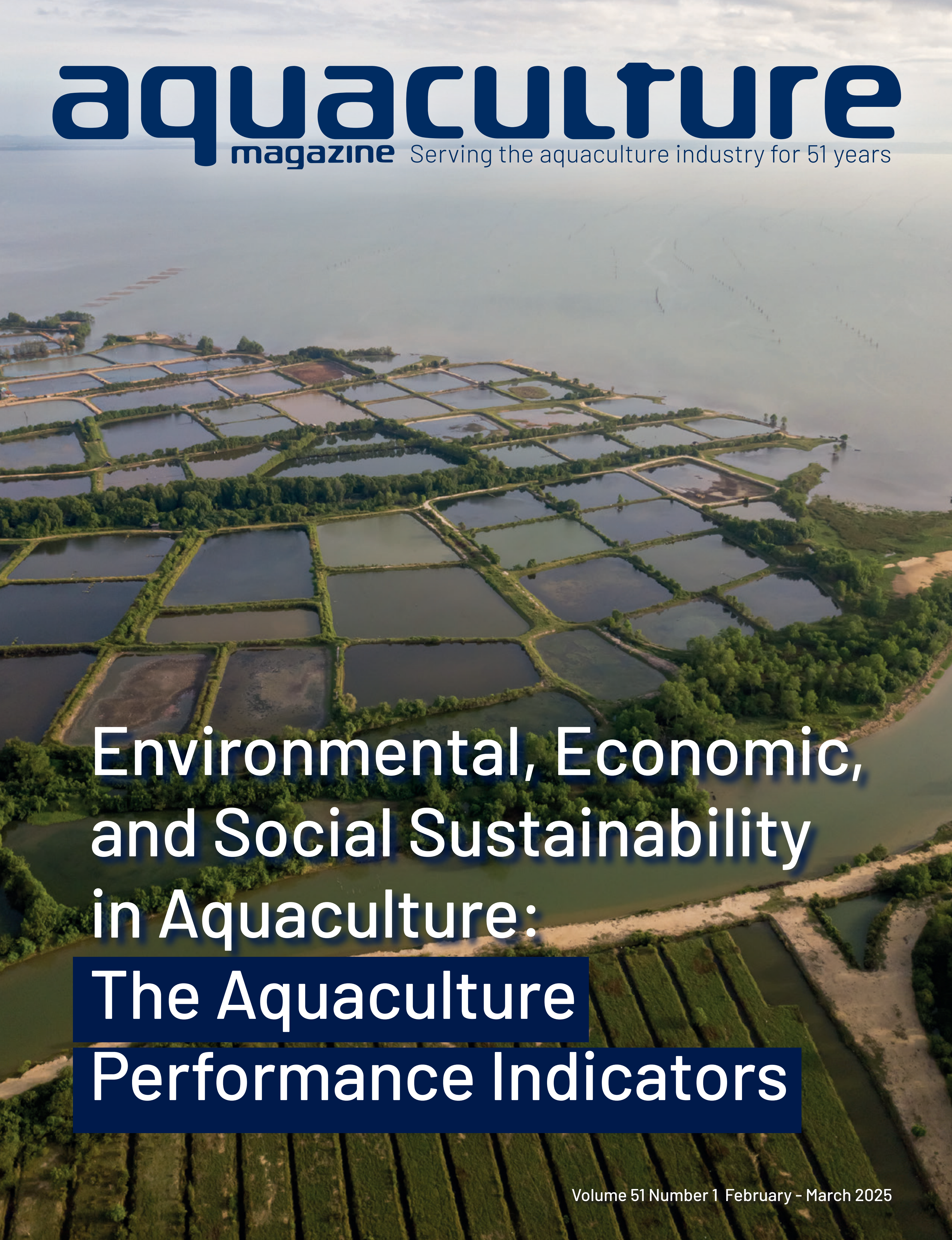


aquaculture magazine
Serving the aquaculture industry for 51 years

Environmental, Economic, and Social Sustainability in Aquaculture: The Aquaculture Performance Indicators

Volume 51 Number 1 February - March 2025

index

Volume 51 Number 1 February - March 2025

aquaculture magazine

Serving the aquaculture industry for 51 years

Editor and Publisher
Salvador Meza / info@dpinternationalinc.com

Contributing Editor
Marco Linné Unzueta

Editorial Coordinator
Karelys Osta / edicion@dpinternationalinc.com

Editorial Design
Perla Neri / design@design-publications.com

Sales & Marketing Coordinator
crm@dpinternationalinc.com

Sales Support Expert
sse@dpinternationalinc.com

Operations Coordination
Johana Freire / opm@dpinternationalinc.com

Business Operations Manager
Adriana Zayas / administracion@design-publications.com

Subscriptions: iwantasubscription@dpinternationalinc.com

Design Publications International Inc.
401 E Sonterra Blvd. Sté. 375
San Antonio, TX. 78258
info@dpintertnatinonalinc.com
Office: +210 5043642
Office in Mexico: (+ 52)(33) 8000 0578 - Ext: 8578

Aquaculture Magazine (ISSN 0199-1388) is published bi-montly, by Design Publications International Inc.
www.aquaculturemag.com

editor`s comments

✱ Marco Linné Unzueta
Associate Editor

Biotechnologies: Development and Research to Challenge Production

The development of aquaculture biotechnologies is guided by various factors, including specific objectives, the type of producers, species acceptability, and commercial potential. Additionally, these advancements depend on the availability of productive inputs and support services, the scale of production, species-specific biological and ecological requirements, and the intended market. Economic profitability, investment considerations, and environmental sustainability also play a crucial role, all of which are reflected in a particular level of technological or biotechnological development.

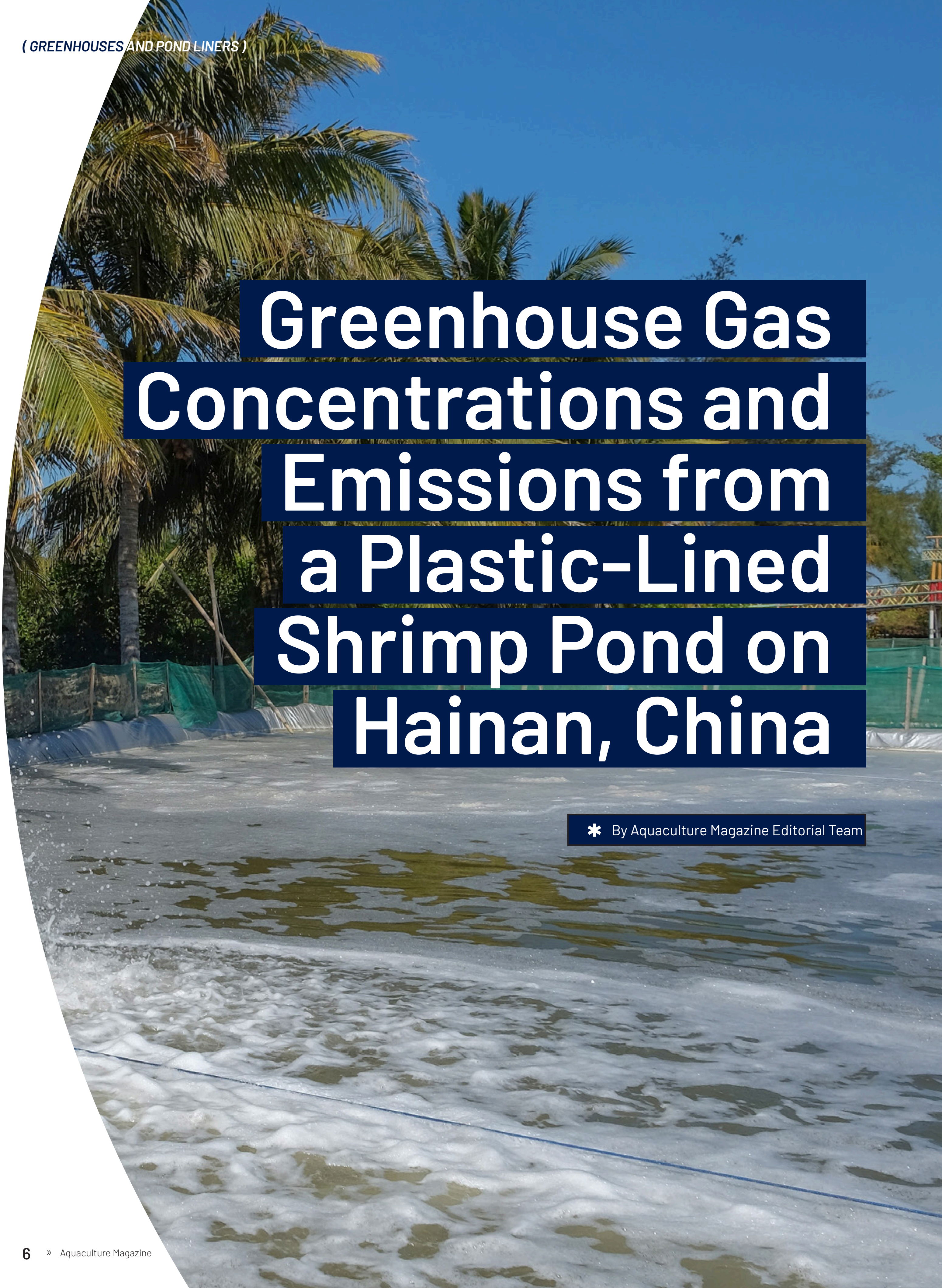
The process of developing aquaculture biotechnologies for any species begins with generating scientific knowledge about the species' biology, life history, and environmental requirements. Given its multidisciplinary nature, aquaculture integrates expertise from various fields, including engineering, hydraulics, pathology, nutrition, and physiology, to establish optimal production processes. However, the extent of biotechnological development varies significantly among species of commercial interest.

Some aquaculture systems have achieved full control over all stages of a species' ontogenetic development, reducing dependence on wild stocks for broodstock or juvenile supply. Conversely, in incomplete-cycle cultures, specimens are sourced from the wild at various developmental stages—typically juveniles for growout to market size or broodstock for reproduction. These systems remain heavily reliant on wild populations. Nevertheless, closing the culture cycle in such systems is a priority to enhance sustainability and production stability. Achieving this requires continued investment in research, resource allocation, and technological advancements while ensuring the conservation and protection of natural aquatic resources.

In essence, aquaculture biotechnology aims to optimize growth rates, minimize mortality, and control biological and environmental variables while maintaining cost efficiency. The field demands a high degree of interdisciplinary knowledge to develop specific biotechnologies tailored to each species' unique biological traits.

Many species remain at a pilot-stage level of biotechnological development, even if not formally designated as such. Due to varying levels of technological advancement across species, it is crucial to analyze and characterize these biotechnologies systematically. Such assessments provide valuable insights into the degree of control over production processes, the scale of implementation, and their potential for commercial expansion and investment decision-making.

Advancing aquaculture biotechnology is essential for enhancing production efficiency, reducing environmental impact, and ensuring long-term industry sustainability. aqm



Greenhouse Gas Concentrations and Emissions from a Plastic-Lined Shrimp Pond on Hainan, China

✱ By Aquaculture Magazine Editorial Team

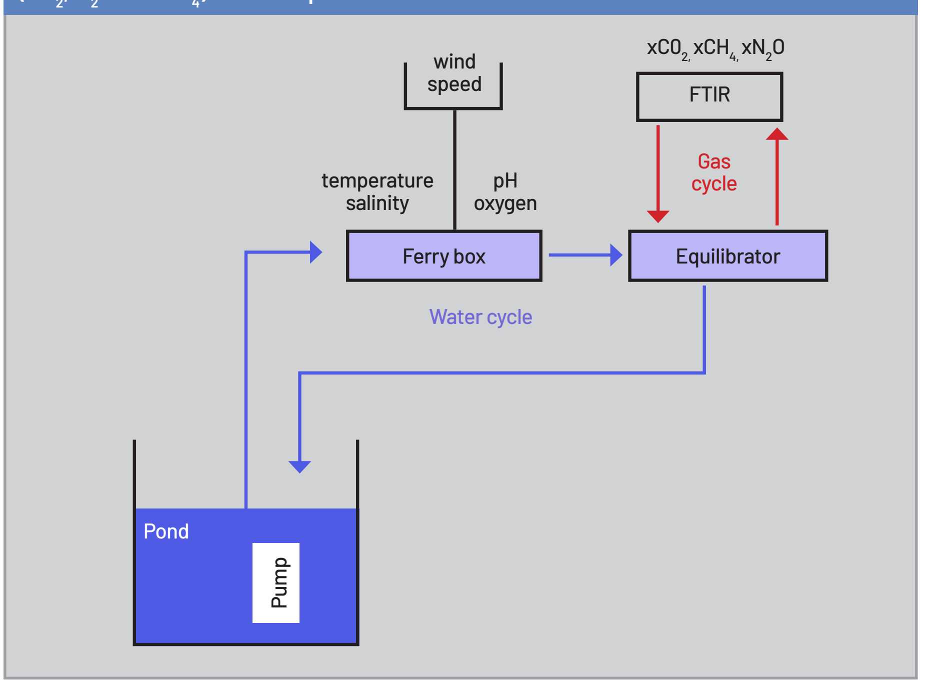
Aquatic food production, including shrimp farming, contributes significantly to global greenhouse gas (GHG) emissions. A study on Litopenaeus vannamei *shrimp ponds in China explored strategies to reduce emissions, such as liming pond water to alter CO_2 levels. While shrimp ponds emit lower methane and nitrous oxide than other aquaculture systems, the processes controlling GHG fluxes remain poorly understood, hindering the development of effective emission-reduction strategies in aquaculture.*

To limit global warming to below 1.5-2.0°C, carbon dioxide removal strategies must offset unavoidable greenhouse gas (GHG) emissions, which include emissions from food production, contributing 23% of global GHG emissions from 2007 to 2017. Aquatic food production is a critical part of the global food system, providing essential proteins and micronutrients. By 2016, aquaculture accounted for 47% of global aquatic food production with shrimp farming, particularly *Litopenaeus vannamei,* becoming increasingly important in China. Despite its growing significance, aquaculture, especially shrimp farming, has a higher environmental impact, with significant GHG emissions due to energy use and nitrous oxide (N_2O) production. In fact, shrimp farming is characterized by a high GHG emission intensity compared to other aquaculture products.

To address this, recent studies have focused on better understanding and reducing GHG emissions in aquaculture. A study on a *L. vannamei* pond in China explored how liming, which raises the pH on pond water, could potentially convert a CO_2 emitting pond into a CO_2 sink. However, the environmental impacts of these treatments remain uncertain due to the emissions associated with their application. The study also examined the low methane (CH_4) and N_2O emissions in the pond, but the processes controlling these emissions are still not fully understood. These findings highlight the need for further research to develop effective strategies to reduce GHG emissions from aquaculture.

Figure 1

Schematic illustration of the GHG monitoring system including the studied pond, the ferry box and the FTIR as well as the Weiss equilibrator, which separates the gases (CO_2, N_2O and CH_4) from the pond water.



Material and Methods

The study was conducted at a plastic-lined *L. vannamei* shrimp pond in Wenchang, China, between April 14 and May 4, 2016. The pond, managed by Hainan Guangtai Marine Animal Breeding Ltd., had an area of 1296 m^2 and a depth of 1.5 m. Water was a mix of farm-treated and seawater (70:30 ratio). Paddle wheel aerators provided oxygen for the shrimp, which were in their grow-out phase. During the 21-day experiment, shrimp were fed a protein-rich diet three daily. The study monitored greenhouse gas (GHG), emissions, including CO_2, CH_4, and N_2O, using a sophisticated system comprising a Ferry Box and a Fourier Transform Infrared Trace Analyzer (FTIR) (Figure 1).

The Ferry Box measured various environmental factors like wind speed, temperature, salinity, pH, and dissolved oxygen, while the FTIR analyzed gas concentrations from water samples. Data were recorded at 5-minute intervals, with some gaps due to equipment failure. The study also utilized floating chamber experiments to calculate the gas transfer velocity (kw) for CO_2 fluxes. A box model was developed to simulate gas exchange, primary production, and oxygen dynamics in the pond. The model incorporated various biochemical processes, including respiration, feeding, and phytoplankton growth, to estimate changes in dissolved inorganic carbon (DIC) and total alkalinity (TA).

Results and Discussion

Physical eater parameters and dissolved gases

The pond water was brackish with salinities ranging from 20.1 to 27.2, pH fluctuating between 7.5 and 8.2 with a mean of 7.9, aligning with conditions in the eastern tropical Pacific Ocean where *L. vannamei* is native. Water temperatures from 26.5 °C to 31.2°C, rising by about 1.5°C during the study. Wind speeds were lower in later periods, resulting in reduced gas exchange rates (kw), especially in periods 3 and 4 (Figure 2). The calculated wk values, following the Wannimkhof and McGillis (1999) method, showed a strong diurnal cycle. Similarly, pH and gas concentrations (N_2O, CH_4, CO_2) exhibited daily cycles, with varying amplitudes, between early and later.

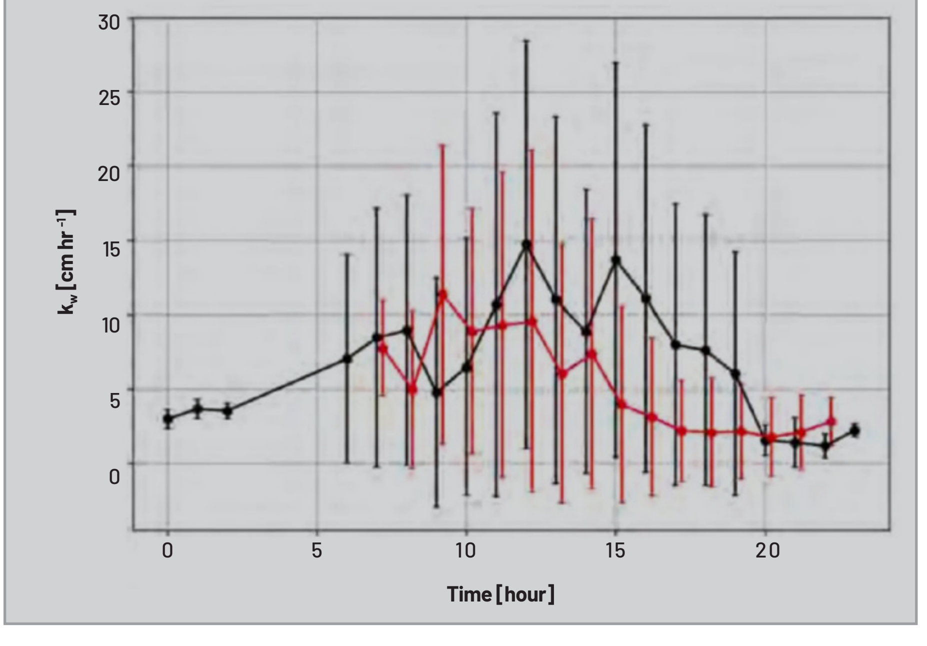
Diurnal cycle of N_2O

In aquaculture ponds, the mechanisms controlling N_2O concentrations are not fully understood. In the ocean, nitrification and denitrification are primary N_2O sources. Nitrification, which is inhibited by light, peaks at night. However, night-time N_2O concentrations were lower than expected, suggesting that nitrification was not the main source. Denitrification, also N_2O source, may act as a sink when oxygen is low, but during this study, oxygen levels were generally above the threshold that would promote denitrification. Hence, denitrification in pond sediments or the shrimp´s gut could explain the diurnal N_2O cycle, with feeding in the morning raising N_2O concentrations. Night-time N_2O concentrations below atmospheric levels in later periods suggest a possible N_2O decomposition exceeding atmospheric input. This shift could be related to reduced wind speeds and changes in oxygen levels, which influenced microbial activity.

