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Opinion

Marine Aquaponics: An Ocean Full of Potential for Sustainable Food Production

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Opinion

The demand for food between now and 2050 has been estimated at 70-100% over the current food supply. Conventional food production approaches demand approximately 70% of the global supply of freshwater and current open field crop production causes loss of biodiversity and increased runoff into receiving streams. Further, salinization of soils and freshwaters is an increasing problem. New food production systems are desperately needed; systems that use less freshwater and produce high quality, fresh foods. Marine aquaponic systems appear one of the options for our future food supply, but the available research is extremely limited.

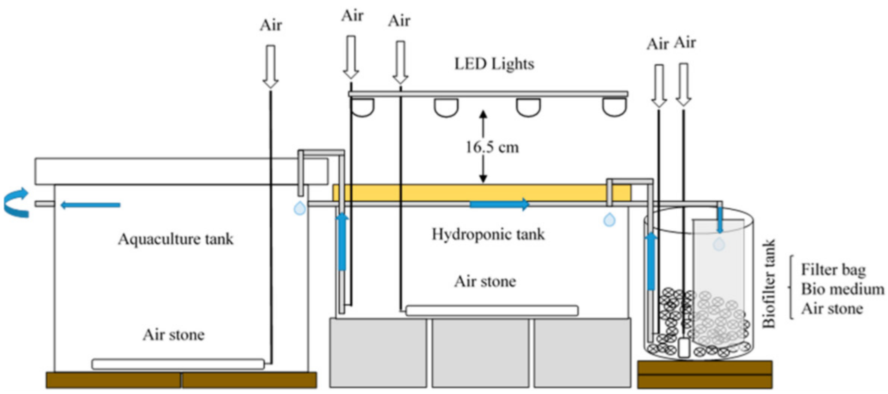

Figure 1: Schematic diagram of an aquaponic system. Blue arrows depict water flow from the aquaculture subsystem, to the biofilter, then the hydroponic tank or grow bed (Figure from Chu and Brown [1]).

Aquaponics is an integrated system in which aquatic animals are raised in one subsystem and plant crops are raised in a separate subsystem (i.e., a combination of aquaculture and hydroponic plant production, (Figure 1). Waste products from the animals serves as the nutrient source for plants. Plant uptake of nutrients then improves water quality and that water is recycled back to the animal subsystem. A third subsystem lies between the animal and plant components containing bacteria that convert excreted ammonia (the primary nitrogenous waste product from aquatic animals) to nitrite, then nitrate, with nitrate serving as the preferred source of N for many species of plants. Aquaponic systems produce more food, on less land, using less water than conventional systems and generate less environmental impact. The aquaculture component is more intensive than the more common earthen culture pond system used in most aquaculture operations and the hydroponic plant crop production is more intensive than conventional open field crop production approaches. Most aquaponic systems operate with freshwater; however, the potential for marine aquaponics is significant. This article will consider marine aquaponics as a food production system practiced indoors in controlled environments, while recognizing outdoor integrated systems are possible and can be found in the private sector [1].

Approximately 97% of the water on Earth is found in oceans, seas and bays [2], which are saline, and approximately 50% of the fish species live in marine habitats [3]. Similarly, the marine environments are host to some of the most popular crustaceans (shrimp, lobsters, and crabs) harvested as food sources. Nine of the top ten seafoods (or blue foods) are marine in origin (https://www.tasteatlas.com/most-popular-seafoods-in-the-world). Development of marine aquaponic systems offers the potential of intensive food and ornamental production of thousands of species.

Matching optimal salinity between the animals, plants and bacteria is a challenge. While the number of fish, crustaceans and mollusks in marine environments is high, saline tolerant or halophytic plants are fewer in number when compared to those intolerant of saline conditions. Clearly, several species of macroalgae are tolerant of full-strength seawater and those have been a focal point of marine aquaponics in several parts of the world. However, many potential plant crops display varying degrees of stress when exposed to high salt environments. There is a growing list of potential plant crops that are tolerant of brackish water (defined here as salinity ranging from 4 to 18ppt, or 7 to 29mS/cm when expressed as conductivity) and a growing list of animals that grow at or near maximal rates in brackish water. Bacterial populations needed in aquaponics also are impacted by salinity, commonly decreasing as salinity increases. Development of marine aquaponics may proceed with a compromise salinity in the brackish water range instead of full-strength saltwater. For inland applications, this approach will lower cost of production as supplemental sea salts are relatively expensive and a brackish salinity offers the opportunity to raise preferred and valuable animal species near major inland markets. There is a great deal of research needed to define appropriate species combinations of animal, plant and bacteria for successful operation of marine aquaponics.

Thermal consideration is another critical factor. The most common freshwater combination in aquaponics is tilapia and lettuce, which is a thermal mismatch that commonly employs a compromise temperature. Optimal temperature for tilapia is 28 °C, while optimal temperature for most varieties of lettuce is 17 °C. Marine aquaponics will likely face a similar consideration as species combinations are targeted. Ease of production coupled with production rates and economic return will likely influence species choices and compromise salinity and temperature considerations. However, optimizing growing conditions for both crops is the ideal production scenario.

