

## STUDIES ABOUT THE FISH FARMING DEVELOPMENT IN AQUAPONIC SYSTEMS: A REVIEW

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### Abstract

*Recirculating aquaculture systems have experienced a remarkable growth over the last decade all over the world. Aquaponics is a soilless agriculture system that synergistically combines aquaculture and hydroponics. The paper presents different types of aquaponic system designs that can sustain many fresh water species of fish like Carp and Tilapia. Aquaponics has great potential to become a sustainable technology for nitrogen-rich waste remediation with simultaneous year-round production of high quality fish and vegetables while conserving the water. The common carp (Cyprinus carpio) was the first species developed to have an organic production standard in 1994 in Austria. Later on organic aquaculture standards have been created for other species of fish and sea food. This review provides some necessary background to worldwide conventional small scale aquaponic systems.*

**Key words:** ecological aquaculture, aquaponics, recirculating aquaculture systems.

### INTRODUCTION

*„Ecological aquaculture is an integral part of our common planetary wisdom and cultural heritage, and is an essential part of our future evolution as a sophisticated species living in peace with the Earth's complex ecosystems.”* (Costa Pierce, 2015).

The importance of aquaculture can be evaluated from an economic, social and environmental point of view, but especially from the multiple uses of the final product which can directly be offered for human consumption or can be distributed as raw material towards different industries. According to Food and Agriculture Organization, fish products own more than 14% of the animal protein products consumed globally. Moreover, we must admit that the development of the fish products industry can be the answer to a major problem that our fast growing population is facing. Demand and offer dynamics is characterizing the fish products market. Modified fishery resources, economy's climate and environmental conditions directly influence the market. Modernized aquaculture systems can be the solution to all these fluctuations. Aquaculture represents the fastest growing industry in the animal protein foods sector. Recording an annual growth rate bigger

than 10%, fisheries can easily represent a quarter of the global fish production.

### 1. THE HISTORY AND CONTRIBUTION OF AQUAPONICS

Early civilizations from Asia and South America have applied the concept of using fish waste to fertilize plants millennia ago. Studies conducted in the late 1970's by the New Alchemy Institute and by the North American and European academic institutions have helped aquaponics to evolve into the modern food production. The success of aquaculture and hydroponics integration before 1980's was poor due to technological limitations. Later in the 1980's and 1990's, the system design has evolved. Recirculating aquaculture system was the design that permitted water recycling and also optimal nutrient buildup for plants to grow. Biological filtration and optimal fish to plant ratio were the key concepts that allowed this integrated system to work. A study led by the North Carolina State University demonstrated that the integrated hydroponic and aquaculture system can be suitable for growing plants and raising fish in arid and water poor areas. Water consumption in the integrated system was just 5 percent of that used in a regular pond for growing fish. Although the system is in use since the 1980's,

there are few researchers and practitioners that follow this new method of food production (Somerville et al., 2014).

James Rakocy is known as the father of aquaponics. Through his research at the University of Virgin Islands he developed vital ratios and calculations in order to maximize fish and vegetable production while maintaining a balanced ecosystem. During his research, interests for malnutrition, world hunger, wastewater management, ornamental fish, were brought together and combined into aquaponics. His main idea focused on diminishing the need for daily water exchange with new water due to buildup of nitrate ions in RAS (recirculating aquaculture systems). Aquaponic systems usually exchange less than 1% of the system's daily water compared to a 5-10% water exchange in RAS. This problem was solved by using plants to remove nitrates (Rakocy et al., 2006).

Subhendu Datta talks about Organic aquaculture as representing a new approach in fisheries development. As defined by the USDA's National Organic Standards Board (NOSB) „Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.” (Datta, 2006).

This description of organic agriculture can help us to better understand organic aquaculture. The term of organic is a very sensitive one. Organic practices cannot ensure that final products are absolutely free of residues. A purpose would be to minimize and reduce as much as possible air, water and soil pollution. The main goal of an organic food production process is to optimize the health and productivity of soil life, plants, animals and people (Datta, 2006).

Aquaculture represents the production of plants and aquatic animals under controlled conditions. There are multiple types of aquaculture systems that can combine one or more species of fish and other aquatic animals with different plants. Environmental conditions can influence conditions and species selection. Water salinity, temperature, oxygen level are probably the most important when concluding an aquaculture system. The major aquaculture systems are pond culture, cage culture, raceways, integrated and

recirculating. Every system has different characteristics that can influence the production of organic foods or not.

