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Promoting Aquaculture Literacy — A Shared Responsibility



Greetings. I hope that 2025 is off to a good start for each of you. I was fortunate to be able to attend the Aquaculture 2025 meeting in New Orleans, LA recently and was impressed by the scope and scale of the event. Steering committee chairs Jay Parson, Sandra Shumway, Michelle Walsh, and Paul Zajicek did an amazing job organizing the event. I think it is one of the largest shows I have attended in relation to the number of scheduled presentations, workshops, posters etc. There were over 2500 attendees from 77 countries including 404 students. There were a staggering 120 sessions that included 1330 oral presentations and 183 posters. Many thanks to all our sponsors and trade show exhibitors who make the meetings possible. It was great to see so many friends and colleagues in attendance and I enjoyed meeting many newcomers as well.

While the meeting was a great success, there was concern among attendees about some of the U.S. political decisions to discontinue support for many federal workers involved in aquaculture. These individuals play a vital role in the coordination, management and promotion of U.S. aquaculture and are often the link to international counterparts. If we are to fulfill the promise of the blue revolution and provide food for the next 2 billion people, it will take all of us, including governmental support.

I was very pleased to see a full-day session dedicated to Aquaculture Education, Extension and information transfer. These activities are critical to not only workforce development but also improving aquaculture literacy in general. There is no doubt that aquaculture will play an increasingly important role in providing healthy, low environmental impact protein for the world's growing population. HOWEVER, there are still many misconceptions among the public related to aquaculture, its benefits, its potential and the associated risks. The aquaculture community has the science-based information necessary to dispel the myths and misinformation surrounding aquaculture and help people lead healthier lives.

Promoting aquaculture literacy, especially through education, has many benefits. Professional development for teachers improves teaching capacity and ultimately delivers a more competent workforce. Exposing youth to more career opportunities positively impacts the next generation of aquaculture professionals including scientists and practitioners. The big picture social benefits of educating people about sustainable aquaculture include environmental protection, economic growth, job creation, and better public health outcomes. Aquaculture literacy lays groundwork for a future where aquaculture contributes positively to food security and the health of our planet. The WAS membership is a deep well of knowledge and we need to make a concerted effort to use this knowledge to help others appreciate the diversity and potential of aquaculture. This publication is an excellent outlet for your knowledge, please consider contributing.

I look forward to the next big gathering at the World Aquaculture Safari at the Speke Resort Munyonyo, near Entebbe Uganda, June 24-27. I hope to see you there.

— David Cline, President, World Aquaculture Society

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Water — The Main Ingredient



At various points in my career, I have heard the argument that freshwater aquaculture makes more sense than marine farming due to "technical, economic and resource constraints." And the best evidence of these advantages has been the meteoric growth of inland aquaculture over the past century. However, the environmental assumptions under which these assessments were made are probably no longer valid. Water shortages are coming in many parts of the world. Actually, they have already begun. Although it may not be obvious to the casual observer, we are living on a steadily drying planet.

A recent publication from the United Nations' Convention to Combat Desertification should give us all pause. The report, The Global Threat of Drying Lands: Regional and global aridity trends and future projections, provides a stark assessment of where we are and where we're going. More than 75% of the world's land has become permanently dryer in the past several decades. Significant areas have transformed from humid to dry ecosystems, with far less annual rainfall. Crops, grazing lands, natural habitats and people will be threatened throughout the world if these trends cannot be reversed. And unfortunately, it appears they cannot. Slowed, perhaps. Maybe even halted. But almost certainly not reversed any time soon.

What makes this situation so dire is that, while drought conditions can be catastrophic, they eventually end. In contrast, rising aridity will require long-term adaptation. No amount of waiting or hoping will bring us to a point of recovery. To quote the above-mentioned report "the drier climates now affecting vast regions across the globe will not return to how they were." And, as the soils become drier, we can expect loss of soil fertility, wildfires, crop losses, desertification, and food and water insecurity.

And yes, even if conditions don't deteriorate to that point, inland aquaculture may become a thing of the past in many regions. Currently, about 62 percent of the world's aquaculture production takes place in inland waters. Species like carps, catfishes, tilapias and crayfishes are all contributing significantly to food security in numerous countries. From this point onward, however, suitable land and freshwater will be scarcer with every passing year. Expansion of inland aquaculture will be impossible in many parts of the world, and severely constrained in many others. Increasingly, the next generation of aquaculturists will need to look to the sea.

China, already an aquaculture pioneer and leader for thousands of years, is doing just that. The country's marine aquaculture sector is seeing more investments, more innovations and more species with each passing year. Offshore environments in China and many other countries can be particularly punishing, but entrepreneurial engineers are developing structural innovations to minimize losses. The expansion of deep-water marine ranches — or blue granaries as they are called, is accelerating. Automated feeding systems, AI powered monitoring and management, underwater imaging systems, and novel feed formulations to optimize digestibility and minimize waste are all contributing to industry growth. And solar- and wind-power solutions have been applied to address the energy needs of grow-out facilities often located 50 to 100 km or more from the nearest harbor.

The shift to marine aquaculture will require substantial effort across the sector, and a more pragmatic approach from policy makers and regulatory agencies. In some countries this may make the difference between food security and famine. The traditional objections to offshore aquaculture from those who have no concerns about where their next meal will come from must be dealt with using sound science and keeping in mind the ever-increasing need for protein from aquatic species. Critics might actually find some solace in the fact that the environmental benefits resulting from shifting our future focus to marine aquaculture could be substantial. Recent research suggests that the overall carbon footprint of marine aquaculture is approximately 40 percent lower than that of inland aquaculture. The difference is largely due to reduced greenhouse gas emissions (nitrous oxide and methane) resulting from biogeochemical processes, along with feed and energy consumption lifecycle components.

The advancement of marine aquaculture may unfold by choice or by necessity, but if current climatic and demographic trends continue, it will probably be inevitable.

— C. Greg Lutz, Editor-in-Chief

Latin American and Caribbean Chapter



The Latin American and Caribbean Chapter of the World Aquaculture Society (LACC-WAS), the Institute of Aquaculture and Environment of the Universidad Austral de Chile, Puerto Montt campus, and the Salmon Technology Institute (INTESAL) have joined forces to jointly organize the Latin American and Caribbean Aquaculture Congress 2025 (LACQUA25), to be held in Puerto Varas, Chile, from October 6 to 9, 2025, at the Enjoy Hotel.

LACQUA2025 will bring together experts on topics of global relevance to the development, sustainability, and growth of Latin American and Caribbean aquaculture. It will also present one of the largest regional trade shows with a wide range of inputs and services for the sector. This is the first time Chile has hosted this important congress, confirming the importance of the sector for the country.

The organizing committee has chosen the event slogan "Governance: A Pillar for the Sustainability of Aquaculture in the Context of Climate Change." The FAO emphasizes the need to harness the oceans to improve food security and the resilience of aquatic food systems in the face of climate change. To this end, it has launched the Blue Transformation program, whose first objective is the sustainable intensification and expansion of aquaculture to meet the global demand for aquatic foods, with benefits equitably distributed. However, the diversity of aquaculture in Latin America and the Caribbean alone (species, scales and modes of production, levels of development, and socioeconomic impacts) introduces great complexity when facing a threat such as climate change. Governance is a fundamental pillar for advancing sustainability in a climate change scenario, especially adaptive governance, which emphasizes flexibility and adaptive capacity in decision-making, allowing for the adjustment of policies and actions in response to uncertainty and environmental changes. Thus, it is imperative to adopt governance styles that embrace the specificities of aquaculture and the local effects of climate change but also connect with regional scales to combine efforts and accelerate adaptation processes in Latin America and the Caribbean.

This edition will feature keynote lectures by international and national experts in the aquaculture sector, as well as oral and poster presentations of scientific papers on the following topics: nutrition and feeding of aquatic organisms; reproduction, larviculture, fingerling production; aquaculture and ecosystem conservation; health, biosecurity, well-being of aquatic organisms; physiology and genetics of aquatic organisms; production systems and socioeconomics; processing and added value; socioeconomics and agribusiness; sustainable aquaculture, standards and certifications; and education and careers in aquaculture.

All abstracts are welcome, and submissions are now open. The deadline for abstract submissions is July 31, 2025. For more information about the event and booth sales please contact Carolina Amezquita at carolina@was.org.

We also invite all members to renew their memberships and propose candidates to participate in the Board. The available positions are Secretary and one Director.

— Luis Andrés Gonzalez-Agraz, President

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CALLING ALL READERS

DO YOU HAVE SOMETHING YOU WOULD LIKE TO CONTRIBUTE TO *WORLD AQUACULTURE*?

We'd love to see it! We welcome general features, articles and news covering a variety of aquaculture-related topics, preferably well-illustrated with photographs and line art. Published quarterly, the magazine keeps WAS members up to date with research results and reviews of aquaculture trends and topics. You do not need to be a member of the Society and there are no page charges. Guidelines for authors are available here.

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"A leader takes people where they want to go. A great leader takes people where they don't necessarily want to go, but ought to be."
— Rosalynn Carter, First Lady of the United States from 1977 to 1981



This Chapter Report has been really hard to write. As the brand new (since last week) incoming President of the United States Aquaculture Society (USAS) Chapter of the World Aquaculture Society (WAS), this first Chapter Report usually delivers a welcoming President's message, introduces the new Board, and describes recent accomplishments as well as uplifting goals for the upcoming year. There are recent accomplishments and uplifting goals, but I think I'll save those for next time. For me to highlight those right now feels hollow, insincere, and out-of-touch with many of our members.

The mission of the USAS is to provide a national forum for the exchange of timely information within the U.S. aquaculture community through workshops, meetings, Annual Conferences, educational programs, and publications. Our USAS membership, as well as the WAS membership, is looking to the U.S. Chapter for an "exchange of timely information" on the current state of the "U.S. aquaculture community."

The USAS values people, their ideas, and their contributions to the science of aquaculture and the aquaculture industry. A significant segment of our membership is dedicated to advancing the science, research, and development underpinning aquaculture production in the United States. Others are committed to extending and disseminating these R&D efforts to farmers, the biomedical industry, or other public stakeholders, including students. Some members work directly for federal, state, or tribal government agencies focused on natural resource management, supporting economic development through aquaculture, stocking imperiled or economically important species, or restoring healthy habitats by cultivating reef-building or vegetative species. Many are also employed by consulting firms, contracting companies, nonprofit organizations, academic institutions, and other entities that support agency missions via federal grant programs. All of these professionals have been significantly impacted as recent federal changes have created uncertainty surrounding their ability

(CONTINUED ON PAGE 10)

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Korean Chapter

Challenging to Become the World's No. 1 Oyster Export Country — Oysters as the Next Representative Export Product Following Gim (Laver)



The Ministry of Oceans and Fisheries (MOF; Minister Kang Do-hyung) announced the Development Plan for Oyster Aquaculture at the Cabinet Meeting on State Affairs and the Economic Ministers' Meeting on January 9. The ministry plans to provide new growth engines for the oyster aquaculture industry by creating oyster-only fishing ports and aquaculture complexes and targeting the European market with USD 160 million in individual oysters and processed oyster products by 2030.

Oysters are enjoyed by both Eastern and Western cultures, and the global market size will have reached USD 600 million as of 2022. Korea is the world's third largest oyster exporter, following France (USD 140 million) and China (USD 120 million).

The Oyster Aquaculture Industry Development Plan contains three strategies to achieve two goals: increasing oyster production by 100,000 tons by 2030 (300,000 tons in 2023 to 400,000 tons in 2030) and doubling oyster exports by 2030 (USD 80 million in 2023 to USD 160 million in 2030) under the vision of becoming the world's No. 1 oyster export country.

Strategy 1 - Production Facilities and Technological Innovation

• *Consolidation of the oyster industry from aquaculture-only fishing ports to supporting industrial complexes, including processing plants*

The ministry will consider building an oyster industry cluster and an aquaculture-specific fishing port for oysters, and integrate the oyster industry from dedicated ports to processing plants and other supporting industrial complexes. The ministry will consider establishing an integrated oyster farming complex and creating dedicated oyster farming ports. The ministry plans to increase the efficiency of the oyster production process by relocating about 400 oyster shucking and processing plants scattered across major oyster-producing areas (Tongyeong and Geoje in Gyeongnam-do and Yeosu in Jeonnam-do Province) into the integrated complex and dedicated oyster farming ports. In addition, facilities necessary for oyster production, such as oyster seed production facilities and processing plants, will be built within the integrated industrial complex.

• *Establishing an automated and smart oyster production process to promote industry modernization*

In addition, automation of oyster production sites, which mostly rely on manual labor, will be promoted. Conveyor belts and customized equipment (shellers, washers, automatic sorters, etc.) will be distributed in shared work sites. Work ships that can automatically harvest oysters at sea, perform primary washing, etc., will be distributed to improve the working environment.

Strategy 2 - Expansion of Market Base

• *Promoting domestic oyster consumption by expanding processed oyster products and expanding oyster check-off funds*

The ministry will support producing and selling new processed oyster foods for food processing companies. The ministry will also promote cooking recipes using oysters to diversify the domestic oyster market, which is mainly consumed as shelled oysters. In addition, the ministry plans to significantly expand the size of the oyster self-help check-off fund, which is currently only KRW 500 million, and strengthen the oyster industry's consumer promotion function.

• *Targeting global export markets and expanding influence in existing markets. Targeting USD 160 million in oyster exports by 2030*

The ministry will support the entry into the European market, which prefers high-value whole oysters; unlike common oysters, single oysters are sold with their shells intact, which are larger and have higher added value, to diversify export markets. To this end, the ministry will actively support converting general oyster farms to single oyster production farms, increasing the share of single oysters' production, which is 1% of the total oyster production, to 30% by 2030. In addition, the ministry will expand our influence in export markets such as the United States and Japan, which account for 71% of the total oyster export value. The ministry will support exporters in covering the costs required to obtain international certifications required by importing countries to strengthen their export competitiveness.

Strategy 3 - Strengthening Sanitation and Safety Management, etc.

The ministry will continue to install facilities to prevent the inflow of pollutants from land and sea, preserving clean oyster waters and producing safe oysters. It will also increase the sewage system coverage rate near oyster production areas and strengthen education on pollutant discharge behaviors for small vessels. In addition, the ministry will process oyster production byproducts through hygienic and environmentally friendly methods by recycling oyster shells as raw materials for steel mills, power plants and construction materials through the oyster shell resource facility completed in November of last year.

Minister Kang Do-Hyung said, "Unlike other seafood, oysters are widely consumed in large quantities, so this is an opportunity for Korean companies to enter the global market," adding, "Through these measures, we will transform the traditional oyster industry into an automated and smart industry to produce high-quality, safe oysters and strengthen our industrial competitiveness so that we can become the world's number one oyster exporter."

Development and Distribution of the NIFS's Eco-friendly RAS Model for Rainbow Trout

The National Institute of Fisheries Science (NIFS; President Choi Yong-seok) of the Ministry of Oceans and Fisheries developed a "popular rainbow trout recirculating aquaculture system (RAS) model" to promote the development of an eco-friendly inland aquaculture industry, and distributed it to the Korea Trout Aquaculture Association on January 9.

The breeding environment, including temperature, can be artificially controlled, making it possible to produce cold-water fish

such as salmon year-round. In Korea, it isn't easy to grow salmon during the summer.

The two "Rainbow Trout Recirculating Aquaculture System (RAS) Distribution Models" that have been distributed this time were developed through an MOU with the Korea Trout Farming Association in 2022 and the operation of a field research laboratory, and include four patented technologies, including solid waste automatic removal technology. They practically collaborate to apply the research results directly to the field from the early stages to be used immediately in the industrial field. Among the four patented technologies, three that have completed the patent registration process will be transferred to the Korea Trout Farming Association in the first half of this year. One has completed the patent application process with the Korean Intellectual Property Office on November 20 last year.

A total of 167 trout farms in Korea produce about 3,000 tons of trout annually. However, most (about 95%) use the traditional flow-through aquaculture method, which uses and discharges breeding water once, and only 5% use the recirculating filtration method.

The distribution of recirculating filtration aquaculture systems is urgently needed to replace the imported salmon market, which consumes more than 60,000 tons annually, and to prepare for climate change and the depletion of inland water resources.

Accordingly, the NIFS began full-scale research in 2021 on the development of an entry-level RAS model. The main goal was to develop a Korean model suitable for the domestic environment and operating methods while reducing construction costs compared to overseas RAS.

To this end, the NIFS has developed a prototype of domestic equipment capable of controlling the environment, such as the automatic removal of solid waste, high-efficiency fluid biological filtration, and flow rate of the breeding tank, for the first time in Korea, and have distributed industrialization technologies necessary for the automation and smartization of fish farms to the field.

The Korea Trout Farming Association announced that the recently distributed inland circulating filtration aquaculture system (RAS) model is the first standardized system in Korea. Compared to existing systems and the construction area of the effluent sedimentation tank (within 30% of the aquaculture water area), it can reduce the construction area by 20%. It is expected to contribute significantly to establishing an automation foundation in aquaculture sites where labor is insufficient.

President Choi said "The newly developed affordable Rainbow Trout Recirculating Aquaculture System (RAS) model will contribute to the transition of the aquaculture industry to smart and automated systems, as well as to the response to climate change and natural disasters, the strengthening of the competitiveness of domestic trout aquaculture production, and the development of a sustainable and eco-friendly inland aquaculture industry." He added" We will continue to do our best to provide practical help to fishermen through field-oriented research."

Revitalizing the Inland Water Industry into a High Value-Added Industry

• *Policy Operation Direction to Revitalize the Inland Water Industry with the goal of 49,200 tons of inland fishery production by 2028*

The Ministry of Oceans and Fisheries (MOF; Minister Kang Do-hyung) announced that it established the Policy Operation Direction to Revitalize the Inland Water Industry to increase its competitiveness. Inland aquaculture in Korea began in 1929 with the distribution of carp seedlings at the Jinhae Fish Farm. In the 1980s, it produced 50,000 tons of aquatic products, but production has decreased since the mid-1990s. Inland aquaculture in Korea is around 1% of the total aquatic product production.

Inland aquaculture using freshwater is more adaptable to cutting-edge technology than seawater aquaculture, and the need to foster the inland aquaculture industry is being raised as sea catches are decreasing due to climate change and other factors. Accordingly, MOF has prepared this measure intending to produce 9,200 tons of inland aquatic products by 2028.

Strategy 1: Support Tailored to Each Local Inland Water Industry

First, the ministry will promote the K-River Village Project to converge the inland water industry with retail/processing and leisure/tourism industries to foster it into the 6th industry that reflects regional characteristics. To this end, the ministry will conduct an introductory survey on fishery production, accessibility, and tourism characteristics centered on the five major rivers, including the Han River and Geum River, in 2025 and create three K-River Villages by 2028. Moreover, it will provide 7 ~ 9 weeks of aquaculture education/training for young people who wish to return to the fishing village to engage in inland water aquaculture and create a youth aquaculture farm for rental.

Strategy 2: Transition to Advanced, High Value-Added Aquaculture

By the end of 2024, Goesan, Chungcheongbuk-do Province, and Hwasun, Jeollanam-do Province will complete phase 1 smart aquaculture farms capable of remote monitoring and control based on ICT. And phase 2 smart aquaculture farms capable of autonomous and complex control of water temperature, water quality, etc. will be subsequently constructed.

Moreover, the ministry will develop new high-value-added aquaculture products such as sea squirts and freshwater shrimp, including technology for producing artificial seeds for the domestic aquaculture of eels, of which approximately 80% of fry depends on imports. It will also develop technology to breed high-value-added varieties such as eels and herbal plants to foster the aquaponics industry. Through this, the ministry aims to implement the eco-friendly transition of inland aquaculture and the convergence of agriculture and fisheries industries.

Strategy 3: Expanding Consumer Markets and Improving Production Management

To ensure the smooth supply of inland aquatic products, distribution facilities such as the Inland Aquatic Product Distribution and Sales Center in Yongin, Gyeonggi-do Province, scheduled for completion in 2025, will be expanded to the Yeongnam and Honam regions. In addition, convenience foods using catfish and eel will be developed, and research on the health benefits of marsh snails and other ingredients will be conducted to promote consumption. Support will be provided to address non-tariff barriers in export countries,

(CONTINUED ON PAGE 10)

Asian Pacific Chapter



Time is a significant factor. We were prepared to participate in World Aquaculture 2025 in Qingdao, China; however, the event was regrettably canceled by the China Society of Fisheries, the organizing body, just three months before its scheduled date. In light of this situation, the World Aquaculture Society (WAS) conference management team has opted to relocate the event to India, now designated as World Aquaculture 2025 India, which will be held in Hyderabad from November 10-13, 2025. This change enables us to maintain the commitment to delivering an outstanding experience for the participants.

World Aquaculture 2025 India will be hosted at the Hyderabad International Convention Centre – Novotel, Hyderabad City from November 10-13, 2025. This event signifies the return of World Aquaculture to India after the successful Asian Pacific Aquaculture 2019 (APA19) held in Chennai. The rapid expansion of aquaculture in the Asia-Pacific region, especially in India, makes the 2025 event a prime occasion for the World Aquaculture community to redirect its attention towards India, specifically in Hyderabad. Renowned as the "City of Pearl," Hyderabad is pivotal to the progress of aquaculture in India, distinguished by its robust economy, flourishing aqua sector, and strong infrastructure in fisheries, equipment production, and logistics.

The rescheduling of the event has also affected the organization's regular activities. The WAS-APC was prepared to conduct elections for new BOARD members; however, the postponement of the event to November has delayed the election process. Nevertheless, the nomination process and selection of candidates for the election are ready to proceed.

Abstracts that were submitted earlier for WA2025 China will still be reviewed by the Program Committee, and all registrations will remain valid. A new submission of abstracts is currently being processed for the India event. The deadline for abstract submissions has been extended to August 31, 2025. Exhibitors who have already reserved a booth for the trade show in China and wish to transfer their booking to the trade show in India will receive an updated manual along with all pertinent information. New bookings for the India event are currently being accepted.

I anticipate that numerous aquaculture and fishery specialists from India and neighboring countries will attend this event and gain valuable insights. I extend a warm invitation to all individuals interested in participating, whether they are academics, research scientists, students, or exhibitors. *— Bibha Kumari, President*

Korean Chapter, continued from page 9

such as sanitation management standards to develop overseas markets. Furthermore, to manage the supply and demand of inland aquatic products, items subject to supply and demand observation will be expanded to include catfish and mudfish in addition to the existing trout and eel by 2026.

Stricter monitoring of origin labeling will be enforced for imported mudfish and eel to ensure a safe distribution system for inland aquatic products, and domestic eel and trout farms will be supported in registering for HACCP (Hazard Analysis and Critical Control Points).

Strategy 4: Establishing a foundation for sustainable inland fisheries

For stabilizing the management conditions of inland fishers, the ministry is considering adding apple snails to the list of disaster insurance-covered items currently applied to four species, including catfish and leather carp, and improving the system to allow small-scale open-field inland fishers to receive direct payments. To promote the inland aquaculture industry, the government will form a policy consultative body consisting of local governments and inland fishers to collect opinions from the field and resolve pressing issues.

"Inland aquaculture has played a significant role in Korea's rise as a leading fishing nation, and the recent emergence of cutting-edge technologies presents an opportunity for the inland water industry to make a comeback. The government will continue to support fostering inland waters aquaculture as a high value-added industry by upgrading it and to help transform the inland sector into a sixth industry that revitalizes regional economies through connections with leisure and tourism," Minister Kang Do-hyung said.

— Han-kyu Lim, President

USAS Chapter, continued from page 7

to continue working to advance aquaculture in the United States.

To our members and partnering colleagues: Your passion, support, and service to the U.S. aquaculture community has not gone unnoticed. We deeply appreciate the invaluable contributions you have made, and we recognize the profound impact of your work. Thank you for your unwavering dedication through the substantial changes we experienced in the past few weeks. As we acknowledge the loss of valued colleagues, we remain focused on delivering exceptional service to the members of our Society and supporting one another. *— Michelle L. "Mick" Walsh, President*

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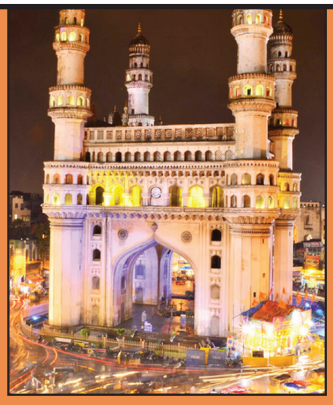
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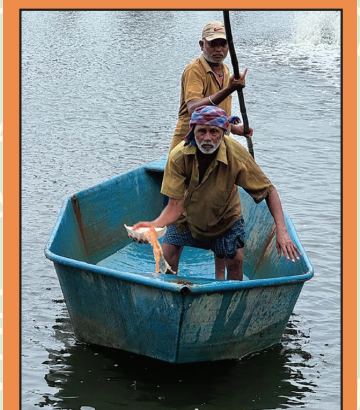
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African Chapter



Welcome to the exciting year 2025! At WAS-AC, we aim to carry forward the energy, enthusiasm, wisdom, and progress that have defined us in previous years and to build upon them in this new year.

I am pleased to share that Aller-Aqua has renewed its sponsorship of WAS-AC for another three years until 2027. We again join Aller-Aqua in the slogan, "Let's grow together!" As always, Aller-Aqua is expected at our World Aquaculture Safari Conference 2025 and other regional platforms this year. Thank you, Aller Aqua, for your role in aquaculture development in Africa!

The Chapter's membership has grown rapidly, from fewer than 400 members in 2018 to over 1,300 today. This impressive growth is due to WAS's complimentary membership packages for students and small-scale aquaculture practitioners from Africa. Our focus as a society is to meet the needs and aspirations of these membership categories, which are vital for the future of fisheries and aquaculture development in Africa.

2025 will be especially significant for WAS-AC as we host a global conference in Africa for the second time—the World Aquaculture Safari 2025 (WA25) in Entebbe, Uganda, from June 24 to 27, 2025. We expect attendance to exceed 2,000 participants with a program packed with exciting sessions, features, and over 120 exhibition stands. Make sure you don't miss this event! Register now, as there will be something for everyone at WA25 in Uganda!

I extend my gratitude to many of our collaborators and partners who have already committed to participate in this event. Special thanks go to the GIZ, the World Bank, WISHH, Aquagroup Feeds, the African Union, and Aller-Aqua for signing conference sponsorship agreements, along with many others who are yet to do so.

(CONTINUED ON PAGE 14)

Aller Aqua Extends Sponsorship for the African Chapter of World Aquaculture Society (WAS-AC) to December 2027

WAS-AC is proud to announce the extension of Aller Aqua's sponsorship to the Chapter for another three years through December 2027. Aller Aqua has been the Chapter's Founding Gold Sponsor from its inception in November 2018. During this term, the feed company has "walked and grown together" with WAS-AC on various activities to build capacity on aquafeeds development and supply chains. WAS Director John Cooksey recently signed the renewal Agreement with Aller Aqua, which would see the company branded as "Corporate Sponsor" on WAS-AC platforms.

As the largest fish feed producer in Africa, with factories in Egypt and Zambia, and one of the largest employers in its aquaculture industry, Aller Aqua has committed to continue to support the capacity development of farmers on the continent through free technical training workshops and collaborations with development organizations and NGOs.

Aller Aqua has strongly promoted and participated at the past three annual Aquaculture Africa Conferences (AFRAQs), in Egypt (2022), Zambia (2023) and Tunisia (2024). They are scheduled to feature again at this year's World Aquaculture Safari Conference scheduled in Entebbe, Uganda on 24-27 June 2025. In addition, within the framework of this renewed agreement both parties and their partners will develop joint activities on aquafeeds capacity building, training programmes and engagement platforms beneficial to fish farmers. These will be delivered through national, regional in-person and virtual meetings, as well as outreach activities — and shared through each entity's publicity platforms.



Aller Aqua continues to collaborate with development organizations and NGOs.



Aller Aqua has participated in prior Aquaculture Africa Conferences, and will be present in Entebbe.

Spotlight on World Aquaculture Safari 2025, Uganda as Industry and Development Partners Show Strong Interest

In June 2025, Uganda meets the world for the World Aquaculture Safari 2025 Conference (WA25 Uganda). Themed "***Aquaculture on the Rise***", the conference, which is being organised by the World Aquaculture Society, is expected to bring together nearly 2000 participants from around the world. As always, the organizers intend to foster knowledge exchange, collaboration, and innovation within the sector. The event also aims to address some of the sector's challenges whilst showcasing new technologies for sustainable and resilient aquaculture practices.



The EU-funded TRUEFISH Project, overseen by the Lake Victoria Fisheries Organisation (LVFO) is the lead sponsor for the event. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has just committed to Gold Sponsorship for the event. GIZ, through its *Global Programme Sustainable Fisheries and Aquaculture* has supported previous Aquaculture Africa Conferences in Egypt (2022), Zambia (2023) and recently in Tunisia (2024). WA25 will once again affirm GIZ's commitment to sustainable aquaculture development in Africa, focusing on value chain approaches, capacity building, and promoting environmentally friendly and socially responsible practices.

Moreover, the return of developmental organisations who featured in previous AFRAQs is inspiring. The World Bank, African Union agencies, FAO, WorldFish and others have expressed commitment to deliver special side-sessions and workshops covering some key thematic areas including relevant global and regional processes, technologies and innovations, investment, trade, value chain competitiveness as well as partnerships.

Uganda is an ideal location for showcasing the booming development of aquaculture in East Africa. In addition to existing large scale aquaculture ventures flourishing along Lake Victoria, Uganda has a sizeable, small to medium scale aquaculture subsector. Some of the SME farms have become models for sustainable practises in an African context. They are playing a key role in the country's local food fish production and also assure the viability of aquafeed supply chains. Having seen the great potential the country has, a number of large-scale aquafeed factories are being established in Uganda. The WA25 trade show is expected to feature nearly 150 exhibition booths.

Overall, Uganda — known as the "Pearl of Africa," is ready to offer international visitors its diverse and unique tourism experiences and cultural explorations. The country boasts wildlife safaris including natural landscapes, game reserves, gorilla trekking, birdwatching and — not forgetting, the source of the mighty Nile River, and much more! The country's main urban centres especially in Kampala and Entebbe have a lot to offer for enthusiastic travellers — from local cultural experiences to traditional, mouthwatering cuisines. Uganda stands ready to provide various adventure activities that will leave you amazed throughout your stay!

The WA25 Conference dates are 24-27 June, 2025 at Speke Resort Munyonyo, Entebbe (www.spekeresort.com) — a world class conference and exhibition facility on the shoreline of Lake Victoria. Registrations and submission of abstracts are still open. All conference details will be updated on the event page on https://www.was.org/meeting/code/afraq25. For all enquiries on WA25 Uganda contact worldaqua@was.org or africanchapter@was.org. For more information on the exhibition and sponsorship opportunities, please contact Worldaqua11@was.org or Etienne_Hinrichsen@landell-mills.com.

African Chapter, continued from page 13

Lastly, I wish to introduce the incoming WAS-AC Executive Board Members who were inaugurated in Tunisia during AFRAQ24: Dr. Francisca Delgado - Secretary (Angola), Dr. Judith Makombu - Regional Director (Central Africa), Cameroon, and Ms. Alushe Hitula - Regional Director (Southern Africa), Namibia.