Environmental pH is another factor that will likely be a compromise among taxa raised in systems. Optimal pH for marine fish is generally considered in the range of 8.1-8.4, while the optimal pH for halophytic plants is 5.4-6.8. Optimal pH for ammonia and nitrite oxidizing bacteria is 7.3-8.0. We described this challenge as the "pH conundrum" [4]. Aquatic animals tend to be tolerant of pH ranges outside optimal, but suboptimal pH for plants can reduce nutrient uptake from the environment. Using a flocponic system (biofloc is a term describing the purposeful addition and maintenance of a complex bacterial community and use of biofloc approaches in aquaponics has been termed flocponics) with Pacific white shrimp and red orache, minutina, Swiss chard, okahijiki, and kale, we identified that some plants overcame decreased growth at pH 7.5 when additional carbon was added to the system [4]. Further research is needed in the area of optimal water quality that optimizes healthy populations of all three taxa.

As production of plants and animals intensifies, disease issues commonly appear. Many of the disease issues have been identified for major crops including fish, crustaceans, mollusks and plants. Maintaining biosecurity (one of the distinct advantages for controlled environment agriculture) is a critical factor. Animals and plants must be quarantined prior to stocking into production systems and sources of crops must be carefully considered, preferably sourced from disease-free providers [5]. Treatment of diseases in aquatic animals is challenging and disease in plant crops can significantly inhibit production and market value of products. In controlled environments, disease issues should be lower than in outdoor production scenarios, but must be considered in the planning stages of development, not after diseases appear. For example, bacteria are one of the more common pathogenic taxa, yet how does one treat bacterial disease in systems containing requisite bacterial population that must be healthy? Loss of ammonia- or nitrite-oxidizing bacteria can lead to increases in these toxic compounds, significant stress on the animals and impaired nutrient uptake in plants. Genetic selection of animal and plant crops resistant to disease would be a valuable line of research [6].

Plant crops have been and are continually undergoing selection by botanists and horticulturists for varying traits. However, there has not been a line of research attempting selection of plant crops for intensive production in the unique environment of aquaponics, where water and nutrients are provided continuously. This environment is substantially different from soils in terms of moisture availability and nutrient concentrations, but more similar to hydroponic plant crop productions; similar, but not identical. Similarly, there has been relatively little genetic selection for aquatic animals raised in aquaponic systems. The Genetically Improved Farmed Tilapia (GIFT) may be the most successful genetic selection line of research with fish and reports conclude the benefits of fast growth are realized in controlled environment aquaponic systems. Further, they are tolerant of brackish water. Genetic selection programs are underway with several additional marine species including red sea bream, gilthead sea bream, Asian seabass, rainbow trout, Atlantic salmon, Pacific white shrimp, abalone, and pearl oysters, among others. The species combinations that have been evaluated to date are in Table 1. This summary only represents studies conducted in controlled environments and does not include the wealth of published information on outdoor systems such as Integrated Multitrophic Aquaculture (IMTA) evaluations. Given the number of potential species combinations, this is simply a drop in the ocean [7].

Table 1: Species combinations evaluated for marine aquaponics.

Note: Summaries are those that evaluated coupled aquaponic systems operated in controlled environments.

Animal	Plant	Salinity	Reference
Tilapia (*Oreochromis niloticus x O. aureus*)	Broccoli (*Brassica oleracea*), kohlrabi (*Brassica oleracea var. gongylodes*), beets (*Beta vulgaris*), Swiss chard (*B. vulgaris*), ruby chard (*B. vulgaris*) basil (*Ocimum basilicum*), celery (*Apium graveolens*), chives (*Apium graveolens*), lettuce (*Lactuca sativa*), and mint (*Mentha spp.*)	2.4	[5]
European sea bass (*Dicentrarchus labrax*)	Sea aster (*Tripolium pannonicum*), minutina (*Plantago coronopus*), and samphire (*Salicornia dolichostachya*)	16	[6]
Platy (*Xiphophorus sp.*)	Sea purslane (*Sesuvium portulacastrum*) and saltwort or okahijiki (*Salsola komarovii*)	13-17	[7]
Pacific white shrimp (*Litopenaeus vannamei*)	Red orache (*Atriplex hortensis*), okahijiki (*S. komarovii*), and minutina (*P. coronopus*)	10, 15 and 20	[1]
Sea bream (*Sparus aurata*)	Rock samphire (*Crithmum maritimum*)	8, 14, and 20	[8]

Most of the water on earth is saline, food demand is increasing and the preferred blue foods among consumers are largely marine in origin. Adoption and development of marine aquaponics is a logical addition to our current food production complex. Given the numbers of potential species and species combinations, there is a great deal of research needed to realize this potential [8].

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