Integrated Multi-Trophic Aquaculture and the Future of Food

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This article asserts the thesis that 1) the rapid development of aquaculture is the only way to avert future world hunger, 2) the only form of food production that can accommodate this large world population growth is integrated multi-trophic aquaculture (IMTA), 3) to develop IMTA food production on this scale, it will be necessary to eliminate the regulatory barriers that impede entry of new aquaculture ventures, and 4) even if technical and regulatory obstacles can be overcome, large-scale IMTA will not emerge unless sufficient capital is allocated to finance the new business enterprises that are necessary.

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Increasing Food Demand

According to the United Nations another 2.9 billion people must be fed in the world by 2050. In addition, the rising middle class in developing countries is creating new demand for animal protein. The salient question is: where will the new food come from to meet the rapidly emerging demand?

The Bren School of Environmental Science and Management (University of California at Santa Barbara) has concluded that production of this additional demand for food by conventional agriculture would generate an unacceptable level of greenhouse gases, exceed the global fresh water supply and require new land the size of South America. Because the supply of arable land is shrinking, not expanding, the world cannot farm its way out of hunger. World fisheries are at their sustainable limits. For these reasons, terrestrial agriculture and natural fisheries cannot supply the large amounts of animal protein that will be required soon.

Dean Steve Gaines of the Bren School reports that good aquaculture that minimizes social disruption and environmental damage produces animal protein with the least environmental impact of any other form of animal production by a wide margin. Scientists at Bren also calculate that the amount of ocean surface required to produce sufficient amounts of farmed fish is equivalent to only the area of Lake Michigan. Therefore, ocean space is unlikely to limit the expansion of fish and shellfish production.

Unfortunately, growth of conventional aquaculture now faces major regulatory and capital constraints. Given these constraints, one must ask: where will the protein needed to feed future occupants of our planet come from? Even if regulatory constraints are removed, another critical question is: where will we get the financial capital to build the facilities to produce this large amount of fish and shellfish? Consider the alternative.

Global consumption of animal protein averages 63 kg per capita annually. At this level of consumption, we will need to produce 200 million t more edible fish protein per year to feed the world population in just over 30 years. Assuming a generous 50 percent fillet yield, an annual production of 400 million t more fish will be required. This necessary increase in production cannot be achieved by present aquaculture systems. With an average protein retention of 20 percent for many aquaculture species, 2 billion t more plant protein will be needed annually to feed this amount of fish. Assuming 50 percent protein in these grain products, the new additional plant protein required will be 4 billion t more than is now produced annually.

If advances in fish and shellfish genetics and the science of fish nutrition advance to allow grain to supply all necessary protein in fish feeds to fill this need, it is unlikely that terrestrial agriculture can produce sufficient amounts of grain. Global grain production in 2012 was 2.2 billion t, increasing at an average of 1.3 percent per year. If this growth rate continues over the next 32 years, world grain production would be 3.7 billion t or 1.5 billion t more than is currently being produced. Even with these favorable assumptions, this increase falls far short of the new required amount of 4 billion t of grain to feed the new fish production. These approximate calculations are likely to be optimistic and understate the amount of grain protein that will be necessary to produce the volume of fish and shellfish the world will require.

To fill the global demand for additional animal protein, aquaculture will have to 1) produce seafood protein from lower amounts of plant protein in feeds through improvements in nutrient retention, 2) lower costs of production so that consumer prices are affordable, allowing aquaculture products to compete with other animal proteins, and 3) reduce greenhouse gas emissions (including from transportation) to acceptable levels. There is only one way meet these requirements.

Integrated Multi-Trophic Aquaculture (IMTA)

In recent years much attention has been devoted to IMTA production. These systems are designed to use waste metabolic products of the main species being cultured as a nutrient source to grow other species. For example, dissolved ammonia and carbon dioxide released from metabolizing aquatic animals can become nutrients for aquatic plants located nearby. These plants then become commercial crops for sale or become feed for aquatic animals within the system. This cycle mimics nature.

In IMTA systems, nutrients are recycled to grow multiple species of plants and animals. This nutrient recycling provides greater use of feed inputs into the system. For example, mussels and macroalgae grown near salmon net pens capture suspended solids and dissolved nutrients to produce two additional commercial crops.

Further refining this concept, multiple species of plants and animals can be grown in land-based contained systems where the plants that produce protein are fed to fish and shellfish and metabolites discharged by the animals fertilize the plants. Nutrients imported into the system can be protein-based pellets for fish or dissolved fertilizers for plants. Nutrients cycle back and forth between plants and animals. Metabolic products of one species become nutrient sources for others. Protein retention in the system then increases and a greater percentage of input nutrients are eventually exported from the system as valuable crops. IMTA is considerably more efficient than conventional aquaculture.