Our gratitude to Dr. Festus Idowu Adeosun from Nigeria for his service as Secretary of the Chapter from 2022 until the end of 2024. I always salute the roles of my executive board, committee members, and staff, who continue to work tirelessly, with agility and enthusiasm, to address various chapter business elements.

I have participated in the just-ended Aquaculture 2025 in New Orleans, USA. I look forward to sharing with you my experiences in my next column. Otherwise, I look forward to meeting many of you at the upcoming World Aquaculture Safari 2025 in Entebbe, Uganda. Please continue to visit our website www.was.org for new developments and updates. — *Foluke O. Areola, President*

Honours and Awards 2024

Each year since 2023, the WAS African Chapter (WAS-AC) will celebrate individuals, companies and organisations who have made significant contributions to the Chapter and to the development of aquaculture in Africa, in fields of scientific research, education, technological innovations, communications and information exchange. These recipients have transformed our understanding of aquaculture in Africa, impacted many aquaculture actors positively by contributing to solutions for the advancement of sustainable aquaculture in Africa.

Honourees and awardees were celebrated this year at the Aquaculture Africa 2024 Conference (AFRAQ24) in Hammamet, Tunisia (19 to 22 November 2024) - where over 1200 attendees from more than 70 countries gathered. The awards were presented by the Guest of Honor, Tunisian Minister of Agriculture, Water Resources and Fisheries (Hon. Ezzedine Ben Chiekh) and WAS-AC President (Ms Foluke Areola) witnessed by the African Union Development Agency (AUDA-NEPAD) and other high-level state guests. The WAS applauds the achievements of the 2024 award recipients and thank all membership, nominators and supporters for their dedication to this program.

WAS-AFRICA HONORARY AWARD 2024

The award is conferred upon an identified individual who has made a longstanding and significant contribution in the establishment and support to the Chapter's operations

Mr. BLESSING MAPFUMO (EXECUTIVE OFFICER: WAS AC), South Africa - He was a critical player in the establishment of the Chapter. Blessing is the Chapter's pilot, flying the Chapter successfully through its startup and first 5 years of operation, working tirelessly to support the membership, Executive Board and conferences and other aquaculture programmes throughout the continent!





AQUACULTURE INNOVATION AWARD 2024

This award is to be presented to a WAS Member for innovations in a specific type of Aquaculture Technology (eg IMTA, RAS, Pond technology etc) OR for contributions to develop aquaculture technology for a species (eg Tilapia, Shrimp, Catfish etc)

Dr. ASHRAF GODA - (Egypt, North Africa) - he is a leader in the development of sustainable aquaculture systems technologies (IMTA/Aquaponics and Pond technology). In 2021, Dr Goda was amongst the top 2% of the most cited scientists in various disciplines (USA based Stanford University – List of World's Top 2% Scientists)





AQUACULTURE INDUSTRY AWARD 2024

This award is presented to an Industry player who has given selflessly to improve aquaculture in Africa; and support to the WAS-AC; fostered collaborations with aquaculture organisations to promote best practices and innovations; publicized the importance of sustainable aquaculture development and creates business models that benefit a diverse range of aquaculture actors in Africa.

AQUACULTURE AFRICA MEDIA (AAM) - for their contributions to the Chapter's establishment and outreach throughout the continent, organizing and hosting African aquaculture webinars and social media platforms.



SPECIAL CERTIFICATE OF APPRECIATION 2024

This is given to a State entity (relevant government Ministry) in appreciation for the role and commitment in hosting of an annual Aquaculture Africa Conference.

MINISTRY OF AGRICULTURE, WATER RESOURCES AND FISHERIES, TUNISIA – for their role and commitment in successfully hosting AFRAQ24 in Hammamet, TUNISIA.





SPECIAL CERTIFICATE OF APPRECIATION 2024

Host and Conference Chairperson (Aquaculture Africa 2024), AFRAQ24

Dr. NADIA CHERIF National Institute of Marine Science and Technology (INSTM) TUNISIA.





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Congratulations to the 2024 Winners, Honorees and Awardees!!

United States Aquaculture Society (USAS) Student Subunit 2024 Annual Report Summary

Julianne Grenn, Abdulmalik Oladipupo, Michelle Walsh, and Adriane Michaelis

USAS Student Subunits play an integral role in furthering the missions and reach of USAS and WAS. Subunits allow graduate, undergraduate, and even high school students to engage with different types of aquaculture at local scales and create social, educational, professional, and outreach opportunities for student members (Grenn & Walsh, 2024a; Grenn *et al*., 2024b).

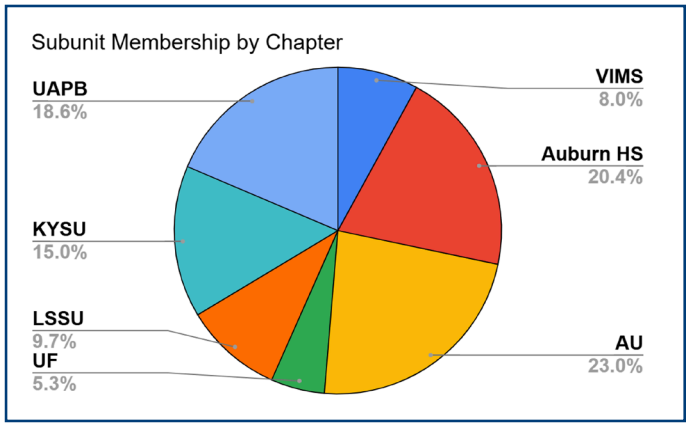


FIGURE 1. *Student membership numbers split by active USAS Student Subunit Chapter. Table 1 explains the acronyms used for each included subunit.*

Each year, subunits are asked to submit an annual report outlining their accomplishments to remain in good standing as official USAS Student Subunits. Seven subunits (Table 1) completed the requirement for reporting year 2024 and are considered active. Active subunits are eligible to apply for the annual Student Subunit Project Grant ($1,000 in available funds — competitive) and the Student Subunit Travel Support Award (covers one student early bird conference registration, currently a $295 value — one awarded per active subunit) to attend the annual USAS Aquaculture America or WAS Triennial conference. Annual reports are published on the USAS Student Subunit webpage and outline each subunit's membership, activities, struggles or concerns, chapter changes, and treasurer's report (https://www.usaquaculture.org/for-students).

Membership: Auburn High School reactivated its subunit status in 2024, whereas the remaining six active subunits (Table 1) maintained their status from 2023. There are 113 total students involved in the seven active USAS Student Subunits, with chapter membership ranging from six students at the smallest subunit (UF) to 26 participating in the largest subunit (AU) (Fig. 1). Student membership in 2024 is slightly down from 2023, by seven students (120 active members in 2023 vs. 113 in 2024).

Activities: The subunits reported hosting or attending 60 different events throughout the year that ranged from social activities to research projects to public outreach — 26 were linked to networking, professional development, trainings, and conference attendance; 14 encompassed social activities such as bowling, cookie decorating, rock painting, roadside and stream clean-ups, and regular meetings for elections and general business; 9 were outreach focused as subunits staffed booths at local festivals, helped teach community members how to fish and clean their catch, led tours of subunit maintained facilities, and partnered with special education classes to teach students about water quality in aquariums; 7 were tied to fundraising through plant, shrimp, and craft sales and grant writing for various awards; 2 were tied to research projects centered on shrimp and crayfish production; and 2 were associated with recruitment of graduate and undergraduate students at institutional career and club fairs.

Chapter Struggles and Concerns: Although each chapter is unique and operates independently, several themes emerged as challenges faced by multiple subunits. Four subunits reported obstacles with engaging undergraduate and graduate student populations. A few subunits operate on or aspire to operate on satellite campuses, which proves difficult when coordinating social events, meetings, transportation, and research projects. Four subunits called for better recruitment strategies of members, generally and for diversity purposes, and volunteers to aid with system upkeep and fundraising efforts. Three subunits named better communication within their subunit and between subunits as a necessity, and one subunit wanted smoother transitions during officer changeover each year. Three subunits identified social media as a challenge — needing a larger presence or noting that regular

TABLE 1. List of subunits that submitted a 2024 annual report.

Number	*Subunit Name*	*Abbreviation*
1	Auburn High School	Auburn HS
2	Auburn University	AU
3	Kentucky State University	KYSU
4	Lake Superior State University	LSSU
5	University of Arkansas Pine Bluff	UAPB
6	University of Florida	UF
7	Virginia Institute of Marine Science	VIMS

posting and continuous work can be overwhelming during the school year. Lastly, one subunit noted plant and animal production challenges, growing system issues, and institutional barriers.

Chapter Changes: Chapters are required to report any major changes to subunit operations from year to year. The VIMS subunit dissolved its president-elect position, while the Auburn HS subunit re-activated its chapter after several years of inactivity. The UF and LSSU subunits reported changes in membership and leadership positions after senior members graduated. These two subunits are relatively small, which made these changes especially noteworthy. Most subunits reported increased activity on social media platforms (e.g., Instagram, Facebook, Aquaculture Information Exchange, etc.) through hosting more in-person events.

Treasurer Reports: Two subunits reported no financial activity over the last year. The remaining subunits (based on self-reporting) spent $4,450 total, with $3,331 going toward travel awards for subunit members and the remaining $1,119 spent on social activities, supplies, and meeting costs. Subunits were awarded $2,250 in external grant awards, including $1,000 from the USAS Student Subunit Project Grant, and fundraised $2,833. The subunits collectively have $9,550 in available funds, with another $5,200 ($14,750 total) pending fundraising sales and institutional funding.

Subunit Plans for 2025: As the student subunits are wrapping up the first quarter of another year, many participated and presented at the Triennial Aquaculture 2025 conference in New Orleans, LA, USA. Subunits were again featured in the USAS Student Subunit Showcase, both as oral and poster presentations.

To learn more about how to form a USAS Student Subunit, see Grenn & Walsh (2024a). For an overview of the history of USAS Student Subunits, see Grenn *et al*. (2024b).

Notes

Julianne Grenn*, Abdulmalik Oladipupo, Michelle Walsh, and Adriane Michaelis

* Corresponding author: jgrenn@d.umn.edu

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Grenn, J., M. Walsh, K. Hartman, C. Engle, A. Kelly, D. Cline, R. Lochmann and D. Straus. 2024b. USAS Student Subunits: History and Impact. World Aquaculture Magazine, 55(3):64-65.





LEFT: Kentucky State University Student Subunit members help collect data for a member's research project. RIGHT: University of Florida student subunit members and Minorities in Aquaculture University of South Florida intern helping out in the lab with aquaculture and invasion ecology work.







LEFT: Lake Superior State University student subunit members toured the Red Cliff Hatchery while in Bayfield, WI for the 2024 WI Aquaculture Conference. RIGHT: Auburn University subunit members alongside additional volunteers, friends, and families packing shrimp for the Annual Shrimp Sale, which is their largest club fundraiser each year.

The Journal of the World Aquaculture Society Editor's Choice Awards 55(6)

• ***Kumar, G., Hegde, S., van Senten, J., Engle, C., Boldt, N., Parker, M., Quagrainie, K., Posadas, B., Asche, F., Dey, M., Aarattuthodi, S., Roy, L. A., Grice, R., Fong, Q., & Schwarz, M. (2024). Economic contribution of U.S. aquaculture farms. Journal of the World Aquaculture Society, 55(6), e13091.*** https://doi.org/10.1111/jwas.13091

In this paper, the authors completed an extensive study based on primary, farm-level data to assess the economic contribution and impact of aquaculture in the U.S. The authors determined that U.S. commercial aquaculture supported 22,000 jobs and contributed $4 billion annually to the economy. They also estimate that the total economic impact would be three to four times higher if aquaculture products are followed through downstream marketing channels. What is critical in this work is the clear relationship of aquaculture businesses to other economic sectors that support this industry, and the realization of how regulatory and other policies can have a profound effect on local, regional, and national economies. They were able to show that the greatest economic contribution came from foodfish farms followed by mollusk farms. Interestingly, the freshwater farming sector contributed more than twice that of marine aquaculture, and they suggest that regulatory barriers pose the greatest limitation to aquaculture growth in the U.S. This has been especially true for marine aquaculture, especially marine finfish in offshore and coastal areas, where clear permitting processes need to be developed and streamlined. In conclusion, the authors highlight that U.S. aquatic resources would support substantial aquaculture growth in both the freshwater and marine sectors.

• ***Spada, N. N., Fairchild, E. A., & Trushenski, J. T. (2024). Tolerance of juvenile lumpfish (Cyclopterus Lumpus) to high rearing densities. Journal of the World Aquaculture Society, 55(6), e13089.*** https://doi.org/10.1111/jwas.13089

This applied research study provides a foundation for understanding how density impacts the culture of lumpfish (*Cyclopterus lumpus*), which are reared primarily as cleaner fish for sea lice control on Atlantic salmon (*Salmo salar*). Challenges for the intensive rearing of this species have been noted and include behavioral characteristics such as excessing fin nipping and aggression between juvenile conspecifics. The authors of this paper take a deeper look at density-dependent interactions during the culture of this species. In this study, they tested four rearing densities (40, 60, 70, and 90 g/L) for two size classes of juvenile lumpfish (2- and 13-g) over an 8 week study period. Growth, survival, and fish aggression were assessed. For 2-g fish, it was found that mean weight gain ranged from 170% to 307%, and specific growth rates ranged and 1.77% to 2.50%. For 13-g fish, weight gain and specific growth rate ranged from 286% to 471% and 2.42% to 3.10%, respectively. It was found that lower density rearing resulted in more rapid growth for lumpfish, and although aggression only occurred in larger lumpfish at the higher fish densities, there was no mortality in any treatments. This study provides baseline fish culture criteria and recommendations for juvenile lumpfish rearing density. The authors suggest that a broad range of densities could be targeted without affecting lumpfish welfare. Although facility-specific decisions will be based on the operational plans and needs of the salmon farms targeted for sea lice control, results from this work provide valuable information for hatchery managers related to fish growth and aggression.

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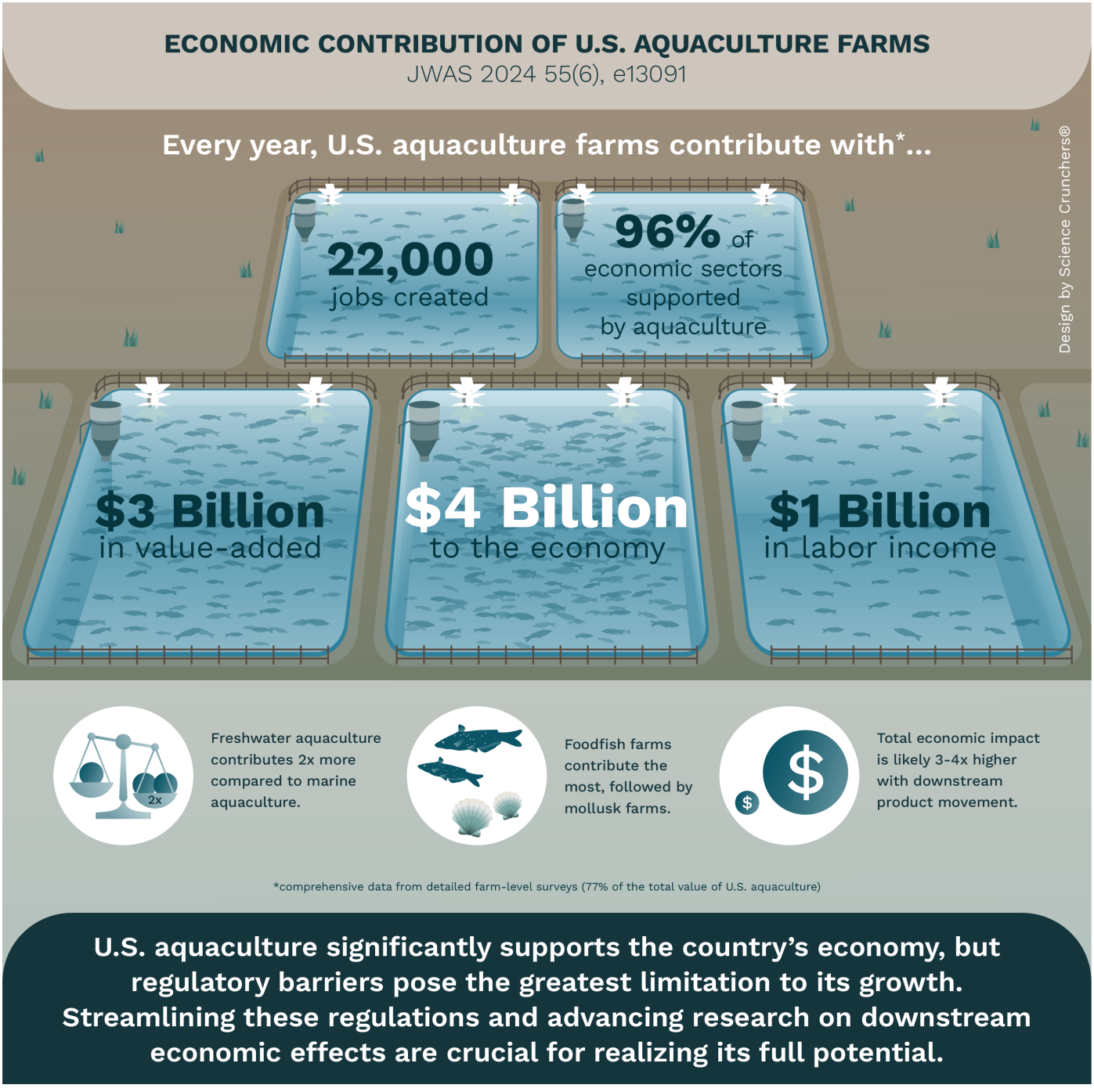
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* *Editor's choice paper*



WORLD AQUACULTURE 2025 INDIA

Novotel Hyderabad Convention Centre, Hyderabad, India November 10-13, 2025

FOR IMMEDIATE RELEASE

Relocation of World Aquaculture 2025 Event from China to India

Due to the China Society Fisheries (CSF) having cancelled the World Aquaculture 2025 event, which was originally scheduled for April 24-27, 2025, in Qingdao, China. After careful review and consideration of current circumstances, the association has made the difficult decision to cancel the event. However, in response to this development, World Aquaculture Society (WAS) has made the decision to move the event to India and replace it with World Aquaculture India, which will take place from November 10-13, 2025, ensuring that the event will continue in a new location.

This relocation allows us to continue providing an exceptional experience for our attendees. Despite the challenges posed by this change, we are committed to offering and ensuring a successful event and are excited about the opportunities this new location presents. We believe it is a positive development, and it is the right time to return to India after our first successful experience.

World Aquaculture 2025 INDIA will take place at the Hyderabad International Convention Centre – Novotel from November 10-13, 2025. This marks the return of World Aquaculture to India after the successful Asian Pacific Aquaculture 2019 (APA19) event in Chennai. With Aquaculture continuing to grow rapidly in the Asian-Pacific region and particularly in India, the 2025 event is the perfect time for the World Aquaculture community to focus on India again at Hyderabad. Hyderabad plays an important role in India's maritime development with its advanced marine economy, robust marine industry and strong foundation in marine fishery, marine equipment manufacturing, and marine transportation.

We sincerely apologize for any inconvenience this may cause to our attendees, partners, researchers, exhibitors and supporters, and we thank you for your understanding and continued support. Additional information regarding the new event details, including the updated event and venue, will be posted on our website soon.

Please be advised that all the previous abstracts you submitted to WA2025 China will continue to be processed by the Program Committee and all registrations will continue to be valid. The abstract submission deadline has been extended to August 31, 2025. For the Exhibition, if you have already booked a booth and would like to keep your booth while exploring the new location, we will send you the updated manual and all other relevant information. Please note that the venue has changed, and we will provide all necessary details to assist you in this transition.

We greatly appreciated your interest in World Aquaculture China and invite you to join us at World Aquaculture India this November. We look forward to welcoming you to a truly remarkable event in India.

We look forward to seeing you in India!

- For conference management inquiries, contact Mr. John Cooksey at worldaqua@was.org.
- For booth and sponsorship details, reach out to Mr. Mario Stael at mario@marevent.com.
- For General inquiries, contact WAS-APC Executive Officer at apcsec@was.org.

USAS CHAPTER ARTICLE:
Navigating the Currents of Change in U.S. Catfish Nutrition Research

Fernando Y. Yamamoto and David J. Wise

The catfish industry is the largest producer of food fish in the U.S., reaching ~170 thousand tons in 2023 and generating $443 million in sales (USDA, 2024). This accounts for over 58% of gross food fish sales in the nation, with an economic impact of ~$1.9 billion when including variables for sales and expenditures (Hegde *et al*., 2021). In catfish farming, feed represents the main production cost, and the efficient use of this resource is critical for farm profitability. Over the past 2 decades, the US catfish industry has changed its production practices to overcome the challenges imposed by the economic recessions (2008 and 2012), bacterial outbreaks, and competition with other fish products. The adoption of new technologies such as intensively aerated ponds, the attenuated *Edwardsiella ictaluri* vaccine and its delivery method, as well as the production of the channel and blue catfish hybrid on an industrial scale, enabled the intensification of the earthen pond systems and increased farm productivity (Hegde *et al*., 2022). Despite the now widespread production of hybrid catfish, the available feed formulations still rely on requirements originally established for the channel catfish (*Ictalurus punctatus*).

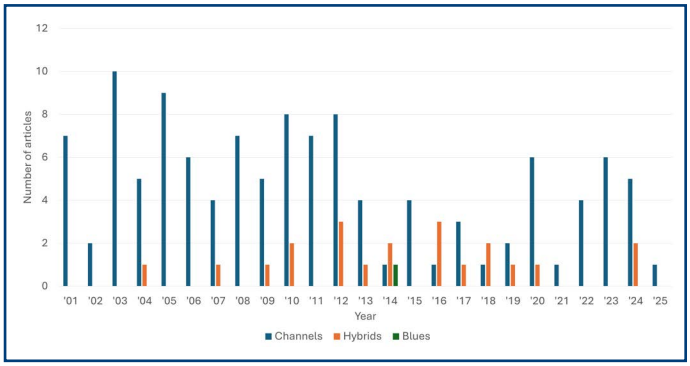


FIGURE 1. *Frequency of articles on catfish nutrition studies conducted in the US and published in peer-reviewed journals for the past 25 years. There were 139 articles found within this timeframe, and frequency data was distributed per year with the different animal models.*

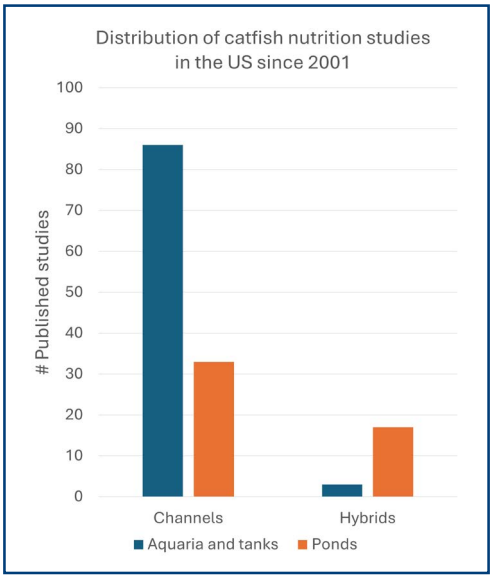


FIGURE 2. *Number of catfish nutrition studies conducted in the US published in peer-reviewed journals. The articles surveyed are presented in different experimental conditions and animal models.*

The history of channel catfish nutrition research in the United States has been well documented in a literature review from Drs. Ed Robinson and Menghe Li (2020), both former faculty of the Thad Cochran National Warmwater Aquaculture Center. Their review highlighted the key scientists, research focus areas, and geographic distribution over the decades. Yet, tracing back some of the scientific publications on *Ictalurus* sp. nutrition from U.S. institutions over the past 25 years, limited research articles have been published with hybrids when compared to channels (Figure 1).

Hybrid Catfish

The hybrid catfish can be obtained by artificially inducing the spawning between the female channel catfish (*Ictalurus punctatus*) and the male blue catfish (*Ictalurus furcatus*). For the past 10 years, hybrids have been the predominant catfish farmed in the US, mainly in the state of Mississippi (Hegde *et al*., 2022). When compared to channel catfish, hybrids have demonstrated higher disease resistance, faster growth rate, greater fillet yield and increased harvestability. As previously mentioned, despite being the preferred farmed *Ictalurid*, only a handful of nutritional studies using hybrids can be found in the literature. This can be credited to the poor production performance of this fish observed in aquaria studies (Yamamoto *et al*., 2024a), a trait likely inherited from the blue catfish, which has consistently shown high feed conversion ratios (FCR) in these conditions (Webster *et al*., 1992, 1995a; 1995b). In glass aquaria, the hybrid catfish are skittish when exposed to human interaction, and they usually cower in the back of the tanks. If we take a closer look at the scientific literature surveyed, we will see that most of the nutritional studies using hybrids were conducted in experimental ponds (Figure 2). In our laboratory, several attempts were made to fix this issue, and the best approach developed was to cover the front of the aquaria (and sides for the tanks at the edges) with peel-and-stick paper and monitor feeding activity through the bottom of the glass tanks.

Under intensive pond production, a significant drawback for this hybrid is their size disparity (Figure 3), as unevenly sized fish can complicate the filleting process, ultimately leading to monetary penalties from processing plants to the catfish farmers (Wiese *et al*., 2006). In nature, the blue catfish has been considered an apex predator by some ecologists, presenting a preference for consuming animals

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(insects, crustaceans, mollusks, mammals, birds, etc.), but at the same time with an opportunistic feeding behavior, where ~16-33% of aquatic vegetation could be found in their gastrointestinal tract (Schmitt *et al*., 2017, 2019). Nevertheless, as they grow larger, blue catfish seem to transition from an omnivorous to a piscivorous feeding behavior. Thus, it is fair to wonder if an inherited carnivorous behavior could be passed from the blue parent to its hybrid offspring, potentially leading to a higher energy requirement and promoting these size disparity issues when offered omnivorous feeds.

Another impressive and distinct feature of hybrids is their feeding activity in earthen ponds. Whereas channels appear to emerge from the bottom of the pond to consume the floating extruded feed, the hybrids display an aggressive feeding frenzy while swimming in schools near the surface. These behavioral differences likely require additional energy for metabolism, possibly increasing their requirement for calories. In fact, a recent study in a recirculating system observed that hybrids had better swimming performance and a higher metabolic rate when compared with channels and blues (Gerhart *et al*., 2024). This highlights the necessity to look back and tailor formulations to optimize the growth performance of this hybrid, especially when it accounts for more than half of U.S. catfish production.



FIGURE 3. *Dr. Brian Bosworth, a research geneticist at USDA-ARS, holds two hybrid catfish of noticeably different sizes, despite belonging to the same population.*

Alternative Ingredients

Solvent-extracted soybean meal (SBM) and cottonseed meal have been the primary protein feedstuffs in catfish (*Ictalurus* spp.) formulations during the growth-out life stage (Li and Robinson, 2021). Prices of these commodities have been highly volatile in the past five years due to several global events (*e.g*., the pandemic in 2020, drought in South America, and international conflicts) that have disrupted the supply chain and greatly impacted feed prices. All livestock sectors struggled during this period, and it was no different for the American catfish industry, where feed prices had record highs in 2022. These events drove apprehension in the industry, and investigating affordable alternative ingredients with steady supply became a priority to minimize surges in feed prices. In this context, a domestic solution can be a higher reliance on corn-derived products from the biofuel industry. The United States is the leading global producer of fuel ethanol, with an output of approximately 57 billion liters/year (Renewable Fuel Association, RFA, 2022). The primary substrate for American ethanol production is corn, and after fermentation, corn stillage can be used to feed terrestrial animals or further processed and included in fish feeds (Anderson and Almeida, 2019). This nutrient-rich biomass can be further refined into novel alternative ingredients, such as high-protein distillers dried grains (HPDDG) or corn fermented protein (CFP). Both ingredients have superior nutritional value to conventional DDGS (25-30% protein, 6-9% lipid, <14% fiber). This is achieved by fractionating a portion of the fiber and oil, which concentrates the residual proteins from the grains and yeast (Distillers Grains Technology Council, DGTC, 2021). HPDDG (36-48% protein; 4-6% lipid; <12% fiber) and mechanically separated CFP (>48% crude protein; 1-5% lipid; <8% fiber) are protein ingredients with comparable, if not superior, nutritional values to cottonseed meal and dehulled soybean meal, respectively, but amino supplementation may be necessary (*e.g*., lysine and arginine). Recently published studies have investigated the use of CFP and HPDDG in channel catfish feeds (Nazeer *et al*., 2022; Paladines-Parrales *et al*., 2025; Yamamoto *et al*., 2024b), showing promise as alternative protein sources for catfish feed. Their adoption could create a valuable niche market for both industries, depending on availability and pricing.

Fishmeal replacement has been investigated for an array of cultured fish species for a long time. As the demand steadily increases for high-quality protein ingredients from other aquaculture industries or other livestock, the price of forage fishmeal is becoming cost-prohibitive to be included in the feed formulation of omnivore fishes, especially for the U.S. catfish industry. And yet, some formulations for fingerling feeds still rely on this top-shelf ingredient. The high nutrient digestibility, balanced amino acid profile, and absence of antinutritional factors set the menhaden fishmeal as a "gold standard" for the aquaculture feed industry. However, alternative ingredients such as poultry by-product meal and other processed animal proteins (PAPs) have managed to fully replace this ingredient without impairing the production performance of other farmed aquatic animals. In general, rendering by-products have high protein content (ranging from 50-80%), good palatability, and no antinutritional factors, but in some cases, some essential amino acids may be deficient (*e.g*., lysine, methionine, and tryptophan) when compared to menhaden fishmeal. For catfish, conflicting

results were observed when replacing menhaden fishmeal with PAPs in fingerling diets. Some of the studies presented no differences in production performance, and others showed a suppressed growth for catfish offered feeds formulated with animal-derived ingredients (*e.g.*, meat and bone meal). The processing conditions, storage, and nutrient profile of PAPs can largely affect the production performance of any fish species when replacing high-quality fishmeal. The manufacturing processes of these ingredients have greatly advanced since most of these studies were conducted, ensuring more consistent and better-preserved PAP ingredients. And, it is interesting to revisit the idea of completely eliminating the forage fish-derived fishmeal from catfish feeds.

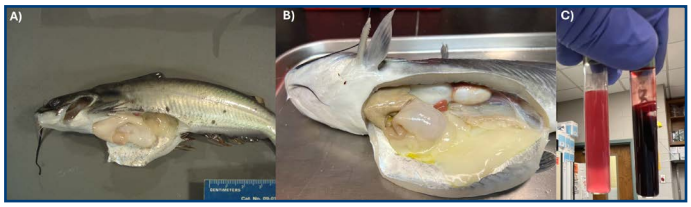


FIGURE 4. *(A) Channel catfish fingerling exhibiting feed-related anemia. (B) Hybrid catfish diagnosed with idiopathic catfish anemia. Both cases (A and B) were animals from commercial facilities submitted to the MSU CVM Aquatic Research and Diagnostic Laboratory* (photos courtesy of Dr. Lester Khoo). *(C) Blood samples from an anemia outbreak at the Thad Cochran National Warmwater Aquaculture Center: on the left, anemic hybrid catfish; on the right, a healthy hybrid catfish* (personal repository).