Are recirculating aquaculture systems revolutionary? Aquaponics represents a system that combines recirculating aquaculture with hydroponics. This could be answer to the organic aquaculture because it is gaining increased attention as a bio integrated food production system.

## 2. TYPES OF AQUAPONIC SYSTEMS

There are three types of most commonly used aquaponic systems, classified based on types of grow bed, namely nutrient film technique (NFT), floating-raft (deep water culture) and media-filled (flood and drain) (Engle, 2015).

### 2.1. Media bed technique

For small - scale aquaponics, the most popular designs are media-filled bed units (Figure 1).

Media-filled type is the simplest aquaponic system that does not require separate biofilters because it contains media (e.g., pumice stones or clay beads) in the grow bed for nitrification (Zou et al., 2016). A siphon is used to fill and drain the water in order to supply oxygen by direct contact between plant roots and the air (Bernstein, 2011). Strongly recommended for most developing regions, these designs are suitable for beginners because of their simplicity, have a relatively low initial cost and are efficient with the space. The medium is used, in media bed units, to support the roots of the plants and also the same medium has the function of a filter. Both biological and mechanical, these double functions being the main reason why media bed units are considered the simplest. Anyway, this technique of media bed might become, at a larger-scale, relatively expensive and unwieldy. If fish stocking densities exceed the bed's carrying capacity, media may become clogged and separate filtration might be needed due to this. In media beds with larger surface area exposed to the sun the water evaporation is higher. There are some very heavy media (Somerville et al., 2014).

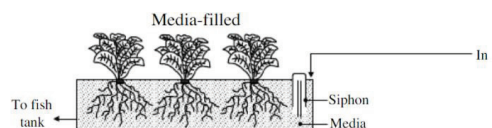


Figure 1. Media bed aquaponic system

## 2.2. Nutrient film technique

A hydroponic method using horizontal pipes each with a shallow stream of nutrient rich aquaponic water flowing through it is the NFT (Figure 2). The plants are able to use the thin film of nutrient-rich water from the top of the pipes where they are placed, within holes.

Popular methods for commercial operations, both the NFT and DWC are, when scaled up, more viable financially than media bed units.

Due to the fact that the water is completely shielded from the sun, this technique has a very low evaporation but it might not be appropriate in some locations with inadequate access to suppliers and it is far more expensive and complicated than media beds.

In urban applications, especially when some aspects such as weight limitations or vertical space are taken into consideration, this technique is proved to be most useful. NFT type provides high oxygen to the plant roots that facilitates high yield of vegetables (Somerville et al., 2014).

However, NFT is only suitable for small vegetable species because the grow bed cannot support high quantity of roots due to potential blockage of recirculating flow (Chérif et al., 1997; Engle, 2015).

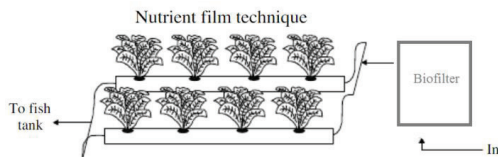


Figure 2. NFT aquaponic system design

The aquaponic systems have several common and essential components which include a fish tank, a biofilter, hydroponic containers and a mechanical filter.

Energy is used by all systems to circulate the water through the plumbing and pipes as aerating the water.

For every unit a crucial component is represented by the fish tanks and so, up to 20 percent of the entire cost of an aquaponic unit can be formed by the fish tanks cost.

In order to survive and thrive, the fish require certain conditions and consequently, the fish tank should be chosen really wisely. Several important aspects to consider are the shape, color and material (Somerville et al., 2014).

## 2.3. Deep water culture technique

Another method is DWC which requests suspending plants in some polystyrene sheets, while having their roots descending into the water (Figure 3).

For large commercial aquaponics that grow one specific crop (typically basil, lettuce or salad leaves), this method is more suitable for mechanization being also the most common.

Where access to materials is limited, this technique might not be suitable for some locations, being also, on a small-scale, more complicated than media beds (Somerville et al., 2014).