Phytoplankton biomass serves as a low-cost food source for L. vannamei, *and its uptake of ammonia helps mitigate its toxic effects.*

Figure 2

Diurnal cycles of kw for CO2 (Wanninkhof and McGillis, 1999) and wind speeds measured during periods 1 & 2 (black line and circles) as well as periods 3 & 4 (red line and circles) including standard deviation versus time.



Diurnal cycle of CH_4

CH_4 exhibited a less pronounced diurnal cycle compared to N_2O. Its concentrations were consistently higher than atmospheric levels, a phenomenon not fully understood but likely linked to sediment processes and organic matter breakdown. Possible sources include microbial activity in oxygen-rich waters and zooplankton grazing. The higher CH_4 concentrations in later periods may reflect increased sediment accumulation, though sediment data are lacking to confirm this.

Diurnal cycles of CO_2, dissolved oxygen, and pH

The pronounced daily cycles of CO_2, dissolved oxygen, and pH indicate the importance of primary production and respiration. Photosynthesis during the day fixes CO_2 and raises pH, while respiration at night increases CO_2 and lowers pH. These cycles affect oxygen availability, with oxygen saturation higher during the day and lower at night. Despite lower nighttime oxygen levels, it remained above the hypoxic threshold, ensuring sufficient oxygen for *L. vannamei.* Paddle wheel aerators were used to maintain oxygen levels, especially at night.

Primary production

Primary producers, such as phytoplankton, are not the main focus in shrimp ponds but are beneficial dure to their roles in oxygen production, shading shrimp, and ammonia re-

Despite its growing significance, aquaculture, especially shrimp farming, has a higher environmental impact, with significant GHG emissions due to energy use and nitrous oxide (N_2O) production.

moval. Phytoplankton biomass serves as a low-cost food source for *L. vannamei*, and its uptake of ammonia helps mitigate its toxic effects. Primary production rates in shrimp ponds typically range from 2-12 g C m^2d^{-1}, with the study pond potentially reaching up to 27.8 µmol C $L^{-1}hr^{-1}$, comparable to other well-managed ponds.

Quantitative estimates

A numerical model was developed to simulate GHG production and emission. The model used measured data to predict CO_2, N_20, and CH_4 fluxes. Although the model simplified some aspects, it captured the general trends and allowed for comparisons between observed and calculated cycles. The calculated primary production rate in periods 1 & 2 peaked at 30 µmol C $L^{-1}hr^{-1}$, consistent with field measurements. The model also replicated diurnal cycles of gas concentrations, with minor discrepancies in timing and peak values, likely due to the model's simplifications of anaerobic processes.

Periods 1 & 2. During these periods, the model predicted a steady-state for oxygen, N_2O, and CH_4 after approximately two days, with slight underestimation of N_2O and CH_4 peaks. The model also indicated that CO_2 concentrations would increase over time due to food respiration, However, with lime addition, CO_2 levels could be reduced, shifting the pond from a CO_2 sink to a CO_2 source after day 6.

Periods 3 & 4. For periods 3 & 4, the model indicated lower wind speeds and gas exchange rates, leading to different dynamics in CO_2, N_2O, and CH_4 production. The model´s results were consistent with the observed transition from CO_2 sink to source, even without lime addition. Increased N_2O production rates and a switch from a night-time N_2O source to a sink were likely influenced by reduced oxygen levels, which affected microbial processes.

GHG fluxes

Net CO_2 uptake was observed at 0.25 ± 0.36 mmol C m^2hr^{-1}, increasing with paddle wheel aerators. However, the impact of lime addiction on CO_2 fixation and pH made it uncertain wheth-

A numerical model was developed to simulate GHG production and emission. The model used measured data to predict CO_2, N_2O, and CH_4 fluxes.

This informative version of the original article is sponsored by: REEF INDUSTRIES INC.

er the pond could be considered a true CO_2 sink, GHG emissions were quantified at 9.05 ± 11.34 µg CH_4 $m^2 hr^{-1}$ and 2.43 ± 3.74 µg N_2O $m^2 hr^{-1}$, These fluxes were lower than those observed in estuarine or earthen ponds, suggesting that plastic-lined shrimp ponds may emit less GHG. Overall, this study provides insights into biogeochemical processes affecting GHG fluxes in intensive shrimp farming.

Conclusion

The data from our GHG monitoring system, aligned with model results, suggest that liming could convert a pond from a CO_2 source to a CO_2 sink. However, CO_2 emissions from lime production, delivery, and water treatment raise questions about whether liming results in a net CO_2 sink. Transforming mangroves into aquaculture sites may act as a CO_2 source by reducing organic carbon burial. While CH_4 and N_2O emissions were low compared to other aquaculture systems, the underlying processes remain unclear. The use of plastic to shield pond waters from ambient environments could reduce emissions. However, the limited understanding of these processes hinders the development of strategies to lower GHG emissions in shrimp cultures.

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled *"GREENHOUSE GAS CONCENTRATIONS AND EMISSIONS FROM A PLASTIC-LINED SHRIMP POND ON HAINAN, CHINA"* developed by: *RIXEN, T.- Leibniz Centre for Tropical Marine Research University of Hamburg; DREWS, M.- Leibniz Centre for Tropical Marine Research; VAN ASPEREN, H. - Institute for Environmental Physics; DAORU, W. - Hainan Academy for Ocean and Fishery Science; KLEMME, A. - Institute for Environmental Physics; THORSTEN, W. - Institute for Environmental Physics.* The original article, including tables and figures, was published on *FEBRUARY, 2023*, through ESTUARINE, COASTAL AND SHELF SCIENCE. The full version can be accessed online through this link: https://doi.org/10.1016/j.ecss.2023.108278

Applied Science: Innovating Against the Tide

✱ By David Ulloa Walker

Basic and applied science are complementary, but the former is the basis for the latter. Sometimes the urgency for results and the anxiety for commercial success lead us to skip steps and lose focus on the basics, the fundamentals that underlie the phenomena or processes being studied, and this is when patience and perseverance are necessary allies.

Innovation, as a successful result of applied science, is what allows companies to generate value to sustain themselves over time in a changing environment, but they must be faithful and consistent with what defines these processes. The temptation for companies to label themselves as innovative is great because it is an attribute valued by the market, and in a digital world, visibility and approval are magnets to wear what is fashionable. The same is true for other concepts or qualities that are socially attractive and trendy, such as: energy efficiency, circular economy, sustainability, animal welfare, including some more classic and equally valid ones such as carbon footprint, blue revolution, green or environmentally friendly technologies, renewable energies, carbon neutrality. All of these concepts have in common a concern for the environment and respect for nature, and are often cited in the business world.

At the end of the last century, Peter Drucker anticipated the fundamental role of aquaculture and was a visionary for his time. In his extensive work on leadership and business management, he wrote that innovation is based on discipline and methodical work rather than sudden inspiration.

Within the global aquaculture industry, the salmon industry is a leading player and is dedicated to providing high quality and healthy protein for human consumption and is therefore subject to a variety of demands from the food market and stakeholders, including governments, shareholders, suppliers, customers, local communities, NGOs, employees and others. In this context, it is important to understand that sustainability is environmental, social and economic, and that it is only possible to be responsible with the environment and the surroundings if companies are economically viable.

Therefore, in a world where aquaculture is a reality, and in particular the salmon industry is one of the most prominent, Chile is part of this leadership, being the second world producer, being for the local economy, the main exporter of food, representing 7% of total exports and contributing with 2.1% to the National GDP (Central Bank of Chile). This po-

Just as salmon swim against the current to return to their place of origin, it is also necessary to return to the basics, to the fundamental principles that govern natural phenomena, and from this understanding to move on to the search for practical solutions to the challenges that afflict society and, more specifically, the companies that try to solve them in order to gain market space.

Innovation, as a successful result of applied science, is what allows companies to create value in order to maintain themselves in time in a changing environment; it is necessary to be faithful and consistent with what defines these processes.

sition brings with it great responsibility, which is why innovation based on science is the key to a better industry.

As a manager of a technology supplier *(Imenco Aqua)*, I will focus my analysis on this segment. Technology companies are constantly looking to differentiate themselves, to add value to their products and services, to be preferred by customers, as a condition to stay relevant in a highly competitive world. Innovation can be at the product, process, or business model level, and can be disruptive or incremental. Researching the state of the art and how to patent new developments is an increasingly necessary and recommended practice.

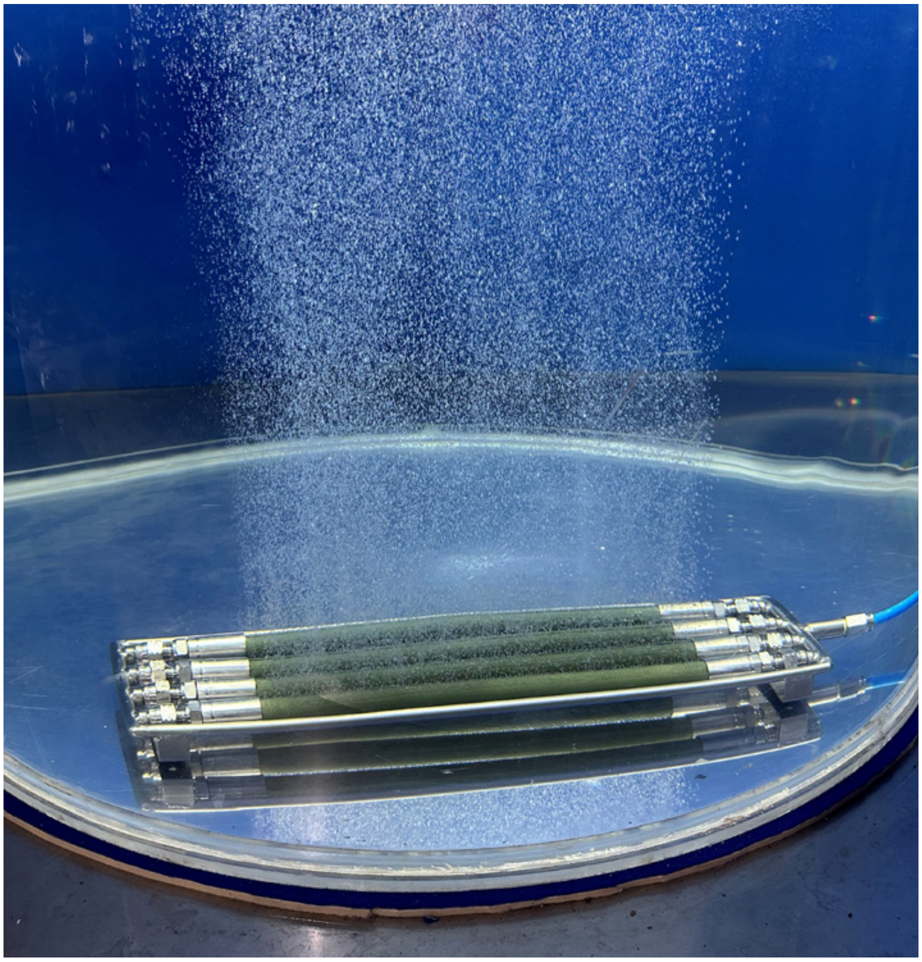
In my constant quest to explore, study and analyze the environment, I am concerned to see that some companies, in order to remain visible, fall into the temptation of simply using concepts such as innovation as a label. In a recent talk I attended as part of the audience, I was struck by the fact that this is more common than

one might think and extends to other industries. It has been written about in a somewhat harsher and more categorical way, with a powerful and critical message such as "Innovation can be theater", an article by Steve Blank, something we should reflect on, as marketing can be seductive, but at the same time integrity must be maintained, innovation is not something superficial.

Technology companies have to deal with the challenge of bringing solutions to market and innovation. The former is the responsibility of the commercial area: marketing is measured in terms of sales, and all efforts are focused on the present, on what sells today. Innovation, on the other hand, is focused on the future, on what will be sold tomorrow, it requires different times, its own leadership or governance, to make real innovation, it requires a strategy, resources, with appropriate personnel, it is a long-term task, with discoveries, successes and mistakes, the latter as Thomas Edisson rightly said, not failures, but that he had discovered 999 ways not to make a light bulb. There are also emblematic cases where the result of an innovation comes from another industry, such as the invention of the zipper to close large packages, which was then transferred to the clothing industry, and many others where they are achieved simply by "accident", such as in the medical field, which was the origin of Viagra.

Returning to the concept of the title about innovating against the current, it is an analogy to reinforce the idea of "swimming" against the current trend, although marketing forces push to be perceived as innovative, this will only be meritorious and real if it is the consequence of a systematic work, based on scientific knowledge, tests and validations that give technical support to the value proposition of the products and services offered in the market.

One way to innovate is to learn from and imitate nature (biomimicry) to solve technological challenges. A clear example of this is the countercurrent mechanism present in salm-



Technology companies are constantly seeking to differentiate themselves, to add value to their products and services, to be preferred by customers, and this is a condition for remaining relevant in a highly competitive world.

on respiration in the uptake of oxygen dissolved in the water at the level of the secondary lamellae, where the blood circulates in one direction and the water in the opposite direction, which is a highly efficient transfer mechanism that has been imitated and applied in various devices, to mention one, the heat exchanger.

I have given this example not by chance, because in an intensive culture system, dissolved oxygen is a critical variable and having devices (diffusers) that efficiently transfer this gas is something that has a positive impact on the growth and welfare of the fish. In this particular case, the same principles of innovation mentioned above apply to oxygen diffusers. At *Imenco Aqua* we have worked on systematic, methodical, standardized and scientifically based tests to validate our solutions, and I have no doubt that most of the current developments on the market have also moved from an initial innovation phase to commercial products. What I have been critical of, however, is when, for commercial purposes, applications, attributes, properties, even scopes beyond what these products were designed for, are exceeded. A concrete example is some of the publications or marketing campaigns about the properties of nanobubbles that go beyond the strictly technical, even omitting relevant contexts when compared to other technologies. In science, magical results such as the metaphor of products that claim to be "silver bullets" are not part of scientific rigor.

In summary, the invitation is to return to the essence, to the science that underpins technological progress. Although this is a slow and long-term process, it always bears fruit, and the most important thing is that this way of working generates confidence "inwards", towards all those who participate in a company and are witnesses of this effort, as well as "outwards" towards the customers who are the users. Paradoxically, working in a laboratory, test bench or any research unit does not require thinking about marketing (although successful cases are destined for the market), it only requires sticking to the results and findings, in the end you have to do the right thing because it is the right thing to do. As Simon Sinek postulates in his book The Infinite Game, companies must have a purpose, a just cause that goes beyond results, where excellence allows all players (companies) to remain relevant, transcendence goes beyond profits, it is to generate benefits for all. That is why it is good to swim against the current, not to go against others, but simply to return to the origin, to what motivates and drives us to achieve our goals. aqm

* David Ulloa Walker.
Ph.D. in Aquaculture, Pontificia Universidad Católica de Valparaíso.
General Manager *Imenco Aqua Chile*.
Photography: *Imenco Aqua*.

Environmental, Economic, and Social Sustainability in Aquaculture: The Aquaculture Performance Indicators Largest Markets

Aquaculture is revolutionizing global food production, surpassing fisheries as the main seafood source. However, concerns persist regarding its environmental impact and social equity. Using the Aquaculture Performance Indicators (APIs), this study evaluates 57 aquaculture systems across 19 dimensions, revealing that economic, social and environmental sustainability are often complementary.

✱ Aquaculture Magazine Editorial Team

Aquaculture is a recent and rapidly growing component of the global food production system, surpassing fisheries as the primary source of seafood for human consumption. It has the potential to support livelihoods, food, security, and environmental sustainability. But concerns persist regarding its ecological and social impacts. The lack of comprehensive data has hindered systematic comparisons of global aquaculture production systems.

This study uses data from the Aquaculture Performance Indicators (APIs) across 57 aquaculture systems to assess sustainability across eco-

Analyzing 57 aquaculture case studies, results indicate positive and statistically significance correlations between environmental, economic, and social sustainability, suggesting that trade-offs do not exist among these pillars on average.

Policy and investment decisions will be critical in ensuring that aquaculture continues to balance economic, social, and environmental objectives effectively.

nomic, environmental, and social dimensions. Findings indicate that, on average, these three pillars are complementary, with a weaker link between economic and environmental sustainability and a stronger link between social and environmental aspects. The study also explores key controversies, including the sustainability of freshwater versus marine aquaculture and the preference for monoculture over polyculture. High performing species and aquaculture typologies are identified, emphasizing the role and investment in sustainable aquaculture.

Environmental concerns, such as habitat destruction, nutrient pollution and reliance on wild fish for feed, can be mitigated through governance and market incentives. For instance, rising fishmeal prices have prompted the industry to explore alternative protein sources. Additionally, aquaculture´s greenhouse gas emissions compare favorably to other food systems.

Social sustainability remains controversial, particularly in the Global South, where aquaculture markets often cater to urban and international demand. Large-scale, automated marine farms may contribute little to employment and food security, while contract farming can exacerbate social inequality. However, aquaculture has also been linked to economic development, poverty alleviation, and increased access to nutritious food. The APIs enable global comparison by evaluating 88 outcomes measures across 19 dimensions. Data from 57 case studies, covering 41% of global production, show regional disparities, with higher sustainability scores in the Global North.