If IMTA systems can be designed to achieve 80 percent protein retention, the future global need for 4 billion t of grain protein can be reduced to 1 billion t. For an IMTA system providing 80 percent protein retention, feed costs would decrease to $0.17/kg of fish produced and total costs would decline to $0.40/kg. This is a major cost reduction to a level close to costs of production for other animal proteins.

A conventional single-animal aquaculture system with an assumed level of 20 percent protein retention releases 80 percent of the feed inputs to the environment. By contrast, an IMTA system with a hypothetical 40 percent protein retention wastes only 60 percent of the nutrients in feed. As a result, protein inputs to this new system produce twice as much animal protein as in conventional aquaculture systems. In short, IMTA yields much more protein with much less waste.

Similarly, an IMTA system with 60 percent overall protein retention wastes only 40 percent of imported nutrients. For the same nutrient inputs as the conventional system, the IMTA system with 80 percent retention efficiency will further reduce waste. At this level of protein retention, a given amount of nutrient inputs into conventional aquaculture systems produces four times as much animal protein when used in an IMTA system.

Figure 1 shows the relationship between nutrient waste and retention as retention increases. If IMTA systems can be designed to achieve 80 percent protein retention, the future global need for 4 billion t of grain protein can be reduced to 1 billion t of additional plant protein. This is a profound difference of global importance.

Economic Impact

If consumer prices of seafood are to approach other forms of animal protein such as beef, pork and poultry, total growing, processing and distribution costs for aquaculture products must be reduced. We cannot expect widespread consumption of aquaculture products at current consumer price levels that are uncompetitive with other animal protein sources. In most forms of fish production, feed accounts for over half the cost of production. If we can reduce overall feed costs in aquaculture production systems, we can reduce total costs of fish protein to consumers.

For example, assuming that feed accounts for 75 percent of total farm-gate production costs in a conventional single species aquaculture system with 20 percent protein retention and assuming the total cost to grow fish is $0.91/kg, feed costs are $0.68/kg of fish. All other growing costs would be $0.23/kg. In contrast, with an IMTA system providing 80 percent protein retention, feed costs would decrease to $0.17/kg of fish produced and total costs would decline to $0.40/kg. This is a major cost reduction to a level close to costs of production for other animal proteins.

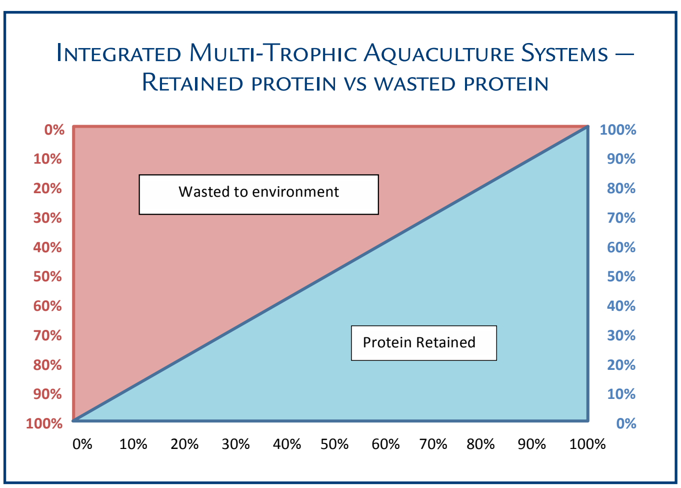

FIGURE 1. *Percent protein retention in products*

Capital Required to Produce the Additional Amount of Fish

In my recent book *AQUACULTURE: Will it rise to its potential to feed the world* ?" I roughly estimate the capital to build aquaculture facilities, with concomitant feed milling, processing and other infrastructure, requires an average of $4.50/kg of production capacity or $4,500/t. This capital cost may be higher or lower depending upon the species grown and facility location, but these capital costs are useful assumptions for this analysis.

For the additional 400 million t more annual fish production required, approximately $1.8 trillion of new capital must be allocated to aquaculture over the next 30 years. This is admittedly a rough approximation. Over the next 30 years, this necessary investment will average $60 billion annually in new plant and equipment. Although this is a large amount of capital needed to build new facilities and related infrastructure, it is a small amount compared to the US total domestic investment in plant and equipment. In 2016 that figure was $1.6 trillion. This number is confined to the US economy. Much of the capital required for new aquaculture likely will be financed in foreign economies. While large, the amount of new capital should not be limiting.