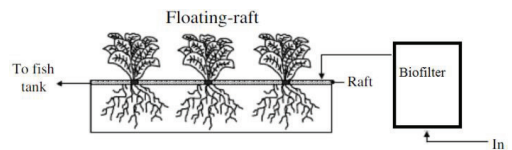


Figure 3. DWC aquaponics system

In 2006, Wilson A. Lennard and Brian V. Leonard conducted a comparison between these three subsystems. Murray Cod (*Maccullochella peelii peelii*), Green Oak lettuce, and *Lactuca sativa* were used to test for differences.

The Murray cod recorded identical feed conversion ratio and biomass gains in all the 3 subsystems. Lettuce yields also gained biomass in the following relation MFBS > DWC > NFT. Phosphate removal recorded no significant difference in the compared subsystems while nitrate removal was significantly less efficient in the NFT. In conclusion NFT is the least effective subsystem used in this test when referring to biomass gain and nutrients removal probably due to low levels of root contact with water (Wilson et al., 2006).

In 2017, another comparison was made by A.A. Forchino, H. Lourguioui, D. Brigolin, R. Pastres. The objective was to evaluate the environmental impact. The test compared two different aquaponics techniques Raft System and Media Filled Beds System using the Life Cycle Assessment. Rainbow trout (*Oncorhynchus mykiss*) and lettuce (*Lactuca sativa*) were considered as cultivated species in both systems. Functional unit (FU) was set for 1kg of produced lettuce and the trout was defined as a co-product. The ratio of production resulted in an allocation of 91.6 % for lettuce and 8.4 % for trout. Both

systems used the same fish tank and the same water input. Emissions of nitrates and phosphorus were not taken into account because they have a neutral impact on the environment as previously underlined by Foteinis and Chatzisyneon (2016). Period of the test was set to 1 year and life cycle production of the lettuce was set to 21 days. Abiotic Depletion (AD), Global Warming Potential (GWP), Acidification (AC), Eutrophication (EU) and Cumulative Energy Demand (CED) were compared for the 2 subsystems. Environmental impacts studied by A.A Forchino can be observed (Figure 4). It is conclusive that Media Filled Bed System has a higher impact on the environment. In both techniques energy consumption played a key role, electricity representing the highest energetic cost. In conclusion, energy could be saved by optimizing the water flow, growing the number beds served by each pump and lowering the number of water pumps. (Forchino et al., 2017).

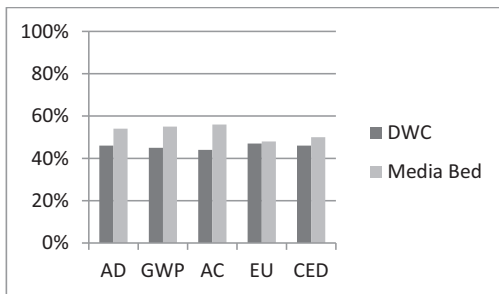


Figure 4. Comparison between DWC system versus Media-Filled Beds system using CML-IA and the Cumulative Energy Demand methods

### 3. WATER QUALITY IN AQUAPONIC SYSTEMS

Water is the most important subject to understand. It is the life-blood of the recirculating system and the medium through which the plants get the necessary nutrients and the fish receive the oxygen. There are discussed the following key water quality parameters: temperature, dissolved oxygen (DO), total nitrogen, pH and alkalinity of the water. The effects understanding of each parameter is decisive due to the fact that every parameter has an impact on all three organisms in the unit - plants, fish and bacteria. Keeping the high quality of the water in the aquaponic system is crucial. Even though some water parameters seem difficult to understand

there is simple test kit that allows the user to easily interact and control the water (Somerville et al., 2014).

As a form of integrated agriculture, aquaponics combines the techniques of aquaculture and hydroponics. The culture water is evacuated from the fish tank which contains the fish metabolic waste, passing first through a mechanical filter which retains solid waste and after that through a biofilter which oxidizes ammonia to nitrate, all of it in a continuously recirculating unit. Travelling then through plant grow beds, where the plants assimilate the nutrients, the purified water returns finally to the fish tank (Figure 5). Bacteria can convert fish waste into accessible nutrients for plants with the help of the habitat offered by the biofilter. Dissolved in the water, these nutrients can be then absorbed by the plants. Cleaning the water and preventing the water from becoming toxic due to the harmful forms of nitrogen (ammonia and nitrite), the process of nutrient removal allows the plants, fish and bacteria to prosper symbiotically. If the system is properly balanced, all the organisms work together to create a healthy environment for each other (Somerville et al., 2014).