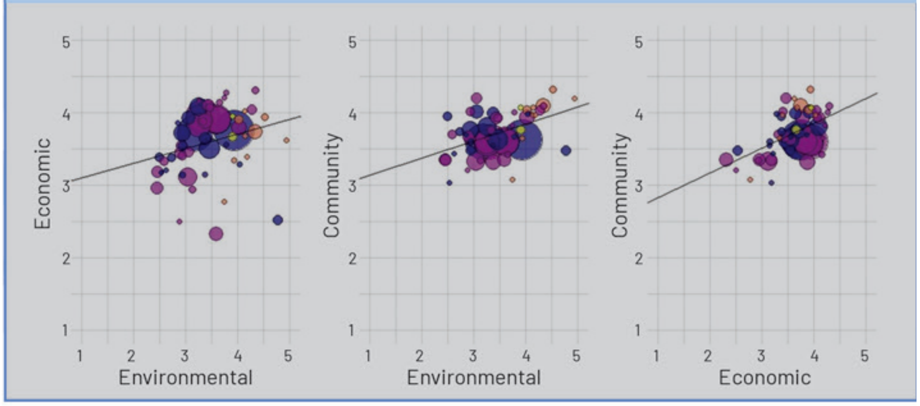
Methods

APIs assess the environmental, economic, and social performance of aquaculture systems, which are typically industry groups producing one species within a country. APIs include 88 output indicators grouped into 19 dimensions, scored on a 1-5 scale, capturing global variation. Environmental performance assesses feed use, water use, and ecosystem impact. Economic performance examines market benefits, while social performance considers livelihoods and wages. Additionally, 66 input indicators evaluate management approaches, regulations, and infrastructure.

Between 2020 and 2021, APIs were applied to 57 aquaculture systems, covering 41% of global production and 37% of its value. Assessment's span 21 countries and 40 species, with finfish (50%) dominating the sample. Data collection involved expert scores using targeted data, proxies, and interviews, ensuring consistency. Despite some underrepresented sectors, results remain stable across different analyses.

Figure 1

Correlations of the pillars of sustainability for 57 aquaculture systems. Correlation results (coefficient and p value) are as follows: Environmental—Economic (0.33, 0.012), Environmental—Community (0.45, < 0.001), Economic—Community (0.55, < 0.001). Crustaceans (blue), finfish (purple), mollusks (orange), seaweed (yellow), and the size of the bubble represents production value.



Results

Synergies and trade-offs among the three pillars of sustainability

Analyzing 57 aquaculture case studies, results indicate positive and statistically significance correlations between environmental, economic, and social sustainability, suggesting that trade-offs do not exist among these pillars on average (Figure 1). The correlation between environmental and economic sustainability in aquaculture (0.33) is weaker than in fisheries (0.52), as aquaculture´s environmental impacts are less directly affecting productivity, aquaculture farmers can control many production variables, particularly in intensive systems. Regulations and market incentives, such as ecolabels, may be necessary to limit environmental externalities (Pincinato, et al., 2021; Bush, 2013; Asche; 2021). The correlation between environmental and social sustainability (0.45) is stronger than in fisheries (0.23), likely due to aquaculture´s fixed location, which fosters local social benefits. The correlation between economic and social sustainability (0.55) confirms that aquaculture supports community development, poverty reduction, and food security.

Production environment, technologies, and species

Aquaculture performance varies by production environment, technology, and species (Figure 2). Freshwater and marine aquaculture perform similarly in sustainability, challenging the assumption that one is superior (Belton et al., 2020; Costa-Pierce, 2022). Monocultures outperform polycultures in all three-sustainability pillars, contradicting the belief that polyculture optimizes resource use (Chopin, et al., 2012). While monoculture´s higher economic and social scores are expected, its environmental advantage suggests that well-managed monoculture can be more sustainable than assumed.

Among key species, mollusks perform best environmentally due to their filter-feeding ability, which eliminates reliance on manufactured feeds and fishmeal while providing ecosystem services (Barret, 2022). However, mollusks face economic challenges due to vulnerability to environmental stress and disease (Advelas, 2021 and Moor et al., 2022). Salmon scores high across dimensions due to technological advancement and efficient feed use (Ytrestøyl, 2015) but its industry is characterized by high foreign investment, raising concerns about local community benefits (Phyne, 2010; Hishamunda, 2014 and Young, 2019). Carp, typically produced in extensive systems, scores lower economically due to low-value production (Kumar, 2016 and 2018). The greatest variability among species is observed in local ownership, trade, and environmental metrics, such as certification, feed use, and effluent management.

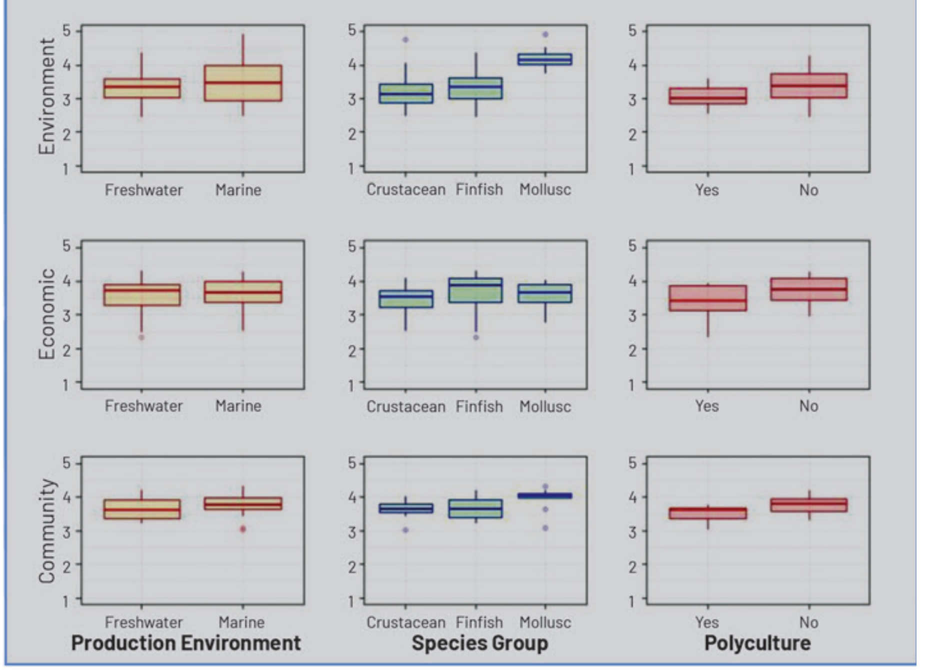
International trade

Aquaculture´s expansion is closely linked to global seafood trade, with export-oriented production often promoted as a strategy for economic growth and poverty alleviation (Anderson, 2018 and Gephart, 2015). Shrimp farming in Southeast Asia has been particularly scrutinized for its environmental and social impacts (Belton & Little, 2008; Primavera, 1997; van Mulekom et al., 2006 and Rivera-Ferre, 2009). In low-income countries, export-oriented aquaculture outperforms domestic production in environmental ($t(32) = 2.206$, $p = 0.035$) and economic sustainability ($t(28) = 2.6558$, $p = 0.013$) contradicting claims that support that exports lead to greater environmental degradation (van Mulekom et al., 2006). This suggest that export industries may be improving due to market-driven sustainability incentives. However, community performance does not significantly differ between export and

Aquaculture production systems vary widely in terms of space, production technology, species, and market. The identification of negative outcomes is some species and dimensions serve not as a rejection of the food production technology, but to inform policy and investment decisions.

Figure 2

Relative performance in each of the three pillars of sustainability by production environment, species group, and mono- versus polyculture. Production environments are categorized into freshwater and marine environments, and species groups into crustaceans, finfish, and mollusks.



domestic aquaculture (t(22) = 0.410, p = 0.686).

In high-income countries, domestic aquaculture scores higher environmentally than export-oriented production (t(8) = -2.829, p = 0.0210), while economic performance remains better for exports (t(6) = -2.829, p = 0.0210), while economic performance remains better for exports (t(6) = 3.945, p = 0.070). These findings suggest that production for domestic and export markets yields different sustainability outcomes, influenced by development status. Export markets in wealthy nations demand sustainable practices, incentivizing improved environmental performance in developing countries. However, domestic markets in the developing world lack similar incentives, limiting sustainable production.

Overall, aquaculture exhibits complex sustainability dynamics, influenced by production methods, species, and market orientation. Policy and investment decisions will be critical in ensuring that aquaculture continues to balance economic, social, and environmental objectives effectively.

Discussion

Aquaculture production is rapidly growing, but it is also a heavily criticized food system as environmentally and socially unsustainable practices are perceived to arise in pursuit of economic objectives. This study utilized data collected with the APIs for 57 aquaculture systems and depicted that on average the three pillars of sustainability are complementary, suggesting no systematic trade-offs between economic, environmental, and social sustainability.

Hence, sustainable aquaculture production is possible, and fundamental trade-offs among economic, ecological, and social sustainability should not be viewed as the norm, even though they may exist in specific cases. However, the results also indicate that there is significant variation in the degree of sustainability in different aquaculture systems, supporting the observation of Naylor et al. (2021) that it is a highly heterogeneous industry. The heterogeneity is highly interesting, and the results indicate that some important debates most likely are over-simplified.

This is most obvious in the discussion on the relative merits and potential of freshwater versus marine aquaculture. The results indicate that

this is not a particularly interesting distinction, as the systems are performing quite similarly in all three sustainability dimensions. Rather, there are other factors that seem to be more important, such as the difference between mollusks and finfish or the degree of control over the production process.

Aquaculture production systems vary widely in terms of space, production technology, species, and market. The identification of negative outcomes in some species and dimensions serve not as a rejection of the food production technology, but to inform policy and investment decisions. The data also provides a baseline of the average performance of the sectors as well as for different species groups. However, these analyses are just the beginning, and continued development of the APIs database will facilitate analysis on more detailed questions and will significantly help improve the sustainability of the aquaculture sector. An expansion of the database will be beneficial as it will allow analysis of specific sub-systems and make the sample more representative of global aquaculture. For instance, additional observations for seaweed would facilitate analysis of one of the most rapidly growing parts of the aquaculture sector.

Conclusion

Aquaculture is a rapidly expanding food production system with both challenges and opportunities for sustainability. This study, using the APIs, shows that economic, social, and environmental sustainability are often complementary, though variations exist across species, production methods, and market dynamics. While certain systems face environmental and social concerns, governance, policy, and investment can drive improvements. Future research and expanded data collection will be essential to refining strategies that ensure aquaculture´s role in sustainable global food production. aqm

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled *"ENVIRONMENTAL, ECONOMIC, AND SOCIAL SUSTAINABILITY IN AQUACULTURE: THE AQUACULTURE PERFORMANCE INDICATORS"* developed by: *GARLOCK, T. - Auburn University; ASCHE, F. - University of Florida & University of Stavanger; ANDERSON, J. - University of Florida; EGGERT, H. - University of Gothenburg; and ANDERSON, T. - University of Florida &University of California at Davis.* The original article was published on JUNE 2024, through NATURE COMMUNICATIONS. The full version, including tables and figures, can be accessed online through this link: https://doi.org/10.1038/s41467-024-49556-8

Review: Recent Applications of Gene Editing in Fish Species and Aquatic Medicine

Aquaculture is a crucial sector for global food production and trade. Gene editing techniques, particularly clustered regularly interspaced short palindromic repeats-Cas9 (CRISPR/Cas9), are transforming the industry by enabling precise genetic modifications in fish species. These advancements enhance disease resistance, growth, and reproduction, making aquaculture more efficient and sustainable. Additionally, RNA interference (RNAi) is emerging as a powerful tool for gene silencing and functional genomics.

✱ By Aquaculture Magazine Editorial Team

Introduction

Fish industry

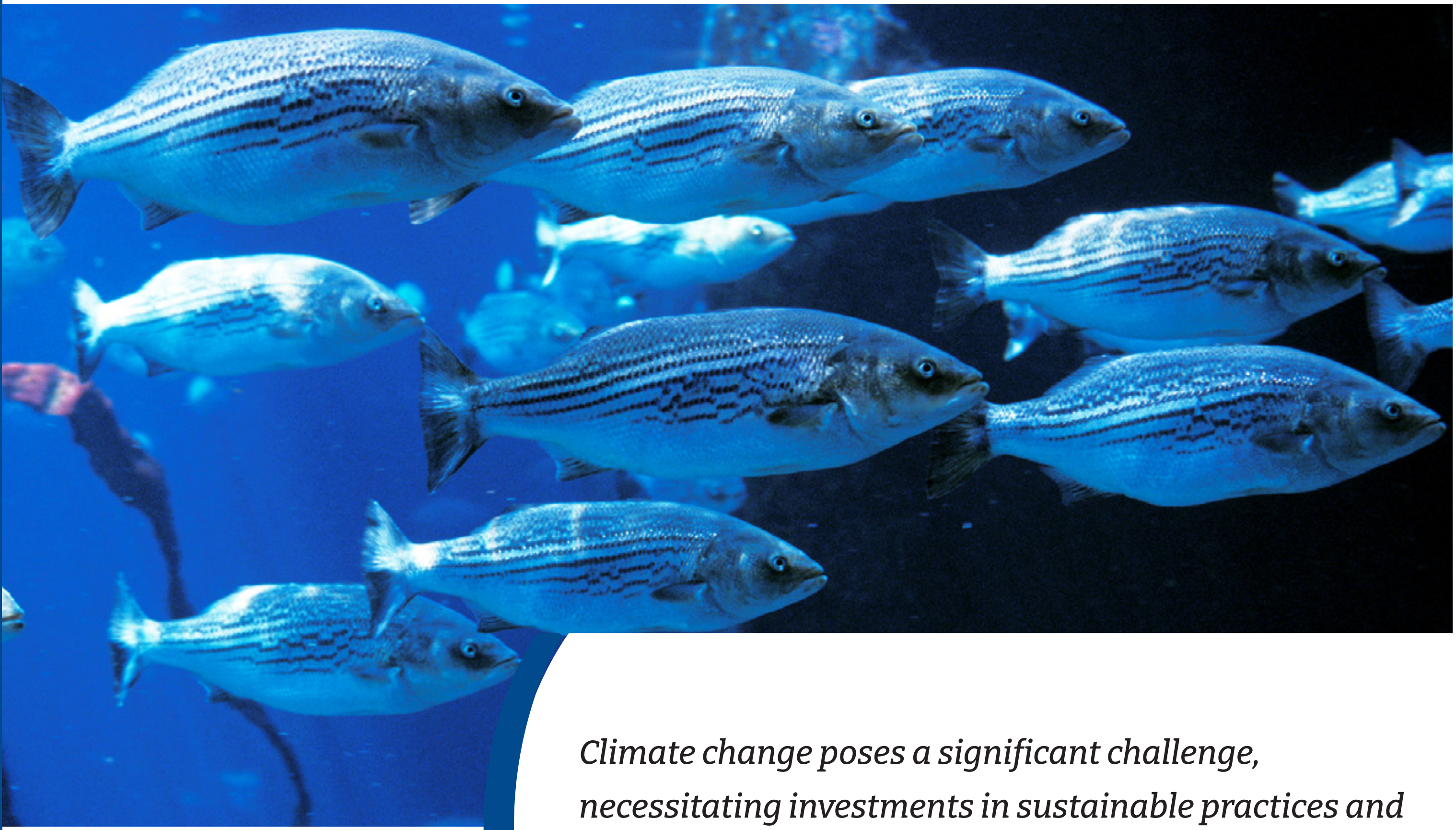
Global fish production has become the fastest-growing food sector in recent decades. Aquaculture now produces more fish biomass than beef and even capture fisheries (including non-edible species) (Edwards et al., 2019). In the 21st century, aquaculture and fisheries production have expanded significantly (Food Agriculture Organization, FAO, 2022). Aquaculture production surged from 5 million to 63 million tons, while capture fisheries increased from 69 million to 93 million tons over 30 years (FAO, 2014).

Food fish consumption grew at an annual rate of 1.4%, reaching 20.5 kg per capita in 2019. In 2020, aquaculture accounted for 178 million tons of food fish, with finfish (57.5 million tons), mollusks (17.7 million tons), and crustaceans (11.2 million tons) being the primary contributors. Asia led production (91.6%), with China dominating since 1991. Other key producers include Vietnam, Bangladesh, Egypt, Norway, and Chile. By 2050, with a projected global population of 10 billion, food production must become more efficient. Fish is an essential protein source, rich in omega-3 fatty acids, vitamins, and minerals (FAO, 2012).

The industry has seen a shift toward farming fed aquatic species, which has driven production growth and reduced fish prices. However, climate change poses a significant challenge, necessitating investments in sustainable practices and new technologies (FAO, 2022; Boyd et al., 2020). Genetic modification could support aquaculture expansion and improve fish health (World Bank, 2013).

Gene editing

Gene engineering techniques emerged in the late 20th century to modify genomes precisely (Perota et al., 2016). Advances in genetic engineering have



Climate change poses a significant challenge, necessitating investments in sustainable practices and new technologies. Genetic modification could support aquaculture expansion and improve fish health.

significantly impacted medicine, particularly in gene therapy (Cathomen, 2008). Gene editing allows targeted deoxyribonucleic acid (DNA) modifications via engineered nucleases. It enables precise trait alterations, such as allele corrections or interspecies transfers (Malik, 2020; Gratacap, 2019). DNA repair mechanisms, primarily DNA repair mechanisms, primarily nonhomologous end-joining (NHEJ) and homology-directed repair (HDR), are crucial for post-editing recovery (Takate, 1998; Lans, 2012).

Zinc Finger Nucleases (ZFNs)

ZFNs are engineered proteins used for gene editing (Choo, 1994). They consist of zinc-finger DNA-binding domains fused with the Fok I endonuclease. ZFNs introduce double-strand breaks (DSBs) at specific genome sites, triggering nonhomologous end joining (NHEJ) mediated repairs (Cathomen, 2008; Tang, 2015). Despite their precision, off-target effects remain a challenge (Carroll, 2014). This technique has been successfully applied to zebrafish and human cells (Palpant, 2013; Hockemeyer, 2009).