Iron Supplementation and Catfish Anemia

Idiopathic catfish anemia has been an ongoing issue affecting U.S. catfish farms for decades. It was first documented by Dr. Tom Lovell in 1983 as "no blood" disease, and it typically manifests in early spring or late fall. Normal packed cell volumes (PCVs) in commercially raised catfish typically range from 20–40%, with higher values observed in summer. However, anemic fish often exhibit critically low PCVs of 10% or less, lethargy, and respiratory distress under otherwise adequate dissolved oxygen concentrations. Larger, food-sized fish are most affected by this disease, which is also characterized by low circulating iron, decreased iron levels in the liver, prolonged clotting time, pathological accumulation of fat in the liver resulting in a pale liver that often floats (fatty liver) and light-colored skin, gills and viscera, leading to the industry-coined term 'white lip' (Figure 4).

Early evidence suggested that anemia was related to feed, although feed analyses indicated diets were nutritionally complete. Feed-related anemia has been documented in channel catfish in Alabama and Georgia and possibly in Louisiana. For example, in 1983, feed-related anemia was reported on 39 of 166 catfish farms in west-central Alabama, with weekly mortality rates reaching 5%. Losses ceased when fish were temporarily offered feed from a different manufacturer. Hepatic lipidosis (fatty liver) is the most prominent characteristic of fish suffering from feed-related anemia (Dr. Lester Khoo, personal communication). Possible causes of this form of anemia include feed contaminants from ingredients or possibly microbial degradation of nutrients, which can interfere with red blood cell production. Differently from feed-related anemia, iron-responsive anemia is typically observed from farms in the delta region of Mississippi and Arkansas. While both forms of anemia appear to be associated with the lack of red blood cell production, their etiologies are unknown. The pathology of fish suffering from iron-responsive anemia is similar to feed-related anemia but lacks a fatty liver, suggesting different causes for this disease. Following iron supplementation, research has demonstrated that intraperitoneal and dietary iron supplements promote normal production of red blood cells (Camus *et al*., 2014).

Historically, iron sulphate supplementation in catfish feeds has been a standard practice when this element can mitigate gossypol toxicity derived from cottonseed meal. With the anemia issues, it has been normal to supplement a bit more of this inorganic source of iron as a prophylactic measure to improve red blood cell formation and prevent anemia. When anemia cases are not feed-related, the supplementation of iron has been shown to improve the production of erythrocytes in diseased fish, relabeling the disease in these conditions as "iron-responsive anemia". Several investigations evaluating different iron concentrations and sources have been conducted, especially in the 1990's and early 2000's, and no adverse effects were observed for channel catfish. Experiments in our laboratory, however, showed that elevated concentrations of dietary iron sulfate can be a double-edged sword; whereas higher hematocrits could be observed even in healthy catfish, an increase in disease susceptibility was observed when fish were challenged with the bacteria *Edwardsiella ictaluri*, the causative agent of enteric septicemia of catfish (Yamamoto *et al*., 2024a; Yamamoto *et al*., 2024c). During an infection, fish have physiological mechanisms to restrict the circulation of iron and deprive the pathogen of this nutrient. Our findings hypothesized that elevated doses of iron sulfate in the diet may bypass these limiting mechanisms and allow the bacteria to thrive during an infection. Until more research is developed on this front, and we better understand what is causing this mysterious disease, it is extremely important to use iron-fortified feeds as a remediate approach for catfish anemia instead as a prophylactic measure. Especially when bacterial diseases, which are more frequent in the warmer months, may be able to take advantage of these supplemental doses and possibly aggravate losses during an outbreak.

Intestinal Microbiota and Feed Additives

With the continued development of high-throughput sequencing technologies, it has become more affordable to survey the intestinal bacterial community in fish nutrition studies. This has been a useful tool to understand possible shifts in the gut microbiota. For example, when feed supplements included in the feeds might promote the proliferation of beneficial bacteria, or the other way around, if alternative ingredients can disrupt gut bacterial communities. The intestinal microbiota can symbiotically interact with their host by aiding the digestive function and gastric development, maintaining intestinal mucosal barriers, teaching the immune system during the developmental stages, and conferring increased disease resistance.

Bacterial diseases comprise most losses for catfish farmers, and these pathogens use a fecal/oral route of infection, with a predilection for intestinal tissue. In pond culture, the gastrointestinal tract of farmed catfish is continuously exposed to a variety of opportunistic microorganisms and toxins that can naturally occur in the nutrient-rich pond water, increasing their susceptibility to intestinal diseases. In this sense, dietary probiotics can be a useful prophylactic measure to

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inhibit pathogen proliferation in the intestine and promote fish growth. While evaluating the differences in the intestinal microbiota of hybrid catfish with great size disparities but from the same cohort, it was quite intriguing to observe a higher relative abundance of *Lactococcus spp.* using next-generation sequencing from the intestinal contents of fish that were overperforming in the ponds. In this study, we also isolated a bacterial species, *Lactococcus lactis* MA5, which presented beneficial features to be a potential native probiotic (Huang *et al*., 2024) for hybrid catfish. In a separate study comparing the microbiota of hybrids and channel catfish juveniles in different intestinal segments, we observed increasing bacterial community diversity along the intestinal tract, wherein the most diverse communities were found in the posterior segment. Additionally, differences between hybrids and channels were observed, including differences in abundances of *Cetobacterium,* a bacterial genus demonstrated to confer benefits to some fish hosts (Older *et al*., 2025 *in press at Physiological Genomics*).

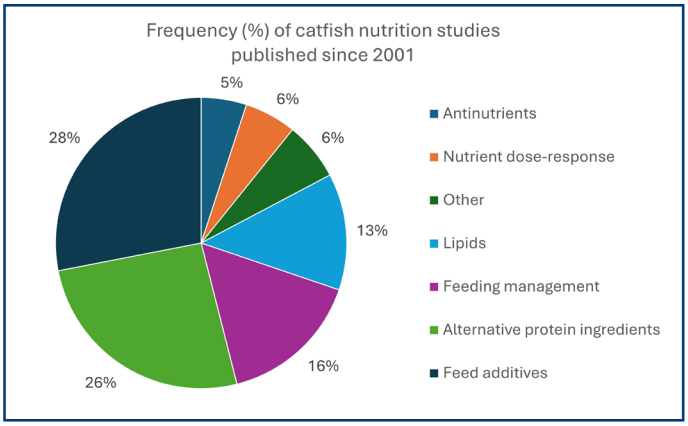


FIGURE 5. *Frequency of the nutrition topics surveyed from the scientific literature published for* Ictalurus *spp. from 2001-2025.*

Several other catfish nutrition studies performed at Mississippi State within the past few years have assessed how various feed ingredients can affect the intestinal microbiota. These studies include the evaluation of feed supplements, alternative protein and lipid ingredients, and chemotherapeutics. For most studies, the catfish intestinal microbiome presented high resilience, with little to no modification in the composition, structure, and diversity of microbial communities. Although a 10-day course of the antibiotic florfenicol caused initial microbiota disruption, communities returned to homeostasis within a matter of days (Older *et al*., 2024). This robust intestinal microbiota may be linked to the natural biology and feeding behavior of catfish in the wild. Despite abrupt changes in nutrient sources during feeding trials, the bacterial communities appeared unaffected. But it is also important to point out the limited taxonomic resolution of the methods used, which only enable the bacterial genus to be the highest taxonomic level that can be reliably identified.

Feed additives have been the most popular topic in catfish nutrition research conducted over the past 25 years, comprising 28% of the published articles (Figure 5). The use of probiotics, plant-derived extracts, enzymes, insect by-products and different sources of minerals, amino acids, and vitamins were popular topics explored by scientists in the U.S., who used *Ictalurus spp.* as an animal model. It is of the utmost importance to better understand the nutritional strategies that we have at our disposal, such as feed additives, that can be used to intervene and reduce the frequency of disease outbreaks in catfish culture.

Conclusions

The U.S. catfish industry has come a long way, demonstrating resiliency and adaptability in the face of the challenges encountered over the last quarter century. Research innovations, such as hormone injections for spawning hybrids, development of vaccines, and improved aeration methods, have greatly assisted in increasing production efficiency. Still, there is always room for improvement in many areas of catfish aquaculture, including nutrition. Rising feed costs, driven by supply chain disruptions and global market volatility, have put pressure on feed millers to find affordable alternatives. Plant derived ingredients like high-protein distillers dried grains and corn fermented protein, and processed animal products have been refined and have emerged as viable and stable products to be included in catfish feed formulations.

Catfish anemia remains a long-standing issue, with sporadic outbreaks causing concern across farms. While iron sulfate supplementation has been a go-to solution for iron-responsive anemia, recent findings suggest that excessive dietary iron could increase susceptibility to bacterial infections. Until the root causes of catfish anemia are fully understood, iron-fortified feeds should be used carefully as a reactive measure rather than a blanket preventative approach. The role of intestinal microbiota in catfish nutrition is another emerging area of interest. Studies indicate that dietary interventions, including probiotics and other feed additives, can positively influence gut health and improve disease resistance. Despite the resilience of the catfish intestinal microbiome, continued research into microbial interactions and their implications for fish health and growth is still needed.

Looking ahead, a more holistic approach is envisioned to catfish nutrition research, by integrating not only the production performance measures, but also considering health parameters and how dietary manipulations can increase disease resistance. With advances in laboratorial technology, the development of novel ingredients, and a better understanding of how intestinal microorganisms can influence host health, the science of fish nutrition and health will continue to contribute to the productivity and sustainability of the U.S. catfish industry for years to come.

THE U.S. CATFISH INDUSTRY HAS COME A LONG WAY, DEMONSTRATING RESILIENCY AND ADAPTABILITY IN THE FACE OF THE CHALLENGES ENCOUNTERED OVER THE LAST QUARTER CENTURY. RESEARCH INNOVATIONS, SUCH AS HORMONE INJECTIONS FOR SPAWNING HYBRIDS, DEVELOPMENT OF VACCINES, AND IMPROVED AERATION METHODS, HAVE GREATLY ASSISTED IN INCREASING PRODUCTION EFFICIENCY. STILL, THERE IS ALWAYS ROOM FOR IMPROVEMENT IN MANY AREAS OF CATFISH AQUACULTURE, INCLUDING NUTRITION.

Notes

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Advancements in Twin Screw Technology for Aquafeed Production: A Comparative Study

Anders Haubjerg

Farmed fish have in recent years consolidated a position as one of the most sustainable sources of dietary protein, thanks to their exceptional feed conversion ratios (FCR) compared to terrestrial livestock (Tacon and Metian, 2015). With the rising global demand for high-quality protein and increased emphasis on effective water management policies, aquaculture is confronted with both significant challenges and promising opportunities for sustainable growth (FAO, 2020). As the industry develops, managing production costs — particularly feed formulations and raw materials — remains a critical challenge.

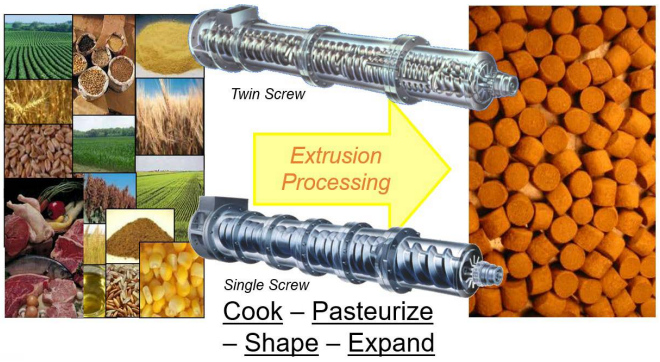


PHOTO 1. *Single- or twin-screw extrusion processes utilized for decades to cook, pasteurize, shape and expand raw materials into homogenous aquatic feed pellets.*

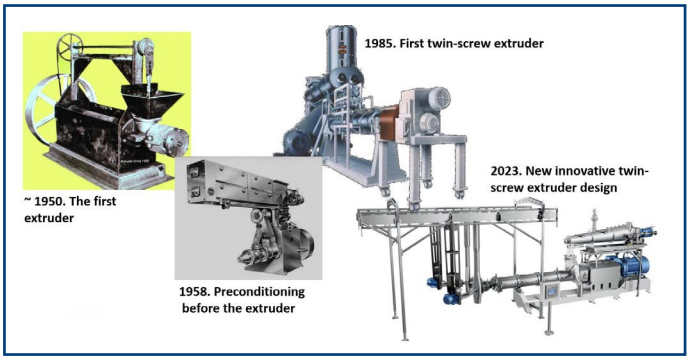


PHOTO 2. *A few of the historical steps in extrusion development for the past 75 years.*

The Aquafeed Triad

The end game in aquaculture is about promoting fish growth, health and survival at the least possible expense. Feed cost is a large part of the expense, whilst fish growth, -health and -survival entail effects from feed nutritional composition as well as technical feed quality. Technical feed quality involves all the attributes of the feed that effectively allow transport of nutrients to — and uptake in — the fish. Factors include physical qualities like durability, fat retention properties, size uniformity, density/buoyancy and hardness as well as physicochemical factors such as water activity and oxidative stability (Thomas & van der Poel, 1996).

In aquafeed manufacturing, raw material and formulation costs make up a substantial part of the operating expenses. Sometimes costs can be further challenged if constraints are put onto the formulations, driven by production to be able to deliver on quality. Examples could include a minimum starch inclusion, a maximum inclusion of soy, beans or another ingredient or — for high fat feeds — a minimum inclusion of hardened oils (which is an expensive component that promotes fat retention but can reduce fish growth). It can be very expensive to specify how the nutrients are put together, straying away from a least cost formulation (LCF) optimum. On the other hand, producing feeds solely considering a LCF perspective is not without risk and might eventually become much more expensive, if (when) technical quality rock bottoms. From above it becomes evident that *somewhere* in this triad of compromises between nutritional fish requirements, LCF considerations and producing pellets with high technical integrity, lies the competitive edge in sustainable aquaculture.

Enhancing Raw Material Flexibility with Advanced Extruder Design

Extrusion technology plays a pivotal role in the manufacturing of aquaculture feeds. The raw materials are pasteurized, cooked, shaped and expanded into the well-known cylindrically shaped feed pellets. The ability to achieve good quality based on upstream choices (raw materials, processing conditions, grinding and mixing) can be termed as the 'processing window.' Sometimes this will be wide to allow for several combinations of raw materials and processing conditions, while at other times it could become very narrow. For the reasons discussed above, the *extrusion platform* that effectively expands the processing window to allow for raw material flexibility — minimizing formulation constraints while delivering acceptable technical quality — will undoubtedly prove to be the most cost-effective production solution in the long term.

Traditional single-screw (SX) and twin-screw (TX) extruders have long been employed. Each offers unique benefits while presenting distinct limitations. Recent innovation in twin-screw extrusion ('AFX') is specifically targeted to aquatic feeds. It employs fundamentally different screw elements that are more resilient to wear and that modify the energy transfer dynamics within the extruder barrel. This study aims to assess and justify the claims regarding the enhanced performance and processing flexibility of the AFX system compared to traditional TX and SX technologies.

TABLE 1. A STANDARDIZED 'SALMON FEED' FORMULATION USED ACROSS ALL RUNS AND EXTRUSION PLATFORMS.

Salmon feed recipe in benchmark study	*Meal (%)*	*Finished product (%) (if coated)*
Whole wheat	22	14
Vital Wheat Gluten	8	5
Soy Protein Concentrate	47	30
Fishmeal	23	14
Fish oil (in coater- not applied here)	0	25
Rapeseed oil (in coater- not applied here	0	12

Trial Design

The study was designed to compare the three extrusion systems:

- ***'AFX' (Advanced Twin-Screw Technology):*** Features innovative screw elements designed for enhanced wear resistance and flexibility.
- ***'TX' (Traditional Twin-Screw Technology):*** Represents the standard twin-screw design used in many current, and often more demanding, applications.
- ***SX (Single-Screw Technology):*** A simpler, robust extruder with a single screw. This represents what is often and historically used in many feed extrusion applications.

Comparative production runs were conducted using a standardized salmon feed formulation (Table 1) over five different sets of processing conditions on three extrusion platforms (AFX, TX, SX). All runs utilized similar setup for feeding and preconditioning equipment. The utilization of five different sets of processing conditions was to mimic resilience towards operator choice as well as to test for raw material flexibility (e.g. different 'intrinsic levels' of moisture and fat).

The different run conditions tested on each of the three extrusion platforms were:

1. High SME/STE* ratio. This run condition will utilize mechanical energy more than thermal energy to cook, bind and shape the feed pellets.
2. Low SME/STE. Higher levels of steam to the conditioner and to the extrusion barrel than in '1'.
3. Low water addition [water inclusion dropped by ~4% (of dry feed rate)]
4. Low oil addition (0%)
5. High oil addition (4%)

*SME=Specific Mechanical Energy, STE=Specific Thermal Energy.

Whilst all runs fall into the category of stress testing the 'process window,' e.g. as different extrusion operator experience and approaches, particularly runs 4 and 5 are examples of testing raw material flexibility, mimicking different intrinsic lipid levels of fat in the recipe. Common to all runs was that a product bulk density off the extruder of 400 g/L was targeted. To achieve as good-of quality products as possible and density on target, any processing parameters could be altered, *aside from* the parameters that specify the actual characteristics of the particular run condition, for example, in run '3,' water inclusion was preset.

Production rate was approximately 700 kg/h across all runs. Identical upstream conditions were maintained and all runs utilized the same die with 6.5 mm holes, targeting a ~9 mm grower feed. Temperatures in the dryer following the extrusion step were maintained constant at ~112 °C. Retention time in the dryer varied from 27-32 minutes to obtain a final moisture target of ~9%, accounting for different process water and steam settings in the extruder.

The bulk density evaluation was done immediately as the product exited the extruder. Once the quality and density of each run was optimized, the run was logged and product samples were taken from the dryer outlet, corresponding to the retention time in the dryer, when dryer moisture was also on target.

The evaluation of pellet physical quality attributes for each run was carried out on the dried pellets:

- Pellet diameter 1 + 2: 30 pellets from each run were measured using a digital caliper on the shorter (1) as well as on the longer side (2).
  - Circularity: Diameter 1 / Diameter 2.
  - Surface Area/Volume: 2*(D1+D2+4L)/(L*(D1+D2))
- Pellet length
- Durability: Assessed using tumbler box method to gauge resistance to fragmentation and abrasion (ASAE, 1991).
- Bulk Density (ϱ): The measured pellet density across different runs.
- Oil uptake, vacuum (%): Measuring the amount of oil in pct that pellets were able to absorb and retain under vacuum @ 200 mbar for 2 minutes, with a 45 sec. release of vacuum.

Results

The first objective of the trial was to assess the ability to reach the bulk density target across each of the 5 different processing conditions. Figure 1 indicates that runs on SX were able to get to target density, except for the lower and higher oil addition runs '4' and '5.' Runs on the TX were able to get to target density except the higher oil inclusion. AFX was generally able to achieve target densities across the different run conditions.

It is observed that the water levels used across the AFX runs varied significantly compared to those in the TX and SX run series, cf. Figure 2. This variation can be explained by AFX's improved ability to respond to and utilize moisture as a process variable, ensuring density while maintaining a consistently high-quality product. As expected, water levels were higher when oil inclusion in the diet was low and vice versa. This adjustment compensates for changes in melt viscosity within the extrusion barrel, maintaining die pressures and physicochemical properties necessary for proper pellet expansion and achieving desired bulk density. Water inclusion on SX for the low oil inclusion run ('4') was also high, but here this compensation failed to

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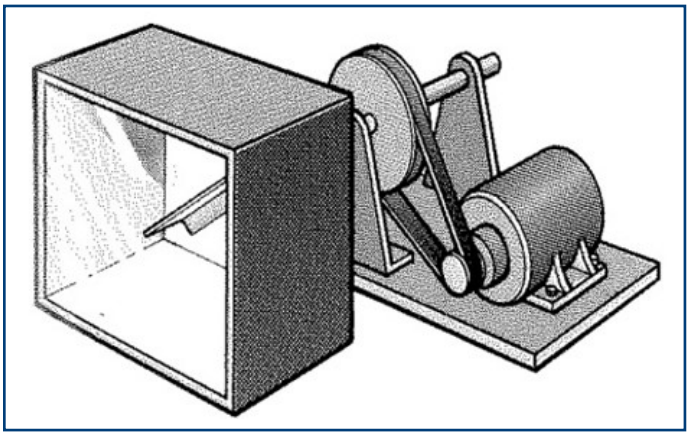


PHOTO 3. *A schematic of the Tumbling Box used to measure pellet durability.*

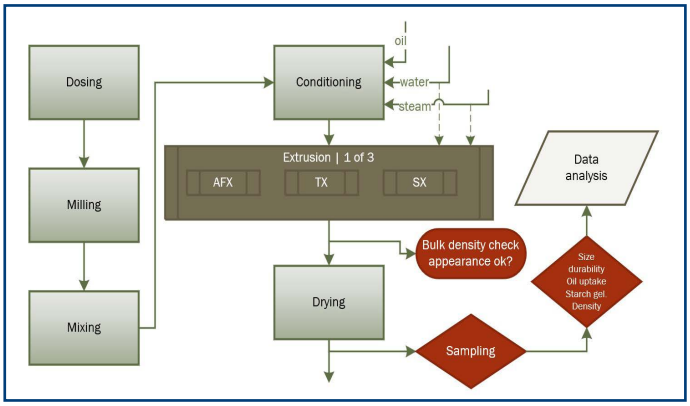
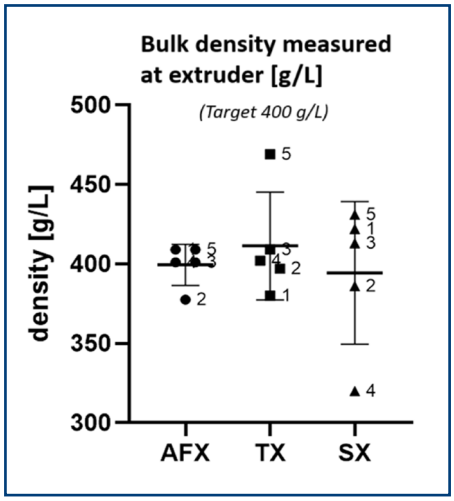
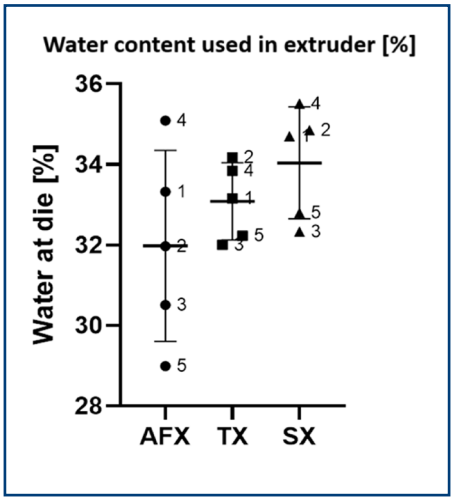
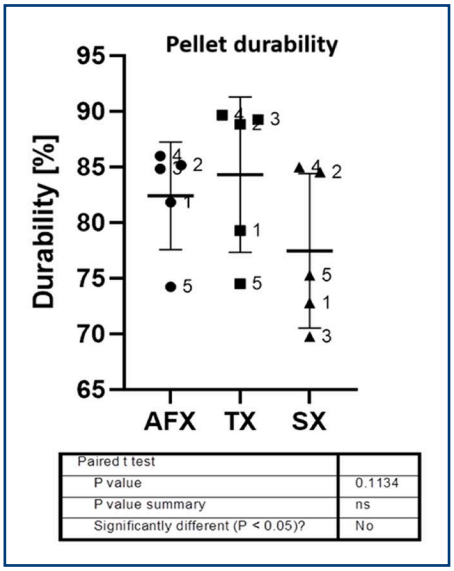


PHOTO 4. *A flowchart of the experimental approach in the benchmark trial of the three extruders, AFX, TX and SX.*







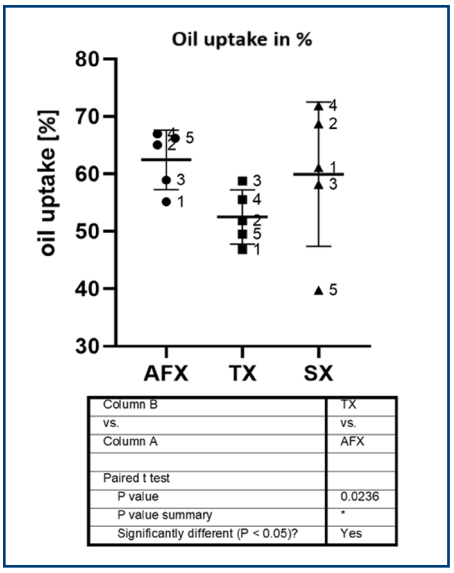
LEFT, FIGURE 1. *The ability to reach density target of 400 g/L for each run conditions across the extrusion platforms (1: High SME/STE, 2: Low SME/STE, 3: Low water, 4: Low oil, 5: High oil).* MIDDLE, FIGURE 2. *Water inclusion for AFX and TX was in average 2 % less than on SX and 1 % less than on TX. Also, it appears the ability to achieve target density is countered by successful alteration of processing water.* RIGHT, FIGURE 3. *Durability of pellets produced on AFX and TX compared to those for SX was seemingly higher, though data insufficiency does not evaluate this as statistically significant, at p=0.11.*

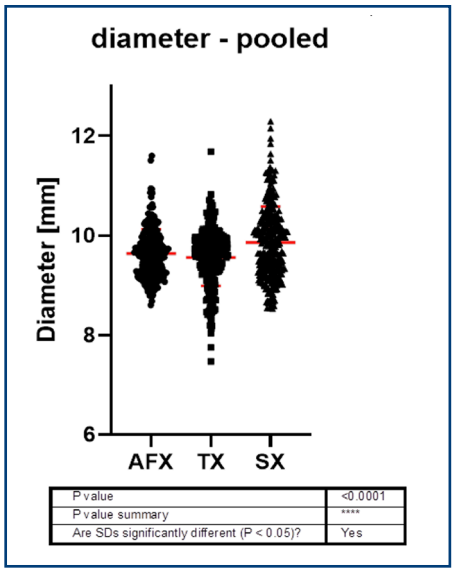
yield a needed elevation in bulk density towards the target. Simply put, the ability of AFX to effectively apply a wider range of process moisture levels is what enabled it to achieve target densities across all runs. It is also worth taking note that the AFX runs in average utilized 2% less water inclusion across all runs than SX and 1% less than the TX runs. This yields improved resource efficiency and sustainability, from reduced energy costs associated with drying.

When looking at the durability across all the different runs, both of the twin screw technologies stand out as slightly better than the SX runs (Figure 3). However, this effect was not statistically significant due to the amount of data and number of runs carried out. It can be observed though, that the run '3' on the SX, which utilized lower water gave 15-20% lower durability than in the twin screw runs. All products were tested for gelatinization levels of starch, and numbers generally fell between 86-93% across all runs — with no pattern. Hence, it is not 'inadequate cooking' of starches that gave the SX run '3' with lower water a poor durability value. More likely this could be from protein alignment, porosity, pellet shape and mechanical properties of the pellets.

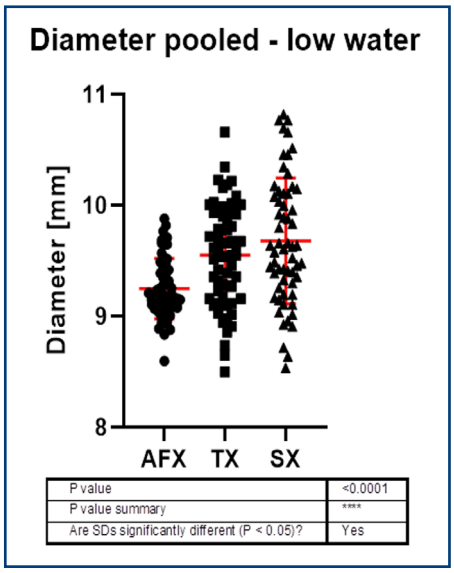
In aquafeed manufacturing, particularly for high-energy feeds, coating dried feed pellets with oil is crucial to achieving the desired digestible energy levels. This is essential not only for salmon feed but also for most other cold-water finfish, as their dietary requirements include high energy density for optimal growth and performance. Figure 4 shows how the different runs perform for oil uptake amount when vacuum coated with a rapeseed oil. All pellets were allowed to settle and excess oil removed prior to being weighed and assessed for oil uptake. While pellet density surely influences the amount of oil uptake, the cell structure also plays a crucial role in *retaining* the oil through adsorption and capillary forces. Feed pellets produced on the AFX platform exhibit a uniform and high level of oil uptake across all run conditions. This high level is significantly different than the TX runs (p=0.02) which shows a uniform behavior across runs. For the SX runs, the oil uptake varies substantially across the different runs. Part of this is due to the differences obtained in density, e.g. runs SX4 and SX5.

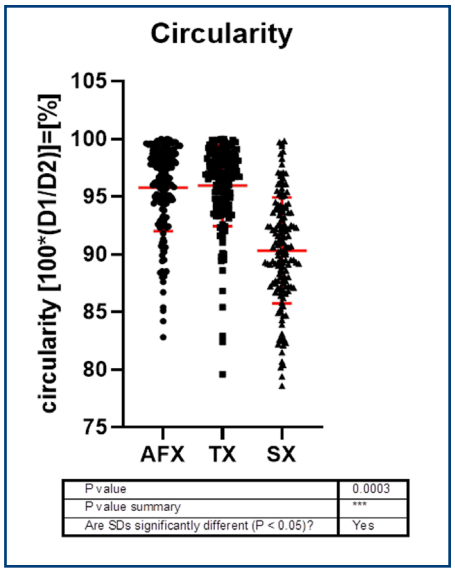
Pellet uniformity is also a crucial quality aspect of aquatic feeds, primarily due to its impact on downstream processing. Pellets of varying sizes do not dry or cool at the same rate, potentially leading to differences in physicochemical properties such as water activity and lipid crystallization strength within the pellet. The most immediate





LEFT, FIGURE 4. *Oil uptake in vacuum across the three runs. AFX is superior to TX, where SX runs were generally varying a lot depending on run conditions and corresponding well with density.* RIGHT, FIGURE 5. *Diameter measured for all runs, each for 30 pellets. AFX pellets have significantly less standard deviation in diameter across all runs, than for pellets in TX and SX runs.*





LEFT, FIGURE 6. *Diameter measured for runs using lower water inclusion, runs '3'.* RIGHT, FIGURE 7. *Circularity of pellets across all runs and extrusion platforms. Pellet from SX runs was significantly less circular and had much higher variation in obtained circularity.*

effect of size non-uniformity is, however, observed during the coating process. Larger pellets may remain unsaturated with oil due to insufficient diffusion time or vacuum strength, while smaller pellets may absorb excess oil, resulting in surface wetness and increased likelihood of oil leakage. This issue becomes evident when a handful of coated pellets is placed in water. Larger, unsaturated pellets may float due to lower density, whereas smaller, oil-saturated pellets will leach oil readily into the water.

Beyond processing concerns, pellet size uniformity directly affects feeding performance, particularly for smaller pellets, as it influences sinking velocity and surface tension (Eriegha *et al*. 2017). Figure 5 illustrates that all runs on the AFX platform had a significantly lower standard variation on diameter than in both TX and SX runs. Figure 6 further shows this effect, zooming in on the runs with low water addition ('3') across the three extrusion platforms. These run conditions seem to have caused more strain on TX and SX than for AFX, as seen by the outcome of variation in pellet diameters.