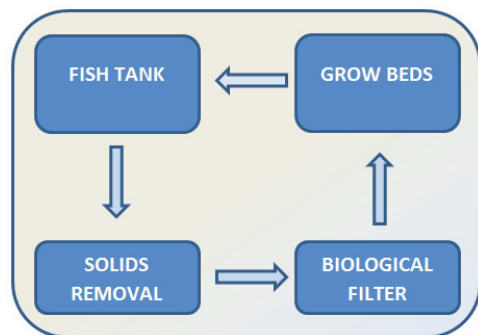


Figure 5. Aquaponic system water cycle

#### 3.1. Biofiltration

The conversion of ammonia and nitrite into nitrate by living bacteria is commonly known as biofiltration. Due to the fact that the fish waste is dissolved directly in the water and the size of these particles is too small to be mechanically removed, most fish waste is not filterable using a mechanical filter and so, aquaponic systems use microscopic bacteria in order to process this microscopic waste. Because ammonia and nitrite are toxic even at low concentrations but the plants need the nitrates to grow, biofiltration is

essential in aquaponics. Besides, the very fine solids not captured by the clarifier will be broken down by the dynamic movement of water within the biofilter and that will prevent the further waste build up on the plant roots in DWC and NFT. Still, following the design of the system developed at the University of the Virgin Islands, some large aquaponic facilities do not use a separate biofilter because they mostly rely on the units' wet surfaces, on the plant roots and direct plant uptake to have the ammonia processed. Thanks to the fact that the grow beds themselves are perfect biofilters, the separate biofiltration is unnecessary in the media bed technique. In terms of aquaponics, mineralization refers to the way that bacteria processes and metabolizes the solid wastes into nutrients for plants. Although processing these wastes differs from biofiltration and requires a separate consideration, solid wastes that are trapped by the mechanical filter contain nutrients, too. More nutrients will be added back to the plants by retaining the solids within the overall system because there are subjected to some mineralization any wastes which remains on the mechanical filters, within the biofilters or in the grow beds. If the wastes are left in place for longer, more mineralization will be allowed and a longer residence time of the waste in the filters is leading to more nutrients being retained in the system and more mineralization too. Nevertheless, if not properly managed and mineralized, this same solid waste will consume oxygen, block water flow and lead to anoxic conditions, these leading to production and denitrification of the dangerous hydrogen sulfide gas (Somerville et al., 2014).

### 3.2. Mechanical filtration

Mechanical filtration is arguably the most important aspect of the design. Mechanical filtration is the separation and removal of solid and suspended fish waste from fish tanks. It is essential to remove these wastes for the health of the system, because harmful gases are released by anaerobic bacteria if solid waste is left to decompose inside the fish tanks. Moreover, the wastes can clog systems and disrupt water flow, causing anoxic conditions to the plant roots. There are several types of mechanical filters. The simplest method is a screen or filter located between the fish tank and the grow bed. This screen catches solid wastes, and needs to be

rinsed often. Similarly, water leaving the fish tank can pass through a small container of particulate material, separate from the media bed; this container is easier to rinse periodically. These methods are valid for some small-scale aquaponic units, but are insufficient in larger systems with more fish where the amount of solid waste is relevant. There are many types of mechanical filters, including sedimentation tanks, radial-flow clarifiers, sand or bead filters and baffle filters; each of them can be used according to the amount of solid wastes that needs to be removed. A dedicated vessel that uses the properties of water to separate particles is called a clarifier. The water that is flowing faster is able to carry more particles than the water that is moving slower, usually, and consequently, the clarifiers are constructed in such a way as to slow down or to speed up the water so that to remove the particles concentrate on the bottom (Somerville et al., 2014).

### 3.3. Nitrification process

A crucial element of the whole nitrogen cycle seen in nature, the nitrification process is the most important biological process in aquaponics that transforms  $\text{NH}_4^+$  to  $\text{NO}_3^-$  in the presence of oxygen (Hu et al., 2015).

The essential chemical element for all life forms is the chemical element Nitrogen (N) which is present in all amino acids that compose all proteins, these being essential for many key biological processes for animals such as enzyme regulation, cell signaling and the building of structures (Somerville et al., 2014).