Transcription Activator-Like Effector Nucleases (TALENs)

TALENs, derived from Xanthomonas bacteria, employ DNA-binding proteins and Fok I nucleases to induce double-strand break (DSBs). They offer high specificity and efficiency but are labor-intensive and expensive (Joung, 2013; Lamb, 2013). Their applications include gene modification in model organisms, but the need for simpler alternatives has led to the development of more advanced techniques (Malik, 2020).

Clustered Regularly Interspaced Short Palindromic Repeats- Cas9 System (CRISPR/Cas9)

CRISPR/Cas9, discovered in 2012, revolutionized gene editing due to its simplicity, cost-effectiveness, and efficiency (Malik, 2020; Jinek, 2012). It uses guide RNA (sgRNA) to direct the Cas9 endonuclease to target DNA sequences, enabling precise edicts. The system is widely used in various fields, including biomedical and agricultural applications (Xu, 2020).

Gene silencing

RNA interference (RNAi) regulates gene expression by inhibiting mRNA translation (Singh, 2019; Hood; 2004). Dicer enzymes process double-stranded RNA (dsRNA) into small interfering RNA (siRNA), which guides the RNA-induced silencing complex (RISC) to degrade target mRNA

Aquaculture faces significant challenges from infectious pathogens. Gene modification techniques can improve disease resistance, enhance production efficiency, and support fish health.

(Singh, 2019; Sen, 2006). RNAi plays a role in immune defense and gene therapy innovations (Hood, 2004 Wang, 2007).

Applications in aquaculture

Aquaculture faces significant challenges from infectious pathogens. Gene modification techniques can improve disease resistance, enhance production efficiency, and support fish health (Gotesman, 2018). Fish serve as effective bioreactors for medical applications due to their short generation intervals and cost-effective maintenance. Gene editing has been successfully applied in fish breeding, spawning, and disease management, offering promising advancements for the industry (Lucas, 2013).

Gene Editing in Fish Farm Species Using CRISPR/Cas9 and Other Gene Editing Tools

Over 70 aquatic fish genomes have been deciphered in recent decades. CRISPR/Cas9 and other gene editing tools are advancing aquaculture by enabling sterility, disease resistance, pigmentation, and growth improvement. These innovations offer solutions to significant challenges in aquaculture.

Gene editing in fishery science

Zebrafish, widely used as a model organism, has contributed to breakthroughs in genetic modifications, toxicology, and host-pathogen interactions. CRISPR/Cas9 has successfully modified genes in various species, including Atlantic salmon, medaka, and tilapia. In Nile tilapia, targeted gene mutations have been efficiently transmitted to offspring, demonstrating the high efficacy of CRISPR/Cas9 in non-model species.

Gene editing in mono-sex population

Gene editing can create mono-sex fish populations, improving yield rates and preventing unwanted reproduction in the wild. In tilapia, genes determining female sex have been knocked out to influence sex differentiation. Traditional hormone treatments for sex reversal pose ecological risks, but gene editing offers a sustainable alternative. Medaka fish studies using TALEN demonstrated effective gene knockout for reproductive regulation.

Gene editing in sterility of fish

Sterility prevents ecological risks posed by escaped farmed fish. Using ZFN technology, sterile channel catfish were produced by disrupting the pituitary luteinizing hormone gene. In Atlantic salmon, CRISPR/Cas9 knockouts of the dead end *(dnd)* gene eliminated germ cells, preventing gene flow between farmed and wild populations. Pigmentation genes *(slc45a2)* have also been targeted, producing albino salmon.

Gene editing in reproduction

The kisspeptin-encoding gene—*Kiss1 (Kiss1/Grp54)* system regulates reproduction in vertebrates. In zebrafish, TALEN-engineered mutations in kiss2 genes showed that reproductive potential remained unaffected, suggesting differences between mammalian and fish reproductive strategies.

Gene editing in fast-growing fishes

Cold-water fish species often have slow growth rates due to genetic and environmental factors. CRISPR/Cas9 has been used to disrupt myostatin, a muscle growth inhibitor, in common carp, leading to increased muscle mass. Similar approaches have been applied to slow-growing species like snow trout to enhance growth rates.

Gene editing in ornamental fishes

Targeted gene editing has facilitated the development of ornamental fish desired colors and pigmentation. ZFN, TALEN, and CRISPR/Cas9 techniques have been used to mutate pigmentation-related genes in zebrafish, resulting in inheritable light-colored eyes and loss-of-function phenotypes. The CRISPR/Cas9 system has enabled efficient gene knockouts, affecting multiple loci simultaneously (Figure 1).

Gene editing in pigmentation

TALEN gene editing in cavefish *(Astyanax mexicanus)* targeted pigmentation genes resulting in mosaic-patterned loss of melanin. A recent study in Nile tilapia demonstrated heritable red pigmentation through CRISPR/Cas9-mediated mutation in the *slc45a2* gene, confirming its applicability in aquaculture (Figure 2).

Gene editing in growth

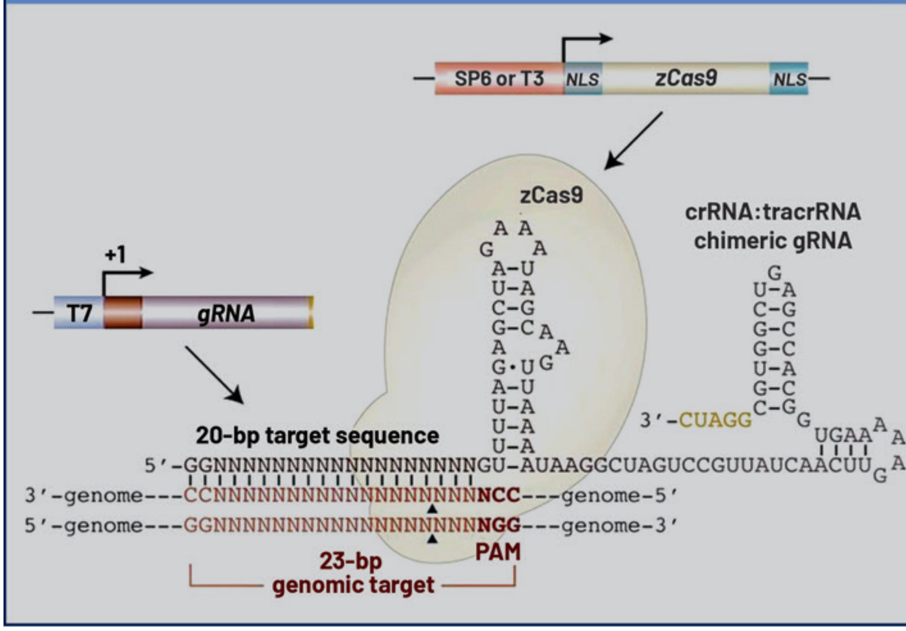
Growth enhancement via gene transfer has led to size increases of up to 300%. CRISPR/Cas9-mediated knockout of the myostatin (MSTN) gene in channel catfish increased muscle growth and body weight. This approach could significantly boost aquaculture productivity.

Gene editing in body configuration

Transgenic modifications have improved fish nutritional properties. Zebrafish engineered with salmon desaturase genes showed increased omega-3 fatty acid levels, a result also observed in carp and catfish. These modifications enhance the nutritional value of farmed fish.

Figure 1

Genome editing with CRISPR/Cas9 nuclease system in zebrafish *(Danio rerio)*.



Gene editing in oomycetes

Aphanomyces invadans causes epizootic ulcerative syndrome (EUS), a significant threat to fish populations. CRISPR/Cas9 targeted serine protease genes in this pathogen, effectively preventing virulence. Experimental fish exposed to gene-edited *A. invadans* showed no signs of infection, highlighting CRISPR/Cas9´s potential in disease management and drug development. These advantages demonstrate the transformative potential of gene editing in aquaculture, improving sustainability, productivity, and ecological balance.

Gene Silencing in Fish Medicine

The RNA interference (RNAi) tool has been widely used to analyze gene function in aquatic diseases and develop antiviral therapies for livestock and aquatic species. Most studies on RNAi in fish have been conducted on zebrafish *(Danio rerio)*, a key model for aquaculture and biomedicine.

Gene silencing in viral disease of fish medicine

RNAi-based therapies have been used to inhibit viral replication. In one study, small interfering RNA (siRNA) targeted the nucleoprotein (N) and phosphoprotein (P) transcripts of the viraemia of carp virus (SVCV) in *epithelioma papulosum cyprinid* (EPC) cells, reducing replication. Another study used siRNA to inhibit cyprinid herpesvirus-3 (CyHV-3) in common carp brain (CCB) cells by targeting thymidine kinase (TK) and DNA polymerase (DP) genes. Multiple viral genes must be targeted for optimal inhibition.

Gene silencing for gene function studies in fish medicine

Short hairpin RNA (shRNA) has successfully inhibited zebrafish gene expression. Studies targeted wnt5b and *zDisc1* genes, demonstrating effective knockdown. Another study used an in vivo-transcribed T7 plasmid system to silence the green fluorescent protein *(gfp)* and *no tail (nt1)* genes, confirming RNAi machinery activity in zebrafish cells.

Gene silencing in oomycetes

In *Saprolegnia parasitica*, an aquaculture pathogen, silencing the tyrosinase *(SpTyr)* gene reduced melanin production and altered cell morphology, demonstrating RNAi as a functional tool.

Gene silencing in crustaceans

Despite limited genomic data on crustaceans, RNAi has proven effective. Studied showed RNAi-mediated inhibition of white spot syndrome virus (WSSV), yellow head virus (YHV), and Taura syndrome virus (TSV) in shrimp *(Penaeus monodon)*. Additionally, RNAi targeted the pmYRP65 receptor protein, preventing YHV entry.

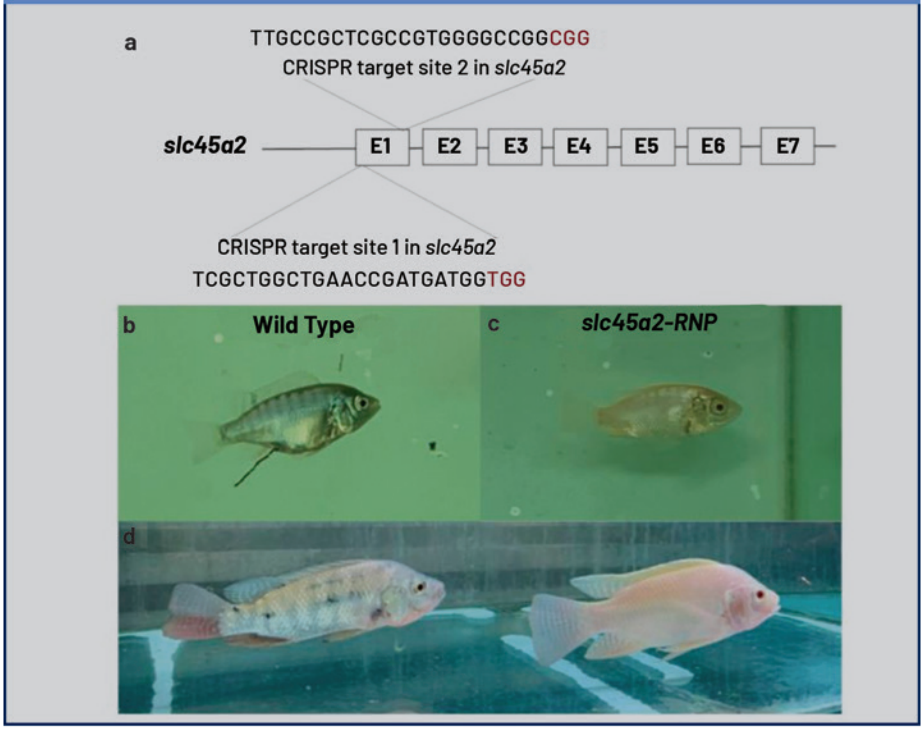
In bacterial infections, silencing the *prophenoloxidase* (proPO) gene in freshwater crayfish *(Pacifastacus leniusculus)* impaired immune defenses, while silencing pacifastin enhanced immunity. RNAi also inhibited crustacean hyperglycemic hormone (CHH) in *Litopenaeus schmitti*, reducing glucose levels. RNAi continues to be a powerful tool in understanding aquatic diseases.

Conclusions

The ethical concerns surrounding CRISPR-Cas9 revolve around balancing benefits and risks. Off-target mutations, unintended genetic alterations, and potential cell death pose significant challenges. Efforts to improve accuracy through enzyme variants are ongoing. The high cost of tools and reagents further limits accessibility. Environmental risks include the unintended release of genetically modified (GM) organisms, potentially disrupting ecosystems through gene drive extinction. Off-target mutations can amplify across generations, making control difficult. Additionally, concerns exist regarding health risks, biodiversity reduction, and the ethical implications of genetic modification.

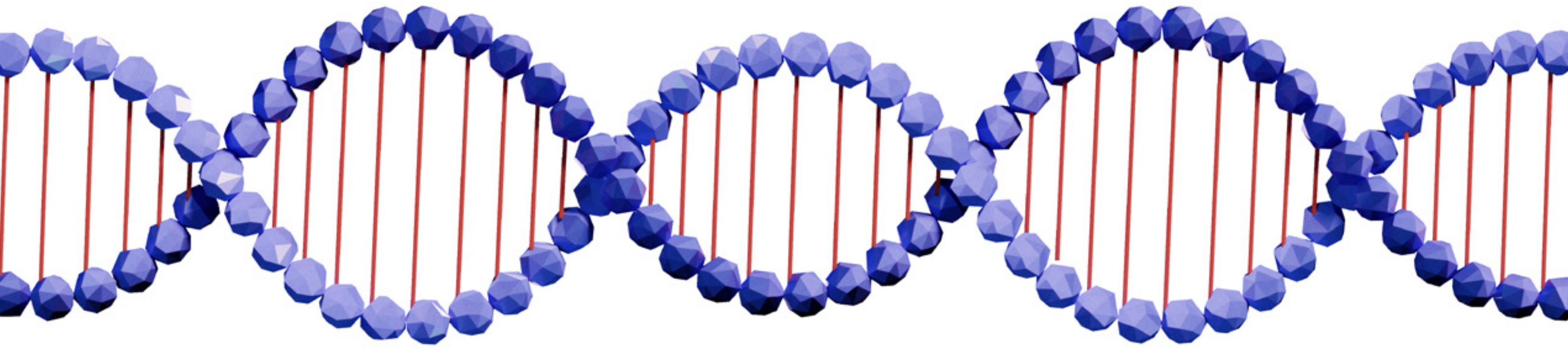
Figure 2

Different phenotypes between wild adult and slc45a2 mutant adult Nile tilapia shows the phenotypic analysis of tilapias after microinjected at the single-cell stage with RNPs. (a) Shows Nile tilapia zygotes were containing slc45a2-exon1-specific gRNAs 2 and 3. (b) Shows the embryo with a normal gray-black pattern and dark eyes at 1-month post fertilization. (c) Shows slc45a2-RNPs-injected mutant fish with 97–99% loss of melanin in the skin and no melanin in the eye. (d) Shows post sexual maturation, F0 mutant displaying a complete loss of melanin.



Gene editing is transforming aquaculture, enhancing genetic traits through selective breeding and biotechnologies. CRISPR/Cas9 enables precise modifications in species like Atlantic salmon and zebrafish, improving disease resistance and growth. RNA interference (RNAi) also plays a role in gene expression silencing. Despite advancements, regulatory, economic, and ethical challenges remain, influencing public acceptance and industry growth. aqm

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled *"REVIEW: RECENT APPLICATIONS OF GENE EDITING IN FISH SPECIES AND AQUATIC MEDICINE."* developed by: *GUTÁSI, A., HAMMER, S., EL-MATBOULI, M., and SALEH, M. - University of Veterinary Medicine, Vienna, Austria.* The original article, including tables and figures, was published on APRIL, 2023, through ANIMALS. The full version can be accessed online through this link: https://doi.org/10.3390/ani13071250



Transcriptome Analyses of mRNA and Circular RNA Reveal Dietary Supplementation with Freeze-Dried *Lactiplantibacillus plantarum* Primes Immune Memory of Whiteleg Shrimp (*Penaeus vannamei*) Against Pathogens

✱ By Aquaculture Magazine Editorial Team

Shrimp aquaculture plays a crucial role in global food security but faces significant challenges, particularly from diseases that cause severe economic losses, especially in Asia. Major diseases include bacterial infections like acute hepatopancreatic necrosis disease (AHPND) and viral threats such as white spot syndrome virus (WSSV). Due to their lack of adaptive immunity, shrimp rely on innate immune responses to combat pathogens.

To enhance shrimp immunity, research focuses on immunostimulants, which improve disease resistance. These include synthetic compounds and naturally derived substances from plants, fungi, and bacteria. Lactic acid bacteria (LAB), such as *Lactiplantibacillus plantarum*, are widely used in shrimp aquaculture as dietary immunostimulants. Studies have shown that LAB supplementation improves growth, gut microbiome composition, and immune responses in *Penaeus vannamei*, increasing survival rates against infections.

Advancements in transcriptome analysis have deepened our understanding of shrimp immunity, including immune responses to AHPND and WSSV. Additionally, noncoding RNAs, such as circular RNAs (circRNAs), regulate immune gene expression. However, the effects of immunostimulation on circRNA expression remain unexplored.

A recent concept in crustacean immunity, "trained immunity", suggests that exposure to immunostimulants like freeze-dried *L. plantarum* (FD-LAB) may enhance immune memory in *Penaeus vannamei*, improving resistance to secondary infections. This study investigates the potential of FD-LAB in priming shrimp immunity.

Materials and Methods

» **Shrimp and Feed Preparation:** Juvenile *P. vannamei* (0.87 ± 0.24 g) were divided into control and

Shrimp aquaculture faces significant challenges from bacterial and viral diseases like acute hepatopancreatic necrosis disease (AHPND) and white spot syndrome virus (WSSV). Recent research highlights the potential of Lactiplantibacillus plantarum *(FD-LAB) as a dietary immunostimulant to enhance shrimp immunity. Transcriptome analysis revealed that FD-LAB supplementation modulates immune-related genes and circular RNAs (circRNAs), boosting immune memory and pathogen resistance.*

FD-LAB groups and acclimatized for seven days. Feed was supplemented with freeze-dried *L. plantarum* (FD-LAB) at 34.2 mg/g. Shrimp were reared in recirculating tanks with monitors water conditions and fed thrice daily for either 8 or 15 days.

