize the benefits of the process. Reduced water exchange and low crop growth rate can create toxic nutrient concentrations in water for fish and crops. On the other hand, the addition of some

micronutrients (Fe^{+2}, Mn^{+2}, Cu^{+2}, B^{+3} and Mo^{+6}), normally scarce in water where fish are reared, is essential to adequately sustain crop production. In comparison to hydroponic culture, crops in aquaponic systems require lower levels of total dissolved solid (TDS, 200–400 ppm) or EC (0.3–0.6 mmhos/cm) and require, like fish, a high level of dissolved oxygen in water (Rakocy et al. 2006) for root respiration.

17.4 Fish Health Management

17.4.1 Fish Diseases and Prevention

While fish diseases caused by bacteria, viruses, parasites or fungi can have a significant negative impact on aquaculture (Kabata 1985), the appearance of a disease in aquaponic systems can be even more devastating. Maintenance of fish health in aquaponic systems is more difficult than in RAS, and, in fact, control of fish diseases is one of the main challenges for successful aquaponics (Sirakov et al. 2016). Diseases which affect fish can be divided into two categories: infectious and non-infectious fish diseases. Infectious diseases are caused by different microbial pathogens transmitted either from the environment or from other fish. Pathogens can be transmitted between the fish (horizontal transmission) or vertically, by (externally or internally) infected eggs or infected milt. More than half of the infectious disease outbreaks in aquaculture (54.9%) are caused by bacteria, followed by viruses, parasites and fungi (McLoughlin and Graham 2007). Often, although clinical signs or lesions are not present, fish can carry pathogens in a subclinical or carrier state (Winton 2002). Fish diseases can be caused by ubiquitous bacteria, present in any water containing organic enrichment. Under certain conditions, bacteria quickly become opportunistic pathogens. The presence of low numbers of parasites on the gills or skin usually does not lead to significant health problems. The capability of a pathogen to cause clinical disease depends on the interrelationship of six major components related to fish and the environment in which they live (physiological status, host, husbandry, environment, nutrition and pathogen). If any of the components is weak, it will affect the health status of the fish (Plumb and Hanson 2011). Non-infectious diseases are usually related to environmental factors, inadequate nutrition or genetic defects (Parker 2012). Successful fish health management is accomplished through disease prevention, reduction of infectious disease incidence and reduction of disease severity when it occurs. Avoidance of contact between the susceptible fish and a pathogen should be a critical goal, in order to prevent outbreak of infectious disease.

Three main measures to achieve this goal are:

- Use of pathogen-free water supply.
- Use of certified pathogen-free stocks.
- Strict attention to sanitation (Winton 2002).

Implementation of these measures will decrease fish exposure to pathogenic agents. However, it is practically impossible to define all agents which could cause disease in the aquatic environment and to completely prevent host exposure to pathogens. Certain factors, such as overcrowding, increase fish susceptibility to infection and pathogen transmission. For that reason, many pathogens which do not cause disease in wild fish can cause disease outbreaks with high mortality rates in high-density fish production systems. To avoid this, the infection level of fish in aquaponics must be continually monitored. Maintaining biosecurity in aquaponics is important not only from an economic point of view but also for fish welfare. Appearance of any fish pathogen in constrained tank space and under high population density will inevitably pose a threat to fish health, both to the individuals that are affected by the pathogen and those still unaffected.

The goal of biosecurity is the implementation of practices and procedures which will reduce the risks of:

- Introduction of pathogens into the facility.
- Spread of pathogens throughout the facility.
- Presence of conditions which can increase susceptibility to infection and disease (Bebak-Williams et al. 2007).

The achievement of this goal involves management protocols to prevent specific pathogens from entering the production system. Quarantine is an important biosecurity component for prevention of contact with infectious agents and is used when fish are moved from one area to another. All newly acquired fish are quarantined before they are introduced into established populations. Fish under quarantine are isolated for a specific period of time before release into contact with a resident population, preferably in a separate area with dedicated equipment (Plumb and Hanson 2011). New fish remain in quarantine until shown to be disease-free. It is advisable in some cases to quarantine new fish in an isolation tank for 45 days before adding them to the main system (Somerville et al. 2014). During quarantine, fish are monitored for signs of disease and sampled for presence of infectious agents. Prophylactic treatments may be initiated during the quarantine period in order to remove initial loads of external parasites.