Difference in pellet diameters in extrusion can come from pellets spatially expanding to a different degree across the die, and temporally different expansion over time (i.e. extruder is 'surging'), but also from a single pellet exhibiting a nonuniform expansion. Figure 7 zooms in on this behavior and it is very evident that pellets produced on a SX platform are significantly less circular than on both twin-screw platforms. In this regard, it should also be noted that since pellets will not obtain a circularity larger than 100 %, the circularity *variation* becomes much less on AFX and TX platforms than on the SX. Circularity of pellets can also be important for downstream bulk handling properties. Pellets that are more uniform in circularity will tend to pack both less densely and more predictably, resulting in consistent bulk density. Pellets more uniform in shape will also experience more evenly distributed forces during handling, leading to minimization of breakage and improved yield.

To consider also axial expansion, i.e. pellet length, Figure 8 zooms in on net surface area/volume for all runs on all three platforms. Again, one-way ANOVA across the 3 runs demonstrates SDs to be significantly different (p=0.02), but what is further noted here is that pellets on the AFX runs are much more evenly distributed around its mean than on TX, and particularly than on SX runs.

This becomes important in that pellets lying a longer distance away from the mean will be those that are highly prone to become unsaturated with oil exhibiting undesired nutritional profiles as well as unwanted buoyancy. Likewise, but on the opposing end of the scale, would be those pellets that are more prone to leaking fat. SX runs and TX runs both produced pellets with surface area/volume that lie further away from the mean, when compared to AFX runs.

Summary

Trial results demonstrate that the twin-screw technology (AFX) consistently and significantly produces feed with lower pellet variation (CV), improved circularity, and higher durability when compared with both the traditional twin-screw (TX) and single-screw (SX) systems. Additionally, the AFX system achieved a similar density

(CONTINUED ON PAGE 30)

TABLE 2. Result overview – feed produced on three extrusion platforms.

	AFX	TX	SX
Pellet CV(D) [%]	2.94	4.84	5.85
Circularity [%]	95.8	95.9	90.3
Durability [%]	82.4	84.3	77.5
Avg. water inclusion [%]	31.9	32.8	33.7
Min-max ϱ across runs [g/L]	378-409	380-469	320-431
Wear cost assessment (experience) [$/ton]	1.35	1.95	1.25

target across all runs while handling water and oil addition more effectively, which indicates a finer and more uniform pellet porosity. Although the TX system exhibited marginally better durability in some runs, the overall performance of the AFX extruder — especially regarding pellet uniformity and shape — show its potential. The results from the three extrusion platforms are summarized in Table 2 below. A wear cost assessment, which is derived from experience of the different extruders operating for years in industry, is included as well. The AFX extruder has screw elements which in nature have dissimilar geometries. Hence, the improved wear cost relative to TX was part of the AFX design criteria and therefore is as expected.

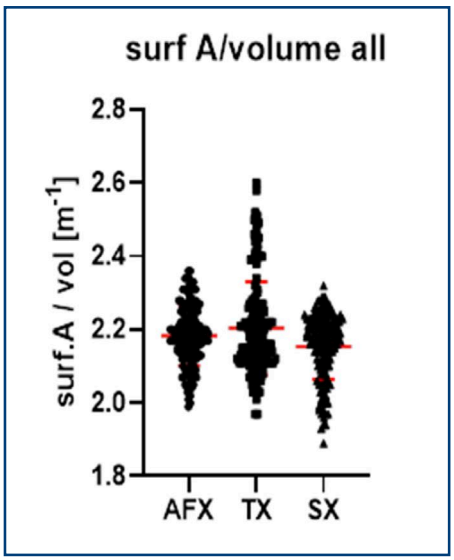


FIGURE 8. *Net surface area/volume for all runs across the three platforms. AFX runs show a more even distribution around the mean compared to TX and SX runs.*

The Future for Sustainable Aquaculture: A New Feed Paradigm

The enhanced performance of the AFX extruder is primarily attributed to its screw design. This design not only improves energy transfer dynamics within the extrusion barrel but also facilitates higher oil inclusion as well as more effective moisture utilization. The trial results signify that the AFX extruder offers several advantages over traditional SX and TX systems. This includes the obtained technical quality attributes across a range of different processing conditions. It also points to the fact that product quality was much more consistent across those different runs, which aimed to mimic operator choice and experience, as well as raw material variability. In further, this was achieved using less overall water addition, reducing downstream drying costs. Lastly, the AFX platform's operational performance is achieved at wear costs comparable to those of a single-screw system, underscoring the potential for long-term resource efficiency.

These trial results validate the core hypothesis: optimizing least-cost formulations and enhancing raw material flexibility through extruder design can lead to improved feed quality and reduced operational costs. In doing so, the AFX platform is positioned to promote both cost-efficiency and environmental stewardship. Although the results are promising, this study is limited by its focus on a single salmon feed formulation. Future research should extend these trials to encompass a wider variety of feed types and production conditions to validate and generalize these findings. Additionally, further investigation into the long-term operational performance and energy consumption of the AFX system will provide valuable insights into both sustainability and economic viability.

Notes

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The enhanced performance of the AFX extruder is primarily attributed to its screw design. This design not only improves energy transfer dynamics within the extrusion barrel but also facilitates higher oil inclusion as well as more effective moisture utilization.

Adapting Mediterranean Aquaculture Larval Feeding Strategies for Tropical Species: A Case Study of Barramundi

V. Carbone, A. Shinn, H. Crieloue, A. van Amerongen, I.N.A. Giri, Haryanti, Y.N. Asih, Sudewi, N.W.W. Astuti, A. Muzaki, K. Mahardika, I. Mastuti, I.G.N. Permana, C.B. Koh, W.L. Quek, Y. He, R. Hidajat, T. Kunthahong, F. Lenzi, T. De Wolf, G. Rombaut and S. Debono

Asian seabass (*Lates calcarifer*), also known as barramundi, is an important finfish species in global aquaculture, ranking 35th among discrete fish species and 42nd across all FAO-identified fish categories. Global production reached 154,281 tonnes in 2022, marking an impressive 735% increase since 2000, with an average annual growth rate of 10.58% (FAO FishStatJ, 2024). As of 2022, barramundi was commercially produced in 18 countries, with Thailand (51,893 tonnes), Malaysia (43,735 tonnes), and Taiwan ROC (17,161 tonnes) leading production.

Larval rearing of barramundi follows a feeding protocol like many marine species, beginning with the green-water technique during early larval development. Traditional protocols incorporate rotifers, followed by co-feeding with *Artemia* and manufactured diets (Boeing, 2020).

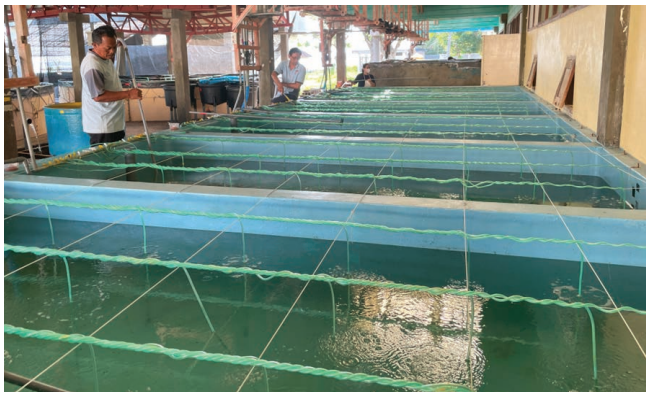


FIGURE 1. *Layout of a small-scale backyard fish production system used for Trial 1.*



FIGURE 2. *Layout of the advanced commercial fish production system used for Trial 2.*

A collaborative study between the BRIN Research Centre, Indonesia, and the SFA Marine Aquaculture Centre, Singapore, evaluated the performance of Natura pRo and ExL feeds under tropical conditions in both a small-scale backyard production system (Figure 1) and in an advanced Mediterranean-style commercial production system (Figure 2). The research focused on two key aspects: 1) The potential for complete rotifer replacement through the early introduction of manufactured feeds during first feeding; and, 2) The impact of various live feed enrichment protocols on larval development.

Materials and Methods

Trial 1: Backyard production system

Asian seabass larvae from a single egg batch were stocked at 16 larvae/L in 4,000 L rearing tanks without pure oxygen supplementation or continuous water exchange. Water temperature was maintained at 28 ± 1°C with a 12:12-hour light/dark photoperiod. All treatments were conducted in duplicate.

This trial compared the effects of dry algae, live feed enrichment, and early manufactured feed introduction against a standard protocol using fresh algae and non-enriched live feed, from hatching to 25 days post-hatch (dph).

In both the Control and Rotifer Substitution (RS) treatments, algae were provided from 2 to 18 dph. In the Control, rotifers cultured with fresh algae were fed until 19 dph. In the RS treatment, enriched rotifers were fed from 2 to 12 dph at 50% of the Control amount.

In the RS treatment, AF *Artemia* was introduced from 10 to 13 dph, followed by enriched *Artemia* from 13 to 23 dph. The Control group received non-enriched *Artemia* from 13 to 23 dph. Different dry diets were used: The Control group received competitor feed from 8 dph onwards. The RS group received the Natura® line from 3 dph onwards (see Figure 3). The trial concluded at 25 dph with the first grading.

Trial 2: Advanced production system

Asian seabass larvae from a single egg batch were stocked at a higher density (30 larvae/L) in 4,000 L rearing tanks under controlled conditions. This system included pure oxygen supplementation and continuous water exchange, with temperature maintained at 30 ± 0.1°C. The trial evaluated rotifer replacement and early manufactured feed introduction compared to standard protocols from hatching to 21 dph (Figure 3).

In both the Control and RS treatments, fresh *Nannochloropsis* algae were provided from 1 to 14 dph. Both treatments received

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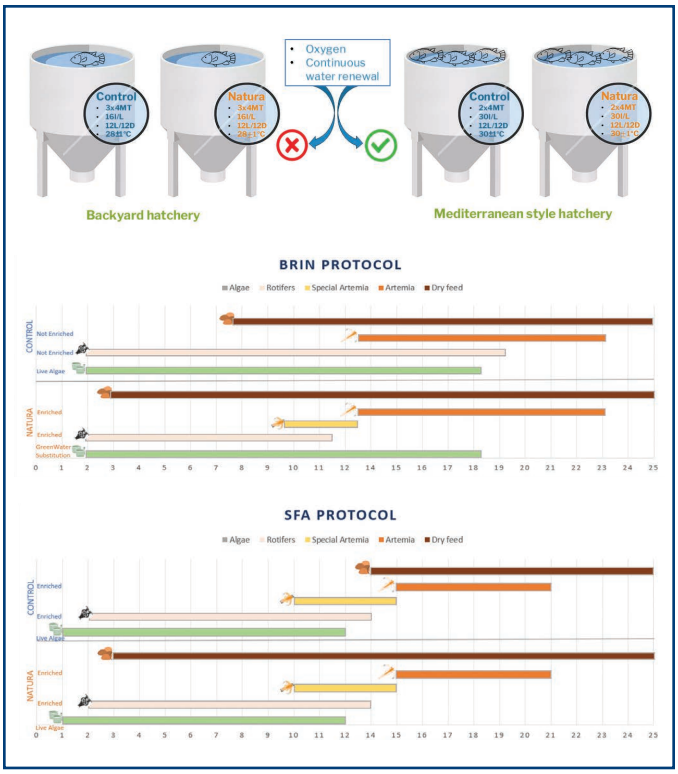
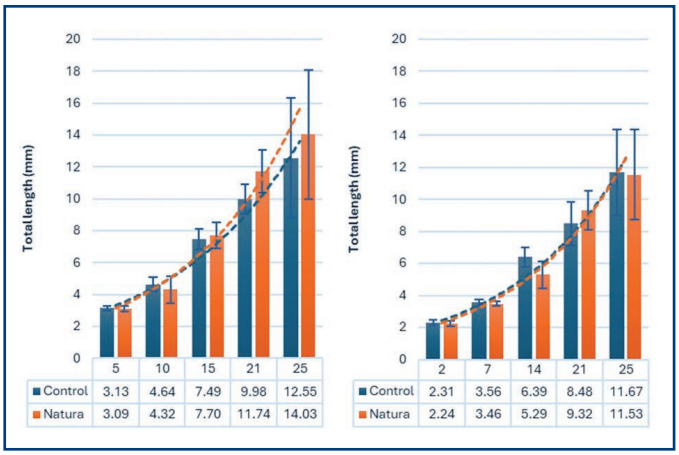


FIGURE 3. *Experimental conditions and feeding protocols used for the backyard (BRIN) system in Trial 1 and for the advanced (SFA) fish production system used in Trial 2.*



	5	10	15	21	25
Control	3.13	4.64	7.49	9.98	12.55
Natura	3.09	4.32	7.70	11.74	14.03

	2	7	14	21	25
Control	2.31	3.56	6.39	8.48	11.67
Natura	2.24	3.46	5.29	9.32	11.53

FIGURE 4. *Total length of the juvenile barramundi reared in the backyard production system at 5-25dph in Trial 1 (left) and in the advanced production system used in Trial 2 at 2-25dph (right).*



FIGURE 5. *Two-day-old (above) and three-day-old (below) barramundi larvae feeding on Natura pRo® <100.*

enriched rotifers from 2 to 14 dph, with the RS treatment receiving 50% less than the Control. AF *Artemia* was introduced from 10 to 14 dph, followed by enriched *Artemia* from 15 to 21 dph. Different dry diets were used: The Control group received competitor feed from 14 dph onwards. The RS group received the Natura® line from 2 dph onwards (see Figure 3). The trial concluded at 21 dph with the first grading.

Biometric measurements

In the first trial using a backyard production system, biometric measurements were conducted every 5 days starting from 5 dph, comparing growth rates. Between 10 and 20 larvae per tank were sampled to assess body development and total length (Figure 4). In the second trial using an advanced production system, measurements were taken every 5–7 days, starting from 2 dph, with 10 to 30 larvae observed and measured throughout the trial (Figure 4).

A salinity stress test was performed in both trials to assess stress resistance before grading. Growth, survival rate, fish size distribution, and feed consumption were evaluated at 25 dph for Trial 1 using the backyard production system and at 21 dph for Trial 2 using the advanced production system.

Results

Larvae readily ingested Natura pRo® <100 from its first application. Figure 5 illustrates their high acceptance of the feed from the beginning.

Significant differences in the total length of larvae fed the Natura diet were observed starting at 15 dph ($p < 0.01$) and 21 dph ($p < 0.01$) in Trial 1 using the backyard production system. In Trial 2, the effect of the Natura protocol did not show significant differences compared with Control (Figure 4).

Survival rates in the Natura treatment were 22% higher in Trial 1 using the backyard production system and 10% higher in Trial 2 using the advanced production system. Rotifer substitution was successful, with a 69% reduction in Trial 1 and 45% in Trial 2 (Figure 6).

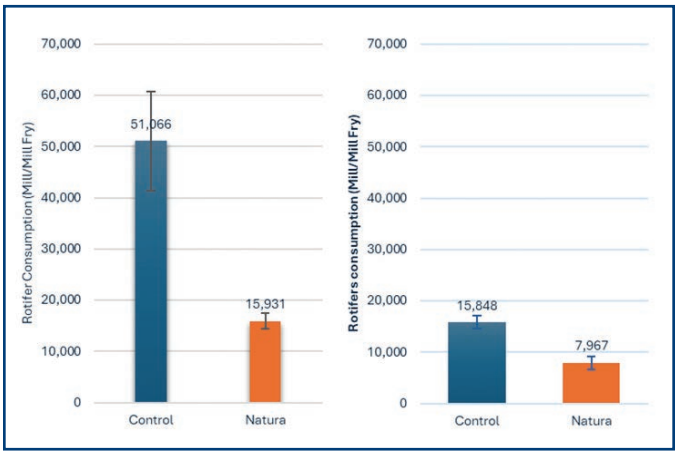


FIGURE 6. *Rotifer consumption (Mill/Mill fry) at first grading in Trial 1 using a backyard production system (left) and in Trial 2 using an advanced production system (right).*

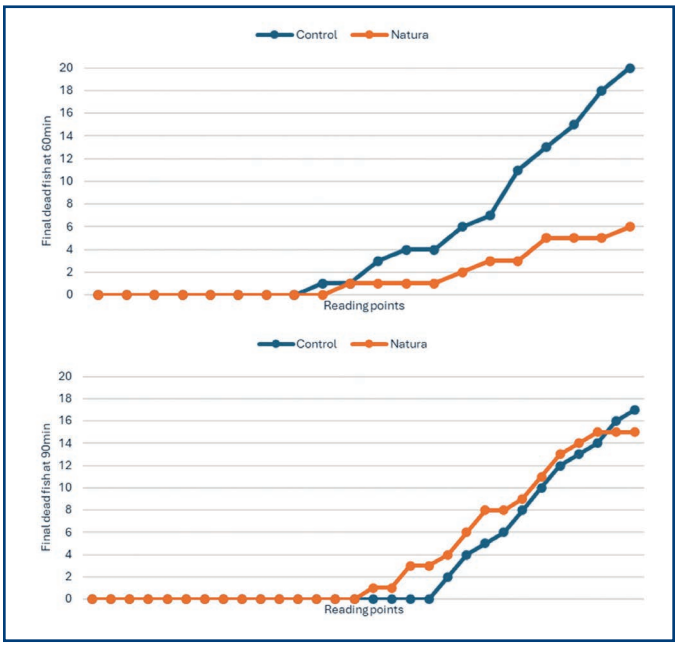


FIGURE 7. *Mortality rate of larval barramundi during a 60 min salinity stress test at 24 dph (70 ppt) in Trial 1 using a backyard production system (above), and during a 90 min salinity stress test at 33 dph (75 ppt) in trial 2 using larvae reared in an advanced production system (below).*

In Trial 1, using the backyard production system, fry fed with Natura consumed 50% more dry feed per thousand fish compared to the Control group. However, in Trial 2, which used an advanced production system, dry feed consumption was similar between treatments

Salinity testing of the fry in both trials, combined with Kaplan-Meier survival analysis, revealed that those fed the Natura protocol exhibited greater stress resistance ($p < 0.001$) (Figure 7).

Asian seabass larvae reared on a reduced enriched rotifer regime with early dry diet introduction exhibited similar growth, improved performance, and higher survival rates compared to those reared under a standard feeding protocol.

Conclusions

This study demonstrates that Asian seabass larvae can be successfully reared with a reduced rotifer feeding regime, achieving high survival rates and good fry quality when using proper live feed enrichment and a balanced diet from the early stages of exogenous feeding. The importance of live feed enrichment, a well-established practice in European aquaculture, should be emphasized in Asian aquaculture hatcheries to improve larval rearing success.

A high-quality diet is fundamental to optimal growth and fry quality in Asian seabass. The Natura pRo and ExL diets, originally developed for European finfish species, demonstrated remarkable versatility under tropical conditions.

Notes

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KOREAN CHAPTER ARTICLE:
WHO WILL BE THE WINNER OF THE HEATED 'LAND-BASED GIM (LAVER) FARMING WAR'?

JONG MYON PARK

K-Gim (Korean Laver) is creating a global sensation, and major companies are competing to cultivate it on land (indoors) instead of in the sea. Companies that have entered land-based laver farming include large companies such as CJ CheilJedang, Dongwon F&B, Daesang Corporation, and mid-sized food companies such as Pulmuone. Why are companies that put profit maximization as their top priority so interested in land-based laver farming? The biggest reason is that the stable supply of raw materials (fresh laver) is disrupted due to recent climate change-induced difficulties in sea laver farming. As the seawater temperature rises, the problem of shortening the cultivation and harvest period occurs. On the other hand, domestic laver (K-Gim) is gaining popularity worldwide due to the spread of K-Culture and K-Food. In the United States and other countries, 'frozen gimbap' has a long shelf life and has become so popular that it sells out.



FIGURE 1. *The laver fronds grow in a land-based farming facility (Indoor tank). Photo provided by Goheung-gun County.*



FIGURE 2. *On-land laver aquaculture research institute. Photo courtesy of Pulmuone.*

FROM BLACK LAVER SHEETS TO EXPORT-LEADING SEAFOOD

Korea has completely absorbed the laver market, which Japan previously dominated. It now accounts for more than 70% of the global laver market. In addition, K-Gim (Korean laver) exports have increased significantly from USD 110 million in 2010 to USD 790 million in 2023, and the number of exporting countries has increased from 64 in 2010 to 124 in 2023. Globally, the demand for Gim (laver, *Pyropia* sp.) is increasing rapidly. The global laver trade volume increased from USD 440 billion in 2014 to USD 1.08 trillion in 2023, with an annual average growth rate of 10.5%.

Last year, the price of laver for domestic consumption soared due to a surge in exports. In comparison, the total production of laver (fresh laver) in Korea remains at 500 to 600 thousand tons, and it is necessary to stabilize prices by increasing supply.

"Both the market size and the number of seaweed export countries have risen to the top in a short period, and laver (Gim) is at the top among seaweeds," said Professor Lim Han-Kyu of Mokpo National University. "It is natural for companies to be interested in it," he analyzed. Mr. Choi Byeong-Rak, the head of the Korea Gim Exporters Association, said, "When large companies are struggling to secure raw materials, they have no choice but to come up with a self-help measure." Meanwhile, the MOF announced the 'Gim Industry Competitiveness Enhancement Plan' on October 31 last year. It includes a plan to support research on land-based laver farming.

The MOF announced, "We plan to develop technology for cultivating laver on land starting next year (2025), distribute laver farming varieties that are resistant to high temperatures after field testing, and establish a stable production system in response to rapidly changing climate." The MOF plans to invest KRW 35 billion in research and development (R&D) for five years starting in 2025 to develop land-based laver farming technology. This year's budget is set at KRW 6 billion.

CLIMATE CHANGE RESPONSE — ESTABLISHING A STABLE PRODUCTION SYSTEM

What are the advantages of on-land laver farming? First, unlike the natural environment humans cannot control, the most significant advantage is that the cultivation environment can be artificially created, such as water temperature, salinity, and nutrients. The second is that the water quality pollution problem is solved. There is no risk of marine pollution or red tide as in the ocean, so clean laver production is possible.

Although there are differences depending on the region and

climate, laver is generally produced from October to April of the following year, and the optimal water temperature for growth is 5~15°C. In recent years, the optimal seedling period has also been delayed from early September to late September due to high seawater temperatures, reducing the production period by about a month.

On the other hand, on-land laver farming cultivates and harvests laver in a large tank, creating a laver growth environment like the ocean. Seedling, cultivation, and harvesting are possible all year round. In addition, introducing an automated system can reduce labor costs and increase productivity. No burden or difficulty of laver cultivation requires management and harvesting on a management ship in the middle of winter. There are also advantages such as prevention of marine disease infection and increased production per unit area.



FIGURE 3. *Land-based laver farm. Photo provided by Jipyeongseon-Yugsang-Gim Co.*

The disadvantage of land-based seaweed cultivation is that the initial facility installation and operating costs are high, so the initial investment burden is high. In addition, the technology and management ability to control the cultivation environment are also considered disadvantages.

How Far has the Development of Land-based Laver Cultivation Technology Come?

So, how far has the development of on-land laver cultivation technology come? CJ CheilJedang Co., the No. 1 food company in Korea that was the first to jump into on-land laver aquaculture research, began developing on-land seaweed aquaculture technology in 2018 and is conducting research with the goal of commercialization in 2028. In 2023, it secured the first on-land aquaculture-specific variety. It developed a special medium (culture solution) that supplies the nutrients needed for laver. CJ CheilJedang Co. is also expanding its on-land aquaculture tanks to over 10 tons, leading to the recent jump into on-land laver aquaculture.

Dongwon F&B has recently entered land-based laver farming. It is betting on cultivating laver on land using lava seawater from Jeju Island. Dongwon F&B signed a business agreement (MOU) with Jeju Technopark Lava Seawater Center in October last year to utilize lava seawater. Lava seawater is salt groundwater rich in mineral elements such as magnesium, calcium, and vanadium. Its advantage is a stable water temperature of around 16°C all year round, so it is confident that it can secure the highest-quality raw materials among competitors.

Daesang Co. began developing land-based laver farming technology in 2023. It plans to invest KRW 2 billion over five years to establish a stable method of cultivating laver for commercialization. This budget is expected to be spent mainly on equipping the technology and facilities for producing fresh laver. Daesang Co. will also form a consortium with Goheung-gun Jeollanam-do Province and participate in the Laver Land-based Farming System Development Project, which the MOF hosts.

Pulmuone has recently been the most talked about food company. Pulmuone began developing land-based aquaculture technology in 2021 and signed a business agreement with Jeonbuk State (special self-governing province) to develop new laver species, conduct joint research on indoor and outdoor aquaculture, and develop the technology. As the first test product using a land-based aquaculture laver, the company launched the 'Deulkkae (perilla) Laver Kalguksu (knife-cut-noodles)' menu at its directly managed vegan restaurant in May. After a three-month test period, it is preparing for commercialization.

Pulmuone is behind CJ CheilJedang Co. in laver aquaculture technology development research but is the fastest in laver research. It began research on seaweed seeds, including laver, in 2014 and, during this process, began research on land-based laver aquaculture technology in 2021. "Pulmuone's laver aquaculture on land is a method of cultivating and harvesting laver by creating an environment similar to the ocean in a large tank called a bioreactor," said Lee Da-Jeong, a researcher at Pulmuone Technology Institute. The researcher said, "We are producing 10kg of experimental fresh laver per month and plan to launch various products, including seasoned seaweed, by 2027."

(CONTINUED ON PAGE 36)

K-Gim (Korean Laver) is creating a global sensation, and major companies are competing to cultivate it on land (indoors) instead of in the sea. Companies that have entered land-based laver farming include large companies such as CJ CheilJedang, Dongwon F&B, Daesang Corporation, and mid-sized food companies such as Pulmuone. Why are companies that put profit maximization as their top priority so interested in land-based laver farming? The biggest reason is that the stable supply of raw materials (fresh laver) is disrupted due to recent climate change-induced difficulties in sea laver farming.

In addition, Shinsegae Food Inc., a subsidiary of Shinsegae Group, did not directly reveal this. Still, the industry expects that it will be able to independently review whether to participate in the business or the possibility of R&D in connection with expanding the seafood processing business.

Local Governments and Fisheries Corporations are also Active

Local governments are also active in onshore laver farming. The MOF is also surprised by the response from companies and local governments. An official from the Aquaculture Industry Division of the MOF said, "We receive many calls regarding onshore laver farming. I think I've received calls from every local government along the West Coast."

Jeonbuk State and Gunsan City signed an investment agreement with Pulmuone, Saemangeum Development and Investment Agency, and Korea Rural Community Corporation for Saemangeum in 2022. The province has decided to invest KRW 6 billion over five years to build an 8,500m^2 'land-based Gim R&D center' on the Saemangeum site.

In addition, Jeonbuk State has established a laver onshore farming consortium with Pulmuone and Kongju National University and is planning to apply for the national R&D project 'Sustainable Premium Laver Seed Production and Onshore Farming Technology Development,' which the MOF will announce the schedule for this month. Jeonbuk State also held the 'International Symposium on Aquaculture of Seaweed' with Pulmuone.

Jeollanam-do Province and Haenam-gun County will also form a consortium with CJ CheilJedang Co. to apply for the national R&D project' Development of Sustainable Superior Laver Seed Production and Land-Based Aquaculture Technology,' which the MOF will launch.

Goheung-gun County, Jeollanam-do Province, announced in December last year that it had succeeded in a first-stage pilot project to overcome the limitations of sea-based laver farming and establish an eco-friendly land-based laver farming production base capable of year-round production. It resulted in the growth of laver fronds on land to a commercially viable size of 40-50cm. In addition, Goheung-gun County plans to form a consortium with Daesang Co. and actively participate in the Gim (laver) land farming system development project, a public offering hosted by the MOF.

Gyeongsangbuk-do Province is challenging a land-based laver farming research project on the East Sea, a barren land for laver farming. The Gyeongbuk Fisheries Resources Research Institute has selected seaweed aquaculture research as one of its five major research projects. It is researching the habitat ecology of seaweed native to the East Sea and on land-based aquaculture. Gyeongsangbuk-do Province announced this on November 14 last year by announcing the 'Marine and Fisheries Transformation Implementation Plan.'

National R&D Project Open for Applications

The MOF announced an open call for applications in January for a national R&D project worth KRW 35 billion to develop technologies for the sustainable production of high-quality laver seeds and land-based aquaculture. The Ministry will conduct a review and evaluation in February and March, select a recipient (one company) in March, and begin the R&D in April.

Small and Medium-sized Private Companies are also Fiercely Challenging Land-based Laver Farming

Representative companies include Jipyeongseon-Yugsang-Gim, Dubeonjjaebada, and Smart Sea Korea. Jipyeongseon-Yuksang-Gim (land-based laver) has been researching two methods at the Buan Gyeokpo Research Institute: a rack method and a scaled-down sea farming method. The company said, "After many years of testing, analyzing, and developing an optimized system for indoor laver farming, we succeeded in trial production and completed a full-scale water tank system in February 2024. We produced Gopchang-gim (fresh laver) on an indoor farm." The company also registered a patent for the 'Land-based Gim Farming System' in December last year. An official from Jipyeongseon-Yugsang-Gim said, 'We will test produce dried laver in February and March,' and added, 'We will be able to harvest 40 to 50 nets (1 net is 120 kg) three times per month at a 1,320 m2 aquaculture farm.'

Dubeonjjaebada (Second Ocean) is a startup developing an onshore laver farming system, Microcean. The company planned an intelligent laver farm with automated machines, smart greenhouses, and control equipment incorporating information and communication technology (ICT). It attracted a seed investment of KRW 500 million from The Ventures and others.

Smart Sea Korea has developed a 'laver farming stand,' a smart farming technology that enables land-based laver farming all year round. Smart Sea Korea has laid the foundation for stable mass production of high-quality laver by creating an environment optimized for laver production without being affected by the climate.

The Problem is 'Commercialization'

Although many companies, local governments, and universities have formed consortia, the response is that it is not a smooth road. An official from the MOF said, "It has been confirmed that it can be farmed on land in the laboratory. However, the problem is commercialization."

Mr. Choi Byeong-Rak, the head of the Korea Gim Exporters Association, was concerned about economic feasibility. It is because space (site) is needed to increase production. "Currently, only Company P has clearly stated its production capacity, but it is only 100 kg per day," said Choi. He also predicted that "even if only a portion of the amount to be secured throughout the year is used for self-sufficiency, it will help stabilize the price of seaweed."

Lim Han-kyu, a professor at Mokpo National University, also said "There is still a long way to go before commercialization. I've heard since I was in school that 'circulating aquaculture is the future of aquaculture,' but it hasn't happened yet," said Professor Lim. "It might be possible to use land-based aquaculture as a supplementary means. Still, it must have economic advantages to be commercialized."

