Polyculture of Fishes in Aquaponics and Recirculating Aquaculture

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Abstract

Polyculture of fishes (and invertebrates) in aquaponics and recirculating aquaculture is a promising way we can return advanced modern agriculture to sustainable agriculture using biological controls. Polyculture would enhance aquaponics by producing a variety of seafood products for local consumption. There has been very little published research on polycultures in aquaponics so much of this work is based on the experience of expert scientists. Because of the lack of previous studies, there is very little statistical data to present. However, it has been confirmed that redclaw lobsters are being polycultured with tilapia; they are cultured in the hydroponics raceways where the plants are grown on floating rafts. The information from the interviews indicates that using physical separation is necessary to prevent negative species interactions. The interviews also revealed that using species that feed at different locations in the water column might be an option. There may be other difficulties associated with the management of broodstock for multiple species. Overall, we need to experiment with polycultures in aquaponics to find ideal combinations that would provide beneficial biological controls.

Methodology

This project began with an initial search for documentation through the use of the UH Hilo library system. Using the key words polyculture and aquaculture in the search window in the Science Direct database produced the most relevant results. When the key words polyculture and aquaponics were used, there were no articles found. Using the former set of key words, there were about 40 articles related to polyculture, almost all of which were referring to polycultures carried out in earthen ponds. Other databases were tried also, but produced fewer and less relevant results. Searches using the key word aquaponics came up with zero results in all but the Blackwell Synergy database which contained one relevant article.

Due to a lack of information alternative sources were sought out. A subscription to the Aquaponics Journal was ordered. Use of a World Aquaculture Society (WAS) membership which includes access to the Journal of the WAS and other publications proved very useful in accessing more practical information. Several fact sheets from the Southern Regional Aquaculture Center (Texas A&M) were printed out especially those related to Tilapia and aquaponics.

At this point it became quite clear that Dr. James E. Rakocy of the University of the Virgin Islands Agriculture Experiment Station is one of the leaders in aquaponics system development and experimentation. Rakocy and his team developed the UVI system which has been duplicated worldwide. Contact was made and Dr. Rakocy agreed to an e-mail interview in the form of a few pertinent questions.

Several exchanges were made and Dr. Rakocy has contributed greatly to the findings of this research.

Rebecca L. Nelson and John S. Pade of Nelson and Pade, Inc. are co publishers of the Aquaponics Journal and consultants for the growing aquaponics industry. They have both contributed greatly to this research. Nelson and Pade provides a variety of educational tools such as DVD videos, Publications such as the Aquaponics Journal as well as books on aquaponics and recirculating aquaculture. A DVD titled "Intro to Aquaponics" was also purchased from Nelson/Pade Multimedia to be used as a source of info for this research. Rebecca L. Nelson agreed to an e-mail interview as well in the form of a few relevant questions.

The literature on this topic was insufficient to make any firm conclusions. However, when the expertise of a few very experienced scientists is taken into account, we can make some generalized hypothesis and recommendations for further research.

Results

From the available data and interviews, some general trends are recognizable. Aquaponics and recirculating systems in general are stocked at high densities (Rakocy, 2007). Not all of the species currently polycultured do well at high densities, so several can be eliminated on the basis of tolerance to crowding. Another trend in the data is the negative species interactions that occur when two or more species (or phyla) are polycultured. Negative species interactions will be magnified with intensive culture. One method of preventing negative species interactions is physical separation. An example is freshwater prawns polycultured with caged tilapia (Danaher et al); the net cage is physically separating the tilapia from the prawns, preventing any physical interactions.

Aquaponics, or the combination of recirculating aquaculture and hydroponics, essentially is a polyculture already (Rakocy). Why polyculture more than one species of fishes in the same culture water? There are many benefits of polyculture that are beyond the obvious added variety of products. Research done by the Southeast Asian Fisheries Development Center experimented with tilapia, grouper, and milkfish in polyculture with giant prawn to see the effect on growth of the luminous bacteria *Vibrio harveyi.* The study has shown that grouper *E coioides* and GIFT tilapia *O. niloticus* hybrid have much potential for polyculture with shrimp or prawns because they have an antibacterial affect on luminous bacteria and also a positive affect on shrimp survival (Tendencia et al, 2006). An important factor in this experiment was that tilapia and other finfish were grown in a 1 m^3 net pen, physically separating them from the prawns in the remaining space of a 3 m^3 concrete tank. Vibrio is a big problem with many shrimp farms worldwide, and most shrimp farms are semi-intensive monoculture. Polyculture can possibly solve many disease problems if the ideal combinations of organisms are used.

