Vol 7 Issue 4 2019

HATCHERYFEED

Advances in feeding early life stage and broodstock aquatic species

DEVELOPMENTS IN FEEDS FOR NURSERIES

Feeds for Marine RAS Nurseries

Phytobiotics and Micronutrients

Feed for European Lobster

Microbial Management

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VOL 7 ISSUE 4 2019

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HATCHERYFEED VOL 7 ISSUE 4 2019

FROM THE EDITOR

As we approach the end of the 2010s, it's a good time to look back and take stock. In this decade, we have seen how the media has changed with the proliferation of digital media, social media and podcasts. Aquaculture has also undergone major developments as the scale of production has increased. Engineering, genetic breeding, biosecurity and alternative ingredients are some examples of developments in the 2010s, and the next decade is likely to see major changes in the environment due to climate change and in resources, macroeconomic and market conditions.

There's no doubt that in the next decade both industries will continue to evolve. And in response to your requests, we'll do it first. In 2020, Hatcheryfeed will become HATCHERY Feed & Management. Our magazine and a new website will cover all the things of importance to hatchery managers: genetics, management, production systems, disease control, etc. and, of course, feed and nutrition. Great things never come from comfort zones.

We thank you for being loyal readers to Hatcheryfeed and look forward to working with you and reporting your successes and developments in 2020.

Lucía Barreiro, Editor Aquafeed.com

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NEWS REVIEW

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Troutlodge achieves welfare certification

Troutlodge has been designated as a RSPCA Assured producer of rainbow trout, a certification of high animal welfare standards in all areas of production.

The RSPCA Assured label is designated by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) for the enhancement of welfare standards for food production. Troutlodge was recently awarded certification for this label. The certification is an important achievement for a number of customers who produce juveniles for subsequent harvest within the scheme. The label also provides additional options for the sourcing of rainbow trout eggs for growers who currently market final product under this brand.

Bivalve aquaculture startup closes €2.7M investment

Portuguese bivalve aquaculture company, Oceano Fresco S.A., has concluded an investment round of €2.7 million led by BlueCrow Capital, a bioeconomy-focused venture capital fund. Proceeds will be used largely to complete the construction and begin operating the company's state-of-the-art biomarine center (hatchery, labs and offices) in Nazaré, on the Atlantic coast of central Portugal.

Oceano Fresco uses cutting-edge tools and a science-based approach to breed and commercialize premium species of bivalves starting with varieties of clam native to Europe. Besides the hatchery and the biomarine center, the company has acquired open-sea concessions for off-shore farming and employs experts in fields ranging from shellfish genetics to commercial plant and animal breeding. Its integrated business model allows the company to control several key steps in the value chain of clam production with the final aim of becoming the world leader in the sustainable production of high-value bivalve species.

AquaMaof plans to double in size in 12 months

Israel-headquartered AquaMaof expects to grow to more than 165 employees and double its size in 12 months by the end of 2020. To support this continuous growth, the company plans to strengthen its technology, R&D, engineering, project management, customer support and purchasing departments. The growth is also backed by two operational R&D centers (in Israel and Poland) and dozens of AquaMaof partners, advisors and subcontractors operating around the globe. AquaMaof's ongoing projects have a combined capacity of about 45,000 tons and they are located in strategic markets, such as Japan, Russia, Germany, France, Canada, Chile and more. Currently on the pipeline for the company, among others are projects in strategic markets such as China and the USA.

