FEEDING BOTH POND AND FISH: A PATHWAY TO ECOLOGICAL INTENSIFICATION OF AQUACULTURE SYSTEMS

By Olivier Joffre and Marc Verdegem

The nutritious pond concept is a novel approach that enables the pond itself to contribute significantly to the diet of the farmed fish/shrimp. Our research shows that feeding the pond by balancing the carbon-to-nitrogen ratio can increase the contribution of naturally occurring food in the diets of the cultured animals, thus enhancing reliance and reducing production costs and environmental impact. Field trials are currently being conducted in Vietnam and Bangladesh to better understand nutrient transfer in aquaculture ponds. The results of these trials will inform the development of products for fish farmers that have high potential for scaling to other developing countries.

Shrimp farmer applying carbohydrate to stimulate microbial activity in the pond, in turn enhancing mineralisation of wastes

Introduction

Aquaculture is one of the fastest growing food production sectors in the world and now provides more than 50% of the fish and shellfish consumed globally. This growth is predicted to continue in the coming years. However, the sector is highly dependent on agricultural crops and wild fish for feed as well as freshwater and land resources for inland aquaculture. At the same time, scientists and policy analysts have raised concerns about the environmental impact of such growth and the need to steer the sector toward more resilient and sustainable production.

As aquaculture has expanded and intensified, so has its dependence on natural resources. Future growth will depend on the sector's ability to overcome this dependence, and increase feed supply while mitigating environmental impact. Research on the impact of aquaculture on surface water quality and greenhouse gas emissions shows that aquaculture is lagging behind livestock and agriculture (Zhang et al. 2015). This is despite significant improvements in recent decades in aquaculture system efficiency through, for example, the reduction and replacement of fish meal and fish oil in diets. At present, however, feeding systems target the cultured animals with little attention paid to the possible contribution of the pond ecosystem and its food web to the animals' diet.

What is a nutritious pond?

In a typical aquaculture production system, the food web (i.e. the food chain within the pond, from phytoplankton, microbes and other organisms through to the fish or shrimp cultured in the pond) is stimulated by uneaten and undigested feed, which essentially acts as an expensive fertiliser in the pond.

This fertiliser is not designed to be efficient for the pond ecosystem, as its nutritional composition is aimed at fish or shellfish and not the other pond organisms. This creates imbalances in the system and in the nutrient cycles. The recycling of animal waste becomes suboptimal, making the pond environment unhealthy and vulnerable to disease. In general, farmers around the world, and especially in developing countries, use a variety of probiotics, prebiotics and other additives to mitigate these imbalances, increasing the production cost without necessarily achieving the desired outcomes.

One solution is a system that feeds both the pond and the cultured animals, limiting imbalances in the nutrient cycles

by producing wastes that are easily decomposed. As a result, mineralisation is fast, the production of natural foods for the animals is optimal, waste accumulation is minimised and the pond environment stays clean and healthy. This is the idea behind the nutritious pond concept, which aims to harness the potential of a largely untapped resource: increasing the harvest of pond nutrients via the food web and turning waste into food for the animals. It is an approach that could, in theory, be scaled to a large number of semi-intensive production systems as it is estimated that more than 60% of all finfish and shrimp comes from these systems. Such an approach would support the intensification of aquaculture while minimising environmental impacts.

The microbial food web is influenced by modifying the dietary macronutrient composition of the feed, e.g. crude protein, fat, starch and non-starch polysaccharides. If nutrients are immobilised in the food web, fewer accumulate in the sediment, reducing the denitrification process and increasing the loss of valuable nitrogen. At present, nutritious pond feeds mainly focus on raising the carbon-to-nitrogen (C:N) ratio in the pond in order to maintain fast recycling of the waste. An advantage is that carbon-rich ingredients are cheaper than nitrogen-rich ingredients, thus reducing feed costs.

Checking shrimp (P. vannamei) growth in a nutritious pond system

Research on feed and nutrient cycles in ponds is limited. There is also limited knowledge on how fish growth relies on feed directly and how it is influenced indirectly by the stimulation of natural food production. Our research is helping to fill that knowledge gap.