A study on polyculture of Tilapia and Australian redclaw crayfish was carried out by the Dept. of Fisheries and Allied Aquacultures, Auburn University, Alabama. What they found was that the ponds with polycultures consistently had lower yields than the controls which had only redclaw (Rouse et al, 1998). There were no signs of the tilapia preying on the redclaw. The scientists doing the experiments attributed the lower yields to the non-aggressive feeding habits of the redclaw. It was concluded that aggressive feeders such as tilapia and common carp (koi) are not suitable for polyculture with redclaw, "at least when allowed to feed freely in the pond" (rouse et al, 1998, p.344). What this means is that they may be suitable for polyculture if grown in net cages or using other means of physical separation. Experiments with tilapia/redclaw polyculture having physical separation would be helpful in determining whether there are any negative interactions besides the physical.

Another option is having the redclaw in the hydroponics tank under the plant roots. There is a farm in Guadalajara, Mexico called BoFish that opened up in early 2007. This farm is growing redclaw in the raceways where the aquaponic lettuce is grown on floating raft aquaponics (Ramos, 2007). There is not a whole lot of information on this, but what little there is says a lot. In a picture of the raceway, you could clearly see that the redclaw had not harmed the roots, rather had prevented buildup of bugs and other critters that would have harmed them. The floating rafts on the surface of the raceways must have effectively kept the redclaw from escaping. Contact was made with Carlos L. Ramos, one of the scientists at BoFish. Ramos (2007) has confirmed that the tilapia and redclaw share the same culture water; this should be considered a polyculture. Ramos (2007) mentioned that the negative effect is that organic matter can build up in the raceway, but on a positive note the redclaw eat some detritus. This is a new farm and the data they collect over the next couple years should be very interesting.

Photo taken at BoFish, Guadalajara, Mexico, showing lettuce and Red Claw Crayfish

Rebecca L. Nelson of Nelson and Pade, Inc. is an aquaponics consultant and the editor/co-publisher of Aquaponics Journal. When interviewed about polycultures in aquaponics she mentioned that she had carried out some experiments in the past. She recorded her data mostly as observations and not figures. The three tanks containing the polycultures contained redclaw/bluegill, bluegill/catfish, and goldfish/koi combinations (2007). These tanks were stocked very lightly, which is usually not the case in aquaponics. Lightly stocking the tanks would reduce nutrient output to the plants and this is undesirable. Out of the three polycultures, the best results were achieved with the catfish/bluegill combination (Nelson, 2007). Two feeds were used for this culture, a floating and a sinking form of pelleted formula. The catfish ate the feed that sank to the bottom while the bluegill browsed the water column (Nelson, 2007). The other two culture units had some problems. In the goldfish/koi tank, there was some nipping at fancy fins and this resulted in some injury and mortality. In the redclaw/bluegill tank, the redclaw all disappeared one by one. This could be due to predation, but more likely escapees since the redclaw have a reputation for climbing out of their culture vessel (Nelson, 2007).

Catfish raised with blue gill by Nelson and Pade

Dr James Rakocy is director of the UVI Agriculture Experiment Station. He has been a great help in this research and putting the facts into perspective. In a fact sheet from the Southern Regional Aquaculture Center, Dr. Rakocy has provided that polyculture can be done indirectly by having a carnivorous species in the hydroponics tank (where the plants are grown on floating rafts). The usefulness of this polyculture is that the predatory fish acts as a biological control to keep down levels of snails, tadpoles, and other small herbivorous pests. When interviewed, Dr. Rakocy maintained a position that polyculturing fishes in aquaponics would lead to many problems. The high densities would lead to negative species interactions, and more difficulty at harvest (Rakocy, Interview, 2007). The opposite effect, if you reduced the stocking rate, would be a diminished capacity to provide nutrients to the plants (Nelson, 2007). Another challenge would be having several types of fingerlings ready at regular intervals (Rakocy, Interview, 2007). This might not be a problem if the farm is near a hatchery, but if you plan on keeping your own broodstock it could be a significant expense.

Discussion

There are a few major challenges when trying to carry polycultures into aquaponics. The aquaculture part of aquaponics is intensive recirculating tank culture whereas polycultures are usually semi-intensive or extensive meaning much lower stocking densities (Rakocy, 2007). Most semi-intensive cultures are grown in earthen ponds that are fertilized to stimulate a natural algae bloom and successive growth of natural zooplankton to be the first foods for the cultured organisms (Abdelghany et al, 2002). The different species occupy separate ecological niches in the pond and there is not much species interaction. In aquaponics the stocking rate is intensive; there is a high level of interaction and the feeds are usually complete formulas for specific fish. Another factor to keep in mind is the added time and effort of stocking more than one species at regular intervals (Rakocy, 2007). In isolated locations this would mean managing broodstock for several species, which is no easy task.