SalmoBreed merges its genetics center

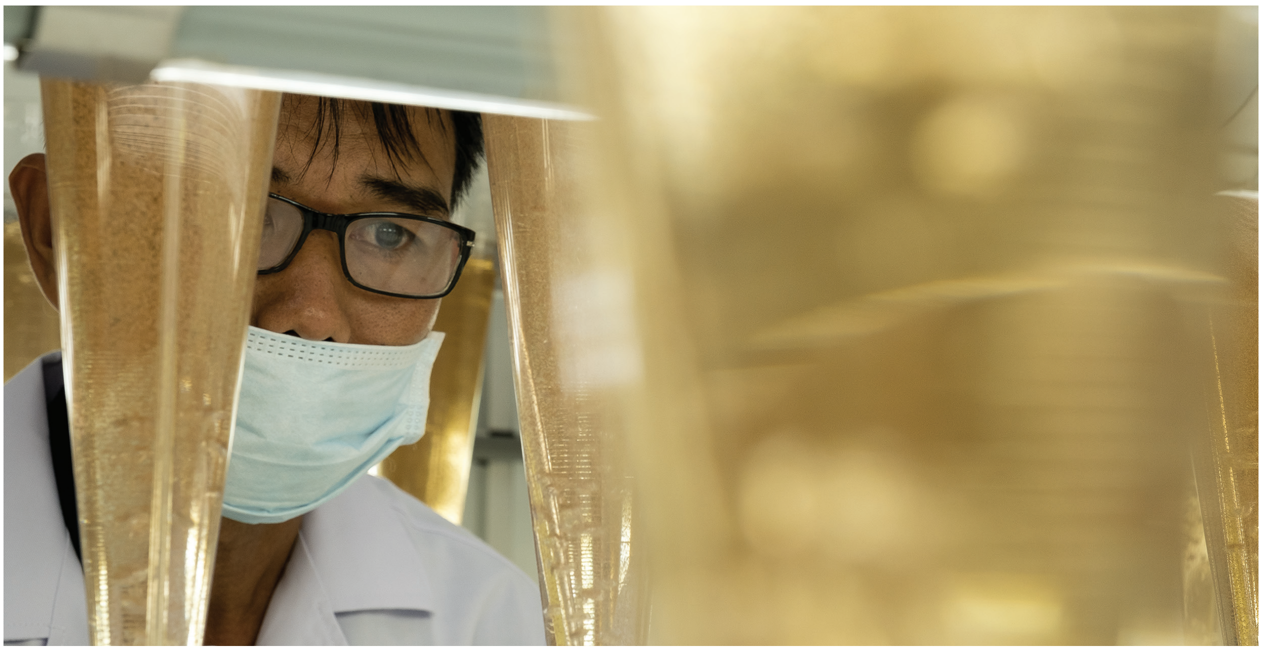
Benchmark owned Akvaforsk Genetics Center AS and SalmoBreed AS merged to establish Benchmark Genetics Norway AS. The combined organization will further strengthen Benchmark's offering to deliver genetic improvements and support aquaculture producers to increase quality, yield, health and welfare.

How new technologies can help you get more out of your Artemia dollar

Geert Rombaut, INVE Aquaculture

SEP-Art SMArt D-FENSE

Recent innovations eliminate cyst hatching efficiency loss.



New technologies help to control the main result-determining factors in Artemia hatching.

Whether you are working with fish or shrimp, as a technician, nutritionist or hatchery manager, Artemia is indispensable for your operations. Artemia cysts have always been the aquaculture industry's most viable and convenient source of on-demand available live feed. The continuous development of Artemia products have gradually made it easier to obtain optimal Artemia hatching performance. This means you get more nauplii – and thus more live feed for your animals – out of every dollar you spend on Artemia. Most recently, technology has come to your aid with brand new innovations that help control some of the main result-determining factors in Artemia hatching that up until now left some room for improvement.

INVE Aquaculture launches a set of three advanced technologies

As part of their commitment to continuously improve the ease-of-use of the Artemia products, INVE Aquaculture (Benchmark's Advanced Nutrition division) has recently added two new additions to their set of Artemia processing technologies. The company's portfolio now offers three s tate-of-the art options that help control three of the main factors that influence the Artemia hatching process. This will allow hatcheries to optimize their cyst hatching performance, simplify their operations and require less time and effort from their staff.

Factor 1: illumination

Artemia cysts need a light impulse to start hatching. This natural light sensitivity means that illumination is an important aspect of the hatchery set-up. Depending on hatchery design and tank size, additional light sources will need to be applied to make sure that all cysts are adequately and evenly exposed. With INVE Aquaculture's new SMArt (Sensitivity Modified Artemia) technology, pre-treated cysts will be able to hatch regardless of light exposure and condition in the hatchery. This is made possible by a newly developed treatment that is applied to the cysts before packaging.

Factor 2: biosecurity

Together with fry or PL, water exchange and equipment, live feed is one of the possible sources of contamination in the hatchery environment. With this in mind, INVE Aquaculture scientists developed D-FENSE, a technology based on plant extracts that aims to suppress the growth of bacteria during the hatching process. This important bacterial reduction results in better larval performance and increased biosecurity due to reduced contamination levels during feeding.

Factor 3: decapsulation

A third crucial and time-consuming process is the thorough separation after hatching of the nauplli from the remaining cyst shell material. Shell fragments or remaining unhatched cysts can jeopardize the biosecurity of the hatchery environment and the fragile digestive system of the animals when swallowed. INVE Aquaculture's patented SEP-*Art* technology provides a magnetic coating on the cysts, adding a unique feature to the shell: complete separation of the nauplii from the shell and unhatched cysts by means of a set of passive magnets. The result is a suspension of pure, clean and active nauplii, without shell material of any kind and this without decapsulation for which bleach or other harmful substances are used.

Now exclusively available on INVE Aquaculture Artemia cysts

All of these innovations represent major milestones in the continuous improvement of hatcheries' performance and ROI as they rationalize the use of manpower and resources and increase the sustainability and environmental impact of the industry.