Notes

Reporter: Park, Jong Myon. Article originally posted on January 17, 2025, HyundaeHaeyang.
https://www.hdhy.co.kr/news/articleView.html?idxno=31117

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Breeding for disease resistance to control *Enterocytozoon hepatopenaei* and White Feces Disease in Whiteleg Shrimp (*Penaeus vannamei*)

Marcela Salazar, Kahsay Nirea, Edna C. Erazo, Andres Suarez, Bruno DeCock, Carolina Peñaloza, Ross D. Houston, M. Hossein Yazdi and Carlos Lozano

Diseases have traditionally been considered one of the main limitations to the expansion and profitability of the *P. vannamei* industry, as modern intensive shrimp farming systems provide nearly ideal conditions for disease propagation. Shrimp are often cultivated year-round without breaks between production cycles; they are raised in ponds, tanks, or raceways at high densities. Water exchange is limited, and moribund animals are not easily culled from the system. This latter point is particularly important, as cannibalism is common, effectively disseminating pathogens.

Diseases have traditionally been considered one of the main limitations to the expansion and profitability of the *P. vannamei* industry, as modern intensive shrimp farming systems provide nearly ideal conditions for disease propagation. Shrimp are often cultivated year-round without breaks between production cycles; they are raised in ponds, tanks, or raceways at high densities. Water exchange is limited, and moribund animals are not easily culled from the system.

After the era of viral infections (IHHNV, TSV, and WSSV) and bacterial diseases (AHPND, NHP), a new threat has emerged: microsporidia, specifically *Enterocytozoon hepatopenaei*, now referred to as *Ecytonucleospora hepatopenaei* (EHP). EHP was initially reported in 2004 in *P. monodon* in Thailand (Chayaburakul *et al*., 2004) and 5 years later it was described as a microsporidia (EHP) based on histological, ultrastructural and phylogenetic data (Tourtip *et al*., 2009). Although initially it was considered a pathogen of minimum risk, the expansion of the industry and the higher stocking densities used in the past decade have led to an increased impact in the *P. vannamei* industry worldwide in recent years. Microsporidia are parasites that reproduce via spores and are classified within the fungus kingdom. They can infect hosts across all animal taxa, from protists to humans. Aquaculture species are particularly affected, as nearly half of the known microsporidian genera infect aquatic hosts, with more than 50 genera shown to infect aquatic arthropods (Stentiford *et al*., 2016).

In decapod shrimp, apart from EHP, five species of microsporidia have been associated with cotton shrimp disease, which affects the muscles of the animals with very low mortality. In the case of EHP, this pathogen affects the hepatopancreas, leading to hepatopancreatic microsporidiosis (HPM). Although EHP by itself is not associated with high mortality, it damages the hepatopancreas, resulting in severe growth retardation and significant size dispersion among the affected shrimp in the ponds. Additionally, it has been suggested that EHP facilitates bacterial colonization in the hepatopancreas of the affected shrimp. A relationship between EHP and white feces disease (WFD) characterized by the presence of floating white feces and the detection of EHP spores in the feces of shrimp has been widely documented in commercial ponds. Although the exact cause of WFD remains unknown, the disease has been reproduced by co-infecting *P. vannamei* with EHP followed by specific strains of *Vibrio parahemolyticus* or *Vibrio alginolyticus*. This mimics what occurs in commercial ponds, where shrimp first exhibit the presence of EHP, and later, during the grow-out cycle, develop white discoloration of the gastrointestinal (GI) tract, with characteristic floating white fecal strings associated with WFD appearing in the pond (Tang *et al*., 2016).

Prevention and management of EHP should begin at maturation facilities by using EHP-free breeders and feed. In larviculture, disinfection, surveillance, and the use of high-quality feeds are also critical tools for controlling EHP. However, controlling EHP is challenging because its spores are highly resistant to disinfection, and horizontal transmission is highly effective, requiring no intermediate host — unlike the microsporidia that cause cotton shrimp disease.

Genetic selection is another strategy to address diseases in the shrimp industry. Family and within-family selection have proven highly effective in creating resistant populations against the Taura Syndrome Virus (TSV), but not against WSSV (Cock *et al*., 2009). In recent years, genomic selection has been increasingly employed in aquaculture species, driven by advances in next-generation sequencing and the availability of reference genomes and SNP arrays for most commercially valuable species, including *P. vannamei*. In traditional family breeding programs, animals are selected based on the performance of their siblings in challenge tests, but the specific resistance of each animal is unknown. By combining genomic selection with challenge testing in the siblings, it is possible to predict individual genomic breeding values (GEBVs) for disease traits in the genotyped breeding candidates. This enables the breeding of resistant stocks without compromising the biosecurity of the breeding nucleus (Houston *et al*., 2020). Since 2018, Benchmark Genetics has been using genomic information to enhance the resistance of animals from their Breeding Nucleus against key pathogens. The first experiment was focused on resistance to WSSV (Lillehammer *et al*., 2020), demonstrating that genomic selection holds significant potential for further genetic improvement of WSSV resistance in the evaluated *P. vannamei* population. In this study we evaluated the power of genomic

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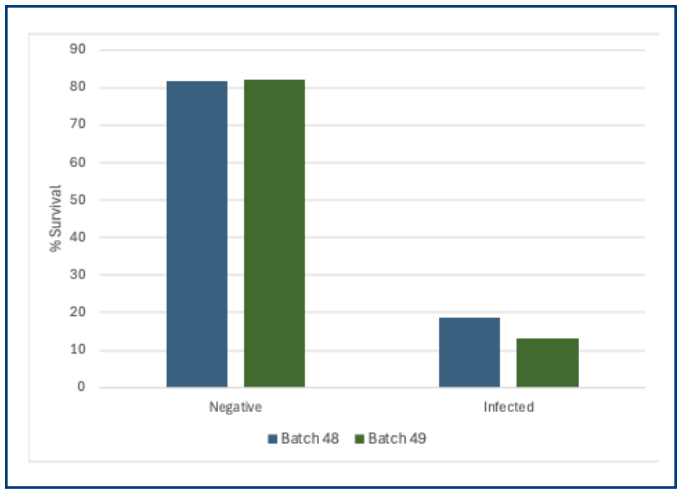


FIGURE 1. *Survival at harvest of the infected tanks and the negative control tanks in EHP+WFD challenge tests from batches 48 and 49.*

selection against EHP + WFD in two consecutive generations of the breeding program for *P. vannamei*.

Methods

Animals from two consecutive batches (48 and 49) from the Benchmark Genetics shrimp breeding program were used in this study. In batch 48, a total of 47 families were produced over 2 days using breeders from batch 47, while batch 49 was composed of 67 families produced in 4 days using breeders from batch 48. All families were produced using artificial insemination (AI). Inseminated females were individually placed in spawning tanks. To minimize the effect of environmental influences during early phases, all families were mixed at nauplii stage for the animals participating in the growth tests. However, a different protocol was used for the challenge test, as final survival needed to be determined. In this case, individual larviculture was performed for each family, and the same number of animals per family was used.

Challenge tests

Upon arrival at the challenge test facilities, shrimp were acclimated in separate small tanks until they reached an average size of over 0.5 grams. The same number of animals were stocked in replicate tanks (10 tanks for the batch 48 trial and 6 tanks for the batch 49 trial). After the pre-challenge phase, animals were challenged with EHP using a cohabitation protocol for seven days. This was followed by a *per os* WFS challenge using the *V. algynolyticus* strain, feeding the animals feed coated with bacterial broth for 3 days. Negative control tanks (2 tanks in batch 48 and 1 tank in batch 49) were not challenged with EHP, and in the *Vibrio* challenge phase, these tanks were fed with feed coated with the culture medium without bacteria. A post-challenge period was conducted for 5 to 6 weeks. Dead animals were recovered on an hourly basis, and tissue samples were collected for genotyping during the duration of the test. At the end of the test, all tanks were harvested. Survivors were individually weighed, tissue sampled, and recorded. Infection was confirmed by both histology and qPCR.

Growth tests

Growth tests using the same batches and families were also

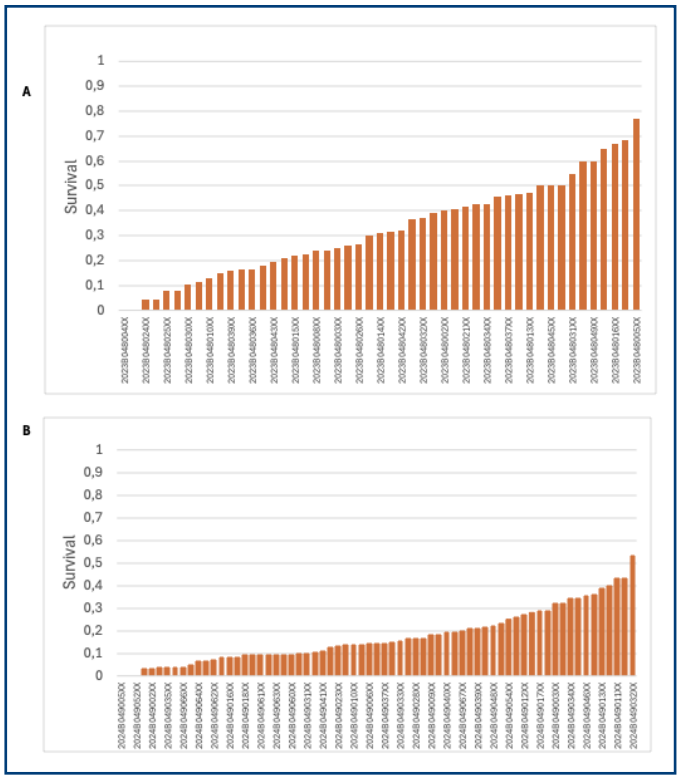


FIGURE 2. *Final survival in the EHP+WFD challenge test in the families from: (a) batch 48 and (b) batch 49.*

conducted in Colombia and Vietnam. In Colombia, larvae from all families were stocked in 50 T tanks at a density of 180 animals/m^2 for batch 48 and 200 animals/m^2 for batch 49. In Vietnam, siblings of the same families were stocked in commercial ponds of 150 m^2 at 86 animals/m^2 for batch 48 and 153 animals/m^2 for batch 49. At harvest, one thousand animals per tank/pond were randomly collected, weighed, sexed, and tissue sampled for genotyping to be used as a training population.

Genotyping

All tissue samples from the challenge and growth tests were sent to IdentiGEN in Dublin for genotyping using a 43K BMK Shrimp SNP-array developed by Benchmark Genetics. This panel was designed using markers identified in several shrimp populations with diverse genetic backgrounds, including all Benchmark lines, with informative SNPs distributed throughout the genome. The SNP array is available for use via Benchmark Genetics' genotyping service, and users are provided with all the relevant map and SNP details. In addition, the SNP array contains a SNP marker located on chromosome 12, described by Pérez-Enriquez *et al*. (2024), which showed over ~97% concordance with phenotypic sex in our population (Peñaloza *et al*., 2024, unpublished data). This SNP was used to assign sex to the animals in the growth and challenge tests in Vietnam.

Selection of Breeders Based on EHP Indexes

To evaluate the effect of genomic selection on progeny response to EHP + WFD resistance, the Genomically Estimated Breeding Value (GEBV) for EHP+WFD survival was calculated for both males and females from Batch 48 based on the challenge test results. These values were then used to classify all families produced in Batch 49 into 4

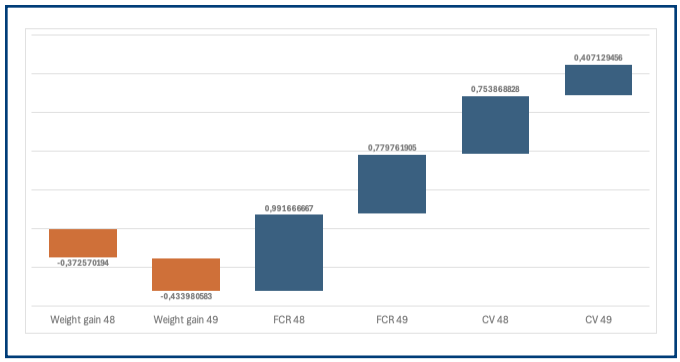


FIGURE 3. *Percent differences in the productive parameters of the infected vs negative control challenge test tanks in batches 48 and 49. Orange boxes show a decrease while the blue boxes show an increase in the respective parameters; FCR= food coversion rate. CV= Coefficient of variation in weight of the survivors.*

groups. Families with GEBVs ranging from -0.13 to <0.0 were categorized as "worst," from 0.0 to <0.13 as "bad," from 0.13 to <0.26 as "good," and from 0.26 to <0.39 as "best." The survival of their progeny was subsequently assessed in the batch 49 EHP challenge test.

Results

Genotyping results

Family assignments using the SNP array were highly successful. In batch 48, after initial quality control, 99.7% of the animals from the growth test and 96.2% from the challenge test were assigned to both parents, lower rates of assignment were found in the dead animals in the challenge test due to DNA degradation. In batch 49, family assignment improved even further, reaching 100% in the animals from the growth tests and 98.5% in the animals from the challenge tests.

Growth tests

Batch 48: In Punta Canoa Colombia (PC), shrimp were harvested after 86 days, at an average harvest weight of 19.44 grams (ADG 0.23). The mean family harvest weight ranged from 16g to 24g, with a coefficient of variation of 8%. Shrimp from 46 out of the 47 families were recovered, with the number of animals harvested per family ranging from 2 to 459 (8 families had fewer than 15 animals). Pond survival in Colombia averaged 92% across three tanks.

In Vietnam, shrimp were harvested after 93 days in the ponds. The average harvest weight was 19.82 grams, indicating an average daily growth rate (ADG) of 0.21 grams. The mean family harvest weight in Vietnam was also variable (range 14g – 23g), with a coefficient of variation of 10%. Shrimp from 45 families were recovered, and the number of animals harvested per family ranged from 1 to 267 (9 families had fewer than 10 animals). In Vietnam, average pond survival across two ponds was 25%. WFD was confirmed in both ponds, while EHP was detected in one pond.

Batch 49: In Punta Canoa, sentinel shrimp were harvested after 95 days in the ponds. The average harvest weight was 26.3 grams (0.28 ADG), with individual weights varying from 9.9 to 38.6 grams. The mean family harvest weight ranged from 19g to 32g, with a coefficient of variation of 9%. Animals from all 67 families were represented, with an average of 14 animals per family harvested

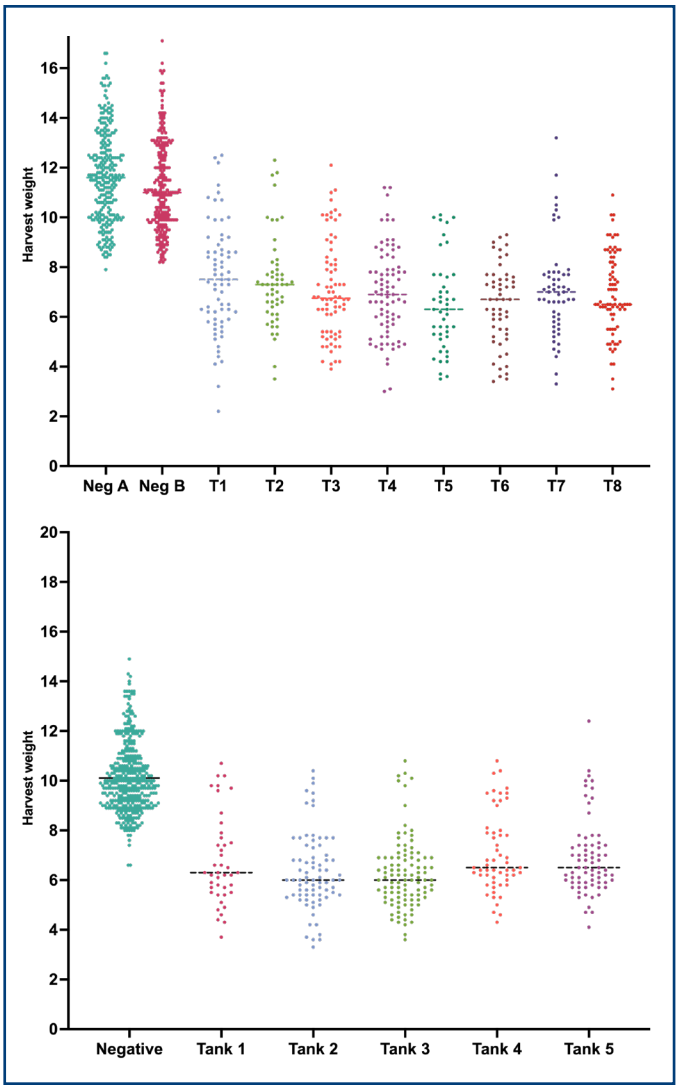


FIGURE 4. *Size distribution of survivors in all harvested tanks from the challenge tests (a) batch 48 and (b) batch 49.*

(ranging from 2 to 34). Only five families had fewer than 5 animals harvested.

In Vietnam, animals were harvested after 76 days in ponds, at an average age of 122 days. The average harvest weight was 15.4 grams (0.20 ADG), varying from 4.6 to 25 grams. Animals from all 67 families were represented, with an average of 15 animals per family harvested (ranging from 3 to 31). Mean family harvest weights varied from 11g to 18.5g, with a coefficient of variation of 10%.

Challenge tests

Both challenge tests produced high mortality in the infected tanks, and histopathology and qPCR analysis confirmed the presence of EHP and WFD in the infected animals. In batch 48, the final survival rate was 18.7%, while in batch 49, it was 13.03%, showing the high impact of the combined EHP + WFD infection. On the other hand, survival rates were above 80% in the negative controls in both trials (Figure 1). Mean family survival for EHP + WFD revealed significant variability in both batches, ranging from 0% to 77% in batch 48 and from 0% to 53% in batch 49 (Figure 2).

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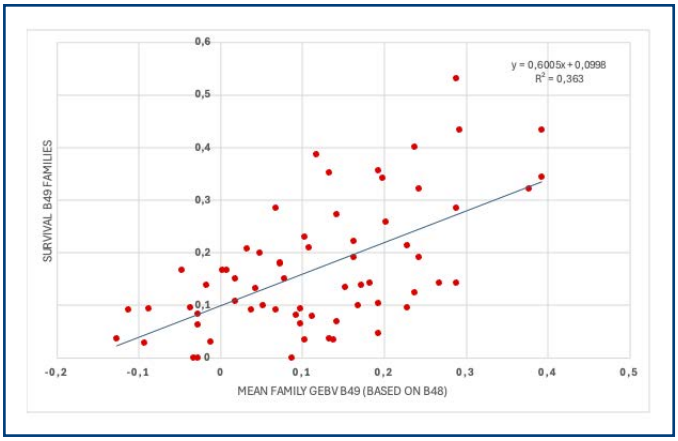


FIGURE 5. *Regression of mean family GEBVs (based on batch 48 parents) on mean survival to EHP in batch 49.*

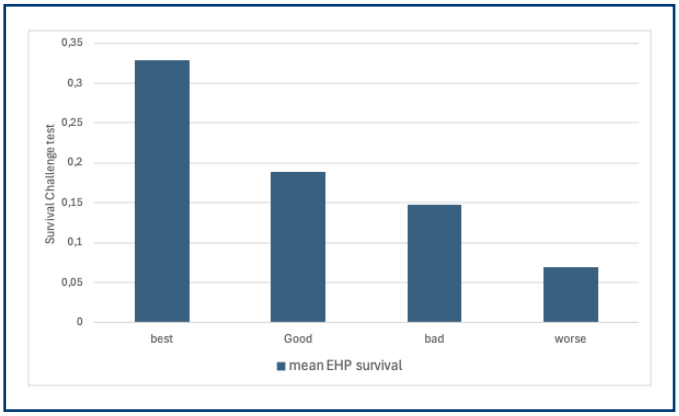


FIGURE 6. *Average EHP survival of progeny (batch 49 families) based on mean parental GEBVs for EHP survival: Worse GEBV from -0.13 to 0.0, bad GEBV from 0.001 to 0.13, good GEBV from 0.131 to 0.26 GEBV and best GEBV above 0.261.*

As expected, the combined infection with EHP + WFD, not only affected survival but also severely affected the growth and productivity parameters of the infected animals when compared to the non-infected controls. In both batches 48 and 49, the weight gain of the survivors showed a reduction of 37.26% and 43.40%, respectively, while the food conversion rate and the coefficient of variation in the final weight of the survivors were significantly increased in the infected controls (Figure 3). Notably, as shown in Figure 4, around 7% of the survivors in both challenge tests reached a weight similar to that of non-infected animals, demonstrating the resistance/tolerance of these animals in the challenge test.

Genetic parameters

Batch 48: Heritability for growth, using genomic information calculated on the randomly sampled animals, was 0.32 ± 0.04 for Colombia and 0.50 ± 0.04 for Vietnam, estimates that were within the expected range for this trait. A moderate genetic correlation of 0.62 ± 0.08 was found between growth in Colombia and growth in Vietnam, indicating a mild interaction of genotypes with the environment across these two locations. This finding suggests that the relationship between the growth of shrimp in Colombia and Vietnam is influenced to some extent by their genetic makeup, responding differently to the respective environments.

The heritability estimate for survival in the EHP challenge test was 0.31 ± 0.06. This magnitude of heritability suggests a greater potential for rapid genetic improvement compared to traits like WSSV, which showed very low heritability (0.03) using a similar model (Gitterle *et al*. 2005). Also, in contrast to other diseases such as WSSV, where the correlation between growth and disease resistance is negative and significant, the genetic correlations between growth (in both Punta Canoa and Vietnam) and survival to the EHP+WFD challenge test were not significantly different from zero. This suggests that integrating EHP survival into the selection index might not significantly affect growth, which continues to be the most economically significant trait (Table 1).

Batch 49: In this batch, we found similar genomic heritability for growth in both environments: 0.47 ± 0.05 for Punta Canoa and 0.49 ± 0.06 for Vietnam. In contrast, the genomic heritability for EHP + WFD resistance in this batch was lower, with a value of 0.17 ± 0.03. The genetic correlation for growth between Punta Canoa and Vietnam was 0.74 ± 0.08, and although this is higher than the correlation found for batch 48, it still indicates a mild Genotype x Environment effect between both environments. In contrast, the genetic correlations between survival in the EHP + WFD challenge test and growth in both environments were slightly negative but not significantly different from zero for this batch, at -0.10 ± 0.13 for Punta Canoa and -0.02 ± 0.13 for Vietnam (Table 3).

Progeny response based on parental genomic indexes

As shown in Figures 4 and 5, EHP+WFD resistance GEBVs of the parents positively correlated with the survival of their progeny. Figure 5 illustrates the regression of mean family EHP survival in batch 49 on the mean family GEBV. Each dot represents a family in batch 49, and the mean family EHP GEBV was estimated solely from batch 48 challenge test results. The figure demonstrates a strong relationship between parental GEBV and offspring survival, with a Pearson correlation of 0.60. Figure 6 shows the average survival of the families originated from the parents classified into different groups. Average survival ranged from 0.1 for the worst groups to 0.33 for the best, demonstrating a clear progression in survival as parental indexes increased.

Discussion and Conclusions

This study demonstrates that genomic selection is an effective method for breeding *P. vannamei* shrimp resistant to co-infection with EHP and WFD. Pooling shrimp from different families early on, combined with the use of a SNP array, enabled the assessment of shrimp performance from early life stages and across different environments. Genotyping proved highly reliable, achieving an average 99.2% parent assignment rate across both batches.

The growth assessment of shrimp families in two distinct environments—tanks in Punta Canoa and ponds in Vietnam—revealed a genotype-by-environment interaction. This indicates that while selecting breeders in Punta Canoa can promote growth in both settings, treating growth in each environment as separate traits could enhance improvement rates.

EHP and WFD resistance in juveniles was found to be moderately heritable, supporting the feasibility of using selective breeding to increase resistance. Several genomic regions were identified as weakly associated with resistance, indicating that numerous genes

TABLE 1. Genomic genetic parameter estimates for growth in different environments and EHP challenge test survival traits in batch 48. The diagonal in bold shows the heritability estimates, the elements below the diagonal show the genetic correlations between traits.

PERFORMANCE TEST	*TRAITS*	*GROWTH TEST*		*CHALLENGE TEST EHP+WFD*
		PC HW	*Vietnam HW*	*Final survival Challenge test*
Growth test	PC HW	**0.32 ± 0.04**		
	VN HW	0.62 ± 0.08	**0.50 ± 0.04**	
Challenge test EHP + WFD	% survival	0.07 ± 0.12	-0.03 ± 0.10	**0.31 ± 0.06**

PC HW= harvest weight in Punta Canoa, VN HW=harvest weight in Vietnam, % survival= Survival in EHP+WFD challenge test.

TABLE 2. Genomic genetic parameter estimates for growth in different environments and EHP challenge test survival traits in batch 49. The diagonal in bold shows the heritability estimate, the elements below the diagonal show the genetic correlations between traits.

PERFORMANCE TEST	*TRAITS*	*GROWTH TEST*		*CHALLENGE TEST EHP+WFD*
		PC HW	*Vietnam HW*	*Final survival Challenge test*
Growth test	PC HW	**0.47 ± 0.05**		
	VN HW	0.74 ± 0.08	**0.49 ± 0.06**	
Challenge test EHP + WFD	% survival	-0.10 ± 0.13	-0.02 ± 0.13	**0.17 ± 0.034**

PC HW= harvest weight in Punta Canoa, VN HW=harvest weight in Vietnam, % survival= Survival in EHP+WFD challenge test.

with small effects contribute collectively. This highlights the potential for genetic improvement through genomic selection.

By evaluating two consecutive batches, we validated the impact of selection indexes in batch 48 on the performance of progeny in batch 49. The correlation between parental indexes for EHP and WFD resistance and offspring performance was evident. Importantly, genetic correlations between EHP and WFD resistance and shrimp weight were not unfavorable, suggesting that enhancing both resistance and growth can be simultaneously achieved without significant trade-offs.

Notes

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Artificial Grass as a Substrate for Microalgae Growth to Feed Hatchery-Reared Juvenile Queen Conch

Manuel Jove, Steffen van Heijningen, Licet Hernandez and Megan Davis

The queen conch (*Aliger gigas*, formally known as *Strombus gigas*) is a large, marine gastropod mollusk found in the warm waters of the Caribbean Sea. The species is currently facing a significant decline in wild populations (Horn *et al*. 2022) and this alarming trend underscores the urgent need for effective conservation strategies. In response to this ecological challenge, the Queen Conch Hatchery located at the Curaçao Sea Aquarium is dedicated to developing technologies for culturing these iconic invertebrates, with the ultimate goals of helping repopulate overfished stocks and restoring natural populations.



FIGURE 1. *Custom made trays with mesh bottom screens that each house 10 juvenile conch. For the control treatment (CONT).*



FIGURE 2. *Fiberglass raceway tanks showing the screen trays used to accommodate the smaller trays that house the juvenile conch. For the artificial grass treatment (ART).*

The life cycle of the queen conch includes a critical juvenile phase, where diet plays a pivotal role in determining growth and survival rates. Juvenile conch primarily feed on benthic microalgae, particularly diatoms and other epiphytic microorganisms, which are essential for development and overall health (Davis and Cassar 2020).

Despite their ecological and economic significance, the optimal rearing conditions for *A. gigas* juveniles in aquaculture settings remain under-researched, especially concerning dietary requirements. Current practices in aquaculture often fail to replicate the complexity and diversity of natural algal communities, potentially limiting the nutritional quality of the diet provided to these juveniles (Davis and Cassar 2020). One study that provided valuable information regarding optimal rearing conditions involved comparable conch aquaculture practices, however with dog conch (*Laevistrombus canarium*), which are only present in Pacific tropical regions (Chang *et al*. 2021). The authors demonstrated that co-culturing (or polyculturing) was much more beneficial to juvenile conch growth and survival compared to mono-culturing without the presence of other species and usually with a single food source. This suggests that juvenile conchs prefer a more natural environment, and can benefit from an enriched or semi-natural environment when cultivated in captivity.

This current study is aimed at enriching the diet of juvenile queen conch by exploring innovative methods to cultivate more natural and nutritious foods, while remaining cost effective in a controlled environment. Building on existing knowledge of microalgae growth on artificial substrates, such as those observed with plastic pollution in marine environments (Nava and Leoni 2021), we investigated the use of artificial turf as a substrate and growth medium for cultivating diatoms and other microalgae.

Our study addressed the research goal to determine if artificial turf can advance sustainable aquaculture practices for growing queen conch juveniles for conservation and restoration. The primary objective was to compare the growth rate of juvenile queen conch fed diatoms and other microalgae on artificial turf to that of juveniles fed the more traditional flocculated diatom *Chaetoceros gracilis*. Our specific questions included:

- Can artificial turf offer an expanded surface area for microalgae to grow on in conch holding tanks?
- Will this enhance the nutritional diversity of the diet available to juvenile conch?
- And, will this promote growth compared to standard feeding practices?

Material and Methods

Queen Conch and Systems. We selected 60 juveniles from a single hatchery batch that ranged in size from 3.5 to 4.1 mm shell length and were 54 days old. For the experiment, 30 conch were divided in groups of 10 in 3 screen trays with artificial grass (ART). The other 30 conch, 10 per tray, were placed in screen trays without artificial grass and were only provided flocculated *Chaetoceros gracilis* (CONT). This species is a diatom known for its nutritional value and is used as a staple in the diet of cultured queen conch in hatcheries, including the Queen Conch



FIGURE 3. *Photosynthesis of the diatoms and other algae created bubbles on the artificial grass, causing buoyancy.*



FIGURE 5. *Iteration II, PVC cut in half and artificial grass attached with glue.*

Hatchery in Curaçao. The juveniles were housed in custom made trays that fit inside fiberglass raceway tanks (Figure 1). The trays have a 250-micron mesh on the bottom and measure: 0.25m long x 0.2m wide x 0.08m operating depth, while the fiberglass raceway tanks measure 1.2 m long x 0.3 m wide x 0.08 m operating depth (Figure 2). The water filtration system was comprised of two pumps and a 100-micron bag filter, which was changed daily. The juvenile conch



FIGURE 4. *Iteration I, a strip of artificial grass with a stainless wire for weight and rigidity.*



FIGURE 6. *Iteration III, PVC cut in half to create concrete semicircles to which the artificial grass was glued.*

maintained on screens only were housed indoors in shallow tanks using the same size screens as the outside juveniles. The water was filtered using a 50-micron pleated cartridge filter.

Artificial turf. The artificial grass (100 percent nylon) was used as a surface area to grow diatoms and other algae species for the juveniles' diet. The artificial grass was put in flow through tanks that were exposed to the sunlight to encourage photosynthetic growth of diatoms.

Although the artificial grass significantly increased the surface area for diatoms to colonize, we encountered a challenge with buoyancy due to oxygen bubbles that were generated during photosynthesis, which caused it to float and made it unsuitable for growing the conch (Figure 3). To resolve the floating issue, we conducted a series of tests before conducting the actual experiment, with different materials to anchor the artificial grass. The first attempt involved using stainless-steel fishing wire, which proved inadequate over time (Figure 4). We then tested the artificial grass with PVC by cutting the PVC in half lengthwise for added surface area (Figure 5). The PVC was insufficient to counteract the buoyancy caused by the oxygen bubbles.