Mono-culture tilapia in a recirculating aquaculture system

Why even bother with polycultures in aquaponics or recirculating systems? There are many possible benefits, but one outweighs the rest and is of significant ecological importance. Polycultures are a form of agrobiodiversity that extend into ancient times and are a key to sustainable agriculture. According to a report by Lori Ann Thrupp (2000) from the Special Biodiversity Issue of the International Affairs Journal, "The homogenization of species and of farming systems increases vulnerability to insect pests and diseases. Purely monocultural systems are highly susceptible to attack, which can devastate a uniform crop, especially on large plantations."(p. 272). Monocultures are an unnatural and unsustainable form of agriculture that has caused many disasters across the world especially after the green revolution. Aquaponics is a step in the right direction, but with further integration and agrobiodiversity would be even closer to truly sustainable and eco-friendly agriculture. With more species, and more phyla, you will have a simulated ecosystem which will have more complete cycling of nutrients and more effective biological controls.

As evidenced by the mass extinctions in the East African Great Lakes, loss of biodiversity can be devastating to entire ecosystems (Kaufman, 1992). There are intricate trophic relationships that cycle nutrients and prevent buildup of organic matter and deli-

Tilapia and freshwater prawns
(photo courtesy Dr. James Rakocy)

cate coevolutionary relationships that allow for the biological control of diseases and parasites. When the biodiversity is destroyed, so are the biological controls. That truth has led to the modern state of covering up one problem with another, until there is nothing left. Susceptibility to disease and parasites has led to the use of harmful chemical pesticides that remain in the soils and make their way into bodies of water. Monocultures deplete the soils of nutrients and chemical fertilizers leave salts that eventually make the soil too salty for most crops to grow. Hopefully we can steer the blue revolution towards agrobiodiversity and avoid the major mistakes of the green revolution. Polyculture of fishes (and other phyla such as arthropods) can increase biological controls and possibly maximize production in aquaponics.

There needs to be much more experimentation to come up with some ideal species for polyculture in aquaponics. The determining factors are evident and can lead to some generalizations. First of all, aquaponics requires that the aquaculture side of the equation be intensive which means crowding a lot of animals in a small amount of space and use of complete feeds. Tilapias are great with crowding, and can be fed organic feeds that do not include fish meal. Koi also do well with crowding, but the flesh of Koi (common carp) is less valuable than tilapia and there would need to be a good reason to grow them such as a high demand for ornamentals (Nelson, 2007). Uddin has shown that prawns can be crowded when substrate is provided, and are mostly bottom feeders (2007). Redclaw crawfish are considered freshwater lobsters and are another attractive species for polyculture, especially since they are currently being polycultured in Mexico. Negative species interactions are a problem, but this can be prevented with physical barriers such as a cage within a tank, or a subdivided tank sectioned off with netting. Using two or more species that feed at different locations in the water column is another possibility. In this case the tank might be subdivided horizontally, and the use of floating pellets and sinking pellets would provide complete nutrition to the bottom feeders and to those that eat floating pellets (Nelson, 2007).

Another form of physical separation is using more than one tank, with separate species in each tank but common culture water. This was briefly mentioned in a SRAC fact sheet on aquaponics, a carnivorous species could be grown in the hydroponics tank to act as a biological control for pests that would otherwise eat the plant roots (Rakocy, 2007). The antibacterial effects of tilapia (and other species) on luminous bacteria could still be realized because the same culture water would be used. This essentially would be another biological control and would provide ecological rewards. The multiple tanks could be set up in series or parallel, and experiments could find the optimum configuration.

The major problems with polycultures in aquaponics are surmountable. Negative species interactions can be prevented by providing physical separation of species. This would also solve problems associated with harvesting multiple species. If physical separation is in place, there should not be problems with high densities because only species that tolerate high densities would be cultured. Other species, such as carnivorous fish in the hydroponics tank, should not be densely stocked anyway so there will be no concern for their tolerance to crowding. The big problem would be maintaining broodstock for several different species, but this might not be a problem if you are near a hatchery.

Species that show much potential for polyculture in aquaponics are tilapia and freshwater prawn, but there must be physical separation or negative species interactions could be a big problem. Further, an additional carnivorous species could be grown in the hydroponics tank. Australian redclaw are being cultured in the hydroponics tanks at BoFish, Guadalajara, Mexico (Ramos, 2007). This polyculture would provide multiple biological controls, and an assortment of valuable products. Experimentation should be carried out on the feasibility and viability of tilapia/prawn polyculture in aquaponics. Species such as catfish, common carp (koi), bluegill, barramundi, trout and others that are successfully being grown out in aquaponics should be polycultured experimentally in aquaponics. Experiments should be done with and without physical separation, and with different levels of physical separation (subdivided tanks, separate tanks, etc.). As prescribed by Uddin (2007), substrates enhance the survival of prawns in polyculture and this should be experimented with in aquaponics as well. Such experiments and their findings could prove very valuable to the evolution of modern agriculture.

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