With Artemia cysts becoming a safer and easier to use product, hatchery operations are simpler and require less time and effort from the technical staff.

INVE Aquaculture's SEP-Art technology at work: the nauplli are separated from the shell by a set of passive magnets. What comes out of the separator pipe are pure, clean and active nauplii.

All three technologies are exclusively available on INVE Aquaculture's Artemia products and brands, such as Artemia AF/BF, Artemia EG/TQ, Artemia HIGH 5 and ARTEMIA IL. The availability of the product will be different per region, depending on the registrations.

INVE Aquaculture offers a wide and specialized range of top quality Artemia cysts from sustainably harvested sources. Some of INVE Aquaculture's Artemia brands offer Great Salt Lake cysts. At Great Salt Lake, the Artemia cysts are carefully harvested and processed as a natural product. The regulated and monitored harvest of Artemia at the Great Salt Lake, makes Great Salt Lake Artemia cysts unique as the best and most convenient live feed available in the rearing of top-quality shrimp and fish in hatcheries worldwide.

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Accelerating performance of marine RAS nurseries

Joana Amaral, Pedro Gómez-Requeni, Antonio Villanueva, Kim Schøn Ekmann, Kyla Meagan Zatti, BioMar

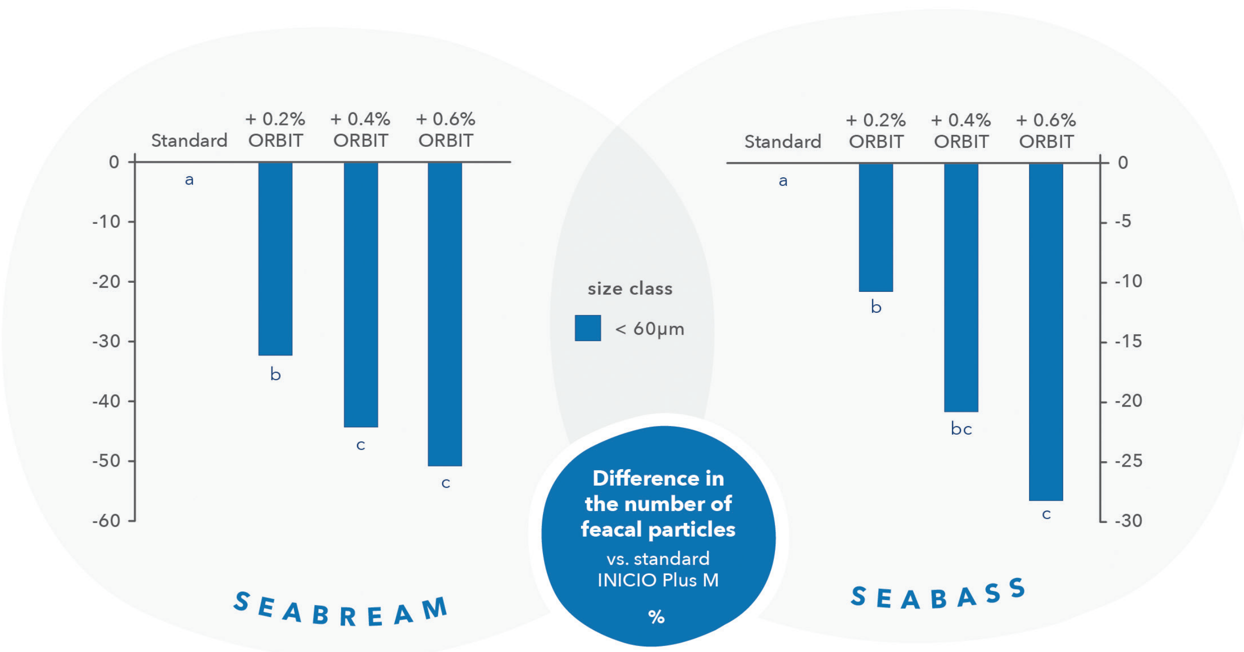

Figure 1. Difference (%) in the concentration of fecal particles smaller than 60 µm for seabream and seabass fry fed on standard INICIO Plus M and on standard INICIO Plus M supplemented with 0.2, 0.4, or 0.6% Orbit package. Different letters indicate statistical differences ($p < 0.05$).

Product development is traditionally characterized as the transformation of a market opportunity into a product available for sale, with traditional approaches often being market-oriented and products specifically developed to satisfy a customer need or to explore a niche. The catalyst of innovative companies such as BioMar are ideas arising from multiple sources, spanning from research and development (R&D) to quality and sales departments. These ideas respond to farmers' needs, resolve product handicaps, consolidate previously delivered solutions, or are plainly ground-breaking. For instance, as the aquaculture sector changes towards economically and environmentally sustainable food production systems, there has been an increasing trend for shifting marine nurseries to recirculating aquaculture systems (RAS). This shift alone is expected to reduce the nursery bottleneck and to shorten production cycles, on account of more stable water quality, lower heating or cooling costs and better production planning. Several logistical advantages are also expected, mainly associated with vaccination of fingerlings and larger mesh sizes in grow-out cages as fingerlings will be transferred to sea at larger sizes. Despite this expansion of RAS towards marine nurseries and the concomitant progress of the associated technologies, the development of aquafeeds for marine RAS nurseries has been largely overlooked.