For disease prevention, certain measures are recommended to reduce risk factors:

- Administer commercial vaccines against various fish viral and bacterial pathogens. Most common routes of application are by injection, by immersion or via food.
- Breed strains of fish which are more resistant to certain fish pathogens. Although Evenhuis et al. (2015) report that fish strains with increased simultaneous resistance to two bacterial diseases (columnaris and bacterial cold water disease) are available, there is evidence that increased susceptibility to other pathogens may occur (Das and Sahoo 2014; Henryon et al. 2005).
- Take preventive and corrective measures to prevent stress in fish. Since multiple stressors are present in every step of aquaponic production, avoidance and management of stress through monitoring and prevention minimize its influence on fish health.

- Avoid high stocking density, which causes stress and may increase the incidence of disease even if other environmental factors are acceptable. Also, high stocking density increases the possibility of skin lesions, which are sites of various pathogen entries into the organism.
- Regularly remove contaminants from water (uneaten food, faeces and other particulate organics). Dead or dying fish should be removed promptly as they can serve as potential disease sources to the remaining stock and a breeding ground for others, as well as fouling the water when decomposing (Sitj-à-Bobadilla and Oidtmann 2017).
- Disinfect all equipment used for tank cleaning and fish manipulation. After adequate disinfection, all equipment should be rinsed with clear water. Use of footbaths and hand washing with disinfecting soap at the entrance and within the buildings are recommended. These steps directly decrease the potential for the spread of pathogens (Sitjà-Bobadilla and Oidtmann 2017). Certain chemicals used as disinfectants (such as benzalkonium chloride, chloramine B and T, iodophors) are effective for disease prevention.
- Administer dietary additives and immunostimulants for improvement of health and to reduce the impacts of disease. Such diets contain various ingredients important for improvement of health and disease resistance (Anderson 1992; Tacchi et al. 2011). There exists a wide range of products and molecules, including natural plant products, immunostimulants, vitamins, microorganisms, organic acids, essential oils, prebiotics, probiotics, synbiotics, nucleotides, vitamins, etc. (Austin and Austin 2016; Koshio 2016; Martin and Król 2017).
- Segregate fish by age and species for disease prevention, since susceptibility to certain pathogens varies with age, and certain pathogens are specific to some fish species. Generally, young fish are more susceptible to pathogens than older fish (Plumb and Hanson 2011).

Maintaining the health of fish in aquaponics requires adequate health management and continuous attention. Optimal fish health is best achieved through biosecurity measures, adequate production technology and husbandry management practices which enable optimal conditions. As mentioned, avoidance through optimal rearing conditions and biosecurity procedures are the best way to avoid fish diseases. Invariably, however, a pathogen may appear in the system. The first and most important action is to identify the pathogen correctly.

17.4.2   Disease Diagnosis (Identification of Diseased Fish)

Early recognition of diseased fish is important in maintaining health of the aquaculture unit in the aquaponic system. Accurate diagnosis and prompt response will stop the spread of disease to other fish, thus minimizing losses.

Examination of live fish starts by observing their behaviour. Constant and careful daily observation enables early recognition of diseased fish. As a rule, fish should be observed for behavioural changes before, during and after feeding.

Healthy fish exhibit fast, energetic swimming movements and a strong appetite. They swim in normal, species-specific patterns and have intact skin without discolorations (Somerville et al. 2014). Diseased fish exhibit various behavioural changes with or without visible change in physical appearance. The most obvious indicator of deteriorating fish health is the reduction (cessation) of feeding activity, usually as a result of an environmental stress and/or an infectious/parasitic disease. The most obvious sign of disease is the presence of dead or dying animals (Parker 2012; Plumb and Hanson 2011).

Behavioural changes in diseased fish may include abnormal swimming (swimming near the surface, along the tank sides, crowding at the water inlet, whirling, twisting, darting, swimming upside down), flashing, scratching on the bottom or sides of the tank, unusually slow movement, loss of equilibrium, weakness, hanging listlessly below the surface, lying on the bottom and gasping at the water surface (sign of low oxygen level) or not reacting to external stimuli. In addition to behavioural changes, diseased fish exhibit physical signs that can be seen by the unaided eye. These gross signs can be external, internal or both and may include loss of body mass; distended abdomen or dropsy; spinal deformation; darkening or lightening of the skin; increased mucus production; discoloured areas on the body; skin erosions, ulcers or sores; fin damage; scale loss; cysts; tumours; swelling on the body or gills; haemorrhages, especially on the head and isthmus, in the eyes and at the base of fins; and bulging eyes (pop-eye, exophthalmia) or endophthalmia (sunken eyes). The internal signs are changes in the size, colour and texture of the organs or tissues, accumulation of fluids in the body cavities and presence of pathological formations such as tumours, cysts, haematomas and necrotic lesions (Noga 2010; Parker 2012; Plumb and Hanson 2011; Winton 2002).