Aquaculture and the Poultry Revolution

Aquaculture is following the path of broiler production in the US during the last half of the 20th century. In 1950, 12 to 15 weeks were required to grow a broiler chicken to market size. At the end of the century, it was reduced to five weeks. Broilers were formerly a high-cost but are now a low-cost source of animal protein.

The following four factors brought about this dramatic change:

- Selective breeding for fast growth.
- Contained environmentally controlled husbandry with the elimination of competing animals for feed from outside the culture system, along with elimination of disease vectors.

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- Veterinary medicine to foster good animal health with disease prevention and treatments to accommodate high-density culture and rapid growth.
- Advanced nutrition with feed formulations using low-cost ingredients while supporting fast growth and optimum health.

Aquaculture products are now high-cost animal proteins just as broilers were 65 years ago. Aquaculture needs to produce animal protein at a low cost. The following four factors will bring this change. They are almost identical to the factors that brought the poultry revolution.

- Continued development in genetics with selective breeding for faster growth, disease resistance, and utilization of a greater proportion of low-cost plant protein from grains in the diets of aquatic animals.
- Improved husbandry in IMTA systems with higher feed protein utilization to bring lower costs along while discharging less polluting waste.
- Advancements in veterinary medicine to further reduce mortalities and foster higher-density culture.
- Advanced nutrition employing lower-cost feed ingredients to support fast growth along with alternative feed commodities to replace costly fishmeal.

Constraints to be Removed

There are three major reasons why aquaculture development in the U.S. and some other developed counties has been constrained: 1) regulatory barriers-to-entry at various levels of government, 2) an adverse public image that discourages consumers, regulators and investors, and 3) a lack of investment capital.

There are various solutions to overcome these constraints to aquaculture development, including:

- Developing a compelling social need for aquaculture in the US and the world with a strong social license to operate. This has already happened in Mississippi (USA), New Brunswick (Canada) and France where the production of catfish, salmon and oysters has flourished while in neighboring areas it has not.
- Developing support for aquaculture at all levels of government as is the case in Maine, Mississippi and Hawaii. These are by far the three highest production aquaculture states in the US. Their good examples show us the way forward.
- Informing the public that aquaculture is the most environmentally sustainable from of wholesome and nutritious animal protein production and that there is a compelling need for IMTA.
- Altering the flow of domestic savings in the US to stimulate greater investments in aquaculture and other forms of innovation. Our tax-favored system of retirement savings has greatly inhibited flows of capital into innovative enterprises such as those for farming fish and shellfish.

The Future of Food

Integrated multi-trophic aquaculture is the future of food. It is the best, and perhaps sole, means to feed animal protein for our rapidly growing global populations in an economically and environmentally sustainable manner.

The volume of plant protein that can be grown in terrestrial agriculture is limited. Therefore the supply of feed for aquaculture production is limited. As I have illustrated, however, the feed supply issue is potentially solvable through IMTA. The need for capital investment may not be solvable. My major concern is how aquaculture entrepreneurs can acquire sufficient capital to stimulate growth to a scale sufficient to avoid a global food disaster.

Capital sources for small innovative aquaculture enterprises barely exist. In the present financial structure of the US, well established corporations have access to sophisticated capital markets but small innovative companies do not. Big corporations rarely pioneer disruptive business activities like IMTA. That is the role of visionary and able entrepreneurs.

My book explains the reasons why capital is unavailable to innovative aquaculture ventures. The present paucity of capital in the wealthiest nation in the world is a major failure of our economic system. If left unresolved, it will continue to be a barrier to the development of aquaculture and therefor to the future of food. The fate of IMTA lies in the hands of small entrepreneurial enterprises that must lead the way in building a large-scale industry.

The capital barrier must be eliminated if IMTA is to achieve its potential.

The capital shortage problem is exacerbated by the erroneous negative public image of aquaculture as environmentally unsustainable. That misperception negatively impacts investors and must be corrected.

IMTA is positioned to fulfill compelling global needs for animal protein because it 1) produces considerably more animal protein per unit input of plant protein, 2) has the potential to lower production costs for fish and shellfish to levels competitive with other animal proteins, and 3) preserves our planet. In my view, most other forms of aquaculture will have difficulty competing economically and environmentally in the future with IMTA. It brings a powerful change to animal protein production and will bring affordable and nutritious food to the world's rapidly growing population at costs comparable to other animal proteins.

If not IMTA, then what form of animal protein production will do this? Consider the alternative. It is the future of food. The need for large scale IMTA is compelling. With IMTA, people in an otherwise hungry world will enjoy more healthy and peaceful lives.