Nitrogen is an essential element for all living organisms because it is the component of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), amino acids, protein and other cell components (Pratt and Cornely, 2014).

The major source of nitrogen input in aquaponic systems is fish feed, which is excreted by the fish in the form of ammonia nitrogen (90%) (M.B. Timmons et al., 2002).

The waste produced by fish is mostly made of ammonia ( $\text{NH}_3$ ) that is metabolized by a specific group of bacteria, named nitrifying bacteria. These bacteria are very important for aquaponics because they are able to transform first the ammonia into nitrite compounds ( $\text{NO}_2^-$ ) and after that into nitrate compounds ( $\text{NO}_3^-$ ). Even if for the plants are useful both ammonia and nitrates to

help them in the growing processes, the nitrates can be easier assimilated by their roots. The process of nitrification by bacteria, which is natural and takes place in soil, similarly happens in the water, too. The fish excreta that are released in the culture tanks are the animal wastes for aquaponics. Changing the fish waste ammonia into the easily assimilated nitrate, so useful for plants, is made by the same nitrifying bacteria which live on land and will also naturally be found in the water or on every wet surface (Somerville et al., 2014).

In aquaponic systems, nitrification ensures nutrients for the plants and releases ammonia and nitrite that are toxic. In the nitrification process there are involved two main groups of nitrifying bacteria: the ammonia-oxidizing bacteria (AOB) and the nitrite-oxidizing bacteria (NOB). First, AOB bacteria change ammonia ( $\text{NH}_3$ ) into nitrite ( $\text{NO}_2^-$ ). Next, NOB bacteria transform nitrite ( $\text{NO}_2^-$ ) into nitrate ( $\text{NO}_3^-$ ). After the ammonia is oxidized (oxygen added to) by the AOB, it is created the nitrite ( $\text{NO}_2^-$ ) and further the NOB oxidize the nitrite ( $\text{NO}_2^-$ ) into nitrate ( $\text{NO}_3^-$ ) (Figure 6) (Ebeling, Timmons and Bisogni, 2006).

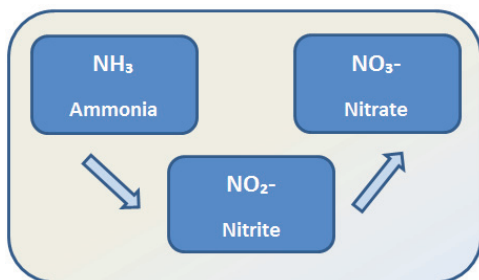


Figure 6. The nitrification process

In aquaponics the most common AOB is the genus *Nitrosomonas* and the most common NOB is the genus *Nitrobacter*. Ammonia oxidizing archaea (AOA) is responsible for oxidizing ammonia under extremely low  $\text{NH}_4^+$  concentrations (about  $2 \mu\text{g N/L}$ ) due to their physiological diversity, leading to toleration and adaptation to extreme nutrient limitations (Martens-Habbena et al., 2009). Thus, nitrification by AOA does not significantly occur in aquaponic systems (Hu et al., 2015).

As a conclusion, the ecosystem from the aquaponic unit relies totally on the bacteria. Ammonia concentrations in the water tank will

kill the fish if there are no bacteria. In order to manage the ammonia level and to keep it close to zero it is vital to maintain a healthy bacterial colony all the time (Somerville et al., 2014).

### 3.4. Water pH and temperature

An important impact on all aspects of aquaponics, mainly on the plants and bacteria, has the water pH. This controls the access of the plants to micronutrients and macronutrients. pH is a main factor that controls fish metabolism, microbial activities and affects the availability of nitrogen to plants (Kuhn, et al., 2010).