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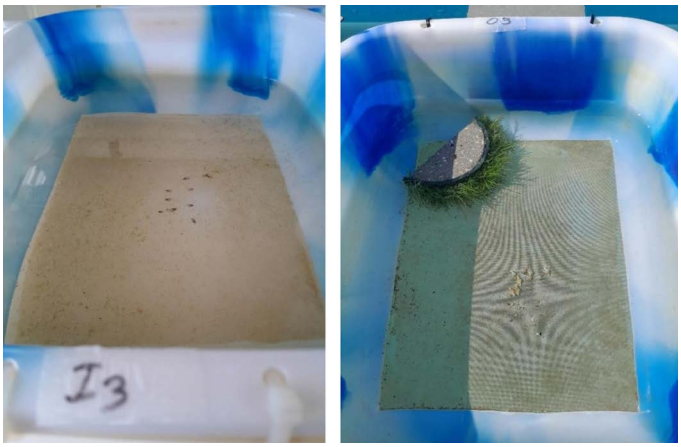


FIGURE 7. *Left: Control tray with juvenile conch. Right: Tray with juvenile conch that have access to artificial grass.*



FIGURE 8. *Measurement with the ocular micrometer.*

The third test included the use of concrete. Concrete was mixed and cured in a segmented 3" PVC pipe cut in half lengthwise. The artificial grass was then attached to the concrete semicircles (Figure 6). This method effectively overcame the buoyancy problem, keeping the artificial grass at the bottom of the tank.

To initiate microalgae growth, we introduced elements from natural environments, including rocks with naturally growing algae, and cultured *Chaetoceros gracilis*. This approach aimed to create a diverse microalgal community, mirroring the natural diet of juvenile queen conch. Figure 7 shows the final setup, with juvenile conch in control trays and in trays containing the artificial grass.

Control groups were provided with daily feedings of *Chaetoceros gracilis* microalgae: 5 mL of flocculate during the first two weeks of the experiment, increased to 10 mL in the last three weeks. In contrast, groups exposed to artificial grass substrates were not given supplemental algae; instead, they relied on the naturally growing microalgae in their tanks and on the artificial grass. The artificial grass was changed weekly with grass that was submerged and exposed to sunlight for seven days to encourage natural microalgae growth before being placed in the trays.

Data Collection. Our study collected and analyzed data on the diatom and algae species present and the growth rates of the queen conch juveniles to assess the effectiveness of these feeding sources. We conducted a detailed examination of the diatom species that grew on the artificial grass blades using a compound microscope with 100X and 400X magnification. Samples were taken every two to three days to observe the composition of the diatoms, and other algae were identified to genus.

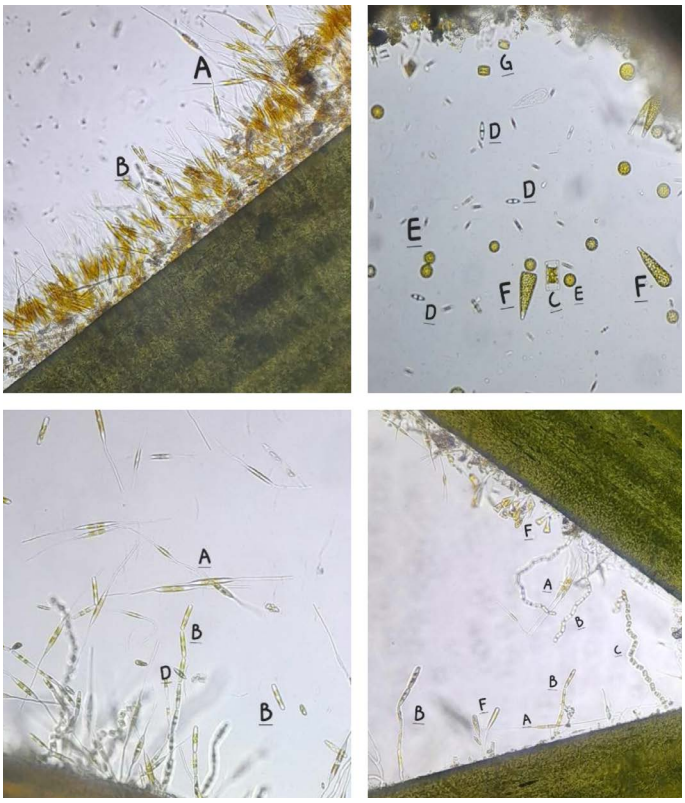


FIGURE 9. *Diatom growth on artificial turf blades after 5 days of growth. Species observed include:* A. Nitzschia sp., B. Pinnularia sp., C. Tabellaria sp., D. Navicula sp., E. Stephanodiscus sp., F. Licmophora sp., G. Melosira sp.



FIGURE 10. *Left petri dish: individuals from the ART group after 26 days. On the right, individuals from the CONT group after 26 days.*

To quantify the growth of diatoms on the artificial grass blades, we used a dilution technique. The average blade measured 25 mm long and 1 mm wide. After 5 days of growth, 3 blades were collected, placed in 5 mL of distilled water, and cleaned mechanically for about 2 minutes then observed with the compound microscope to observe if the blades had shed all microalgae. From each sample of dilutions, two counts were carried out using a Neubauer counting plate. This was an approximate count since it was impossible to remove 100 percent of the cells from the artificial grass blades.

We measured the length of the conch initially, at 14 days and after 26 days in the experiment. The conch shells were measured from the apex to the siphonal canal. Initial measurements and day 14 measurements were done with an ocular micrometer (Figure 8). When the samples reached 10mm a caliper was used.

Results

Diatoms on the Artificial Grass. A variety of diatoms was found growing on the artificial grass blades. The most frequently observed species were of the genera *Navicula*, *Nitzschia*, *Pinnularia*, *Melosira* and *Tabellaria* (Figure 9). Counting by approximation the quantity growing on the artificial grass, by averaging two counts on a Neubauer plate, yielded an average of $12x10^4$ cells/mL. When multiplied by 5 mL of the dilution this would give an estimate of 625,000 cells of microalgae for each blade observed. There are about 320 blades in 1 patch of the artificial grass that was provided to each replicate of 10 conch, therefore, this yielded a total cell count of about 200 million cells available for the conch. In standard conch aquaculture procedures, juvenile conch at the size used in this study are fed flocculated *Chaetoceros gracilis* (Davis and Cassar 2020). The cell count is about 1.53×10^9 cells/mL. If the 28-day old conch are provided with 74 mL of flocculated *C. gracilis*, this would be equivalent to about 1.13×10^{11} cells.

Average length (mm)							
	Artificial grass			Control			
			increase			increase	
Measurement 1 (t=1)	3.52	n=30		3.92	n=30		p=0.346
Measurement 2 (t=14)	7.62	n=26	4.1	4.49	n=30	0.6	p<0.001
Measurement 3 (t=26)	10.63	n=26	3.01	5.84	n=29	1.34	p<0.001

TABLE 1. *Juvenile conch growth rates in the ART (artificial grass in tanks) group versus CONT (control group just fed* C. gracilis*).*

Growth Rates. A key indicator of the success of our system was the growth rate of the conch after their introduction to the tanks with artificial grass. Table 1 shows the average growth rates of juveniles fed the two diets in the two different systems. The growth of the conch on the artificial grass in outside systems (ART, n = 30) and those that were inside and fed *C. gracilis* (CONT, n=30) were compared using a two-way ANOVA to assess the effects of treatment group (ART vs CONT) and time (T1, T2, T3). This approach allowed for the evaluation of both individual and interactive impacts of treatment group and growth intervals.

At T1, ART vs CONT showed no significant differences ($p=0.346$). At T2 (14 days after the first measurement), the conch in the ART group exhibited a significant growth increase compared CONT ($p < 0.01$). At T3 (12 days after the second measurement) the ART group again exhibited significantly greater growth ($p < 0.01$). A visual representation of this growth difference can also be seen in Figure 10.

Discussion

The utilization of artificial grass as a substrate for microalgae cultivation, especially diatom growth, presents a novel and interesting approach to enhancing the dietary conditions for juvenile queen conch (*Aliger gigas*). Our findings indicate that artificial grass supported a diverse and nutritious diet for the conch. This effective diatom cultivation led to significant improvements in the growth rates of juvenile conch when compared to traditional substrate and food.

Notably, the types of diatoms grown on artificial grass were among those highly beneficial to the diet of juvenile conch, such as *Navicula* sp., *Nitzschia* sp., and others. This diversity is desirable for replicating algal communities that conch encounter in their natural habitat. The growth rates observed in the ART group (artificial grass treatment) were significantly higher than those in the CONT (control: regular feeding protocol) group. This shows the potential of natural diatoms to grow on artificial grass, possibly improving the nutritional quality and availability of microalgae in an aquaculture setting.

This study highlights that using specific substrates or enrichment in an aquaculture setting can influence the development of cultured species, in our case: juvenile queen conch. The adoption of artificial grass as a substrate possibly more closely replicates the complexity of natural habitats and might also present a sustainable and cost-effective method to address nutritional challenges. Interestingly, despite a quantitative reduction in algae availability (based on cell count) within the ART group compared to normal *Chaetoceros gracilis* feeding (CONT), a significant enhancement in growth rates was observed over 26 days. This suggests that environmental complexity, or enrichment, plays a crucial role in nutritional dynamics. This might be driven or strengthened by behavioral responses of the queen conch to the presentation of their food, indicating an additional layer of environmental enrichment.

The observations made in the current study highlight the intricate interplay between physical environment and biological responses, suggesting that there are benefits of substrate use in aquaculture settings that extend beyond mere nutritional provision. Other substrates could even further encompass broader ecological and behavioral dimensions. Our study is not without limitations, though. The specific environmental conditions within our experimental setup, such as water temperature and light exposure, may have influenced the outcomes. Furthermore, while we observed an increase in growth rates, the study did not fully explore the survival rates and long-term health impacts on the juvenile conch, indicating another area for future research. Our conch experienced a mortality rate of 13 percent (n=4) in the ART group (with artificial grass) versus 3 percent (n=1) in the CONT group over the course of the experiment.

It is also important to consider the potential issues associated with using artificial grass, especially the breakdown of plastic and possible toxicity. This aspect was only briefly explored in literature during our study, but it's crucial for long-term experiments and health implications to evaluate the safety and environmental impact of plastics in aquaculture. It is a necessary step to ensure the safety and sustainability of these practices.

Future studies should thus focus on the abovementioned, but also on optimizing the artificial grass substrate for broader applications within aquaculture, firstly investigating its effects over a longer period of time, in larger groups, and possibly also in other species. The latter becomes interesting when thinking about clam, oyster or shrimp culture, which on a larger scale might benefit from increased growth rates when cultured.

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Tilapia (*Oreochromis* spp.) Aquaculture in Saudi Arabia: A New Start and New Practices

Benjamin C. Young, Saif Algethami, Anwer Abed Alazwari, Faris Alghamdi and Ali Al Shaikhi

In furtherance of economic and rural development, tilapia (*Oreochromis* spp.) has been cultured in inland Saudi Arabia since the 1980s. Initially, the main aquacultured species was Nile tilapia (*Oreochromis niloticus*). However, due to economic development, market demand, and environmental factors, marine shrimp aquaculture started, in the 2000s, to contribute significant production. In comparison, freshwater aquaculture development has been slower (Young and AlMoutiri, 2022).

In 2023, Saudi Arabia produced approximately 139,949 tons aquaculture, while mariculture production (including marine shrimp and finfish) was recorded at 92,491 tons. Pacific white shrimp (*Litopenaeus vannamei*) farming has accounted for more than 70% of the total mariculture production since the 2010s. The major mariculture species in Saudi Arabia's aquaculture industries are the Asian sea bass (*Lates calcarifer*), gilt-head bream (*Sparus aurata*), Sabaki tilapia (*Oreochromis spilurus*), and sobaity seabream (*Sparidentex hasta*) which contributed over 30,000 tons to total mariculture production in 2023.

Saudi Arabia's total tilapia aquaculture production is around 45,200 tons, and in 2023, tilapia farming accounted for almost 32% of national aquaculture production. The second highest production is North African catfish (*Clarias gariepinus*), which is about 1,230 tons. Therefore, tilapia is essential in the national aquaculture sector for rural development and food security (Alshaikhi *et al*. 2023).

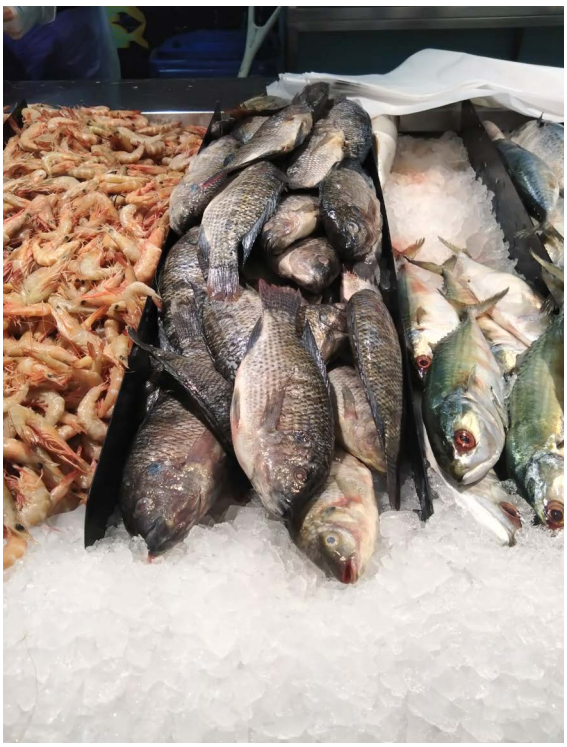


FIGURE 1. *Fresh tilapia at local supermarkets. Source: Benjamin C. Young.*



FIGURE 2. *Live tilapia at local supermarkets. Source: Benjamin C. Young.*

Tilapia farming is still widespread in Saudi Arabia because of the high demand for the local market. Although mariculture has grown, tilapia farming is still essential in the country. Tilapia is a popular seafood product. The market price of fresh tilapia in the local supermarket is around USD 5-6/kg (Figures 1 and 2). Notably, the market price of imported frozen whole fish is only USD 1-3/kg. Unlike other leading tilapia production countries selling to the export market, Saudi Arabia's tilapia product was sold in the domestic market (Young *et al*. 2021).

Issues of Tilapia Aquaculture in Saudi Arabia

The tilapia aquaculture industry has faced many issues regarding the lack of high-quality broodstock, the absence of farm locations, inadequate personnel, and diseases (Young *et al*. 2021). Furthermore, regulations strictly manage the installation of pumping wells, so freshwater resources are also one of the critical costs for farm operations (Young and AlMoutiri, 2022).

In addition, unlike mariculture, which a few mega-companies dominate, most tilapia farms are operated by small-scale farmers and scattered across the country (Young and Shaikhi, 2022). There are nine licensed mariculture companies, whereas freshwater fish farms number around 350. In the early stages, the Ministry of Environment, Water & Agriculture (MEWA) struggled to understand the operations and needs of most aquaculture farms due to a lack of guidance policies and measures, and ineffective farm management resulted in inconsistent product quality, difficulties estimating production, and difficulty preventing disease.

Additionally, the MEWA had difficulty monitoring farm operations because of the enormous differences in tilapia farm operating models and facilities and their scattered distribution



FIGURE 3. *Local outdoor tilapia farm. Source: Benjamin C. Young.*



FIGURE 4. *Local outdoor tilapia farm. Source: Benjamin C. Young.*



FIGURE 5. *Local indoor tilapia farm. Source: Benjamin C. Young.*



FIGURE 6. *Tilapia farm operations. Source: Benjamin C. Young.*

before the 2010s (Figures 3-6). This also hindered the implementation of effective measures during disease outbreaks. Moreover, the conditions and quantities of tilapia broodstock remain insufficient for most local hatcheries. Consequently, there is a reliance on producing qualified juveniles on local farms.

Due to the relatively short development history of the aquaculture industry, Saudi Arabia also lacked experienced farm management personnel in the 1990s and 2000s, making recruitment and training of local personnel a significant challenge. The absence of vocational training organizations was also one of the main issues facing the industry.

Saudi Arabia's total tilapia aquaculture production is around 45,200 tons, and in 2023, tilapia farming accounted for almost 32% of national aquaculture production. The second highest production is North African catfish, which is about 1,230 tons. Therefore, tilapia is essential in the national aquaculture sector for rural development and food security.

1. Solution and improvement of tilapia aquaculture in Saudi Arabia

Since 2018, the MEWA has promoted tilapia farming for national aquaculture development under Vision 2030, the national development program in Saudi Arabia, which aims to establish food security and sustainability strategies for the country's environment and agriculture sectors.

The new national development program has integrated government, private, and academic resources into the tilapia aquaculture industry. It aims to improve and strengthen technology transfer, farm management and operations, workforce training, disease prevention, and marketing.

The MEWA has collaborated with local universities, international organizations, and national research centers to improve technology transfer and farm management. They regularly organize training courses and workshops to provide learning opportunities for fish farmers and companies. Moreover, national research centers and multiple semi-official organizations offer assistance and consultation (Figure. 7). They will also provide quality tilapia fry to farmers and companies to improve the overall quality of farm operations.

Regarding disease prevention, the MEWA regularly convenes leading aquaculture companies to hold biosecurity seminars to understand the current operating status of the industry (Figure 8). They also compile annual statistics on fish disease types and

(CONTINUED ON PAGE 50)



FIGURE 7. *Marketing consultation. Source: Benjamin C. Young.*



FIGURE 9. *Aquaculture product promotion. Source: Benjamin C. Young.*



FIGURE 8. *Biosecurity workshop. Source: Benjamin C. Young.*



FIGURE 10. *Saudi International Marine Exhibition (SIMEC). Source: Benjamin C. Young.*

accumulated cases for year-to-year tracking. Additionally, the import of live fish must be strictly regulated to prevent disease outbreaks. Only licensed operators can import live fish; a list of approved companies is maintained for import and biosecurity purposes. The MEWA also provided farmers with free disease prevention and biosecurity manuals and regularly monitored farm operations to prevent disease outbreaks (Ministry of Environment, Water and Agriculture, 2019).

According to the Food and Agriculture Organization of the United Nations (FAO), the global per capita annual seafood consumption was 20.7 kg in 2022. However, since the 2020s, Saudi Arabia's per capita seafood consumption has been approximately 9-12 kg. Notably, the MEWA has been trying to increase this to 13 kilograms by 2030. To encourage seafood consumption and enhance the domestic market, the MEWA actively organizes marketing and promotional activities to promote local seafood products (Figure 9).

2. Future development of tilapia aquaculture in Saudi Arabia

Since 2018, the MEWA has encouraged fish farmers to increase the production of freshwater tilapia and promoted fresh and processed products. The output grew from 3,000 to 45,200 tons during 2010-2023.

The MEWA actively supports the growth and development of the tilapia aquaculture industry. It assists in the search for suitable farming locations, provides technical consultations, and offers vocational training. Moreover, it continues to cooperate internationally to import high-quality broodstock and fry, assisting industry operators in producing quality products. They also encourage the younger generation to participate in the development of the aquaculture industry.

In addition, the MEWA holds the Saudi International Marine Exhibition (SIMEC) annually, which aims to promote Saudi Arabia's aquaculture industry through exchanges among globally relevant private, government, and academic sectors (Figure 10). Moreover, the MEWA continues to seek ways to improve farmers' income through new aquaculture methods, such as aquaponics and solar photovoltaic systems (Figure 11).

Overall, stability of fry sources is crucial for tilapia aquaculture's sustainable development. Hence, it is imperative to prioritize broodstock. Given the limited availability of local hatcheries supplying broodstock and fry, expanding fry production and establishing additional hatcheries is necessary. Moreover, most tilapia hatcheries lack quality broodstock capacity. Current policies are also focused on marketing, preventing disease, and biosecurity.



FIGURE 11. *Saudi International Marine Exhibition (SIMEC) Trade show. Source: Benjamin C. Young.*

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Notes

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Exploring the Aquaculture Potential of *Nandus nandus* in Planted Aquaria

Suman Kumari, Subhra Singh, Gunjan Karnatak, Archana Sinha and B. K. Das

Nandus nandus (Hamilton,1822) is a fish of freshwater systems, belonging to the order Anabantiformes in the family Nandidae. *N. nandus*, commonly known as the Asian leaf fish or Mud perch, is indigenous to South Asia. In India it is locally known with various other names in different regions such as Bheda in Uttar Pradesh, Meni, Roina, and Nadosh in West Bengal (Das and Zama 2000). Talwar and Jhingran (1991) documented the distribution of *N. nandus* across the basins of the Ganga and Brahmaputra rivers, as well as in neighboring countries like Bangladesh, Nepal, and Myanmar (Figure 1). They highlighted its presence in diverse habitats, including paddy fields, ditches, freshwater wetlands, and brackish water environments. Rainboth (1996) provided insights into the habitat utilization patterns of *N. nandus*, emphasizing its preference for sluggish waters in paddy fields and ditches. Gupta (2018) and Paul *et al*. (2020) expanded on this by reporting its occurrence in both open and closed freshwater wetlands, indicating its adaptability to various aquatic environments.

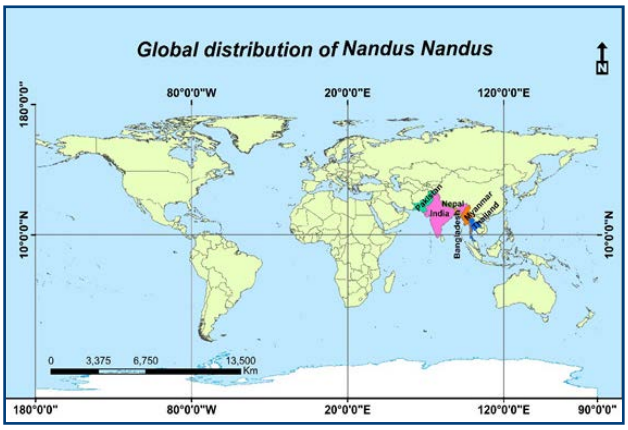


FIGURE 1. *Global distribution of* Nandus nandus.

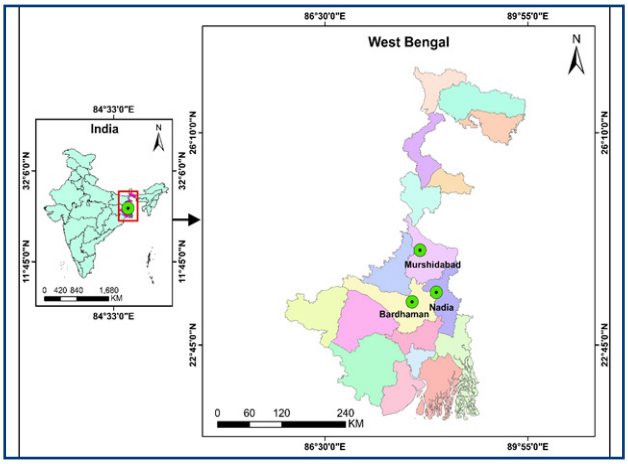


FIGURE 2. *Geographical area of fish collections.*

N. nandus is a highly demanded fish because of its eye-catching color, delectable meat, and high nutrition value with 52.5 percent protein, 2 percent fat, 0.21 percent carbohydrate and 5.7 percent mineral content (Tasnim *et al*. 2023). The physical characteristics of the species, such as its compact muscle structure and minimal intermuscular bones, make this fish an attractive candidate for freshwater aquaculture. It is not only served as a delicacy in various culinary traditions, but it also a commercially important species in the ornamental fish industry (Gupta 2018). The unique characteristics of the *N. nandus* make it an intriguing subject for both food enthusiasts and for aquarists. Recently, the species has gained attention due to its unique characteristics and adaptability to life in planted aquaria.

Hossain *et al*. (1992) explored the ecological interactions of *N. nandus* within its habitat, highlighting its role in freshwater ecosystems. Sarkar *et al*. (2021) assessed the vulnerability of *N. nandus* in the face of habitat degradation caused by anthropogenic activities and natural climatic events. They emphasized the importance of preserving its habitat to ensure its long-term survival. Lianthuamluaia *et al*. (2022) conducted studies on the population dynamics of *N. nandus*, focusing on reproductive parameters and population trends. Their research provided valuable insights into the factors influencing the species' abundance and distribution. The impact of climate change on *N. nandus* was investigated by Rahman (2005), who highlighted the species' vulnerability to changing environmental conditions. Shifts in temperature and precipitation patterns were identified as potential threats to its habitat and population dynamics. Based on the findings of habitat degradation studies, efforts to restore and conserve the natural habitats of *N. nandus* have been recommended (Sarkar *et al*. 2021). This includes measures to mitigate pollution, regulate water flow, and protect critical breeding grounds.

Continuous monitoring of *N. nandus* populations is essential, both for assessing its conservation status and implementing targeted management strategies (Lianthuamluaia *et al*. 2022). Long-term monitoring programs can provide valuable data for informed decision-making. The above literature on the ecological habitat and vulnerability of *N. nandus* underscores the importance of understanding its habitat requirements, population dynamics, and threats faced in its natural environment. Such knowledge is crucial for ensuring the survival of this ecologically and culturally significant freshwater fish species. To reduce the impact of vulnerability an attempt has been made to culture fish in controlled conditions by mimicking the environmental conditions of natural habitats.

Materials and Methods

Sampling site. *Nandus nandus* is a laterally compressed, oval-shaped fish with a curved bottom. It has a metallic shine and varies in color based on habitat and location. Typically, it reaches a maximum length of 20 centimeters (Fishbase.com). Gender determination can

be visually challenging, but males may have larger fins and darker coloration. *N. nandus* were collected from wetlands of three districts Murshidabad, Bardhaman, and Nadia in West Bengal (Figure 2). The fish were collected by fishermen using various traps and water quality parameters of the habitats were assessed. A total of 50 fish were collected and transported to the hatchery as quickly as possible, packed with oxygen.

Experimental tank set up. The aim of this experiment was to explore the benefits of culturing *N. nandus* in various artificially created habitats, assessing their behavior in simulated natural environments, and examining the impact of planted aquaria in providing a conducive setting. Additionally, the study aimed to evaluate the food acceptance and health of these fish in captivity.

Two types of tanks were used: planted or plain glass tanks (91.4 cm x 60.96 cm x 45.72 cm) with hide-outs. The step-wise layering of mud collected from the freshwater zone of Hooghly River, sand and gravel was done to maintain soil aeration. A sponge filter was added to each aquarium to maintain a healthy environment. Because the experiment was conducted in mild winter conditions thermostat-controlled heaters were placed in the aquaria to maintain the optimum temperature (27- 28° C). The aquaria were placed in an area with partial sunlight, allowing better plant growth in the planted tanks. The planted tanks were maintained for one month before stocking fish. During this time the collected fish were kept in a cement tank. The mature planted (A) and plain (B) glass tanks used for captive rearing of *N. nandus* are shown in Figure 3.Top of Form

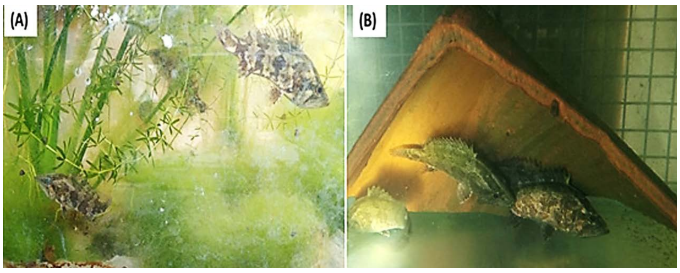


FIGURE 3. *Two different experimental tanks (A) Planted glass tank, (B) Plain glass tank with hideout.*

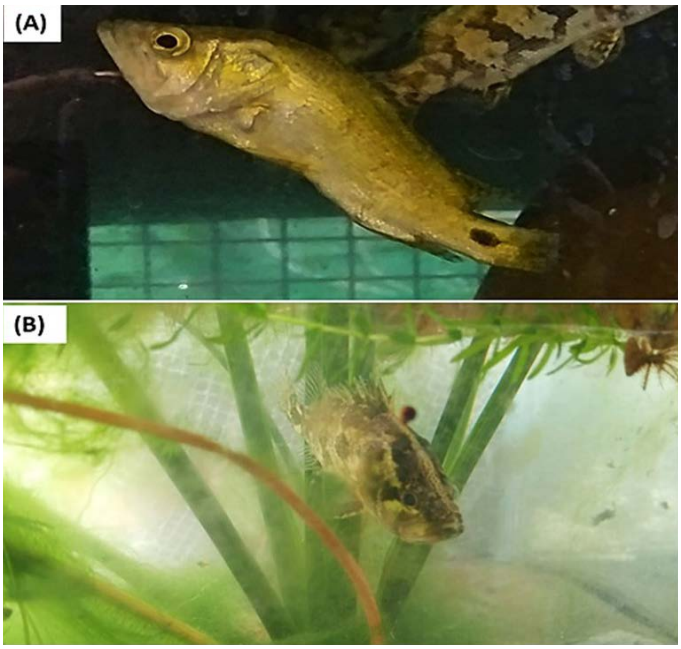


FIGURE 4. Nandus nandus *(A) Dull colored with flaccid fins in plain hideout tank, (B) Brightly colored with erect fins in planted tank.*

Results and Discussion

Growth. The *N. nandus* can hide and are somewhat shy in well-lighted aquaria, becoming more active at dusk. They explore their entire tank and prefer areas with less water flow. Growth of fish in each tank type was evaluated after 7 months of culture. Eight *N. nandus* (7.2-10.3 cm and 7.1-12.3 g) were stocked in a planted glass tank and eight (7.3-10.1 cm and 7.1-12.3 g) were stocked in a plain glass tank with hideouts. After 3 months length and weight of fish in the planted tank were 9.2 ± 0.45 cm and 14.35± 0.86 g, respectively. In the plain glass tank with hideouts fish had grown to 9.4± 0.27 cm and 12.33± 0.95 g. Water quality parameters were similar and acceptable in both environments, including temperature (27° C-30° C), total dissolved solids (252-281ppm), conductivity (279-396 µs/cm), salinity (179-192 ppt), pH (7.7-8.5), alkalinity (150-158 ppm), dissolved oxygen (7.1ppm) and hardness (176-179 ppm).

The growth of *N. nandus* in a planted tank compared to a clear glass tank offers valuable insights into the potential benefits of enriched environments for fish growth performance. Research indicates that the presence of live plants in aquaria can significantly impact fish growth and overall well-being. Several studies have demonstrated that fish reared in planted tanks exhibit accelerated growth rates compared to those in bare tanks (Hargreaves *et al*. 2019, Sookhak Lari *et al*. 2020). The enriched environment provided by live plants offers numerous advantages, including improved water quality, enhanced habitat complexity, and increased availability of natural food sources. Live plants contribute to water quality by absorbing nutrients such as nitrates and phosphates, thereby reducing the risk of water pollution and promoting optimal conditions for fish growth (Bidwell *et al*. 2018).

Additionally, the presence of vegetation provides shelter and hiding places for fish, reducing stress levels and allowing them to allocate more energy towards growth and development (Watanabe *et al*. 2017). Moreover, the naturalistic environment of planted tanks stimulates natural behaviors in fish, such as foraging and exploration, leading to increased activity levels and improved overall fitness (Steenbergen *et al*. 2021). Furthermore, live plants in planted tanks can host microorganisms and small invertebrates, serving as supplemental food sources for fish (Pelc *et al*. 2019). This diversified diet may provide essential nutrients and contribute to improved growth and vitality compared to fish fed solely processed foods in clear glass tanks.

Coloration. The *N. nandus* displayed a striking mottled appearance reminiscent of decaying leaves. Their color ranges from light brown to green with light and dark blotches on the body. These darker patches help them to integrate in artificially created natural surroundings. Interestingly, in a planted tank, the color of the fish remains vibrant and even intensifies over time; however, in a plain

(CONTINUED ON PAGE 54)

hideout tank, the color tends to fade gradually. Research suggests that the presence of live plants in aquaria can enhance the coloration of fish, including *N. nandus*, due to various physiological and behavioral mechanisms. Many studies have documented the phenomenon of enhanced coloration in fish reared in planted tanks compared to those in bare tanks (Bartoszek *et al*. 2018; Dalton *et al*. 2020).