- **RNA Extraction and Sequencing:** Total RNA from shrimp gill and stomach tissues was extracted, and quality was assessed. Library preparation was done using the Illumina Stranded mRNA Prep kit, followed by sequencing on an Illumina MiSeq platform.
- **Transcriptome and circRNA Analysis:** Quality control and differential expression analysis were performed using bioinformatics tools such as STAR, RSEM, and DESeq2. circRNA detection was conducted using the CIRI-quant pipeline.
- **qPCR Validation:** Differentially expressed genes (DEGs) and circRNAs were validated via qPCR. RNA was reverse transcribed, and amplification was performed using specific primers.
- **Bacterial and Viral Challenge Tests:** Shrimp were challenged with *Vibrio parahaemolyticus* (AHPND) or WSSV via immersion. Survival rates were analyzed using the Kaplan-Meier method, including additional tests for trained immunity.

Results

RNA sequencing quality & overview

RNA sequencing was performed on shrimp gill and stomach samples after 8 and 15 days of feeding with FD-LAB or control feed. The sequencing generated ~180 million high-quality reads (Q>30), supporting reliable downstream analyses.

Transcriptome profile & gene expression changes

FD-LAB supplementation led to differential gene expression (DEG):

- Gills: 80 DEGs (8 days), 40 DEGs (15 days) (Figure 1).
- Stomach: 14 DEGs (8 days), 22 DEGs (15 days).
- 17 genes were upregulated, 103 downregulated.
- DEGs included immune-related genes involved in pathogen recognition, antimicrobial response, and immune memory.
- Other enriched pathways: transcription, translation, ecdysis, and metabolic processes.

qPCR validation of DEGs

qPCR confirmed RNA-seq findings, validating immune-related gene expression changes:

- Gills: Upregulation of anti- lipopolysaccharide factor-like (ALF) (8 days), ficolin-1-like (FCN1) (15 days); downregulation of mucin 5ac-like (Muc5ac) (8 days).

To enhance shrimp immunity, research focuses on immunostimulants, which improve disease resistance. These include synthetic compounds and naturally derived substances from plants, fungi, and bacteria.

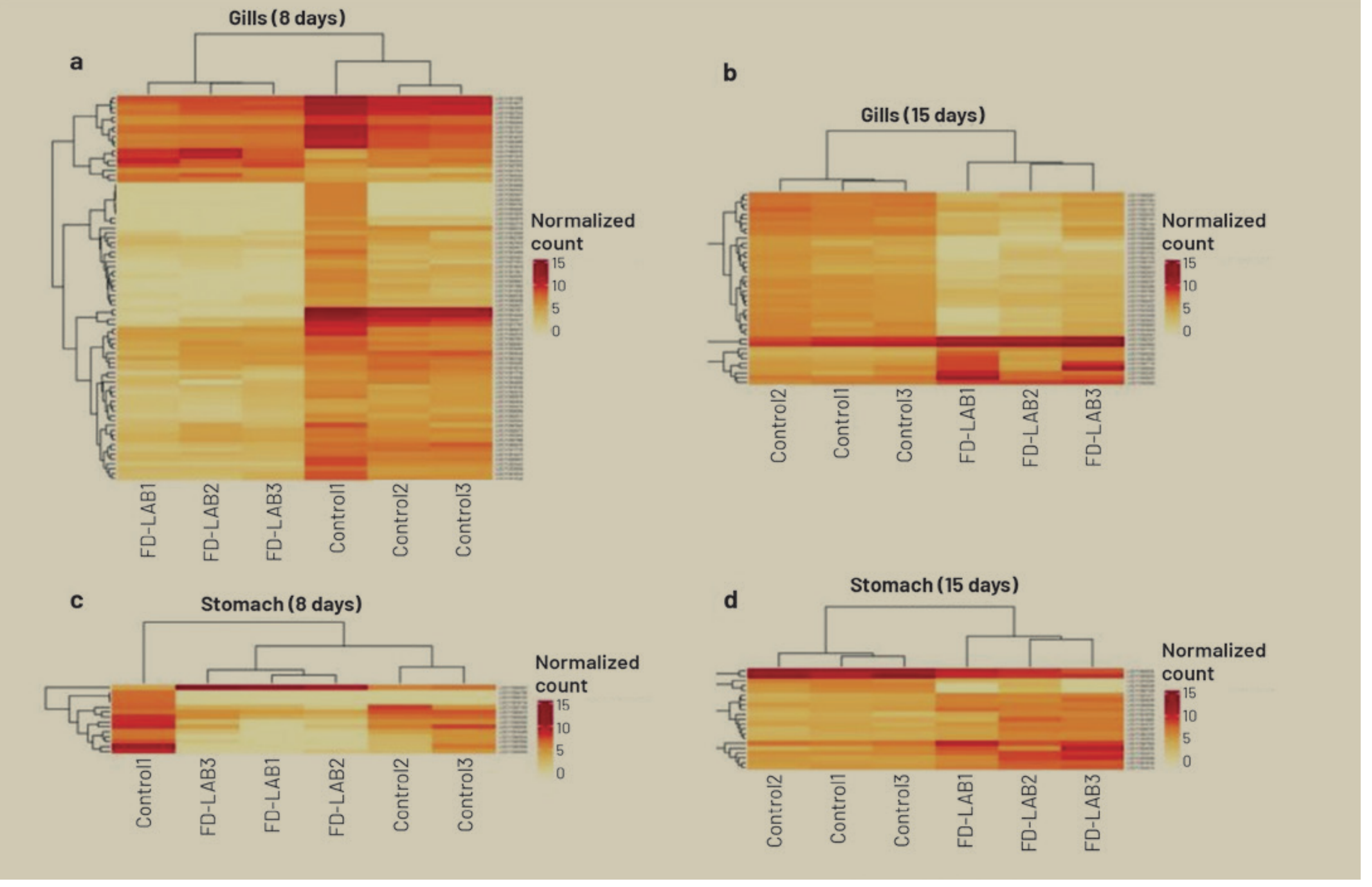
- Stomach: Thiopurine S-methyltransferase-like (TPMT) and leukocyte elastase inhibitor B-like (SERPINB1) upregulated (15 days).
- Additional immune genes (prophenoloxidase [*proPO*], superoxide dismutase [*SOD*], lysozyme [*LYZ*]) were upregulated, particularly LYZ in gills (15 days).

Differential expression of circRNAs

- Gills: 248 DECs
- Stomach: 226 DECs
- Parental RNAs of DECs were linked to immune memory, stress response, and toxin binding.

Figure 1

Heatmap showing the differences between the transcriptome profiles of the (a-b) gills and (c-d) stomach of shrimp fed with either control or freeze-dried whole culture of *Lactiplantibacillus plantarum* (FD-LAB) feeds. Plotted are the normalized counts of the differentially expressed genes (DEGs) with log2 fold change ≥ 2 and p-value < 0.05.



- Gene ontology (GO) analysis indicated roles in molecular functions (heme/ion binding), peptide cross-linking, and cell remodeling.

Validation of differentially-expressed circular RNAs (DECs) via qPCR

- Validated DECs: Down syndrome cell adhesion molecule-like protein (DSCAM), heat shock 70 kDa protein cognate 4-like (HSP70), aminopeptidase N-like (APN), and extensin-like (ETX).
- Gene expression patterns of parental RNAs were largely consistent with circRNAs, confirming modulation upon FD-LAB supplementation.

Trained immunity & pathogen resistance

V. parahaemolyticus (VP_{AHPND}) and WSSV challenge tests:

- 15-day FD-LAB feeding significantly increased shrimp survival rates against both pathogens.
- 8-day feeding improved survival against VP_{AHPND} but not WSSV.
- Post-FD-LAB feeding (7-14 days): Enhanced survival, indicating potential trained immunity mechanisms. (Figure 2).

Discussion

FD-LAB enhances immunity and immune memory in shrimp

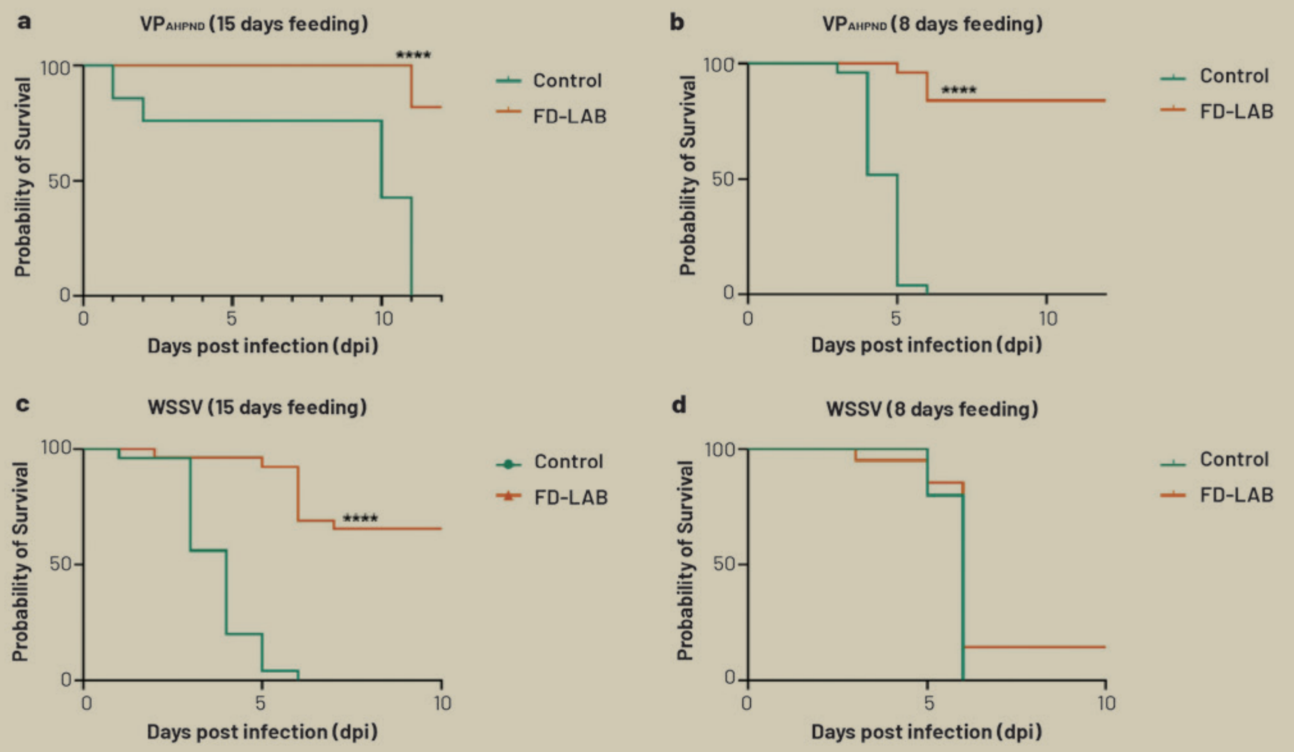
Dietary supplementation with *L. plantarum* (FD-LAB) induced significant transcriptomic changes in *P. vannamei*, particularly in genes related to immunity and immune memory. The whole culture of FD-LAB retains bioactive compounds, enhancing its probiotic potential. Transcriptome analysis revealed the differential expression of *Mucin-5ac (Muc5ac)*, a key component of the mucus barrier, which was downregulated in gills, potentially influencing pathogen resistance.

Regulatory immune proteins such as SERPINB1 were upregulated, suggesting their role in immune modulation and bacterial inhibition. The antibacterial gene anti-lipopolysaccharide factor (ALF) was also upregulated in both gills and stomach, contributing to bacterial and viral resistance.

Genes related to immune memory, including Thiopurine Methyltransferase (TPMT) and Histone H1-delta (HisH1), were differentially expressed. TPMT influences DNA methyl, a key mechanism in trained immunity, while HisH1regulates immune gene expression and has antimicrobial properties. The upregulation of Ficolin-1 (FCN1), involved in pathogen recognition and phagocytosis, suggest an improved immune response. These changes in pathogen

Figure 2

Kaplan-Meier survival curves of *Penaeus vannamei* shrimp against acute hepatopancreatic necrosis disease (AHPND)-causing *Vibrio parahaemolyticus* D6 (VP_{AHPND}) after (a) 15 days and (b) 8 days of feeding, and white spot syndrome virus (WSSV) after (c) 15 days and (d) 8 days of feeding. Asterisks (**** = $p < 0.0001$) denote significant difference against the control group.



recognition receptors (PRRs) indicate immune priming, a hallmark of trained immunity.

Circular RNAs as immune regulators

FD-LAB supplementation also modulated the expression of circRNAs, which play crucial roles in immune regulation. Notable examples include DSCAM, HSP70, EXT, and APN. DSCAM is involved in immune memory and pathogen-specific immunity, while HSP70 function as a damage-associated molecular pattern (DAMP) that activates innate immune responses. EXT and APN were differentially expressed, possibly contributing to antimicrobial responses and resistance to AHPND.

Circular RNAs targeting cuticle protein genes were downregulate, which may have helped inhibit WSSV infection, while those related to Rab genes were upregulated, consistent with previous reports on WSSV resistance in shrimp. These findings suggest that circRNAs influence the regulation of immune-related genes and contribute to trained immunity.

Trained immunity and pathogen resistance

Challenge tests demonstrate the FD-LAB supplementation enhanced shrimp resistance to *V. parahaemolyticus* (VP_{AHPND}) and WSSV. A 15-day feeding period significantly increased survival against both pathogens, while an 8-day period provided protection against VP_{AHPND} but not WSSV.

Seven days after FD-LAB intake, shrimp still exhibited increased survival rates against both pathogens, suggesting trained immunity. However, after 14 days, protection remained against WSSV but not VP_{AHPND}, indicating stimulus-specific immune memory.

Conclusion

FD-LAB supplementation enhances shrimp immunity through the differential expression of immune-related genes and circRNAs. The induced immune priming improves pathogen recognition, antimicrobial responses, and epigenetic regulation, making FD-LAB a promising functional feed additive for disease prevention in shrimp aquaculture. aqm

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled *"TRANSCRIPTOME ANALYSES OF MRNA AND CIRCULAR RNA REVEAL DIETARY SUPPLEMENTATION WITH FREEZE-DRIED LACTIPLANTIBACILLUS PLANTARUM PRIMES IMMUNE MEMORY OF WHITELEG SHRIMP (PENAEUS VANNAMEI) AGAINST PATHOGENS"* developed by: *DOMINGO GUZMAN, J. – Tokyo University of Marine Science and Technology and Industrial Technology Development Institute, NOZAKI, R.; KOIWAI, K., KONDO, H. and HIRONO I. – Tokyo University of Marine Science and Technology, AOKI, M; KUWAHARA, H. and MIKATA, K. – Sumitomo Chemicals Co., Ltd.* The original article was published, including tables and figures, on DECEMBER, 2024, through FISH AND SHELLFISH IMMUNOLOGY. The full version can be accessed online through this link: https://doi.org/10.1016/j.fsi.2024.110091.

Effects of Partial Substitution of Enzymatic Hydrolysate of Poultry By-Product Meal for Fishmeal on the Growth Performance, Hepatic Health, Antioxidant Capacity, and Immunity of Juvenile Largemouth Bass (*Micropterus salmoides*)

✱ By Aquaculture Magazine Editorial Team

The global demand for high-quality animal protein is soaring due to population growth, rising incomes in developing nations, and changing diets in developed countries, driving the rapid expansion of the aquaculture industry. Fishmeal, known for its excellent nutritional value, palatability, and digestibility, has traditionally been the primary protein source in aquatic feed. However, relying on fishmeal for aquaculture is becoming increasingly unsustainable due to supply challenges and rising costs. Therefore, developing novel, high-quality, low-cost protein sources is essential for enhancing the ecological and economic sustainability of aquaculture.

Over the past decades, various alternative protein sources have been explored for aquaculture. However, many have significant drawbacks, including anti-nutritional factors, unbalanced amino acid composition, and poor palatability, digestibility, and absorption, which can hinder the growth and health of aquatic animals. Enhancing these protein sources' quality through processes like heating, cooking, fermentation, and enzymatic digestion has shown promise. Enzymatic hydrolysis, in particular, stands out due to its high biosafety, mild reaction conditions, and environmental friendliness.

Poultry by-products have emerged as a potential fishmeal substitute in aquatic feed. Studies have shown that

In a groundbreaking 95-day study, researchers explored the potential of replacing traditional fishmeal with enzymatic hydrolysate of poultry by-product meal (EHPB) in the diets of juvenile largemouth bass (Micropterus salmoides). *The experiment tested five different diets, gradually reducing fishmeal content while increasing EHPB. The study highlights the potential for EHPB to enhance aquaculture nutrition and sustainability without compromising fish growth and health.*

enzymatic digestion can improve the nutritional value and utilization of poultry by-products. For instance, poultry by-product hydrolysate has been shown to enhance growth in juvenile red drum, and partially replacing fishmeal with poultry by-products improved growth performance and health in various aquatic species. However, the impact of enzymatic hydrolysate of poultry by-product meal (EHPB) on largemouth bass *(Micropterus salmoides)* has not been comprehensively studied.

Largemouth bass is valued for its fine texture, lack of interstitial spines, and high nutritional value, making it a promising candidate for aquaculture. This carnivorous freshwater species requires a high fishmeal content in its diet, about 40-55% dry matter. Previous research on EHPB in largemouth bass has primarily focused on muscle quality, leaving gaps in understanding its effects on hepatic antioxidant and immunological properties. This study aims to fill gaps and evaluate the comprehensive impacts of replacing fishmeal with EHPB on largemouth bass.

Materials and methods

The experimental diet formulations and ingredients used were referenced from Yi's study (Yi et al., 2023) from the lab's previous research (Table 1).

The juvenile largemouth bass feeding trial was conducted at the breeding farm of the Charoen Pokphand Group (Huanggang, China). Before the onset of the experiment, the fish were allowed to acclimate to the feeding environment for two weeks and given commercial feed. Then 600 active fish similar in size were evenly distributed among 15 cages (2.5 m × 2.5 m × 1.5 m) at a density of 40 per cage. The cages were then set in outdoor ponds and organized into five groups with three replicates per group. The initial fish weights and numbers were recorded. The fish were fed to apparent satiety at 6:30 and 18:30 daily. They were weighed and counted every two weeks and the feeding amount was adjusted accordingly. The duration of the feeding trial was 95 days. The fish were fasted for 24 hours before being sampled. They were weighed, enumerated, and collected to measure their growth indices.