All nutrients are readily available at a pH of 6.0 - 6.5 but if this range is exceeded, the nutrients become hardly accessible for plants. A pH of 7.5 can actually lead to iron, phosphorus and manganese nutrient deficiencies. Below a pH of 6 the nitrifying bacteria experience difficulties and its capacity to transform ammonia into nitrate is reduced. Due to this, the biofiltration can be reduced and, as a result, the bacteria reduce the level of the conversion of ammonia to nitrate and so, the levels of ammonia can begin to increase, this leading to an unbalance of the system which is stressful for the other organisms. pH can be periodically adjusted by using potassium hydroxide (KOH) and calcium hydroxide (Rakocy, Shultz, Bailey, Thoman, 2004). Having their own specific tolerance ranges for pH as well, the most used fish in aquaponics have a pH tolerance range of 6.0-8.5. Due to the fact that the pH affects the ammonia toxicity to fish, a higher pH leads to higher level of toxicity. In summary, the ideal water for aquaponics has an optimum pH range of 6-7 and it is slightly acidic. The pH range of 6-7 keeps the functioning of the bacteria at a higher capacity and, at the same time, allows the plants to absorb all the essential nutrients. A pH higher than 8 or lower than 5, requires an immediate attention because such values can jeopardize the entire ecosystem (Somerville et al., 2014).

An important parameter for bacteria mainly, and for aquaponics in general, is the temperature of the water. For bacteria growth and productivity  $17\text{-}34^\circ\text{C}$  is the ideal range of temperature. The bacteria productivity will decrease if the water temperature drops below  $17^\circ\text{C}$ . The productivity can be reduced by 50 percent or even more for temperatures below  $10^\circ\text{C}$  because these low

temperatures have important effects on unit management (Somerville et al., 2014).

### 3.5. Dissolved oxygen

The essential element needed for all three organisms involved in aquaponics: plants, fish and nitrifying bacteria is the oxygen. The amount of molecular oxygen from the water is described by the DO level, which is measured in milligrams per liter. This parameter of the water quality has on aquaponics the fastest and strongest effect. In order to maintain high levels of productivity of the nitrifying bacteria, it is permanently needed an adequate level of dissolved oxygen in the water. Nitrification is an oxidative reaction where oxygen is used as a reagent and thus the reaction stops without oxygen. The most favorable levels of DO are 5-6 mg/liter to avoid the stress to fish and plants (S. Bernstein, 2011).

If DO concentrations drop below 2.0mg/liter, the nitrification will decrease. DO concentration of above 1.7 mg/L was recommended in biofilters to maintain the activity of nitrifiers (Ruiz et al., 2003). Furthermore, in the absence of sufficient DO concentrations another type of bacteria can develop and will transform the valuable nitrates back into unusable molecular nitrogen, through denitrification, which is an anaerobic process (Somerville et al., 2014).

### 3.6. Total nitrogen

The fourth crucial parameter for the water quality is the nitrogen and, as part of all proteins, it is needed for all life. Usually labelled as crude protein and measured as a percentage the nitrogen is entered, originally, in aquaponic systems from the fish feed. The fish use for their growth some of this protein. The main form of this waste is ammonia (NH<sub>3</sub>) which is released by fish through the gills and as urine. They release also solid waste, some of it being converted into ammonia by microbial activity. At certain concentrations, nitrogenous wastes are poisonous for fish but ammonia and nitrite are about 100 times more poisonous than nitrate. Even if the nitrogen compounds are nutritious for plants and they really are the basic components of plant fertilizers, they are toxic for fish. The plants are able to use all three forms of nitrogen (NH<sub>3</sub>, NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup>). Nitrate being by far the most accessible one. Ammonia and nitrite levels should be close to zero in a fully functioning

aquaponic unit, or at most 0.25-1.0 mg/liter. Almost all the ammonia and nitrite should be converted by the bacteria from the biofilter into nitrate (Somerville et al., 2014).

### 3.7. Ultraviolet light

Being photosensitive organisms, ultraviolet (UV) light from the sun is a threat for the nitrifying bacteria, especially in the case of the initial formation of the bacteria colonies, when a new aquaponics system is set up. The UV light does not pose any major problem after the bacteria have colonized a surface (3-5 days). Covering the filtration components and the fish tank with UV protective materials and making sure that the water in the hydroponic component is not exposed to the sun, at least until the bacteria colonies are fully formed, is a very simple way to remove this threat. Nitrifying bacteria are able to grow on large surface area materials being sheltered by UV protective material and having appropriate water conditions (Somerville et al., 2014).

## 4. TYPES OF FISH SPECIES SUITABLE IN AQUAPONIC SYSTEMS

There are more fish species that have recorded excellent growth rates in aquaponics units. Such fish species, which are suitable for aquaponics farming, include: common carp, tilapia, silver carp, grass carp, barramundi, jade perch, trout, salmon, largemouth bass and catfish. Worldwide available, some of these species grow especially well in aquaponics units and they are discussed more detailed in the following sections. It is crucial to appreciate the importance of the availability of healthy fish from reputable local providers when planning an aquaponic facility (Somerville et al., 2014). Some species and some production systems may prove quite difficult to adapt to a traditional „organic” system (Boehmer et al., 2005).