How are we developing the concept into a product?

The nutritious pond project is a five-year research initiative funded by the Netherlands Organization for Scientific Research (NWO) and the WorldFish-led CGIAR Research Program on Fish Agri-Food Systems. It involves a multi-stakeholder approach to embed fundamental and applied research along with product design to adapt the new feeding system to the local technological, social and institutional context.

The project is developing the concept using shrimp *(P. vannamei)* in Vietnam and genetically improved farmed tilapia (GIFT) in Bangladesh aquaculture systems as a model, and an innovation platform to design the technology in order to facilitate its uptake by the sector. Hence, the project involves industry (Nutreco in the Netherlands, Skretting and Viet Uc in Vietnam), universities and research organisations (Wageningen University & Research in the Netherlands, Can Tho University in Vietnam and WorldFish, an international non-profit research organisation based in Malaysia) as well as Vietnamese and Bangladeshi farmers. Additional external stakeholders from the Vietnamese aquaculture sector (international NGOs, certification bodies, extension officers and private sector actors) are also members of the innovation platform and provide feedback during the design process.

Fundamental and applied research conducted by PhD students in Wageningen is shared with members of the innovation platform to inform the design of on-farm trials in *P. vannamei* semi-intensive systems. The fundamental research investigates the natural production of essential fatty acids (a crucial but expensive component of fish feed) by algae in the pond, and the utilisation of this natural food source by the shrimp. Another area of research is the quantification of different paths for nutrient transfer in the pond. We are investigating the direct contribution of formulated feed to animal growth and the importance of the natural food produced by the pond itself and how this contribution changes with different C:N ratios. Findings from this research ultimately aim to improve feed formulation by valorising the contribution of natural foods to shrimp production in semi-intensive ponds.

Finally, a PhD student based at Can Tho University is looking at the interactions of algae and bacteria to find ways to balance their ratio for optimal biological processes in the aquaculture environment. The research is also testing the response of the pond to different types of carbohydrate, the application form and application frequency.

Members of the innovation platform are made up of farmers, researchers, NGOs, extension officers and private sector actors

This array of research, which is providing deep insight into pond ecology and nutrient transfer, is shared with and discussed by different stakeholders involved in the innovation platform to design new protocols for on-farm trials. Platform members defined their requirements and expected performance to evaluate the trials. Since the beginning of the project in 2016, four different formulations combining pelleted feed and different types of carbohydrate (molasses, cornstarch, a mix of rice bran and cassava, or cassava on its own) have been tested in semi-intensive shrimp ponds in Vietnam. In Bangladesh, on-farm testing was performed on GIFT, and the nutritious pond feed was designed as a single pellet with a higher carbohydrate content.

Farmers in Bangladesh check tilapia grown in household ponds using a nutritious, high C:N ratio feed

Results and evidence for a new feeding system

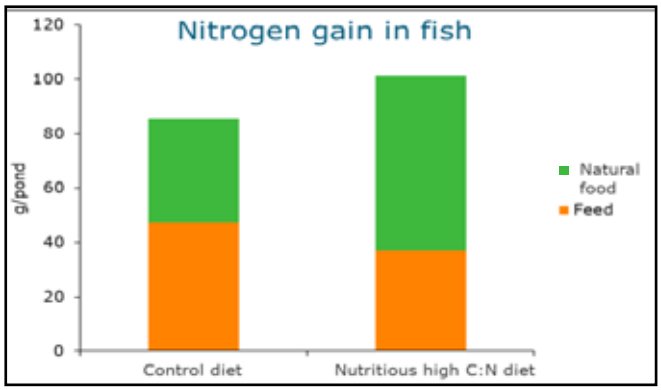
Research in a controlled environment (mesocosm tanks) provided key insights on pond ecology and nutrient transfer. For example, we tested two types of feed: a conventional shrimp diet and a concept diet that did not contain any fish oil or fish meal. An analysis of the weight of organic matter (grams) at the start and end of the experiment in the different components of the pond's food web indicated that the nutrient transfer was not efficient.