Table 1

Ingredient and proximate composition of the experimental diets (% dry-matter basis). Note. The experimental diet formulations and ingredients used cited in Yi's study from our lab's previous research.

Ingredients (%)	Diets of EHPB additive				
	EHPB0	EHPB3	EHPB6	EHPB9	EHPB12
Fish meal	45.00	41.00	37.00	33.00	29.00
"Enzymatic hydrolysate of poultry by-product meal"	0.00	3.10	6.20	9.30	12.40
Soybean meal	13.00	13.00	13.00	13.00	13.00
Blood meal	6.00	6.00	6.00	6.00	6.00
Corn gluten meal	3.00	3.00	3.00	3.00	3.00
Wheat meal	7.00	7.00	7.00	7.00	7.00
Tapioca starch meal	7.00	7.00	7.00	7.00	7.00
Rice bran	7.52	7.52	7.52	7.52	7.52
Mineral mix	1.00	1.00	1.00	1.00	1.00
Vitamin mix	1.00	1.00	1.00	1.00	1.00
Microcrystalline cellulose	2.28	2.36	2.48	2.66	2.74
Squid paste	2.00	2.00	2.00	2.00	2.00
Fish oil	3.70	3.99	4.28	4.47	4.76
Monocalcium phosphate	1.00	1.45	1.85	2.30	2.75
Choline chloride	0.50	0.50	0.50	0.50	0.50
L-lysine	0.00	0.05	0.10	0.16	0.21
L-methionine	0.00	0.03	0.06	0.09	0.12
Total	100.00	100.00	100.00	100.00	100.00
Taurine (mg/kg)	0.00	11.40	22.80	34.20	45.60
Analytical composition (Dry-matter basis)					
Gross energy (KJ)	19.90	19.84	19.84	20.18	19.62

Table 2

Growth performance and morphometric parameters of largemouth bass fed with the experimental diets for 95 days.
Values are mean of three replicates ± SEM (standard error). Means in the same row with different letters superscripted abc indicate the effect was significantly different between groups ($p < 0.05$).
[1] IBW (g), initial body weight; [2] FBW (g), final body weight; [3] Weight gain ratet (WGR) (%) = 100 × (final body weight (g) – initial body weight (g)) / initial body weight (g); [4] Specific growth rate (SGR) (%/d) = 100 × [(ln (final body weight (g)) – ln (initial body weight (g))) / days]; [5] Feed conversion ratio (FCR) = dry feed fed (g) / (final body weight (g) – initial body / weight (g)); [6] Survival rate (SR) (%) = 100 × (Number of fish survived / Total number of fish stocked). [7] Condition factor (CF) (g/cm^3) = 100 × (body weight (g) / body length (cm^3); [8] Hepatosomatic index (HSI) (%) = 100 × (hepatosomatic weight (g) / whole body weight (g)).

Parameters	Diets of EHPB additive				
	EHPB0	EHPB3	EHPB6	EHPB9	EHPB12
IBW[1] (g)	22.25	22.35	22.36	22.30	22.35
FBW[2] (g)	160.80^{ab}	167.92^{b}	158.76^{ab}	157.92^{ab}	151.97^{a}
WGR[3] (%)	622.68^{ab}	651.33^{b}	610.01^{ab}	608.16^{ab}	579.94^{a}
SGR[4] (%/d)	2.08^{ab}	2.12^{b}	2.07^{ab}	2.06^{ab}	2.02^{a}
FCR[5]	1.42	1.34	1.39	1.39	1.55
SR[6] (%)	92.50	85.00	90.83	94.17	85.00
CF[7] (g/cm^3)	2.22^{a}	2.37^{ab}	2.46^{b}	2.47^{b}	2.36^{ab}
HSI[8] (%)	2.40	2.56	2.85	2.61	2.20

Results

Growth performance and morphometry data are listed in Table 2. The fish survival rate (SR) was above 85% for all groups, and none of the experimental diets influenced this metric.

Poultry by-products have emerged as a potential fishmeal substitute in aquatic feed. Studies have shown that enzymatic digestion can improve the nutritional value and utilization of poultry by-products.

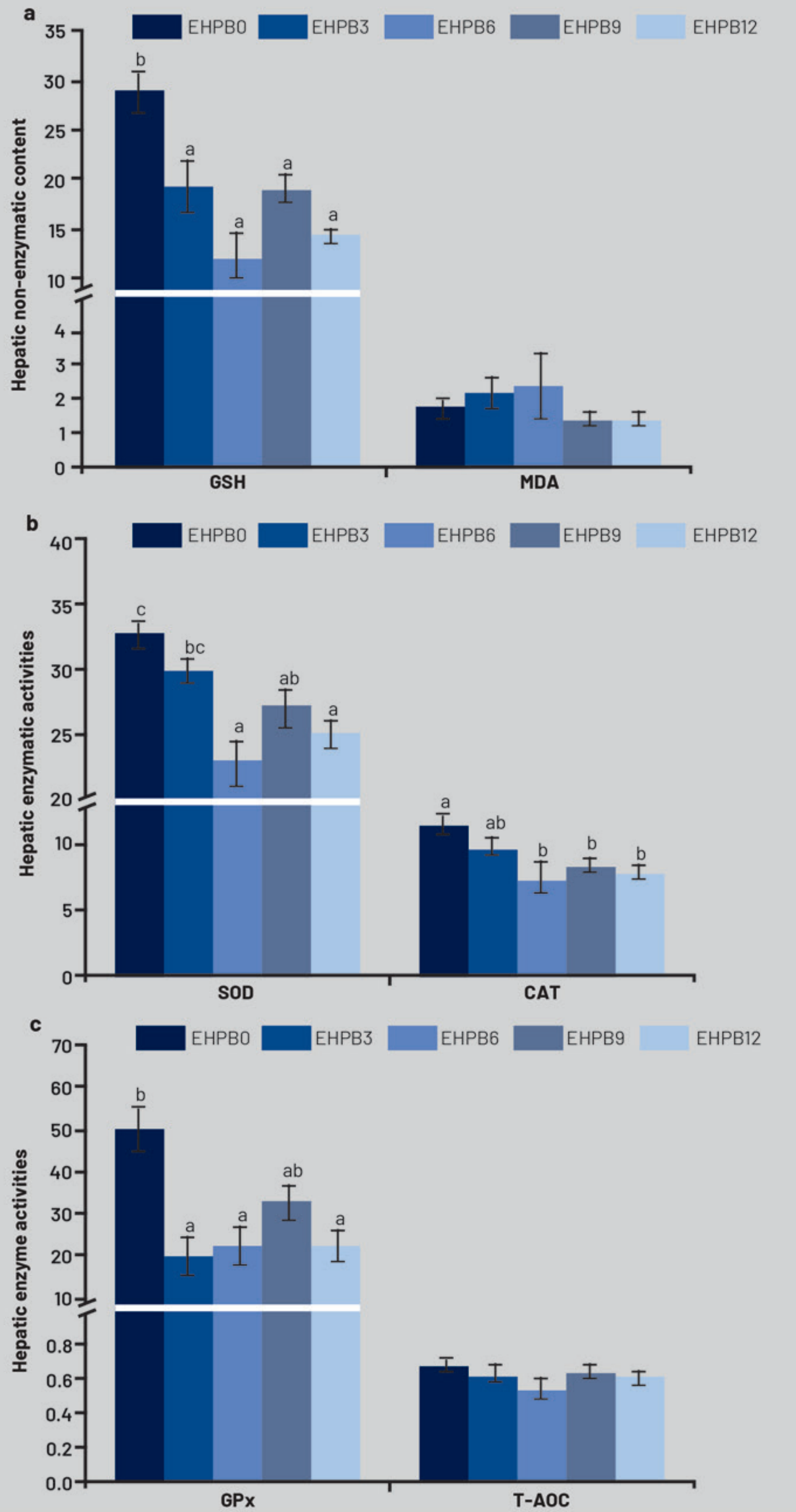
The trends in specific growth rate (SGR) and weight gain rate (WGR) were consistent with that of the final body weight (FBW). Furthermore, the values of these parameters obtained for each EHPB treatment group did not significantly differ from those obtained for the control group (EHPB0). However, FBW, SGR, and WGR decreased with increasing EHPB content.

In terms of whole-body composition, the fish in EHPB0 had the lowest moisture content ($p < 0.05$). In contrast, the crude protein was highest under EHPB0 ($p < 0.05$). The crude lipid and ash content did not significantly differ among treatments ($p > 0.05$). While the glucose (GLU) levels under all EHPB diets except EHPB3 were higher than those under EHPB0. GLU was highest under EHPB12 ($p < 0.05$). Lactate dehydrogenase (LDH), total cholesterol (TC), and triglyceride (TG) were significantly lower under all EHPB except EHPB9 and EHPB12 compared with the control. For the latter two treatments, LDH, TC, and TG had increased relative to EHPB0 ($p < 0.05$).

The hepatic antioxidant-related activity and content parameters are graphically represented in Figure 1.

Figure 1

The enzymatic activities and non-enzymatic content of hepatic indexes in largemouth bass. (a) glutathione (GSH), malondialdehyde (MDA); (b) superoxide dismutase (SOD), catalase (CAT); (c) glutathioneperoxidase (GPx), total antioxidant capacity (T-AOC). Data are expressed as a graphical representation of the mean and error bars (means ± S.E.M). Mean values with different letters superscriptedabc above bars indicate the effect was significantly different between groups ($p < 0.05$).



Substituting up to 12.4% enzymatic hydrolysate of poultry by-product meal (EHPB) in the diet of juvenile largemouth bass can replace 35.56% of fishmeal without negatively affecting growth parameters like final body weight (FBW), specific growth rate (SGR), and weight gain rate (WGR).

Enzymatic hydrolysate of poultry by-product meal (EHPB) can effectively replace a significant portion of fishmeal in largemouth bass diets without compromising growth or health, with an optimal replacement level of around 3.1% EHPB.

EHPB0 had the highest GSH content ($p < 0.05$) (Figure 1a). The same was true for GPX except that its activity did not significantly differ between EHPB9 and EHPB0 ($p < 0.05$) (Figure 1c).

Discussion

This trial demonstrated that substituting up to 12.4% enzymatic hydrolysate of poultry by-product meal (EHPB) in the diet of juvenile largemouth bass can replace 35.56% of fishmeal without negatively affecting growth parameters like final body weight (FBW), specific growth rate (SGR), and weight gain rate (WGR). Similar results were reported in other species, suggesting EHPB as an effective fishmeal substitute.

EHPB's effectiveness lies in enzymatic digestion, which liberates small peptides and free amino acids that enhance appetite, improve feed conversion, and promote growth. Unliked the increased feed conversion ratio (FCR) seen in Atlantic salmon with altered feed palatability, EHPB did not affect the FCR in largemouth bass, even at maximum dosages. However, growth performance decreased with higher EHPB content, with significant differences between the EHPB3 and EHPB12 groups, suggesting an optimal replacement level.

Hepatosomatic index (HSI) and condition factor (CF) analyses indicated no adverse effects from EHPB supplementation. The results showed higher CF values in EHPB6 and EHPB9 compared to the control, suggesting better overall nutritional status. Although crude protein and moisture levels varied, these findings align with previous studies, indicating species-specific responses to EHPB.

Biochemical indices like total protein (TP) and albumin (ALB) were unaffected by EHPB addition, indicating maintained nutrient intake and liver function. Enzymatic activity analysis showed lower levels of glutathione peroxidase (GPX), superoxide dismutase (SOD), and catalase (CAT) in EHPB treatments, suggesting slight negative effects on antioxidant mechanisms. However, no significant changes in malondialdehyde (MDA) content indicated no toxic effects.

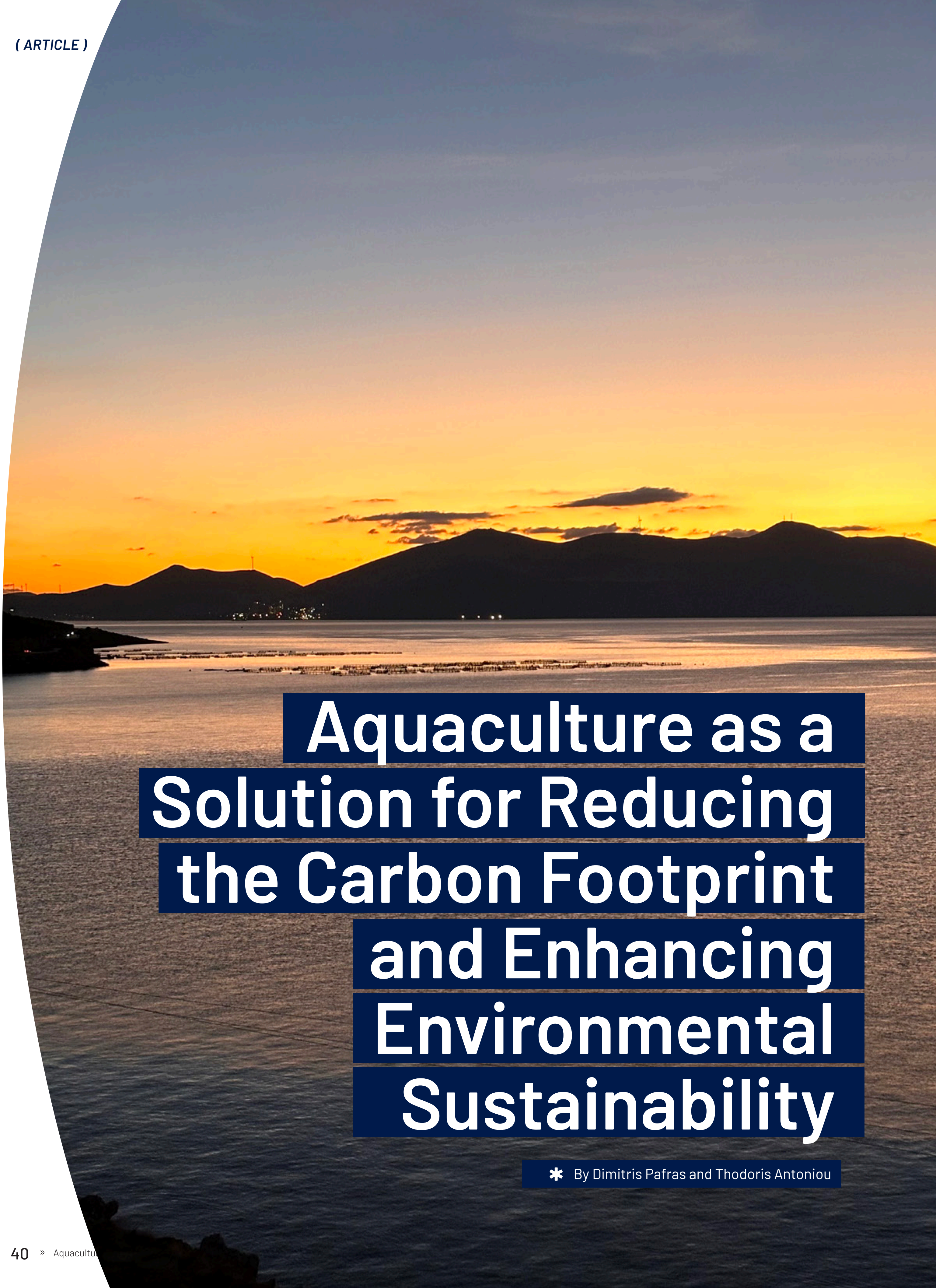
Inflammatory and immune response gene expression analyses revealed overexpression of pro-inflammatory cytokines tnf-α and il-8 in EHPB6, suggesting an inflammatory response at this EHPB level. Conversely, anti-inflammatory il-10 was also elevated, indicating a balanced immune response. Overall, competitive inhibition of amino acid transport likely occurs at higher EHPB levels, affecting metabolism and growth. In summary, EHPB can effectively replace a significant portion of fishmeal in largemouth bass diets without compromising growth or health, with an optimal replacement level of around 3.1% EHPB.

Conclusion

Diets containing a basal fishmeal level of 29% (12.4% EHPB) did not affect the growth performance of juvenile largemouth bass. However, in terms of the expression of genes related to antioxidant performance and immune function, the optimal level of EHPB added to largemouth bass diets was 3.1% (41% fishmeal). The EHPB6 treatment activated the immune system, alleviated oxidative stress, and attenuated inflammation via the MAPK/Nrf2/NF-κB signalling pathways. aqm

This is a summarized version developed by the editorial team of Aquaculture Magazine based on the review article titled "EFFECTS OF PARTIAL SUBSTITUTION OF ENZYMATIC HYDROLYSATE OF POULTRY BY-PRODUCT MEAL FOR FISHMEAL ON THE GROWTH PERFORMANCE, HEPATIC HEALTH, ANTIOXIDANT CAPACITY, AND IMMUNITY OF JUVENILE LARGEMOUTH BASS *(MICROPTERUS SALMOIDES)*" developed by: GU, J. and ZHANG, Q. - Nanjing Agricultural University and Chinese Academy of Fishery Sciences; HUANG, D. - Chinese Academy of Fishery Sciences; ZHANG, L., CHEN, X. and WANG Y. - Tongwei Agricultural Development Co., LTD.; LIANG, H. - Nanjing Agricultural University and Chinese Academy of Fishery Sciences; REN, M. - Nanjing Agricultural University. The original article was published, including tables and figures, on FEBRUARY, 2024, through AQUACULTURE REPORTS. The full version can be accessed online through this DOI: https://doi.org/10.1016/j.aqrep.2024.101990

(ARTICLE)



Aquaculture as a Solution for Reducing the Carbon Footprint and Enhancing Environmental Sustainability

✱ By Dimitris Pafras and Thodoris Antoniou

Climate change is an urgent challenge that requires international cooperation. Since the signing of the Kyoto Protocol in 1997, the role of greenhouse gases (GHGs) and carbon has been emphasized. It is estimated that if emissions are not significantly reduced by 2030, global temperature increase could exceed 2°C, and even with low emissions, there is more than a 50% chance of a 1.5°C increase (IPCC, 2022).

The carbon footprint represents the total greenhouse gas emissions during the lifecycle of a person, organization, or product, measured in CO_2 equivalents (Caro et al., 2015; Sun et al., 2023). In aquaculture, these emissions mainly result from energy-intensive activities such as water management, feed production, and product processing, releasing gases like CO_2 and methane (Macleod et al., 2020). Given its high energy demands, the aquaculture industry's carbon footprint is a critical environmental and societal issue.