### 4.1. Tilapia

Blue tilapia (*Oreochromis aureus*)

Nile tilapia (*Oreochromis niloticus*)

One of the most popular freshwater species which grow in aquaculture systems worldwide are the tilapias, originary from East Africa. Resistant to many parasites and pathogens and handling well the stress, they do best in warm temperatures and are able to tolerate a wide range

of water quality conditions. In spite of the fact that tilapias can briefly tolerate extremes temperatures of the water like 14°C and 36°C they do not feed or grow below 17°C, and they even die below 12°C. Because the ideal range for tilapias, in order to ensure good rates of the growth is between 27-30°C, in temperate climates tilapias might be suitable for winter seasons only if the water is heated. For cool climates, an alternative method is to grow multiple species all year long: during the warmest season tilapia and during the winter changing to trout or carp. If they have ideal conditions, in about 6 months tilapias can grow to maturity (500 g) from fingerling size (50 g). As omnivores, tilapias feed on both plant and animal based feed and they are candidates for many alternative feeds. *Moringa olifera*, duckweed, *Azolla* spp. and other high-protein plants have been used to feed tilapias, but they must be very carefully fed in order to ensure a nutritionally complete feed. The tilapias eat other fish and this should be taken into consideration when breeding and they should be separated by size because if not, they eat their own young. Tilapias which are less than 15 cm eat smaller fish, but when they are larger than 15 cm, they are generally too slow and, due to this fact, they are not a problem anymore. In small-scale and medium-scale aquaponic systems can be easily bred tilapias (Somerville et al., 2014) (Turek Rahoveanu et al., 2018).

#### 4.2. Carp

Common carp (*Cyprinus carpio*)

Silver carp (*Hypophthalmichthys molitrix*)

Grass carp (*Ctenopharyngodon idella*)

The most cultured fish species globally at the present time, carps are originary of Eastern Europe and Asia. The same like tilapias, the carps are tolerant to poor water quality and relatively low DO levels, having a much larger tolerance range for water temperature, nevertheless. Their ability to survive at temperatures as low as 4°C and as high as 34°C, makes carps, in both temperate and tropical regions, an ideal selection for aquaponics. The best growth rates are obtained when temperatures are between 25°C and 30°C and they can grow in less than a year (10 months) from fingerling to harvest size (500-600 g) in proper conditions. When temperatures are lower than 12°C, the growth rates decrease

dramatically. Even if they are smaller than females, the male carps are still able to grow in the wild up to 40 kg and 1-1.2 m in length. They are bottom feeding omnivores, in the wild, eating a large range of foods. They prefer feeding on invertebrates such as insect larvae, water insects, mollusks, zooplankton and worms. There are some herbivorous carp species which also eat the stalks, leaves and seeds of aquatic and terrestrial plants, and decaying vegetation, too. It is easy to train the cultured carps to eat floating pellet feed (Somerville et al., 2014).

#### 4.3. Ornamental fish

Produced mainly for the ornamental fish industry rather than for food fish industry, Gold or Koi carps have also a high tolerance to a variety of water conditions being, therefore, very good candidates for aquaponic systems. Being sold to aquarium stores and individuals for considerably more money than fish sold as food, a popular choice for vegetarian aquaponic growers are Gold or Koi carps and other ornamental fish. Choosing a carp species to be cultured in aquaponics should be done, beyond the climatic characteristics and fish management issues, after a cost-benefit analysis which takes into account the advantages of culturing a fish that is bonier and usually has lower market prices than other species and consequently, less profit (Somerville et al., 2014).