Upon suspicion of deteriorating fish health, the first step is to check water quality (water temperature, dissolved oxygen, pH, levels of ammonia, nitrite and nitrate) and promptly respond to any deviations from the optimal range. If the majority of fish in the tank has abnormal behaviour and shows non-specific signs of disease, there is likely a change in the environmental conditions (Parker 2012; Somerville et al. 2014). Low oxygen (hypoxia) is a frequent cause of fish mortality. Fish in water with low oxygen are lethargic, congregate near the water surface, gasp for air and have brighter pigmentation. Dying fish exhibit agonal respiration, with mouth open and opercula flared. These signs are also evident in fish carcasses. High ammonia levels cause hyperexcitability with muscular spasms, cessation of feeding and death. Chronic deviation from optimal levels results in anaemia and decreased growth and disease resistance. Nitrite-poisoned fish have behavioural changes characteristic of hypoxia with pale tan or brown gills and brown blood (Noga 2010).

When only few fish show signs of disease, it is imperative to remove them immediately in order to stop and prevent the spread of the disease agent to the

other fish. In the early stages of a disease outbreak, generally only a few fish will show signs and die. In the following days, there will be a gradual increase in the daily mortality rate. The diseased fish must be carefully examined in order to determine the cause. Only a few fish diseases produce pathognomonic (specific to a given disease) behavioural and physical signs. Nevertheless, careful observation will often allow the examiner to narrow down the cause to environmental conditions or disease agents. In a serious disease outbreak, a fish veterinarian/health specialist should be contacted immediately for professional diagnosis and disease management options. In order to solve the disease problem, the diagnostician will need a detailed description of the behavioural and physical signs exhibited by the diseased fish, daily records of the water quality parameters, origin of the fish, date and size of fish at stocking, feeding rate, growth rate and daily mortality (Parker 2012; Plumb and Hanson 2011; Somerville et al. 2014).

17.5   Treatment Strategies in Aquaponics

Treatment options for diseased fish in an aquaponic system are very limited. As both fish and plants share the same water loop, medications used for disease treatments can easily harm or destroy the plants, and some may get absorbed by the plants, causing withdrawal periods or even making them unusable for consumption. The medications can also have detrimental effects on the beneficial bacteria in the system. If a medicinal treatment is absolutely necessary, it must be implemented early in the course of the disease. The diseased fish is transferred into a separate (hospital, quarantine) tank isolated from the system for treatment. When returning the fish after the treatment, it is important not to transfer the used medications into the aquaponic system. All these limitations require improvements of disease management options with minimal negative effects to the fish, the plants and the system (Goddek et al. 2015, 2016; Somerville et al. 2014; Yavuzcan Yildiz et al. 2017). One of the most used and effective, old-school treatments against the most common bacterial, fungal and parasitic infections in fish is a salt (sodium chloride) bath. Salt is beneficial for the fish, but can be detrimental to the plants in the system (Rakocy 2012), and the whole treatment procedure must be performed in a separate tank. A good option is to separate the recirculating aquaculture unit from the hydroponic unit (decoupled aquaponic systems) (see Chap. 8). Decoupling allows for fish disease and water treatment options that are not possible in coupled systems (Monsees et al. 2017) (see Chap. 7). One recent improvement for the control of fish ectoparasites and disinfection in the aquaponic systems is the use of Wofasteril (KeslaPharmaWolfen GMBH, Bitterfeld-Wolfen, Germany), a peracetic acid-containing product that leaves no residues in the system (Sirakov et al. 2016). Alternatively, hydrogen peroxide can be used, but at a much higher concentration. While these chemicals have minimal side effects, their presence is undesirable in aquaponic systems and alternative approaches, such as biological control methods, are required (Rakocy 2012).

The biological control method (biocontrol) is based on the use of other living organisms in the system, relying on natural relationships among the species (commensalism, predation, antagonism, etc.) (Sitjà-Bobadilla and Oidtmann 2017) to control fish pathogens. At present, this method is a complementary fish health management tool with high potential, especially in aquaponic systems. The most successful implementation of biocontrol in fish culture is the use of cleaner fish against sea lice (skin parasites) in salmon farms. It is best practiced in Norwegian farms where cleaning wrasse (Labridae) are co-cultured with salmon. The wrasse remove and feed on sea lice (Skiftesvik et al. 2013). Although cleaning is less common in freshwater fish, the leopard plecos (*Glyptoperichthys gibbiceps*), cohabiting with blue tilapia (*Oreochromis aureus*), successfully keeps infection with *Ichthyophthirius multifiliis* under control by feeding on the parasite cysts (Picón-Camacho et al. 2012). This biocontrol method is becoming increasingly important in aquaculture and can be considered in aquaponic systems. Additionally, it must be noted that the cleaner fish can also harbour pathogens that can be transmitted to the main cultured species. Therefore, they must also undergo preventive and quarantine procedures before introduction into the system.