Simulated rearing mesocosm tanks at Wageningen University & Research (WUR), allowing a full nutrient budget to be made considering the cultured animals, water column, sediment and periphyton

The experiment showed that only a small 18% of organic matter ends up as shrimp organic matter, and the rest ends up in the food web. The experiment also showed that shrimp fed a diet without fish meal and fish oil sourced at least 31.5% and 6.2% of their total EPA-gain and DHA-gain (two major types of omega-3 fatty acids) respectively from the algal-based food web. This tells us that, if well managed, a **pond's primary production can significantly contribute to the shrimps' requirement for highly unsaturated fatty acids, indicating that feed formulation could be optimised for this (expensive) dietary component.**

The results also showed that **lowering the dietary protein-to-energy (P:E) ratio below the known optimal ratio does not affect fish productivity.** The concept diet contained only 24% protein and 3% fish meal. In conventional feeds, this is typically between 30-35% protein and 10-15% fish meal. These results were tested in semi-intensive tilapia ponds in Bangladesh (Kabir et al. 2018). Using a low-protein diet, the yield was 21% higher compared to the conventional diet. Analysis of the nutrient transfer in the pond showed that 64% of the growth recorded was achieved from natural food produced by the pond. The analysis also showed that it is possible to manage more than 85% of nitrogen retention in a pond by optimising the P:E ratio of the pond and diet (Figure 1).

Figure 1: Nitrogen gain in fish fed a control diet or a high C:N diet



Nitrogen gain in fish fed a control diet or a nutritious, high C:N diet shows 19% higher retention with the latter (Kabir et al. 2019)

Manipulating the C:N ratio required some empirical tests on *P. vannamei* semi-intensive systems. Our research **showed that a feed load reduction of 20% combined with a C:N ratio of 12, yielded a similar final shrimp weight as in control ponds where 100% of the feed load was applied.** These results directly informed the design of experimental field trials in Vietnam. Some innovation platform members questioned the type of carbohydrate used. Tests in a controlled environment showed that cornstarch yielded significantly higher shrimp production, survival rate, growth rate and a better feed conversion ratio (FCR) than cassava powder. These findings were incorporated in the field trial design.

The results of the trials, conducted annually in a limited number of ponds (three) and control ponds in the Mekong Delta, confirmed the tests in controlled conditions. In on-farm conditions, we were able to raise productivity, lower input costs and increase financial returns from the pond by **reducing the feed load by 10–20% while maintaining a C:N ratio of 12 by adding an external source of carbohydrate.**

The nutritious ponds also displayed a more stable environment than the control ponds, allowing a longer growth period and minimising early disease symptoms. This, in turn, reduced the use of probiotics and other additives, resulting in average financial savings of 10–15%.

The way forward

In a recent study using life cycle assessment to compare the environmental impact of different aquaculture production systems, Henriksson et al. (2018) noted that producing more fish using less feed would result in some of the largest improvements in the environmental performance of most aquaculture systems.

The nutritious pond project has provided evidence that feeding the pond as well as the animal can produce more animal protein with less feed. Now entering its final phases, the project expects to translate its findings into new commercial products such as low-protein feed and culture protocols.

This type of feeding regime has high potential for scaling in developing countries, where aquaculture systems are not intensive and the cost of inputs hinders transition toward more intensive systems using pelleted feed. We believe that this new type of feed management can contribute to the ecological intensification of aquaculture systems, particularly in Africa, where low-cost (but high-quality) feed is required to support the intensification and overall growth of the sector.

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This article is a short summary of research outputs conducted by the authors and three PhD students: Devi Hermsen, Kabir Kazi and Tran Huu Tinh. This work was undertaken as part of the CGIAR Research Program on Fish Agri-Food Systems (FISH) led by WorldFish. The program is supported by contributors to the CGIAR Trust Fund. Funding support for this work was also provided by the Netherlands Organization for Scientific Research (WOTRO) and Science for Global Development (NWO-WOTRO).