Aquaculture has been recognized for its lower carbon emissions compared to other agricultural and livestock practices. This smaller carbon footprint is due to several factors, including the absence of emissions from land use change, improved feed conversion rates and reduced methane production from aquatic animal digestive systems. Thus, aquaculture is proving to be a sustainable solution for sustainable food production with less environmental impact.

The global aquaculture industry plays a key role in meeting humanity's nutritional needs, providing a source of animal protein and other nutrients with a significantly lower carbon footprint than other traditional food production methods. As the world's population grows and the demand for seafood increases, aquaculture is emerging as a sustainable and environmentally friendly alternative to reduce greenhouse gas emissions and enhance global food security.

The selection of species in aquaculture impacts the carbon footprint due to varying feed and water quality needs. Species with high feed consumption and strict water requirements result in larger environmental costs (Feng et al., 2023). For example, species needing fish meal and oil have high emissions. Choosing species with lower carbon footprints helps reduce environmental impact

Dimitris Pafras.

The development of sustainable practices, such as the use of renewable energy sources for farm operations and the optimization of water resource management, can further reduce greenhouse gas emissions.

(Macleod et al., 2020). Feed production contributes over 70% of aquaculture emissions (Hognes et al., 2009). Farmed bivalves emit much less CO_2 compared to wild-caught ones, and shrimp and salmon also show lower emissions when farmed.

Effective water quality management is vital for sustainable aquaculture, affecting both the ecosystem and carbon footprint. Proper control of nutrients and key parameters like pH and dissolved oxygen is essential for farmed species' health and ecosystem balance (Bergman et al., 2020). Poor water quality can increase energy use for aeration and pumps, while improper waste management can reduce yields and harm the environment (Yang et al., 2018). Eco-friendly water management strategies reduce oxygen needs and carbon emissions, improving efficiency and sustainability in aquaculture.

Aquaculture and a Lower Carbon Footprint

Aquaculture has been recognized for its lower carbon emissions compared to other agricultural and livestock practices. According to data from the United Nations Food and Agriculture Organization (FAO), aquaculture produces about 245 million tons of CO_2 per year, accounting for just 0.49% of global greenhouse gas emissions. In comparison, emissions from terrestrial agriculture reach 400-660 million tons of CO_2 per year (Macleod et al., 2020). This smaller carbon footprint is due to several factors, including the absence of emissions from land use change, improved feed conversion rates and reduced methane production from aquatic animal digestive systems. Thus, aquaculture is proving to be a sustainable solution for sustainable food production with less environmental impact.

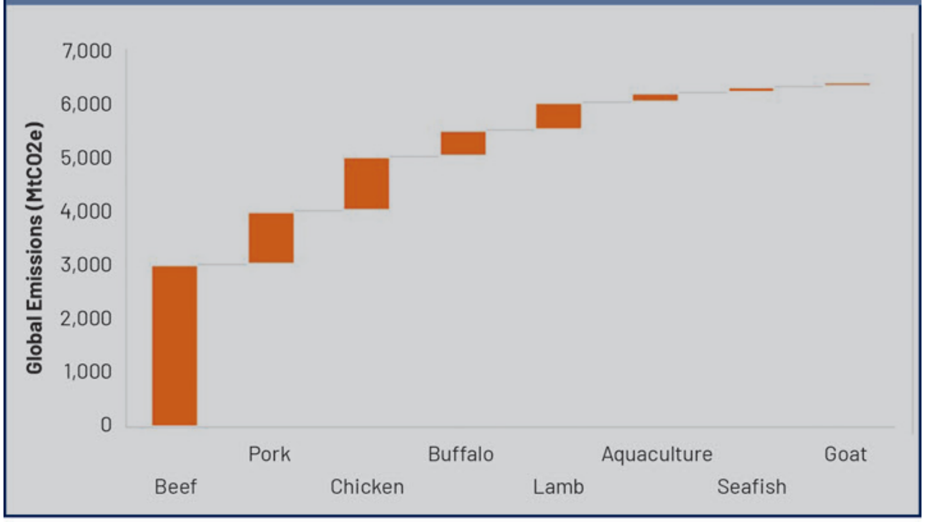
The global emissions from aquaculture are lower than livestock.

Emission Reduction Strategies in Aquaculture

Aquaculture offers significant opportunities to reduce the carbon footprint through the implementation of innovative strategies. The development of sustainable practices, such as the use of renewable energy sources for farm operations and the optimization of water resource management, can further reduce greenhouse gas emissions. In addition, the application of green technologies, such as the development of sustainable feeds that require fewer resources and energy to produce, can improve feed

Figure 1

Comparison of greenhouse gas emissions associated with different types of meat production.



Aquaculture provides jobs and supports local economies, especially in areas where other forms of agriculture are limited.

conversion rates and reduce the environmental footprint of aquaculture.

In addition, strategies to enhance the nutritional performance of aquatic animals, combined with reducing discards and enhancing resource cycling, help to minimize environmental impacts. Initiatives to reduce methane emissions from the digestive systems of aquatic organisms, such as research into the use of alternative plant proteins in feed, are important steps towards sustainable development of the sector.

Socio-economic Benefits and Sustainability

Aquaculture has not only environmental benefits, but also significant socio-economic value. It provides jobs and supports local economies, especially in areas where other forms of agriculture are limited. By providing vital sources of protein, aquaculture enhances food security by reducing dependence on land-based agriculture and its associated environmental impacts. The growing global consumption of seafood highlights the need for sustainable and responsible production, which can be achieved through improved aquaculture practices.

Carbon footprint studies combined with emission reduction strategies are laying the foundations for further enhancing the sustainability of the sector, while aquaculture is increasingly recognized as a solution to reduce global emissions and enhance food production without degrading the environment.

Prospects for the Future of Aquaculture

The future of aquaculture looks very promising, with new technologies and innovative practices promising to make the sector even more sustainable. The development of green technologies and the implementation of sustainable aquaculture management practices will allow for an increase in the production of food with a low carbon footprint, while at the same time reducing the environmental impact of the industry.

Technological developments, combined with the implementation of green strategies, promise a sustainable future for aquaculture. Promoting the use of renewable energy, improving resource management and developing more efficient practices can ensure higher production at reduced environmental costs (Chen et al., 2022).

With these features, aquaculture is recognized as a key pillar in the transition to a green economy, boosting global food production while protecting the environment. aqm

Thodoris Antoniou.

References and sources consulted by the author on the elaboration of this article are available under previous request to our editorial staff.

* Dimitris Pafras.
PhD candidate in Marine Biology & Fisheries & Dynamics.
Thodoris Antoniou.
Hatchery manager, fish farming.

Diversity Generates Progress and Greatness

✱ By Antonio Garza de Yta, Ph.D.

Recently, I have witnessed many debates between different ideologies: the new school versus the old school, the proponents of industry versus the defenders of small scale, the defenders of scientific knowledge versus those who distrust anyone with a degree, those who promote the new trends in animal welfare versus those who think it is an exaggeration of the "woke" movement.

It is true that we all live in a specific environment that has shaped the way we think, act, and feel. Reality, or our reality, depends on our environment. While the proponents of small-scale aquaculture want to create regional genetic centers, training and technology transfer through extension services, and cooperativism as an integrator of the value chain, the proponents of industrial aquaculture want to create investment funds, private genetic centers, and free competition throughout the value chain, just to mention a few minimum points. But it is not only these two sides of development, but also those who promote fish vaccination against those who oppose it, those who are 100% in favor of industrially formulated feeds against those who promote small-scale production, semi-intensive aquaculture against hyper-intensive aquaculture, and the list goes on and on.

There is no doubt that we live in a time of extremes, of contrasts, of ideological confrontations, of disunity, and the aquaculture sector is no stranger to the environment that surrounds it. In all visions we can find great ideas and opportunities... The diversity of opinions, perspectives and feelings is what creates progress and greatness.

Whatever our reality and our way of thinking, we must find points on which we all agree.

But whatever our reality and our way of thinking, we must find points on which we can all agree. The first is undoubtedly sustainability: however we develop aquaculture, it must ensure that future generations can enjoy the same or better resources than we do today. The project must be profitable and improve the quality of life of the people involved; it is not a question of creating poorly paid jobs or involving thousands of people in such a small-scale activity that, no matter how hard those involved try, it will not be profitable. We must avoid perpetuating poverty and become real agents of change. We have to reduce the environmental footprint to a minimum, either by growing aquatic plants or shellfish, which is the most sustainable way to produce food on the planet, or by intelligent intensification, which makes the best use of resources (land, water, food, energy). We must cultivate our organisms in the best possible conditions, not only for their well-being, but also to maximize their growth, prevent disease and, consequently, increase profits.

Everything in life is a balance, and no one in this world has the absolute truth. Therefore, we must try to put ourselves in the shoes of others before we criticize or condemn. Let us return to the ancient and forgotten art of LISTENING, for only by doing so can we learn. Let us try to focus on the middle ground, let us think of the common good. The Roman Empire was the greatest empire in history because of its diversity. If we only surround ourselves with people who think like us, we will hardly innovate. In all visions we can find great ideas and opportunities. It is the diversity of opinions, perspectives, and feelings that creates progress and greatness. So today, more than ever, let us reach out and work together for what we love so much: aquaculture. aqm

* Antonio Garza de Yta is COO of Blue Aqua International-Gulf, Vice President of the International Center for Strategic Studies in Aquaculture (CIDEEA), President of Aquaculture Without Frontiers (AwF), Past President of the World Aquaculture Society (WAS), Former Secretary of Fisheries and Aquaculture of Tamaulipas, Mexico, and Creator of the Certification for Aquaculture Professionals (CAP) Program with Auburn University.

Use and Abuse of Antibiotics
in Shrimp Farming

Antibiotics are chemicals that interfere with microbial (bacterial and fungal) metabolic processes, altering their fitness to survive. The proper use of antibiotics, largely ignored not just for aquaculture but in the treatment of humans as well, entails isolating the bacteria responsible for a given disease outbreak. Using the wrong antibiotic for the specific problem with an improper dosage ensures that selection pressures on the bacterial population drive it towards resistance. Many aquaculturists abuse antibiotics although it is not done everywhere and by everybody.

✱ By: Stephen Newman

Bacteria are complex organisms. We are continuing to learn about how important they are in health and disease. Studies suggest that there is a complex arrangement between the host and the microbiome (the assemblage of bacteria that are present in a given environment). Some believe that the specific composition of the microbiome is what makes animals healthy. Others believe that this composition is not responsible for "good" health. These assemblages allow bacteria to act as groups that differ from how they act singularly. These are known as biofilms. Biofilms are collections of bacteria that are present at high densities and are protected from many environmental impacts by being in a biofilm including some antibiotics and disinfectants.

Shrimp farmers are often heavily focused on the role of vibrio species in shrimp disease. This is for good reason. This genus of bacteria is ubiquitous in marine and freshwater aquatic environments where they play an important role in the recycling of chitin, a major component of the carapace of shrimp and all other crustaceans and insects. Cellulose, a biopolymer found in plants is the most abundant and chitin is the second. There are approximately 150 *Vibrio* species that have been identified to date. While three species are responsible for most of the impact on humans, *Vibrio cholerae* (yellow on thiosulphate citrate bile salts sucrose, TCBS), *V. parahaemolyticus* (green on TCBS) and *V. vulnificus* (green blue on TCBS), only specific strains cause disease. Many strains are benign because they do not contain the toxins that cause the disease. This could be due to the lack of the specific genes, loss of gene integrity, production of a defective gene product, etc. A dozen or so species, again specific strains, cause disease in shrimp and fish. These include *V. alginolyticus* (yellow on TCBS), *V. campbellii*, *V. parahaemolyticus*, and several others. Some are obligate and others opportunistic. Obligate pathogens usually produce acute disease, and it can take a very low level of bacteria to initiate the process in healthy animals. Opportunistic pathogens typically require

> *Some believe that the specific composition of the microbiome is what makes animals healthy. Others believe that this composition is not responsible for "good" health.*

weakened animals, usually as a result of other infectious disease processes although there are many things that can weaken animals.

Any given bacterial population is composed of many different strains. Those strains we can culture are not always the strains that are causing the impact that we are attempting to correlate with the presence of a specific pathological process. Strains vary in their genes and gene expression. Given genera (like *Vibrio*) and species (like *V. parahaemolyticus*) share sufficient traits for them to be considered related to each other. Yet individual strains within the species often vary considerably. This causes considerable confusion among laymen. For vibrios, it has resulted in several widespread myths. Perhaps the one that does the most harm ultimately is based on the ability to digest sucrose, a sugar molecule that is composed of two sugars, glucose and fructose. This sugar is abundant and linked to a variety of health issues in humans. When vibrio's utilize sucrose as a nutrient they produce organic acids as a by-product. These change the pH and on the selective, differential media, TCBS agar, results in yellow colonies. If they do not readily utilize it, one sees green colonies. The ability to use sucrose is not related in any way to the ability to produce disease. Focusing on yellow versus green is not going to eliminate vibrio disease. I have written elsewhere about this and what can be done to lessen the incidence and severity of vibrio disease processes.

Antibiotics are chemicals that interfere with microbial (bacterial and fungal) metabolic processes, altering their fitness to survive. They are not antivirals (although there are some compounds that have antiviral as well as antibacterial activity). Many dozen have been approved for use in humans. A handful only have been approved for use in aquaculture and in the US (https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs), which also regulates what antibiotics can be used on product imported into the US, only a few are approved for very specific usages. For a detailed explanation of how they work, how resistance occurs, etc. we suggest you visit this link (Saloni Dattani, 2024 - "How do antibiotics work, and how does antibiotic resistance evolve?" Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/how-do-antibiotics-work'). There seems to be an inordinate amount of focus on the abuse of antibiotic usage

The antibiotic needs to be used at the appropriate dosage and duration for optimum effectiveness. For aquaculturists, the problem with all of this is time.

in aquaculture despite the fact that the majority of the abuse is in human therapy and other terrestrial agriculture sectors.

Aquaculture is still largely an immature industry. The use of antibiotics is not as much of a concern for domestic consumption as it can be for export. Much of the global production takes place in less developed countries with some notable exceptions such as the farming of salmon mainly produced in Norway and Chile. Farmed shrimp production, largely for export, takes place in Ecuador, India, Vietnam, Indonesia and others. There is no one consistent approach and the paradigms are, it seems, in a constant state of change. Disease is a major impediment to sustainable production. Many diseases are viral in origin with secondary infections, often from vibrios. Primary disease from bacteria is still of course a challenge. Most experienced aquaculture pathologists will tell you that much of what is killing shrimp are mixed infections.

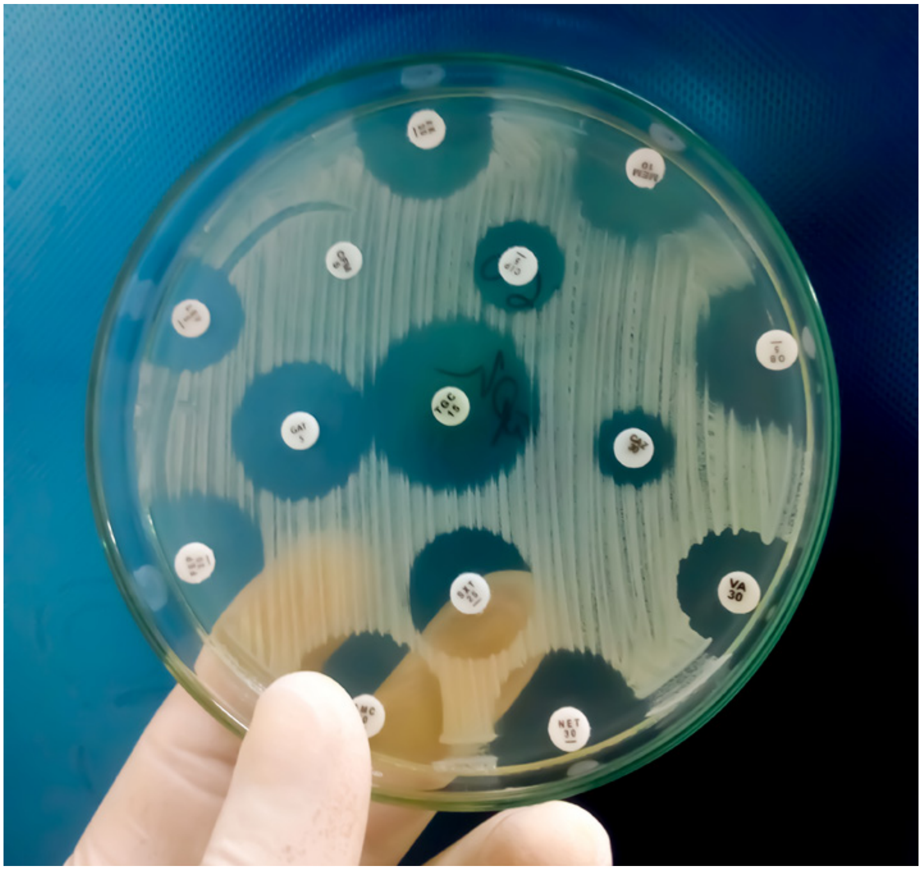
The proper use of antibiotics, largely ignored not just for aquaculture but in the treatment of humans as well, entails isolating the bacteria responsible for a given disease outbreak. If this is a new unreported strain or species, there must be a clear-cut science-based correlation between its presence and the observed disease process. The isolates are screened using standard methods for their susceptibility to a range of antibiotics. This will determine what the best antibiotic to use is. The antibiotic needs to be used at the appropriate dosage and duration for optimum effectiveness. For aquaculturists, the problem with all of this is time. Some diseases appear to move through the population very rapidly making the time between seeing moribund animals (birds can be important in alerting farmers to this) and the population going off feed very short. Panic sets in and the farmers use the antibiotics that are readily available without determining whether they are appropriate. As with human medicine where many of the "older" antibiotics have little to no effectiveness, the tendency is to use the latest most potent antibiotics. Using the wrong antibiotic for the specific problem with an improper dosage ensures that selection pressures on the bacterial population drive it towards resistance.

While biofilms can function to protect bacteria from the action of a wide range of antibiotics, resistance to antibiotics is natural. I refer you to the above (Saloni Dattani, 2024) link which discusses the various mechanisms by which this can occur. All bacteria produce antimicrobial compounds. This is an essential component of their ability to survive and thrive in an environment where there are vast numbers of bacteria competing for nutrients.