Another biocontrol method, still in the exploratory application phase in fish culture, is the use of filter-feeding and filtering organisms. By reducing the pathogen loads in the water, these organisms can lower the chances of disease emergence (Sitjà-Bobadilla and Oidtmann 2017). For example, Othman et al. (2015) demonstrated the ability of freshwater mussels (*Pilsbryoconcha exilis*) to reduce the population of *Streptococcus agalactiae* in a laboratory-scale tilapia culture system. The potential of this biocontrol method in aquaponic systems is yet to be tested, and new studies are needed to explore the possibilities not only for fish disease control but also for control of plant pathogens.

The most promising and well-documented biocontrol method is the use of beneficial microorganisms as probiotics in fish feed or in the rearing water. Their usage in aquaponic systems as promoters of fish/plant growth and health is well known, and probiotics have also demonstrated effectiveness against a range of bacterial pathogens in different fish species. For example, in rainbow trout, dietary *Carnobacterium maltaromaticum* and *C. divergens* protected from *Aeromonas salmonicida* and *Yersinia ruckeri* infections (Kim and Austin 2006) and *Aeromonas sobria* GC2 incorporated into the feed successfully prevented clinical disease caused by *Lactococcus garvieae* and *Streptococcus iniae* (Brunt and Austin 2005). Dietary *Micrococcus luteus* reduced the mortalities from *Aeromonas hydrophila* infection and enhanced the growth and health of Nile tilapia (Abd El-Rhman et al. 2009). Recent research by Sirakov et al. (2016) has made good progress in simultaneous biocontrol of parasitic fungi in both fish and plants in a closed recirculating aquaponic system. In total, over 80% of the isolates (bacteria isolated from the aquaponic system) were antagonistic to both fungi (*Saprolegnia parasitica* and *Pythium ultimum*) in the *in vitro* tests. Bacteria were not classified taxonomically, and the authors assumed that they belonged to the genus *Pseudomonas* and to a group of lactic acid bacteria. These findings, although very promising, have yet to be tested in an operational aquaponic system.

As a final alternative to chemical treatment, we suggest the use of medicinal plants with antibacterial, antiviral, antifungal and antiparasitic properties. Plant extracts have various biological characteristics with minimal risk of developing resistance in the targeted organisms (Reverter et al. 2014). Many scientific reports demonstrate the effectiveness of medicinal plants against fish pathogens. For example, Nile tilapia fed with a diet containing mistletoe (*Viscum album coloratum*) increased the survivability when challenged with *Aeromonas hydrophila* (Park and Choi 2012). Indian major carp showed a significant reduction in mortality when challenged with *Aeromonas hydrophila* and fed with diets containing prickly chaff flower (*Achyranthes aspera*) and Indian ginseng (*Withania somnifera*) (Sharma et al. 2010; Vasudeva Rao et al. 2006). Medicinal plant extracts have also proven effective against ectoparasites. In goldfish, Yi et al. (2012) demonstrated the effectiveness of *Magnolia officinalis* and *Sophora alopecuroides* extracts against *Ichthyophthirius multifiliis*, and Huang et al. (2013) showed that extracts of *Caesalpinia sappan*, *Lysimachia christinae*, *Cuscuta chinensis*, *Artemisia argyi* and *Eupatorium fortunei* have 100% anthelmintic efficacy against *Dactylogyrus intermedius*. The use of medicinal plants in aquaponics is promising, but yet more research is needed to find the appropriate treatment strategy without undesirable effects. As referred by Junge et al. (2017), even though research on aquaponics has largely developed in recent years, the number of research papers published on the topic is still dramatically low compared to papers published related to aquaculture or hydroponics. Aquaponics, still considered an emerging technology, is however now characterized by having great potential for food production for the world's population that, according to the results of the UN World Population Prospects (UN 2017), numbered nearly 7.6 billion in mid-2017 and, based on the projections, it is expected to increase to 1 billion within 12 years, reaching about 8.6 billion in 2030. Nevertheless, considering the potential risks to the sustainability of aquaponics due to fish diseases, development of good ideas, and novel methods and approaches for pathogen control will be our major challenge for the future. There is a pressing need to initiate new knowledge to provide a better basis for management of fish and plant health, and to continue to develop operation and infrastructure systems for the aquaponic industry. The causes of fish losses in aquaponic systems, system-specific diseases and the interaction and alteration of microbial community, along with pathogens, are priority areas for study.

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