#### 4.4. Catfish

Channel catfish (*Ictalurus punctatus*)

African catfish (*Clarias gariepinus*)

An extremely hardy group of fish that tolerate very well wide swings in DO, temperature and pH are the catfish. The fact that they are also resistant to many parasites and diseases makes them ideal for aquaculture. Catfish are able to be easily stocked at densities up to 150kg/m<sup>3</sup>, which is a very high value. These stocking densities require comprehensive mechanical filtration and solids removal, topics that are beyond those discussed in this material. One of many species in the *Clariidae* family is the African catfish. Air breathers, these species are ideal for aquaculture and aquaponics due to the fact that there would not be any fish mortalities in case of a sudden and dramatic drop in DO. For beginners and also for aquaponists who want to grow fish in areas where the electricity supply is not reliable, the



easiest species are catfish. If there is an adequate mechanical filtration, given the high tolerance to low DO levels and high ammonia levels, they can be stocked at higher densities. Regarding the management of the waste, it must be noted that a factor that facilitates greater mineralization is that suspended solid waste produced by catfish is less voluminous and more dissolved than catfish, as tilapias prefer a temperature of 26°C and grow best in warm water, but, the growth stops below 20-22°C in the case of African catfish. The catfish physiology is different from other fish because, even if they can tolerate well high levels of ammonia, as stated by the recent literature, their appetite might be reduced due to an internal regulatory control triggered by high levels of nitrate in their blood for nitrate concentrations higher than 100 mg/liter. Being benthic fish, the catfish occupy only the bottom portion of the tank and raising them at high densities can be affected by the fact that they do not spread out through the water. The catfish can hurt each other with their spines if the tanks are overcrowded and so, one option, when raise catfish, is to allow the fish to spread out along the bottom using a tank with greater horizontal space than vertical space. As an alternative, catfish are raised by many farmers together with another species of fish that utilize the upper portion of the tank, commonly bluegill perch, sunfish or tilapia. The catfish are also able to be trained to eat floating pellets (Somerville et al., 2014).

#### 4.5. Trout

Rainbow trout (*Oncorhynchus mykiss*)  
Cold water fish, belonging to the salmon family, trout are carnivorous fish that need colder water than the species previously mentioned. Their preferred temperature range is 10–18°C and 15°C as an optimum temperature. That's why trout are considered, especially in winter, ideal for aquaponics in Nordic or temperate climate regions. When the temperature increases above 21°C, the growth rates decrease significantly. Trout might not be able to utilize DO properly, even if available, above this temperature. Compared with tilapia and carp, trout need a higher protein diet that means adding larger quantities of nitrogen in the overall nutrient pool per unit of fish feed. While maintaining a balanced aquaponic unit, this occurrence allows for more cultivable areas of leafy vegetables.

Even though generally trout have a very high tolerance to salinity, and many varieties are able to survive in freshwater, brackish water and marine environments, yet these species need better quality of the water than tilapia or carp, especially regarding the ammonia and DO. A successful aquaculture of trout requires a frequent water quality monitoring and also air and water pumps backup systems (Somerville et al., 2014).

#### 4.6. Prawn

Giant river prawn (*Macrobrachium rosenbergii*)  
"Prawn", as term, refers to a various group of stalk-eyed freshwater decapod crustaceans with slender legs, long antenna and long, narrow, muscular abdomens that are found on the bottom of most estuaries and coastlines, as well as in freshwater systems. Their most species are omnivores and they can live from one to seven years. Commonly referred to saltwater and freshwater species, the names of shrimps and prawns are, especially in the culinary sense, often confused. Due to the fact that prawns ingest uneaten fish food, fish waste and whatever organic stuff they find in the water or on the bottom, they can be a very clever addition to any aquaponic system, helping to clean and supporting system health and accelerating organic material decomposition. Because prawns cannot be grown in densities high enough to produce adequate wastes for the plants, it is better to grow prawns and mid-water fish at the same time, in an aquaponic system. Being very territorial, the prawns need a substantial allocation of lateral space as horizontal surface area determines the number of individuals that can be raised. However, surface area and quantity could be increased by stacking layers of netting. Even if the number of individuals that can be stocked is low, there have been tested some polyculture systems with tilapia which had different degrees of success. The needs of most prawns are similar. These including warm temperatures (24-31°C), good water quality and hard water, still, these conditions need to be adjusted considering the grown species. Taking into consideration that prawns have a four-month growing cycle in ideal conditions, it would mean, theoretically, that three crops grow annually. Post-larvae prawns must be bought from a hatchery. Considering the fact that the larval

cycle of prawns is fairly complex and requires special feed and carefully monitored quality of the water, breeding prawns is recommended just for experts, even if they are easier possible on a smaller scale.

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