The enriched environment provided by live plants offers numerous advantages, such as reduced stress levels, increased natural behavior expression, and improved water quality, all of which contribute to vibrant coloration in fish. One possible explanation for the enhanced coloration observed in planted tanks is the psychological well-being of the fish. Fish reared in enriched environments with live plants exhibit lower stress levels and higher activity levels, which may positively impact pigmentation processes (Maas *et al*. 2019). Reduced stress allows fish to allocate more energy towards pigmentation production, resulting in brighter and more vibrant colors.



FIGURE 5. *(A) Filamentous algae growth in planted tank, (B) Manual removal of filamentous algae from the tank.*



FIGURE 6. Nandus nandus *affected by pathogens resulting in (A) Gill rot, (B) Fin rot.*

Body Shape and Fins. *N. nandus* fish exhibits an elongate, flat body resembling a leaf-like structure, adorned with various fins. Particularly distinctive is its elongated dorsal fin, extending along the back and contributing to a profile akin to a leaf. Observations revealed that in a planted tank, the shape of the body and fins remained pronounced and erect, whereas in a plain glass tank, the fins appeared flaccid, and the coloration appeared dull. (Figure 4).

Feed acceptance. *N. nandus* are carnivorous in their natural environment, primarily feeding on small aquatic insects and invertebrates. They are column feeders and as a result of their natural hunting behavior feeding prepared feeds under captivity was a big challenge. However, acceptance of a variety of live and frozen foods, such as brine shrimp, small fish, and tubifex has been observed in captive culture of *N. nandus*. In our study, tubifex was fed to the fishes twice a day. Enhanced feed acceptance of *N. nandus* in a planted tank compared to a plain glass tank was observed, and may be attributed to several factors related to the enriched environment provided by live plants. Live plants offer opportunities for natural behaviors such as foraging and exploration, which can stimulate appetite and increase feeding activity (Steenbergen *et al*. 2021). Planted tanks may host microorganisms and small invertebrates associated with live plants, providing additional food sources for fish. This dietary diversity can enhance feed acceptance and nutritional intake (Bidwell *et al*. 2018).

Challenges in maintenance under tank culture. The proliferation of filamentous algae in planted aquaria is a frequent concern, influenced by various factors such as lighting, nutrient levels, and water circulation. To mitigate the growth of filamentous algae, it is essential to maintain a stable and balanced environment while simultaneously promoting the growth of desired plants and inhibiting algae overgrowth. Regular monitoring is conducted, and if filamentous algae growth is detected, manual removal is performed to prevent hindrance to the free movement of fishes within the tank (Figure 5).

Managing diseases in *N. nandus* presents a major challenge related to its high sensitivity. Infestations of parasites and bacteria are common issues that can lead to various diseases in this species. Skin, fin, or gill inflammation, as well as damage caused by external parasites, are among the common problems encountered during culture (Figure 6), especially in tanks with hideouts. The occurrence of disease in *N. nandus* may be observed to be more prevalent in plain glass tanks compared to planted tanks because of several factors related to the environmental conditions and stress levels experienced by the fish. Planted tanks often exhibit better water quality because of the presence of live plants, which can help in nutrient uptake and oxygenation (Bidwell *et al*. 2018). Improved water quality reduces the likelihood of opportunistic pathogens thriving and causing diseases.

Conclusion

In conclusion, the culture of *N. nandus* within a planted habitat can notably enhance the visual appeal of these leaf-like fish. One potential benefit of rearing *N. nandus* in planted tanks over plain tanks is enhanced coloration. For species such as *N. nandus* an enriched environment provided by live plants offers advantages in terms of water quality, habitat complexity, behavioral stimulation and dietary diversity, all of which contribute to accelerated growth and improved health. This discussion emphasizes the benefits of culturing *N. nandus* in planted tanks; further research could offer valuable guidance for refining fish care methods and enhancing production.

Notes

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ASIA-PACIFIC CHAPTER ARTICLE:
Achieving an Optimal Salinity: The Influence of Salinity Levels on the Immunity of Pacific Whiteleg Shrimp against *Vibrio harveyi* Infections

Zulaikha Mat Deris and Li Lian Wong

Litopenaeus vannamei accounted for 61% of the 9.5 million tons of global shrimp production in 2022 (FAO, 2022). However, extremely intensive culture systems and climatic change have been documented to adversely impact shrimp production yield (Byer, 2021; Kibenge, 2019; Monier *et al*., 2023). According to Hein *et al*. (2022), these two factors might have contributed to environmental stress and the decline of water quality, which in turn led to severe disease infections. In fact, *Vibrio* induced diseases remain a major impediment to the shrimp culture industry (Flegel *et al*., 2009; Oanh & Phuong, 2012; Aguilera-Rivera *et al*., 2019; Lafferty *et al*., 2015; Yu *et al*., 2022). The widespread dissemination of *Vibrio* spp. in shrimp aquaculture ecosystems is attributed to their high proliferation rates and adaptability to environmental changes (Baker-Austin *et al*., 2018).

Litopenaeus vannamei depends on its innate immunity to combat pathogens such as White Spot Syndrome Virus (WSSV), *Vibrio alginolyticus*, *V. cholerae*, *V. harveyi*, and *V. parahaemolyticus* (de La Vega *et al*., 2007; Ali *et al*., 2023; Limkul *et al*., 2023). The expression levels of a series of innate immunity genes which encode antimicrobial and antiviral properties, are crucial for elucidating specific responses to microbial pathogenicity at the molecular level. To our knowledge, there is currently no information available regarding the activation and modulation of the innate immune response of shrimp cultured at varying salinity levels in response to *V. harveyi* infection. However, shrimp mortality has been reported to be highly linked to pathogenic infection and salinity stress. In this study, we aim to investigate the immunological response of *L. vannamei* to *V. harveyi* infection cultured at three salinity levels (5, 20, and 30 ppt). We assessed the survival rate and expression levels of immunity genes to determine which salinity level has made shrimp most susceptible towards *V. harveyi* infection, as well as to evaluate the expression patterns of bacterial toxin genes following pathogen exposure.



FIGURE 1. *Acclimatization process of* Litopenaeus vannamei *post-larvae to different salinity levels.*

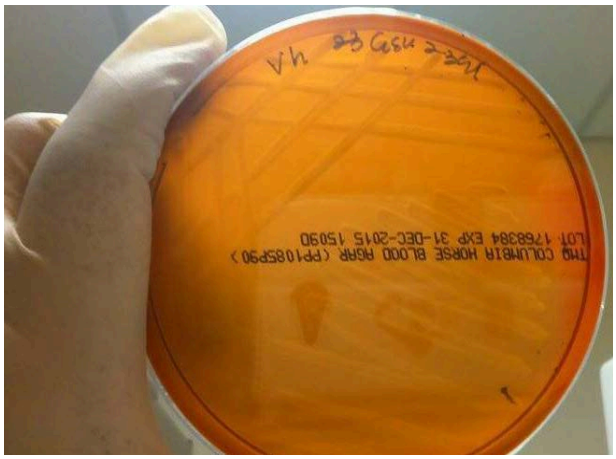


FIGURE 2. *Pure culture of* Vibrio harveyi *on blood agar.*

Study Description

We cultured juvenile shrimp (average of initial weight = 2 ± 0.04 g, mean ± SE) at 5 ppt, 20 ppt, and 30 ppt (control group) in the Institute of Aquaculture Tropical and Fisheries Sciences (AKUATROP), Universiti Malaysia Terengganu (UMT) for 60 days prior to *Vibrio harveyi* infection. To evaluate the responses of *L. vannamei* cultivated at three distinct salinity levels (5, 20, and 30 ppt) towards *V. harveyi* infection, we immersed the shrimp in 2.7 x 107 CFU mL–1 of pathogenic *V. harveyi*, and monitored their survival probabilities for 24 hours post-infection. Following the 24-hour challenge test, we extracted total RNA from the shrimp hepatopancreas prior to quantitative Polymerase Chain Reaction (qPCR) assays of 10 immune-related genes [c-type lectin (c-t), perleucine (Per), calpain-5

(Cal), serine/threonine-protein phosphatases (ST), leucine-rich (Leu), ADP-ribosylation factor (ADP), pancreatic lipase (PL), carboxypeptidase (Car), von Willebrand factor (Von), and Mucin-5A (MU)] and two bacterial toxic genes (LuxR and ToxR).

We normalized the expression level of each targeted gene according to the expression of the elongation factor (EL) gene (housekeeping gene) for each biological and technical sample. We converted the transcript levels of each targeted gene to fold changes by the relative quantification method and compared them between the control and treatment groups (Livak & Schmittgen, 2001; Schmittgen & Livak, 2008). We evaluated the relative fold changes for each gene between the control and infected groups for statistical significance using a t-test in SPSS v.25 (p-value < 0.05). We conducted ANOVA using SPSS v.25 (Liu *et al*., 2013) to assess the significance of gene expression levels at different salinities following infection by *V. harveyi*. We also performed absolute quantification of bacterial genes using the established absolute standard curve (Fukui & Sawabe, 2008). We analyzed Pearson correlation between targeted immune-related genes and bacterial toxin genes using SPSS v.25 prior to visualization using RStudio software v.3.3.3 (p-value < 0.05).



FIGURE 3. *Dissection of shrimp.*

WE NORMALIZED THE EXPRESSION LEVEL OF EACH TARGETED GENE ACCORDING TO THE EXPRESSION OF THE ELONGATION FACTOR (EL) GENE (HOUSEKEEPING GENE) FOR EACH BIOLOGICAL AND TECHNICAL SAMPLE. WE CONVERTED THE TRANSCRIPT LEVELS OF EACH TARGETED GENE TO FOLD CHANGES BY THE RELATIVE QUANTIFICATION METHOD AND COMPARED THEM BETWEEN THE CONTROL AND TREATMENT GROUPS.

Results and Discussion

We discovered that all experimented shrimps were in a moribund state after 24-hour challenge test. All immune genes were up-regulated in *L. vannamei* cultivated at all three distinct salinity levels following *Vibrio harveyi* infection (Figure 4). This indicated that c-t, Per, Cal, ST, Leu, ADP, PL, Car, Von, and MU gene act as the first-line defense mechanism for penaeid shrimp in detecting *V. harveyi*, which serve a crucial role in the innate immunological defense of shrimp (Bi *et al*., 2020). Our qPCR analysis demonstrated that immune-related genes MU (1152.06-fold), ST (17.712-fold), c-t (14.123-fold), PL (59.991-fold), and Per (16.795-fold) exhibited significantly elevated expression in shrimp cultivated at 5 ppt relative to those cultured at 20 ppt and 30 ppt (Figure 4). This demonstrated that shrimp cultivated at low salinity (5 ppt) were more susceptible to bacterial infections, such as *V. harveyi*, in contrast to those at greater salinity. Interestingly, our overall result showed that shrimp cultured at 20 ppt had lowered expression of immune-related genes compared to 5 and 30 ppt after *V. harveyi* infection, suggesting that shrimp cultured at 20 ppt are more resistance toward the *V. harveyi* infection.

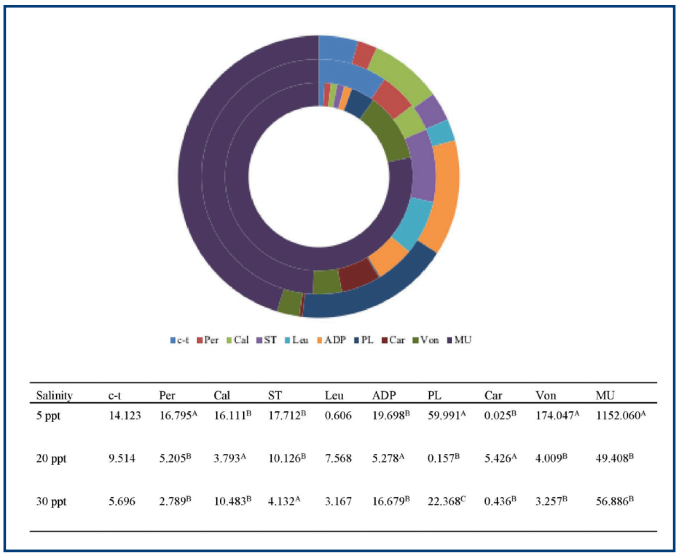
The fold-change analysis has demonstrated that the expression of LuxR gene (2.26-fold change) was significantly highest in shrimp cultured at 30 ppt compared to 5 and 20 ppt (Figure 5). Our study indicates that shrimp cultured at 5 and 30 ppt are more susceptible to *V. harveyi* infection (Figure 5). The high expression of the LuxR gene has been previously reported to be elevated in shrimp infected with *V. harveyi* and *V. parahaemolyticus* (Muthukrishnam *et al*., 2022; Peeralil *et al*., 2020). Given the observed correlation between the expression of the LuxR and ToxR genes, we hypothesized that the expression of LuxR gene may be initiated by the presence of the ToxR gene in infected shrimp (Figure 6) following infection with *V. harveyi*. ToxR is a suitable candidate gene for the exclusive identification of all Vibrio species. Given that shrimp cultivated at 20 ppt had the lowest expression of the LuxR gene, this demonstrated that 20 ppt effectively reduces the infection rate in shrimp, as mentioned in previous studies, where the expression of ToxR gene were observed to be lower at higher or excessively low salinity level of 3 and 5 ppt (Boas et al., 2023; Brown, 2023).

In conditions of excessively low and high salinity, shrimp may prioritize the regulation of proteins involved in osmotic pressure management over immune functions. Additional energy is required to modulate and stimulate ion transportation in the shrimp body in adapting to the changes of the salinity level (Farhadi *et al*., 2022; Nguyen *et al*., 2022; Li *et al*., 2022; Rahi *et al*., 2018). Moreover, both 5 and 30 ppt induce a substantial reduction in immune activity factors, such as c-type lectin, resulting in the inhibition of innate immune responses such as phagocytosis and stress regulation processes (Deris *et al*., 2024). Consistent with previous studies, our results highlighted that salinity changes impacted haemolymph osmosis, induced degradation of plasma membrane, inhibited cytoskeleton modification and intracellular ion transport which further suppress cell viability and phagocytic activities in *L. vannamei* (Zhao *et al*., 2016; Joseph & Philip, 2020).

(CONTINUED ON PAGE 58)

Conclusion

Our findings strongly indicated that selected immune-related genes were involved in the response of *L. vannamei* toward *V. harveyi*. Bacterial toxic genes, ToxR and LuxR gene were significantly involved in *V. harveyi* infection in *L. vannamei*. Shrimp cultured at 20 ppt exhibit the highest resistance to *V. harveyi* infection, demonstrating enhanced expression of immune-related genes, while shrimp cultured at 5 ppt and 30 ppt reserved their energy for osmoregulation process to adapt to salinity changes.



Salinity	c-t	Per	Cal	ST	Leu	ADP	PL	Car	Von	MU
5 ppt	14.123	16.795^{A}	16.111^{B}	17.712^{B}	0.606	19.698^{B}	59.991^{A}	0.025^{B}	174.047^{A}	1152.060^{A}
20 ppt	9.514	5.205^{B}	3.793^{A}	10.126^{B}	7.568	5.278^{A}	0.157^{B}	5.426^{A}	4.009^{B}	49.408^{B}
30 ppt	5.696	2.789^{B}	10.483^{B}	4.132^{A}	3.167	16.679^{B}	22.368^{C}	0.436^{B}	3.257^{B}	56.886^{B}

FIGURE 4. *Expression profiles of multifunctional genes in* Litopenaues vannamei *cultured at different salinity levels after infection by* Vibrio harveyi *(Inner layer: 5 ppt; Middle layer: 20 ppt; Outer layer: 30 ppt). Elongation factor (EL) was used as an internal reference gene to standardize the dataset.*

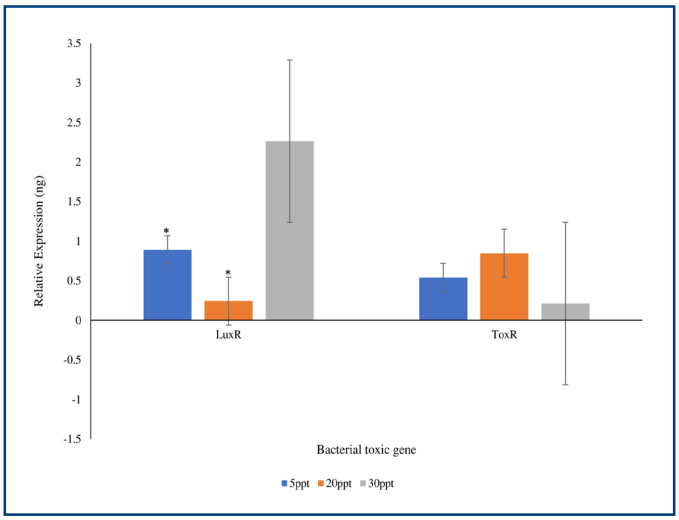


FIGURE 5. *Expression of bacterial toxic genes in* Litopenaues vannamei *cultured at different salinity levels after infection by* Vibrio harveyi. *16SrRNA was used as an internal reference gene to standardize the data.*

Notes

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OUR FINDINGS STRONGLY INDICATED THAT SELECTED IMMUNE-RELATED GENES WERE INVOLVED IN THE RESPONSE OF *L. VANNAMEI* TOWARD *V. HARVEYI*. BACTERIAL TOXIC GENES, TOXR AND LUXR GENE WERE SIGNIFICANTLY INVOLVED IN *V. HARVEYI* INFECTION IN *L. VANNAMEI*. SHRIMP CULTURED AT 20 PPT EXHIBIT THE HIGHEST RESISTANCE TO *V. HARVEYI* INFECTION, DEMONSTRATING ENHANCED EXPRESSION OF IMMUNE-RELATED GENES, WHILE SHRIMP CULTURED AT 5 PPT AND 30 PPT RESERVED THEIR ENERGY FOR OSMOREGULATION PROCESS TO ADAPT TO SALINITY CHANGES.

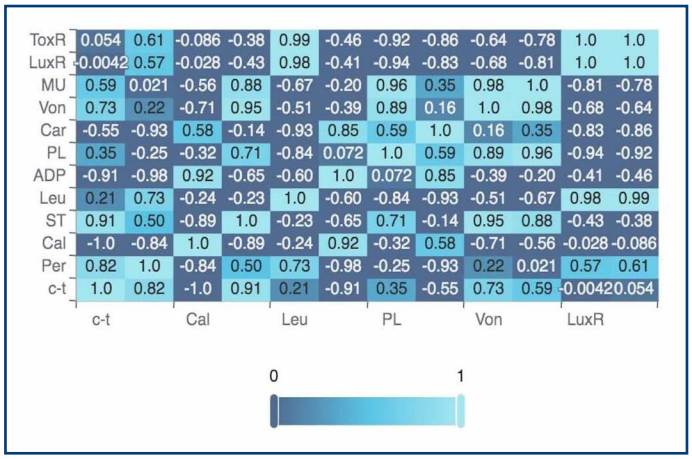


FIGURE 6. *The Pearson correlation heatmap of immune-related and bacterial toxic genes in* Litopenaues vannamei *cultured at 20 ppt followed by* Vibrio harveyi *infection. The colored square represents the strength of the correlation, with positive correlations in light blue and negative correlations in dark blue. The darker the colour, the stronger the correlation (0.80-1.00: Very strong positive; 0.60-0.79: Strong positive; 0.40-0.59: Moderately positive; 0.20-0.39: Weakly positive; 0.00-0.19: Very weakly positive and if negative "-" showed negative correlationship).*

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The Hidden Challenge: Understanding Lice Detachment in Salmon Farms

Gunnvør á Norði, Birgitta Andreasen, Kirstin Eliasen, Tróndur Kragesteen and Signar P. Dam

In salmon aquaculture, the fight against sea lice is an ongoing challenge. In the North Atlantic, the main species causing problems are *Lepeophtheirus salmonis*, better known as salmon lice, which specifically target salmonids, and *Caligus elongatus*, a more adaptable species that infests over 80 types of fish. Managing salmon lice is particularly crucial because they must be kept at low levels to protect wild salmonid populations, which are already struggling because of human activities, such as river development and pollution. As global demand for salmon continues to grow, with millions of tons produced each year, tackling the sea lice problem has become a top priority for aquaculture operations worldwide.

A Global Shift in Treatment Strategies

Over the past decades, salmon farming operations have moved from chemical-based delousing to non-medicinal methods, driven by concerns over chemical resistance and environmental impact. Techniques like thermal, mechanical, and freshwater treatments are now widely used, but these non-chemical approaches have introduced new challenges, especially regarding the crowding process required before delousing.

The Complexities of Crowding

Crowding involves gathering the fish into a confined space before treatment, which can induce stress and inadvertently cause lice to detach from their hosts even before the fish are pumped onto the delousing vessel. This premature detachment means that a significant number of lice may enter the surrounding water, posing a risk of reinfection for both the treated fish and neighboring farms.



PHOTO 1. *Onboard the delousing vessel. Photograph by Sandra Ljósá Østerø.*



PHOTO 2. *Crowding fish for lice treatment.*

Over the past decades, salmon farming operations have moved from chemical-based delousing to non-medicinal methods, driven by concerns over chemical resistance and environmental impact. Techniques like thermal, mechanical, and freshwater treatments are now widely used, but these non-chemical approaches have introduced new challenges, especially regarding the crowding process required before delousing.

Studies have shown that detachment rates can vary significantly, with some reports indicating that up to 50 percent of lice detach under certain conditions. Environmental factors, such as water temperature, current speed, and fish density, all play a role in how lice behave during these treatments. For example, observations from farms in the Faroe Islands reveal that *C. elongatus* is particularly prone to detachment, which presents unique challenges in regions where this species is prevalent, however, few studies have thoroughly quantified lice detachment during crowding, leaving a knowledge gap.

The cost of delousing operations is already high, including both direct expenses and indirect impacts, such as reduced fish welfare and appetite, and increased mortality. If detached lice reattach to the fish or spread to nearby farms, the effectiveness of these expensive treatments could be compromised, potentially requiring more frequent and costly interventions. This highlights a need for a better understanding of this potential

problem that accounts for all stages of lice behavior to ensure that treatment strategies remain both effective and economically viable.

Understanding Lice Detachment: Insights from Recent Research

A recent study conducted at aquaculture farms in the Faroe Islands sheds light on the critical issue of lice detachment during non-medicinal delousing treatments. The research focused on how different stages of salmon lice, as well as the species *C. elongatus*, behave when farmed salmon are crowded before being pumped onto delousing vessels.

Study Overview

Multiple approaches were employed in this study. The research involved counting lice on salmon before, during, and after delousing treatments using the thermal delousing method Optilicer. To complement these observations, a comprehensive dataset from the national sea lice monitoring program, which included data on lice that detached during the sedation of fish was analyzed. In addition, water column sampling was performed to detect and quantify live, free-swimming mobile and adult lice. This multi-faceted approach provided a more detailed understanding of lice behavior during crowding and delousing.



PHOTO 3. *Pumping and sieving sea water samples from the crowded fish.*

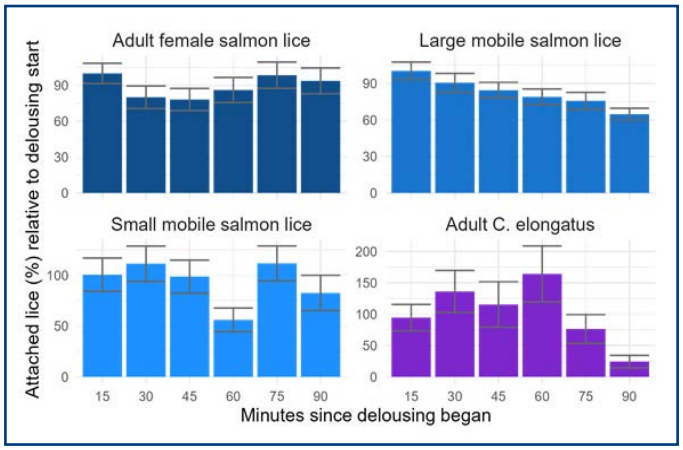


FIGURE 1. *Lice attached on fish during crowding, relative to the abundance at the onset of the crowding process.*

Key Findings

Lice Detachment During Crowding: During the crowding process, large mobile salmon lice steadily detached from the fish, as about 21.6 percent of the lice detached each hour. This was a significant finding, showing that a large portion of lice are lost before the fish even reach the delousing vessel. *C. elongatus* proved to be even more prone to detachment as 77 percent had detached toward the end of the crowding process, making this species particularly difficult to manage.

The study also revealed that the number of attached lice varied greatly over time depending on the stage of development. For instance, while large mobile lice showed a clear and consistent drop in numbers, adult females and small mobile salmon lice didn't follow the same predictable pattern. In some cases, their numbers even increased. Meanwhile, *C. elongatus* showed sharp changes, peaking around an hour into the crowding process before suddenly dropping off. In Figure 1, we present observations from delousing of nine cages at various fish farms. The group large mobile salmon lice includes pre-adult II of both genders and adult males, while small mobile salmon lice are the pre-adult I stage.

Seasonal and lice density effects on detachment rates: The large dataset, comprising over 45,000 individual cage observations from the national sea lice monitoring program, revealed how season and lice density influence detachment behavior during increased fish densities. Notably, the detachment patterns observed during sedation of the fish closely mirrored those seen during crowding. *C. elongatus* had the highest detachment rates, while, among salmon lice, the large mobile stages were the most prone to detach from the fish (Figure 2).

For large mobile salmon lice, warmer seawater temperatures led to a clear increase in detachment rates (Figure 3). They were also more likely to detach when there were fewer lice on the fish. As lice density increased, they tended to stay attached, likely because their chances of encountering a mate on the same fish were higher.

For *C. elongatus*, detachment rates also depended on the abundance of their own species on the fish. Detachment rates increased significantly as the number of *C. elongatus* rose from none to two per fish, but then slightly declined as more lice were present. This pattern suggests that, similar to salmon lice,

(CONTINUED ON PAGE 62)

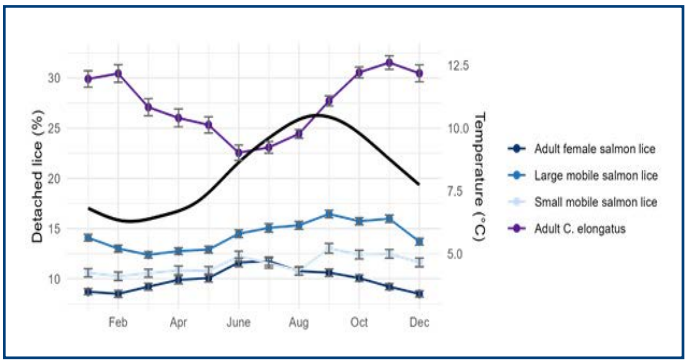


FIGURE 2. *Monthly average detachment rates of mobile and adult stages of the sea lice species* C. elongatus *and salmon lice during sedation of fish in connection to the national sea lice monitoring program.*

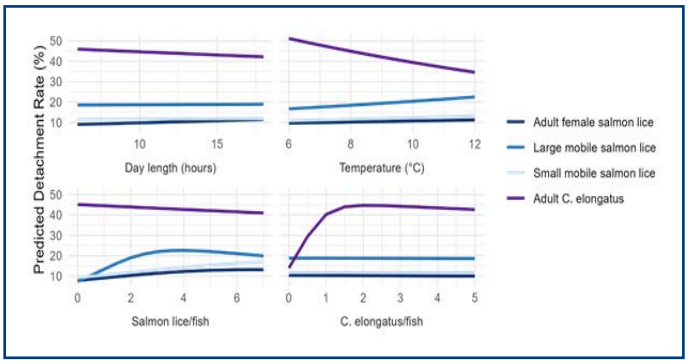


FIGURE 3. *Model results predicting the impact of day length, temperature and abundance of salmon lice and* C. elongatus *on the detachment rates of adult* C. elongatus *and the various development stages of salmon lice.*

C. elongatus may detach more frequently when mates are scarce but reduce movement once a sufficient density is reached, likely related to the increased chance of finding a mate without needing to leave the host.

The influence of season on detachment rates for *C. elongatus* was the opposite of what was observed in salmon lice. Detachment rates significantly decreased as temperature and day length increased, with the highest detachment rates occurring during the winter.

Live Free-swimming lice found in the water: The study revealed that live, free-swimming mobile and adult lice were present in the seawater surrounding the fish during delousing operations. This confirms that lice detach during the crowding process and remain viable, with the potential to infect other hosts. Interestingly the gender balance of free-swimming lice was highly male-biased with more than 90 percent of the lice of both species being males. The number of lice found in the water varied depending on environmental conditions and the intensity of crowding. In calmer conditions with lower current speeds, more lice were detected. However, stronger currents appeared to spread the lice more widely, making them harder to detect.

To better understand these differences, the flux of detached lice was calculated — essentially, determining how many lice were carried away by the water currents. Notably, intense crowding had a particularly strong effect on *C. elongatus* detachment compared to salmon lice. In contrast, for salmon lice, it might seem logical to expect rough weather to increase detachment rates. However, the study found that detachment rates for salmon lice were quite similar in both calm and harsh conditions, challenging some common assumptions about their behavior during delousing.

The Practical Impact of Understanding Lice Behavior

The findings of this study offer new insights into lice detachment behaviour, with important implications for future management strategies. *C. elongatus* stands out for its high mobility, a characteristic well-recognized by the industry. This mobility underscores the importance of using preventive measures, such as in-feed treatments, which are favored by the industry because they can keep lice off the fish for an extended period, reducing the need for frequent interventions or to use specialized nets to catch the lice that fall off during crowding when using non-medical treatments.

THE FINDINGS OF THIS STUDY OFFER NEW INSIGHTS INTO LICE DETACHMENT BEHAVIOUR, WITH IMPORTANT IMPLICATIONS FOR FUTURE MANAGEMENT STRATEGIES. C. ELONGATUS STANDS OUT FOR ITS HIGH MOBILITY, A CHARACTERISTIC WELL-RECOGNIZED BY THE INDUSTRY.

UNDERSTANDING THE BEHAVIORS AND GENDER DYNAMICS OF DIFFERENT LICE SPECIES CAN INFORM MORE TARGETED INTERVENTIONS, MINIMIZING BOTH THE ENVIRONMENTAL IMPACT AND OPERATIONAL COSTS ASSOCIATED WITH FREQUENT TREATMENTS. MOVING FORWARD, CONTINUED RESEARCH WILL HELP REFINE MANAGEMENT PRACTICES, CONTRIBUTING TO MORE SUSTAINABLE AND EFFICIENT AQUACULTURE OPERATIONS.

For salmon lice, the observed male-skewed gender balance among free-swimming lice provides another critical insight. Since it is the presence of adult female lice that typically triggers delousing treatments, the detachment of primarily male salmon lice might have a limited impact on the frequency of treatments. This suggests that the issue of salmon lice detachment during crowding might not be as significant as previously thought.

Understanding the behaviors and gender dynamics of different lice species can inform more targeted interventions, minimizing both the environmental impact and operational costs associated with frequent treatments. Moving forward, continued research will help refine management practices, contributing to more sustainable and efficient aquaculture operations.