Antibiotics can leave residues in the flesh of treated animals. This is a major reason why antibiotics need to be tested and evaluated not just for efficacy against specific organisms, but for the ability of the animals that they are being used on to metabolize them. This impacts dosages, the duration of treatment, and withdrawal times. This is the amount of time needed after the antibiotic treatment is ended for the levels of metabolic residues to be below legal threshold levels. Only a few antibiotics and specific residues are routinely tested for in farmed shrimp at the time of harvest/processing. The vast majority of them are not. Most of the antibiotics that are used in acts of desperation are typically not legal for use in aquatic animals in the countries that the final product is being exported to. Should regulators determine that the risks of these residues are a serious issue then the list of antibiotics and metabolites being tested for could be expanded dramatically. In general, when exporting shrimp treated with antibiotics have been used, it is important to ensure that the specific antibiotic being used is approved for use in the destination country or at the very least that sufficient time has passed to ensure that there are no detectable residues.

Responsible use of antibiotics is something that benefits all of us. It ensures that resistance develops slower. For the most part, resistance is inevitable because of the very nature of bacteria. Even tolerance is problematic because it requires higher dosages for the desired impact. Many aquaculturists abuse antibiotics although it is not done everywhere and by everybody.

The term sustainability has become a marketing phrase with little to no meaning. For aquaculture it means being able to produce a product economically without negatively impacting the production environment. It encompasses waste stream management and progressive disease prevention and mitigation programs among other things. Having effective antibiotics that are used in a responsible manner is an essential component of this process. aqm



* Stephen G. Newman has a bachelor's degree from the University of Maryland in Conservation and Resource Management (ecology) and a Ph.D. from the University of Miami, in Marine Microbiology. He has over 40 years of experience working within a range of topics and approaches on aquaculture such as water quality, animal health, biosecurity with special focus on shrimp and salmonids. He founded Aquaintech in 1996 and continues to be CEO of this company to the present day. It is heavily focused on providing consulting services around the world on microbial technologies and biosecurity issues.

sgnewm@aqua-in-tech.com
www.aqua-in-tech.com
www.bioremediationaquaculture.com
www.sustainablegreenaquaculture.com.

Fraud Impacts Trust (Part 1)

By FishProf

International food trade, especially fish/seafood, has helped to reduce global poverty and hunger, yet illegal trade in food and food fraud undermines the global food system and endangers public health.

The FishProf questions why we are allowing such bad practices in aquaculture/seafood and suggests that we all be more proactive in our industry to eliminate bad practices and poor attitudes that impact trust in the whole supply chain. The aquaculture industry is constantly in the media for the wrong reasons, and it is up to us all to be front and center to ensure we are on top of this matter.

A recent publication, "Illicit Trade in Food and Food Fraud" published by the World Trade Organization (WTO) and written in collaboration with the Food and Agriculture Organization of the United Nations (FAO), food safety nonprofit SAFE, the International Seed Federation (ISF), and other experts in food safety and food crime spanning the supply chain examines the challenges of combating food fraud and illegal practices in food trade. The publication also explains the WTO rulebook and its role in combatting food fraud and illicit food trade.

This shows how a sea flounder fillet is being mentioned yet the species being sold is Basa (a fresh water catfish species). Confusion reigns (Photo: Prof. Jose M. Fernandez Polanco).

The FishProf questions why we are allowing such bad practices in aquaculture/seafood and suggests that we all be more proactive in our industry to eliminate bad practices and poor attitudes that impact trust in the whole supply chain. The aquaculture industry is constantly in the media for the wrong reasons, and it is up to us all to be front and center to ensure we are on top of this matter.

Consumers cheated by retailers. The Dory on offer here in a Queensland fishmonger shop is actually Basa likely from Viet Nam.
Note the FishProf has no axe to grind with Basa or Viet Nam - this is a value for money freshwater product grown, harvested and processed with care and attention by Viet Nam processor and exported to Australia.
The problem is it should be sold as Basa… not Dory.
Dory implies a sea product and whilst there are many Dory's there is a sense of a high priced product.
There is no country of origin shown on the labeling.
The consumer is being cheated.
We need to stamp this out!
This photo was taken by FishProf on 21 May 2024 so this is not an old photo being used again.
The person behind the counter at the retailer shop clearly had 'no idea' and said the boss was 'out'.

The FishProf notices that in the publication, WTO describes illicit trade in food and food fraud as "the buying and selling of products to be eaten, drunk, or grown that are not what they are claimed to be; that fail to comply with health and other regulations (e.g., on quality); and that are smuggled or otherwise produced or traded outside the legitimate market framework." They stress that illicit trade in food and food fraud significantly damages international trade and public health.

Interestingly, the WTO rulebook contains agreements that together create a legal framework for international food trade, helping to combat illicit trade and fraud and, importantly, the document identifies several areas in which improvements could be made to dissuade criminals from engaging in illegal trade or food fraud, through several measures.

WTO rules of particular importance to food safety are the "Agreement on the Application of Sanitary and Phytosanitary Measures," which allows WTO members to regulate food imports based on science and risk assessment techniques, and the "Agreement on Technical Barriers to Trade," which will enable members to address deceptive practices.

Simply put illegal trade of any persuasion in a supply chain makes food safety plans unworkable and food recalls (an essential element of any food safety plan) impossible.

The smuggling of agricultural products is driven by a disparity between the price of a product at its origin and its destination, which can include price differentials deriving from government subsidies. Continuing WTO agriculture negotiations aim to simplify tariff structures, reduce excessively high tariffs and trade-distorting subsidies, and address import and export restrictions to reduce smuggling and illegal trade incentives. The FishProf believes we should all support these processes and bring common sense to reducing import and export restrictions.

Modernizing food safety legislation with all governments is essential, as holistic regulations on detecting, preventing, mitigating, and controlling food/fish fraud can lessen the room for opportunity for fraudsters. Many countries are going through these procedures, and hopefully, FishProf hopes they are looking at what others are doing and learning from those experiences to speed up the processes.

Good industry associations should collaborate with their members and the authorities to raise matters worthy of conducting timely and thorough investigations. FishProf believes there was a time when the industry kept its head down, hoping that no one would notice any questionable practices, but society has moved on!

You only need to look at what is happening in Canada with open pen salmon industry to appreciate how the pendulum swings! One minute you are in business with government support and the next the government are legislating you out of business.

The sector must promote its solid credentials in all activities leading the way. It should no longer be bureaucracy versus industry, as it was in the old days. Everyone should ensure the consumer has confident choices and can look forward to consuming the most nutritious protein on the planet through the enormous variety that aquatic foods offer.

Food Labels Create Confusion

FishProf has noticed recently in European Union that food labeling which was devised to help people make informed choices when buying food, is now under pressure from no less than the European Court of Auditors (ECA).

The ECA are recently reported as saying that consumers are lost in a myriad of labels and brands that can mask deception.

The coexistence of multiple labelling systems—each with distinct meanings and purposes—undermines their intended role of guiding choices with food labelling. These EU Auditors are now warning that too many labels do not assist the consumers, they confuse them.

Keit Pentus-Rosimannus is a member of the European Court of Auditors (ECA) responsible for the audit and she has been quoted as saying "Instead of providing clarity, food labels too often create confusion; there are hundreds of different schemes, logos and claims that people need to decipher."

"Consumers are simply lost. The lack of clarity extends beyond nutritional labels to include environmental claims, slogans, and undefined terms like "fresh," "natural," and "antibiotic-free," many of which risk misleading consumers. The EU rules are full of holes that leave consumers vulnerable, and food companies can and of course are happy to use this legal vacuum," Pentus-Rosimannus warned, adding that food companies present products as healthier or more eco-friendly than they truly are.

The findings of this new report by the European Court of Auditors highlights that while labels provide information on the content and properties of food and EU rules ensure that they provide consumers with basic information, a number of worrying gaps in the legislation have been found, as well as problems with controls and penalties.

Whilst this report is about the EU there can be no doubt that consumers all over the world are exposed to an increasing number of claims, logos, slogans, labels, and scores that can not only be confusing but also misleading.

This audit report covers labels between 2011 and 2023 and included meetings with the Directorate-General for Health and Food Safety and the Directorate-General for Agriculture and Rural Development and interviewed authorities in Belgium, Italy, and Lithuania.

Simply put illegal trade of any persuasion in a supply chain makes food safety plans unworkable and food recalls (an essential element of any food safety plan) impossible.

Suzy Sumner, Head of the Brussels office for Foodwatch International, is reported as saying "What's worst about the ECA report: Rather than a lack of competence, it underlines the lack of political will in the EU's institutions to defend the rights of 450 million EU consumers instead of the interests of a powerful industry. Food labels may often be small in size. Still, they are of huge importance: They shape the eating habits of millions of people and therefore have a massive impact on the health of European consumers."

In the EU regulations require allergens to be emphasized in the ingredient list but, people with food allergies may be faced with overly cautious labeling and vague statements such as "may contain." A lack of harmonized rules at the EU level

Menu showing seafood for conference but sadly failing on correct information.

restricts their choice. Companies may apply the "may contain" wording to play it safe, and the use of this statement is not always based on risk assessments quantifying the presence of allergens. Implementing acts on precautionary allergen labeling have not yet been adopted by the EU Commission.

Clarity is made worse by the increasing number of voluntary labels, logos and claims used to attract consumers. These include "clean" labels about the absence of certain elements such as (e.g., "antibiotic-free" and uncertified qualities such as "fresh" and "natural.").

The EU allocated only about € 5.5 million (USD 5.77 million) to food labeling awareness campaigns from 2021 to 2025, and consumer campaigns by member states are infrequent. For instance, although mandatory, date marking is poorly understood, with people confused by the meanings of "use by" and "best before."

Organizations can also take advantage of weaknesses in checks and penalties, e.g., websites outside the EU are virtually impossible to control for online food sales. Regarding infringements, the EU auditors concluded that fines are not always dissuasive, effective, or proportionate.

COVID-19 saw a rise in the sale of food products via e-commerce which has continued since and, it has been no surprise, that an increased number of complaints about online stores have arisen. Information on such products can be misleading, and their consumption may even be unsafe especially for those who rely on correct labeling.

The Public Need to Have Information

The Auditors reported that control systems in member states are sometimes complex and often involve multiple authorities, which can lead to weaknesses in monitoring, reporting, and sanctions.

Strangely, the EU Commission makes some information notified by member states available to the public via the Rapid Alert System for Food and Feed (RASFF) portal but not details that would allow a product to be identified, such as its name or involved companies. A consumer, for example, could not find the product name on the portal during a recall. Instead, this information might be available in shops or through national authorities' information channels.

While some updates have been made through other regulations – such as the General Food Law and Claims regulation – key aspects like nutrition labelling, green claims, animal welfare standards, and origin labelling remain fragmented, often managed at the national level. The FishProf reminds everyone here that no matter where you are in the world there is a cost-of-living crisis – just think how we could cut costs if we stuck to the basics!

Amazingly it was reported that the EU's main food labelling framework, the Food Information to Consumers Regulation, has not been updated since its introduction in 2011.

Despite discussions during the previous legislative mandate, efforts to modernize these rules stalled, partly due to many political issues and disagreement from certain member states over issues like Nutri-score, the main nutritional labelling in the running to get the nod from the EU.

Pentus-Rosimannus acknowledged the complexity of achieving consensus across the EU, given diverse national traditions and perspectives but said, "This cannot be an excuse for allowing the status quo to continue indefinitely."

Consumer advocacy groups like BEUC (umbrella group for forty-four independent consumer organizations from thirty-one countries) are also urging swift action to address these shortcomings with Emma Calvert, senior policy officer, stressing the urgent need for a unified front-of-pack nutritional label.

"The lack of the promised EU front-of-pack nutritional label deprives consumers of an essential tool to make healthier choices at a time when obesity and overweight rates are alarmingly high," she said.

The European Commission has responded to the ECA report, acknowledging the need for stricter rules to protect consumers from misleading claims but did not specify plans to update the Food Information to Consumers Regulation - which remains a sensitive issue - instead, referencing upcoming rules on environmental claims.

In his efficacious hearing, Christophe Hansen, EU agriculture and food commissioner, admitted the need for greater coherence in labelling. "We have so many voluntary labels that are not harmonized," he said, calling for a "streamlining exercise" to enhance both consumer trust and the functioning of the internal market.

The FishProf is a firm believer in that the proliferation of eco-labels in the seafood industry has led to significant consumer confusion, undermining efforts of genuine producers/harvesters to promote sustainable consumption.

More will follow with "Fraud Impacts Trust" (Part 2) in the next issue.

Good industry associations should collaborate with their members and the authorities to raise matters worthy of conducting timely and thorough investigations.

References and sources consulted by the author on the elaboration of this article are available under previous request to our editorial staff.

Regular contributor The Fishmonger has now morphed into FishProf and will continue contributing to AQUACULTURE but also welcomes all the readers to connect through www.fishprof.com and join in our promotions to increase seafood consumption globally.

upcoming aquaculture events

MARCH 2025

AQUACULTURE 2025
March 6-10, 2025
New Orleans, USA
T: (+1) 760 a751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org
W: www.was.org

AQUAEXPO SANTA ELENA 2025
March 12-13, 2025
Santa Elena, Ecuador
T: +593 99 377 1572
E: aquaexpoec@cna-ecuador.com
W: https://www.aquaexpo.com.ec/

AQUASUR TECH
March 26-27, 2025
Punta Arenas, Chile
T: +56 2 2530 7209
E: ventas@aquasur.cl
W: https://www.aquasurtech.cl/

APRIL 2025

BLUE FOOD INNOVATION SUMMIT 2025
April 8-9, 2025
Londres, United Kingdom
T: +44 (0)1273 789989
E: info@rethinkevents.com
W: www.bluefoodinnovation.com

3rd. INTERNATIONAL CONFERENCE AND EXHIBITION ON AQUACULTURE & FISHERIES (AQUACULTURE HORIZONS 2025)
April 28-30, 2025
Lisbon, Portugal
W: https://www.europeaquacultureconference.com/

MAY 2025

AQUAFUTURE SPAIN
May 20-22, 2025
Vigo, Spain
T: +34620681861
W: https://www.aquafuturespain.com

JUNE 2025

WORLD AQUACULTURE SAFARI 2025
June 24-27, 2025
Entebbe, Uganda
T: +34620681861
W: https://www.was.org

JULY 2025

AQUAEXPO EL ORO 2025
July 20-23, 2025
Machala, Ecuador
T: +593 99 377 1572
E: aquaexpoec@cna-ecuador.com
W: https://www.aquaexpo.com.ec/

AUGUST 2025

AQUA NOR
Aug. 19-21, 2025
Trondhein, Norway
T: +47 73 56 86 40
E: post@nor-fishing.no
W: https://www.aquanor.no/en/

SEPTEMBER 2025

11th. INTERNATIONAL FISHERIES & AQUACULTURE TRADESHOW - ACUIPERU
Sept. 03-05, 2025
Lima, Peru
T: +51 989 177 352
E: thais@thaiscorp.com
W: www.thaiscorp.com/expopesca

VICTAM LATAM
Sept. 16-18, 2025
Sao Paulo, Brazil
T: +31 33 246 4404
E: expo@victam.com
W: https://www.allaquaculture.com/events/victam-latam-2025/

AQUACULTURE EUROPE 2025
Sept. 22-25, 2025
Valencia, Spain
T: (+1) 760 751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org
W: www.was.org, www.aquaeas.org

24th RESPONSIBLE SEAFOOD SUMMIT
Sept. 29, 2025
Cartagena, Colombia
W: https://events.globalseafood.org/responsible-seafood-summit

OCTOBER 2025

LAQUA 2025
Oct. 6-9, 2025
Puerto Varas, Chile
T: (+1) 760 751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org
W: www.was.org

AQUAEXPO GUAYAQUIL 2025
Oct. 20-23, 2025
Guayaquil, Ecuador
T: +593 99 377 1572
E: aquaexpoec@cna-ecuador.com
W: https://www.aquaexpo.com.ec/

NOVEMBER 2025

WORLD AQUACULTURE 2025 INDIA
Nov. 12-15, 2025
Hyderaband, India
T: (+1) 760 751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org
W: www.was.org

advertisers index

ANTIBIOTICS, PROBIOTICS AND FEED ADDITIVES

CARGILL (EMPYREAL)....................................5
www.empyreal75.com

CARGILL (MOTIV)........................INSIDE COVER
www.motivshrimp.com

EVENTS AND EXHIBITIONS

11th. INTERNATIONAL FISHERIES & AQUACULTURE TRADESHOW - ACUIPERU........INSIDE BACK COVER
T: +51 989 177 352
E: thais@thaiscorp.com
W: www.thaiscorp.com/expopesca

AQUACULTURE 2025..1
New Orleans, USA
T: (+1) 760 a751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org

AQUAFUTURE SPAIN......................................39
May 20-22, 2025
Vigo, Spain
T: +34620681861
W: https://www.aquafuturespain.com

AQUACULTURE EUROPE 2025............................27
Valencia, Spain
T: (+1) 760 751 5005
E: worldaqua@was.org
W: www.was.org, www.aquaeas.org

LAQUA 2025..35
Puerto Varas, Chile
T: (+1) 760 751 5005
Fax: (+1) 760 751 5003
E: worldaqua@was.org
W: www.was.org

REEFER CARGO

MSC...BACK COVER
T: +52 55 5091 7070
www.msc.com/seafood

TANKS AND NETWORKING FOR AQUACULTURE

REEF INDUSTRIES...11
9209 Almeda Genoa Road Z.C. 7075, Houston, Texas, USA.
Contact: Gina Quevedo/Mark Young/ Jeff Garza.
T: Toll Free 1(800) 231-6074 T: Local (713) 507-4250
E-mail: gquevedo@reefindustries.com / jgarza@reefindustries.com / myoung@reefindustries.com
www.reefindustries.com

AQUACULTURE MAGAZINE.
Design Publications International Inc.
401 E Sonterra Blvd. Sté. 375 San Antonio, TX. 78258, USA
Office: +210 504 3642
Office in Mexico: +52(33) 8000 0578 - Ext: 8578
Subscriptions:
iwantasubscription@dpinternationalinc.com
Sales & Marketing Coordinator
crm@dpinternationalinc.com | Cell: +521 33 1466 0392
Sales Support Expert
sse@dpinternationalinc.com | Cell:+521 333 968 8515
www.aquaculturemag.com


ALWAYS
FRESH
LEARN MORE
MOVING THE WORLD,
TOGETHER.
msc