Acknowledgments

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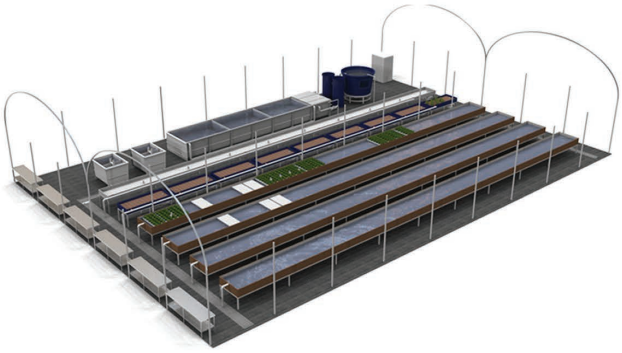
Notes

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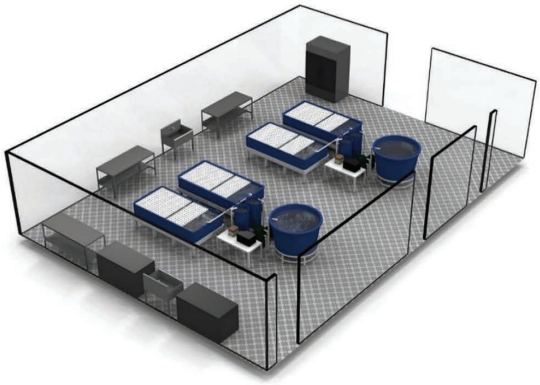
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Managing Marine Oil Pollution: Safeguarding Aquaculture

Potluri Sai Kishore and Arun Konduri

The threat posed by oil pollution to fisheries and aquaculture is significant, as it can cause widespread and devastating consequences for aquatic ecosystems. Heavy crude oils are intricate combinations of organic compounds and transmit supplementary contaminants, such as sulphur, nickel, iron etc. (Cederwall *et al*. 2020). Whether released accidentally or through chronic leaks, the introduction of petroleum hydrocarbons into marine environments has immediate and long-term impacts on aquatic organisms, aquatic habitats, and overall ecosystem health. Unfortunately, the annual average number of global oil spills per decade 1970-2023 is rising prominently due to increases in oil demand and sea trade. On an annual basis starting in 2020, there was an approximate average of 1.3 significant oil spills resulting from tanker incidents. In 2023, a single oil spill involving over 700 metric tons of leaked oil was documented. Every decade witnesses the spillage of millions of tons of oil into aquatic environments, with the potential to greatly affect aquatic habitats (Grosell and Pasparakis 2021).

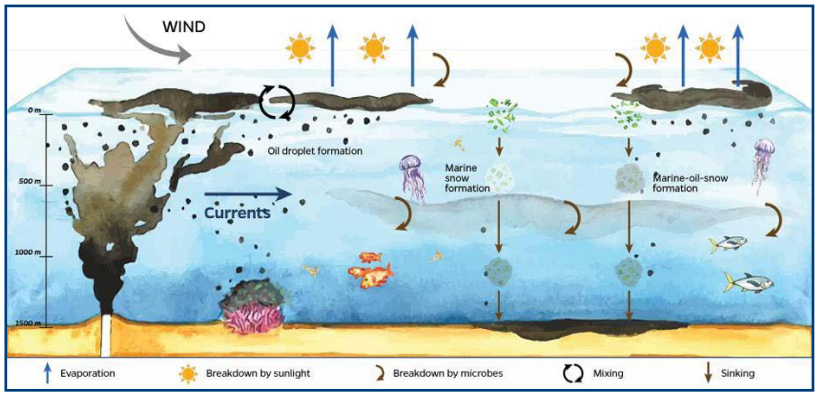


FIGURE 1. *Natural processes that move oil in the marine environment after an oil spill. Source: Maung-Douglass* et al. *(2015).*

Aquatic environments are predominantly susceptible to oil spills because wind and currents can swiftly disperse oil across the water surface, expanding the contamination area and hindering control measures. While some components of the oil may break down and increase exposure and bioavailability, crude oil can reach the water column as tiny droplets. Additionally, heavy oils have the potential to sink in fresh water, layering the sediments and further damaging the environment, particularly for benthic organisms.

Oil toxicity extends its influence across multiple biological systems, such as vision, cardiovascular performance, lipid metabolism, calcium homeostasis, nervous system functions, osmoregulation, pH equilibrium of internal fluids and stress responses. This comprehensive examination aims to explore the various effects of oil pollution on aquaculture while proposing potential strategies to mitigate these environmental challenges.

Basic Classification of Oil Spills

Oil pollution in marine environments arises from several source points, including oil spills, operational discharges from ships, urban runoff, and atmospheric deposition.

1) Minor oil spills: These occur during berthing, bunkering, and other terminal vessel operations, as well as from accidental discharges of oily water mixtures from the bilges of machinery spaces. Minor oil spills, often resulting from seepage or dripping, are frequently overlooked but can be harmful to the local ecosystem and may accumulate in nearby water bodies (Kankara *et al*. 2016).

2) Major oil spills: These occur due to major ship collisions, groundings, fires or other forms of damage, or due to damage of undersea pipelines, drilling rigs, platforms etc. by natural or anthropogenic phenomenon.

3) Dishonourable discharges: Spills that are referred to as "dishonourable discharges" or "midnight dumpers" result from intentional dumping of waste oil and oily waters into the marine environment to save money or time.

Effects of Oil Pollution

Direct Mortality

Oil spills can have an immediate impact, causing mortality due to direct exposure to toxic hydrocarbons. The ingestion of oil-contaminated water can lead to internal damage and disrupt vital physiological processes, causing death in various fish species. Oil slicks have direct physical effects on surface-dwelling animals. Oils are toxic to marine organisms due to the presence of polycyclic aromatic hydrocarbons (PAHs) with low molecular weight. These PAHs enters into the marine animals' bodies through ingestion, gill ventilation and dermal contact. They then produce certain metabolites that can cause cellular damage, mortality and can even impair growth

The threat posed by oil pollution to fisheries and aquaculture is significant, as it can cause widespread and devastating consequences for aquatic ecosystems. Heavy crude oils are intricate combinations of organic compounds and transmit supplementary contaminants, such as sulphur, nickel, iron etc.

and reproduction. Some bottom-dwelling organisms still show high PAH metabolites in their bodies due to decades of oil pollution.

The toxic effects of oil depend on the concentration of the light aromatic components in the oil and the duration of exposure to these components. The presence of oil in spawning and nursery areas can also have severe consequences for fish larvae and eggs. Oil can coat the surfaces of eggs, reducing oxygen exchange and hindering the development of embryos. Additionally, toxic substances in oil can impair the growth and survival of fish larvae (Grosell and Pasparakis 2021; Moller *et al*., 1989).

Indirect Effects on the Food Chain

Oil pollution can negatively impact the amount and distribution of plankton and other small organisms that function as key food sources for numerous fish species. As the light penetration is limited by dissolved oil droplets and dense film on the water surface, the amount of light available for photosynthesis will be minimized leading to lower primary production. This food chain disruption (disturbance of prey species) can result in cascading impacts on higher trophic levels, ultimately leading to decreases in fish populations. Oil pollutants also have the potential to accumulate in fish tissues through bioaccumulation. As predatory fish consume contaminated prey, the concentration of pollutants increases along the food web, posing risks to both fish and human consumers. This bioaccumulation can lead to the phenomenon called tainting, i.e., detection of an odour or flavour that is foreign to a food product as a petroleum taste or smell (Little *et al*. 2021).

Habitat Degradation

Oil spills often contaminate and destroy coastal habitats such as mangroves, sea grass beds, coral reefs and estuaries. These areas serve as critical spawning grounds and nurseries for many fish species. The loss of these habitats can have long-lasting impacts on fish populations. Oil pollution can adversely affect coral reefs and other essential habitat (Lee *et al*. 2015).

Economic Impacts

If any event of contamination of fishing grounds or near-shore habitats occurs, governments impose restrictions as a preventive measure to protect public health. Consumption bans can lead to huge economic losses and long-lasting economic repercussions for local communities. The Deepwater Horizon oil spill in 2010 resulted in an estimated $1.9 billion loss in revenue in the Gulf of Mexico due to fishing closures and decline in seafood demand. Physical oil contamination can foul boats, fishing gear, and mariculture facilities, and it can then be transferred to the catch or production stocks, leading to further economic losses (Little *et al*. 2021).

Effects of Oil Pollution on Aquaculture

Aquaculture facilities, including fish farms and hatcheries, are often vulnerable to oil pollution. Contaminated water in aquaculture facilities can compromise the health of farmed fish, leading to diseases, reduced growth rates, and increased mortality. Bioaccumulation of toxic compounds renders the aquaculture produce to be unfit for human consumption. Contaminated products can pose huge health risks to consumers, leading to market rejection and business disruptions.

Oil pollution can reduce the oxygen levels in water, negatively impacting the aerobic respiration of aquatic organisms, including farmed fish (Lee *et al*. 2015). Disruption of water quality and decreased oxygen availability can lead to stress, reduced growth, and increased susceptibility to diseases in aquaculture species. Certain oil pollutants can bind to sediments, and in aquaculture settings, these sediments can accumulate in ponds or cages. This sediment-bound oil will be inaccessible in specific intensive systems that can persist and continue to release pollutants, posing ongoing threats to farmed fish and other aquatic organisms. Oil pollution incidents can result in significant economic losses for the aquaculture industry. These can even disrupt aquaculture operations by causing severe damage to infrastructure such as nets, cages, feeding equipment etc. The contamination of aquaculture products can lead to market restrictions, trade bans, and decreased consumer confidence, affecting the livelihoods of those involved in the industry (Cederwall *et al*. 2020; Little *et al*. 2021).

Mitigation Strategies

Prevention and preparedness are always superior strategies to avoid unfortunate incidents. Enhanced safety regulations for oil exploration, extraction, and transportation can help prevent spills and minimize the risk of oil pollution. Stringent measures, such as the use of advanced technologies and regular equipment inspections, can prevent major accidents as can regulations. The U.S. Environmental Protection Agency (EPA) is the lead federal response agency for oil spills. The Facility Response Plan (FRP) rules and Spill Prevention, Control and Countermeasure (SPCC) regulations are part of EPA's oil spill prevention program. The U.S. Coast Guard is the lead response agency for spills in coastal waters and deepwater ports. The most important regulations governing pollution prevention by oil from shipping are contained in Annex I of International Convention for the Prevention of Pollution from Ships (MARPOL). These provisions address both accidental discharges and operating measures.

It is critical for the marine aquaculture sector to develop and implement early warning systems (EWS) that can aid in identifying and enabling prompt responses to potential oil spill incidents. Establishing efficient monitoring programs and assessment systems with regular sampling and analysis can help in early detection of contamination. Remote sensing technologies, satellite monitoring, and predictive modelling can aid in the early detection of oil pollution, allowing for timely response measures.

Early warning and automated response capabilities allow early containment of oil pollution - thereby reducing the oil volume spilt and minimizing damage to the environment, wildlife, public waterways and in the case of aquaculture, commercial assets. The Marine Information System is a tool developed to incorporate all the data generated by ARGOMARINE (Automatic Oil–spill and geo-positioning integrated into a marine information system) into a publicly available monitoring and data management system. This ARGOMARINE system has been successful in creating physical and mathematical tools to protect oceans from pollution, particularly oil spills (Tonacci *et al*. 2014).

Booms, skimmers, and other specialized equipment can be employed to contain and recover oil from affected areas, preventing

(CONTINUED ON PAGE 66)

further contamination of aquaculture facilities (Adofo *et al*. 2022; Al-Jammal and Juzsakova 2017). Rapid Response and efficient containment, clean-up and recovery methods are crucial for minimizing damages from oil pollution. Bioremediation involves the utilising microorganisms to degrade and metabolize oil pollutants. This environmentally friendly approach can be applied in both marine and aquaculture settings to enhance the natural degradation of oil and reduce its impact on fish and other organisms.



FIGURE 2. *Algal mats and oiled algae. Source: Little* et al. *(2021).*

Oil Spill Clean-up Techniques

Physical methods

Physical methods such as containment and recovery, shoreline clean-up, and burning are labour-intensive and time-consuming (Idris *et al*. 2013). Hence, several types of equipment are used for oil spill clean-ups including:

- ***Booms:*** Floating barriers designed to contain or divert oil, preventing it from spreading or entering protected areas.
- ***Skimmers:*** Devices used to remove oil from the water's surface, including weirs, oleophilics, and suction skimmers.
- ***Sorbents:*** Materials that absorb or adsorb oil, such as natural fibres (e.g., peat moss), synthetic polymers, and mineral-based products.
- ***Vacuum Pumps and Oil Recovery Vessels:*** Used to suction oil directly from the surface or saturated areas.

Although such machinery is suitable for large-scale spills, it can be ineffective in rough seas or for submerged oil due to limited accessibility, disposal requirements, oil viscosity and saturation capacity.

Chemical Methods

Chemical methods involve the application of substances to alter the properties of oil, making it easier to remove or disperse. These methods include the use of dispersants, surfactants and emulsifiers and are often used in conjunction with physical techniques.

Dispersants include chemicals such as Corexit 9500 and Dasic Slickgone that reduces oil's surface tension and break oil into smaller droplets, thus, preventing it from reaching shorelines and enhancing natural biodegradation (Adofo *et al*. 2022). Surface washing and cleaning agents are applied to hard surfaces to release oil. Solidifiers or emulsifiers react with oil to form a solid mass, making it easier to remove. Certain oxidizing agents like hydrogen peroxide or ozone are used to degrade oil by chemical oxidation and convert it into harmless by-products such as carbon dioxide and water. Although these techniques are effective for restoring contaminated areas, certain challenges such as risk of chemical residue, potential toxicity, secondary contamination, high cost, limited scalability and concerns about long-term environmental effects still persist.

Biological Methods

Biological methods leverage microorganisms and natural processes to degrade or remove oil from the environment. These eco-friendly approaches are highly cost-effective along with enhanced sustainability. But these are very slow processes, requiring significantly more time for getting effective results, and they have limited effectiveness in extreme conditions (Mapelli *et al*. 2017; Ogidi and Njoku 2017; Whitehead *et al*. 2012). Bioremediation involves enhancing natural biodegradation by utilizing natural oil-eating microbes to metabolize hydrocarbons. This technique includes either Bioaugmentation (adding oil-degrading microorganisms to the spill site) or Biostimulation (enhancing the activity of native microbes by adding nutrients and oxygen) (Wilkes *et al*. 2016; Varjani 2017).

Phytoremediation utilizes plants and hydrophytes like salt marsh grasses and mangroves to stabilize contaminants, particularly in coastal oil spill scenarios (Yan *et al*. 2020). While visually restorative, this method is confined to specific habitats and is characterized by a slow recovery process. The application of enzymes to break down oil into simpler compounds involves high production costs and limited scalability. However, these enzymes have demonstrated significant potential in breaking down polymers, aromatic hydrocarbons, halogenated compounds, dyes, detergents, and agrochemical compounds (Bhandari *et al*. 2021). Natural attenuation relies on processes such as evaporation, photo-oxidation, and microbial degradation to gradually reduce oil contamination (Ward and Overton, 2020). However, after the first several days this approach is slow and unpredictable due to minimal human intervention.

Combining techniques such as physical containment, chemical dispersants, bioremediation, and mechanical recovery have been successfully implemented for oil spill cleanup (Madhubashani *et al*. 2021). However, mechanical approaches often pose challenges due to their high cost of recovery over large areas and their limitation to thicker oil layers (Khalil *et al*. 2022).

Restoration and Rehabilitation

Efforts to restore and rehabilitate habitats affected by oil pollution are essential for supporting the recovery of fish populations. Stock enhancement programs, based on the release of hatchery-reared fish into affected areas, can help accelerate the recovery of fish populations that have been impacted by oil pollution, particularly in aquaculture settings. The development of standardized protocols, sharing of expertise, and collective efforts are essential to mitigate the effects of oil pollution on fisheries and aquaculture (Bhowmik *et al*. 2024).

Conclusion

Oil contamination seriously threatens the health and sustainability of both fisheries and aquaculture. The wide-ranging impacts, from direct mortality and habitat degradation to economic losses and contamination of aquaculture products, underscore the

urgent need for comprehensive mitigation strategies. By focusing on prevention measures, early response systems, and habitat restoration, stakeholders can work together to safeguard aquatic ecosystems, guarantee the survival of fish populations, and support the livelihoods of people who depend on fisheries and aquaculture. International collaboration, advanced technologies, and sustainable practices are essential elements in addressing the complex challenges posed by oil pollution and fostering a resilient and sustainable future for marine environments.

Notes

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OIL CONTAMINATION SERIOUSLY THREATENS THE HEALTH AND SUSTAINABILITY OF BOTH FISHERIES AND AQUACULTURE. THE WIDE-RANGING IMPACTS, FROM DIRECT MORTALITY AND HABITAT DEGRADATION TO ECONOMIC LOSSES AND CONTAMINATION OF AQUACULTURE PRODUCTS, UNDERSCORE THE URGENT NEED FOR COMPREHENSIVE MITIGATION STRATEGIES.

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Impacts of Parasite Infestations on West African Mullet Aquaculture

Nike Funmilayo Aladetohun

With an increasing global population, aquaculture has become essential for providing a stable and sustainable source of protein. In 2020, the industry produced approximately 87 million t of fish, accounting for 50 percent of global fish consumption. Aquaculture's rapid growth is vital for addressing food security issues, especially in regions where fish represent a primary protein source. West Africa is one such region, where fish contribute up to 60 percent of animal protein intake in coastal communities. This reliance on fish underscores the importance of maintaining healthy fisheries and stable fish populations.

Among the key species supporting West African aquaculture are mullet fish, particularly *Mugil cephalus* (flathead grey mullet) and *Liza falcipinnis* (longfin mullet). These fish are highly valued for their adaptability to varying salinity levels, nutritional quality, and availability. Local communities depend on mullet not only for sustenance but also as a reliable source of income; however, parasitic infections from organisms like Myxobolus and copepods threaten mullet health, impacting fish growth, reproductive success, and overall survival rates. These parasites, if unmanaged, could reduce fish stock and destabilize the economies that rely on them.

This article examines the histopathological impact of *Myxobolus* and copepod infections on mullet, focusing on how these infections affect fish physiology, reproduction, and growth. By understanding the severity of these infections, stakeholders can develop targeted strategies to mitigate their impacts, ensure sustainable fisheries, and protect the health of mullet populations across West Africa.

This study took place in Nigeria and the Republic of Benin, close West African neighboring counties with historic cultural and economic ties. Some tribes in the Republic of Benin speak the same language as the Yoruba tribe in Nigeria. Lake Nokoue is one of the largest lagoons in the Republic of Benin, opening directly into the Atlantic Ocean through a channel at Cotonou, which is about 24.5 km long. Lagos lagoon is the largest in the southern part of Nigeria and the largest of the lagoon systems of the West African sub-region. The same species of fish, especially mullet species, are found in the waters of the two countries and Lac Nokoue and Lagos lagoon are linked to each other. (Figure 1).

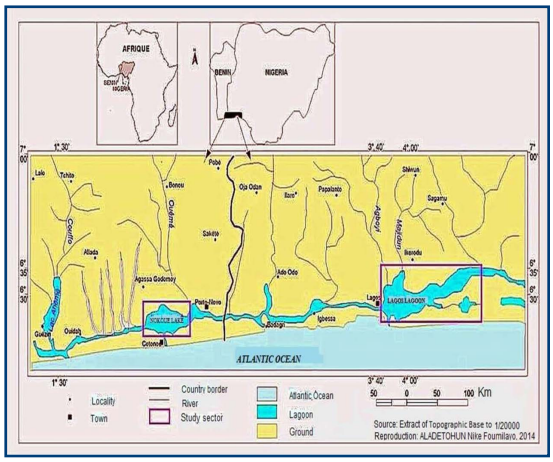


FIGURE 1. *Two areas of study (Aladetohun Nike).*

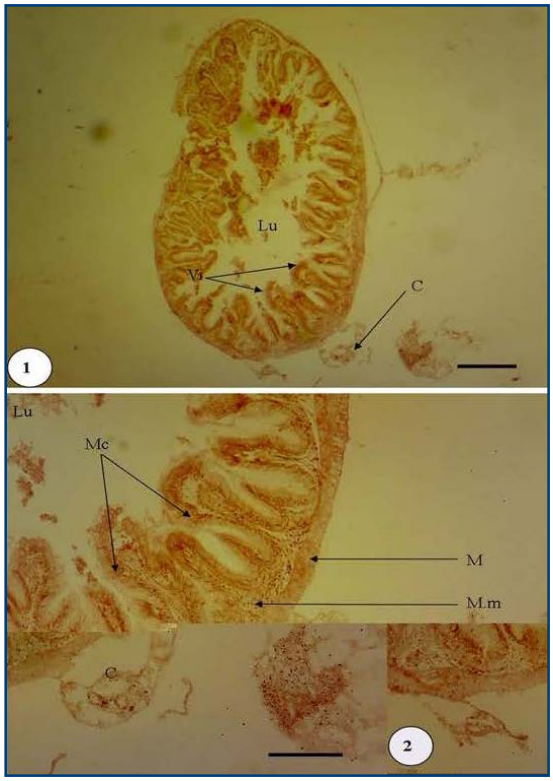


FIGURE 2. *Histopathology of intestine parasitized by* Myxobolus. *Top: Transverse section of mullet intestine, Lu: lumen; Vi: villi; C: cyst. Bottom: Mc: mucosa; M: muscularis; M.m: muscularis mucosae.*

Background and Significance of Mullet in West Africa.

Mullet fisheries are a vital component of West Africa's economy and food system. In the two countries under study, mullet farming depends on fry or fingerlings stocked from natural waters. Protecting mullet populations, therefore, has economic, nutritional and social implications for West African communities. Throughout West Africa, fish is one of the most affordable sources of protein and mullet, in particular, plays a critical role in food security. Due to its affordability, availability, and nutritional value, mullet is a dietary staple in local communities, providing high-quality protein and essential nutrients like omega-3 fatty acids.

Fish processing is also central to the region's economy, particularly among women, who play a significant role in preparing and marketing fish products. Mullet is often dried or smoked to extend its shelf life, allowing distribution to areas without refrigeration facilities. This processing supports food security in remote areas, empowering women economically and contributing to household income.

(CONTINUED ON PAGE 70)

Impacts of *Myxobolus* and Copepod Infections on Mullet

The effects of *Myxobolus* and copepod infections are evident across all life stages of mullet. Fingerlings and juvenile fish often experience slower growth due to disrupted nutrient absorption caused by *Myxobolus* infections in the intestines (Figure 2). This stunted growth increases their vulnerability to predation, reducing the number of fish that survive to adulthood. In adults, parasites primarily target the gills and intestines, where *Myxobolus* cysts cause erosion of cartilage and copepods physically damage gill filaments (Figure 3). This structural breakdown impairs oxygen absorption, causing chronic respiratory stress.

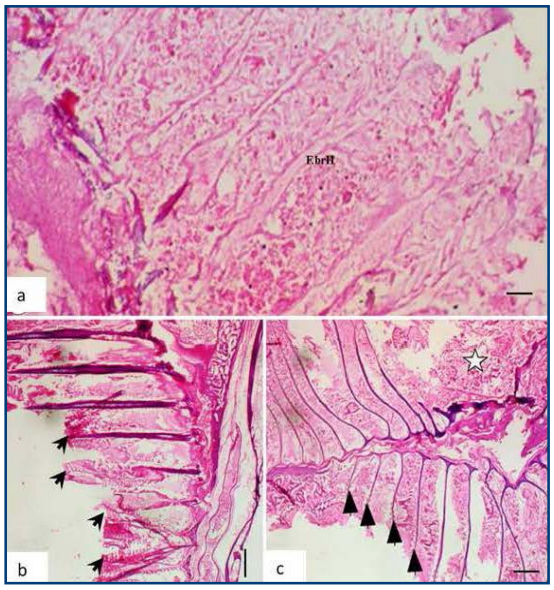


FIGURE 3. *Histopathology of gills infected by Copepoda, a: normal gill filaments; b and c: gill filaments damaged by copepods.*

Environmental factors like water pollution and rising temperatures worsen the physiological effects of these infections. Polluted waters provide a favorable environment for parasites, further compromising the immune systems of infected fish. Additionally, warmer waters contain less dissolved oxygen, exacerbating the respiratory challenges caused by gill damage. This dual impact increases the likelihood of mortality among infected fish, highlighting the need for comprehensive water quality management to mitigate parasite prevalence.

Parasitic infections divert energy from reproductive processes, leading to fewer viable offspring. Female mullet facing chronic infections often experience delayed or incomplete spawning cycles, producing fewer and less viable eggs. Male mullet may also suffer from physical weakness caused by copepod infestations. The overall reduction in reproductive success contributes to declining mullet populations, impacting the long-term sustainability of fisheries and aquaculture activities reliant on these species. These challenges underscore the importance of implementing preventive measures to protect fish health and ensure steady reproductive output.

Stunted growth is a common outcome for mullet infected with *Myxobolus* and copepods. Because of nutrient deficiencies and respiratory impairment, infected fish rarely reach marketable size, resulting in economic losses. Given the centrality of mullet to West African fisheries, addressing the growth impacts of parasitic infections is essential for economic resilience and food security.

Histopathology and Advanced Diagnostic Methods

In this study, histopathology revealed *Myxobolus* clusters in gill cartilage, eroding respiratory structures. Copepod infestations showed erosion of gill filaments and mucosal linings, compromising both respiratory and digestive functions. These insights emphasize the need for early detection and intervention, as untreated infections can have severe consequences for fish health.

Histopathology is often complemented by molecular diagnostics, such as Polymerase Chain Reaction (PCR) and environmental DNA (eDNA) analysis. PCR allows for the detection of parasite DNA in tissue samples, confirming infections at an early stage. eDNA sampling can identify the presence of parasites in water bodies, enabling proactive management. Immunohistochemistry is another technique that stains specific parasite proteins, helping researchers track parasite distribution within host tissues. Combined with histopathology, these methods provide a comprehensive view of parasite-host interactions, enhancing diagnostic accuracy and supporting targeted treatments.

The integration of these techniques enables aquaculture managers to detect infections early and implement effective management practices. By using multiple diagnostic methods, researchers can monitor the spread of parasites more effectively, reducing infection risks in densely populated fish farms.

Future Perspectives: Preventive Measures, Treatment Approaches, and Collaborative Research

Preventive measures are essential for managing parasitic infections in aquaculture. Regular water quality monitoring is crucial for maintaining conditions that discourage parasite growth. Biosecurity protocols, such as equipment disinfection and stock quarantining, also reduce the likelihood of introducing parasites into cultured fish populations. Integrated Pest Management (IPM) strategies, including habitat modification and biological controls, offer eco-friendly solutions that complement traditional approaches.

Genetic research into parasite resistance offers additional preventive options. Selective breeding programs are exploring genetic markers linked to resistance, aiming to produce mullet strains that can naturally withstand infections. These programs have shown success in other aquaculture species and could significantly reduce reliance on chemical treatments.

For established infections, traditional treatments like anti-parasitic drugs remain common but carry environmental risks. Researchers are increasingly exploring alternatives like probiotics that strengthen fish immune systems and inhibit parasite growth within the host. Certain probiotics create unfavorable conditions for parasites, reducing their impact on fish health. Natural remedies, such as garlic and neem extracts, are also gaining attention due to their anti-parasitic properties, offering a more environmentally friendly approach compared to chemical treatments.

Vaccine research is another promising field. Experimental vaccines targeting specific proteins in *Myxobolus* and copepods may help fish develop immunity to these parasites. DNA-based vaccines, in particular, show potential for providing long-term protection. While challenges remain in effectively delivering vaccines in aquatic

settings, advances in vaccine technology and nanotechnology could soon make vaccination a viable tool for parasite control in aquaculture.

Addressing the challenges posed by parasites in mullet farming requires collaboration across the aquaculture sector. Regional partnerships involving researchers, government agencies, aquaculture producers, and international organizations will enable resource sharing and capacity building. Establishing networks for data sharing on infection trends, environmental conditions, and effective treatments will improve the understanding and management of these infections.

Programs led by international organizations, such as the FAO, facilitate knowledge exchange and access to cutting-edge technologies. Collaborative efforts allow West African researchers and fish farmers to benefit from global advancements, such as bio-security protocols and breeding for parasite-resistant strains. Regional approaches that emphasize partnerships and knowledge sharing will be crucial for ensuring the sustainability of mullet fisheries and aquaculture.

Conclusion

As the aquaculture industry continues to expand, a comprehensive approach to parasite management is essential to safeguard fish health and ensure sustainable development. Investing in research, developing robust preventive measures, and fostering regional collaboration are essential steps in addressing these challenges. By committing to sustainable practices and innovation, stakeholders from local fishers to international organizations can play a pivotal role in protecting the future of West African aquaculture. Let this call to action inspire collective efforts to strengthen aquaculture's role in a sustainable and food-secure future.

Notes

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May 29-April 2, 2025
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International Seaweed Symposium 2025
May 4-9, 2025
Victoria Conference Centre
Victoria, British Columbia, Canada

Global Seafood Marketplace
May 6-8, 2025
Fira Barcelona Gran Via • Barcelona, Spain

Aquafuture SPAIN
May 20-22, 2025
IFEVI • Vigo, Spain

RASTECH 2025
June 9-10, 2025
Town & Country Resort • San Diego, CA USA

Aquaculture Canada Conference
June 9-11, 2025
Fredericton Convention Centre
Fredericton, New Brunswick. Canada

World Aquaculture and Fisheries Conference
June 9-11, 2025
Hotel NH Roma Villa Carpegna • Rome, Italy

Seawork
June 10-12, 2025
Mayflower Park • Southampton, United Kingdom

Seagriculture EU 2025
June 17-19, 2025
De Doelen • Rotterdam, The Netherlands

TCRS Shrimp Summit 2025
June 22-25, 2025
Grand Hyatt Bali • Nus Dua, Bali, Indonesia

Aqua Nor 2025
August 19-21, 2025
Trondheim Spektrum • Trondheim, Norway

The Aquaculture Roundtable Series 2025
August 20-21, 2025
Shangri-la Chiang Mai Hotel • Chiang Mai, Thailand

Global Shrimp Forum
September 2-4, 2025
Van Der Valk Hotel • Ultrecht, Netherlands

Ildex Indonesia 2025
September 17, 2025
Indonesia Convention Exhibition • Jakarta, Indonesia

Aquaculture Europe
September 22-25, 2025
Palacio de Congresos / Sercotel Soralla Palace
Valencia, Spain

Responsible Seafood Summit 2025
September 29-October 2, 2025
Intercontinental Cartagena • Cartagena, Colombia

7th NordicRAS Workshop
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November 3-5, 2025
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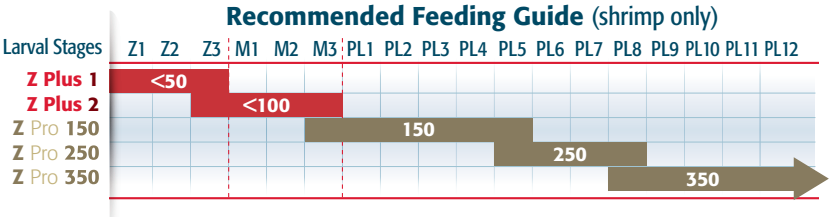
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