Building on the idea of developing a novel feed product specific for marine RAS nurseries, BioMar took advantage of its strong expertise in RAS aquafeeds. The following three concepts of the Orbit range of specialized feeds for freshwater RAS were the

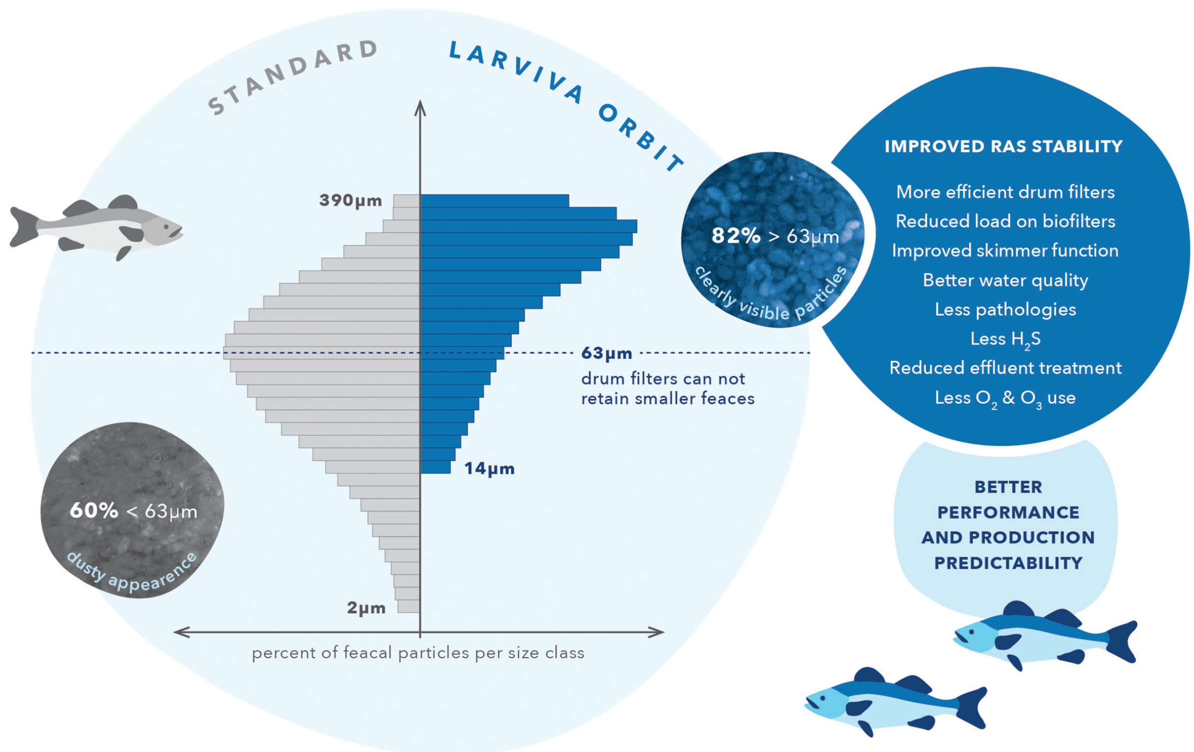

Figure 2. The effect of LARVIVA Orbit on the structure of seabass fry (6 to 15 g body weight) feces. The stability of the feces was assessed in terms of particle size distribution (% of particles within each size class from 2 to 390 µm, central graph) and fecal visual scoring (either fecal discharge in a dusty matrix, small grey circle at the bottom left side or clearly visible fecal casts, small blue circle at the upper right side). The benefits of a larger proportion of fecal particles >63 µm on RAS stability, performance, and predictability are also shown.

cornerstones of the new product: nutrition, pellet quality and fecal stability. The first two concepts are already covered by BioMar's LARVIVA nursery feed range for fish larvae and small fry, more specifically by feed type INICIO Plus M with its optimal protein to energy ratio, perfectly balanced amino acid composition, and targeted raw material selection. Therefore, the focus on the development of the new product – LARVIVA Orbit – was fecal stability.

Fecal structure stability by LARVIVA Orbit

The next step in BioMar's product development process for a specific feed for marine RAS nurseries was a thorough R&D assessment involving multiple small-scale trials performed externally with research partners. As such, a small-scale trial was conducted at CTAQUA (Cádiz, Spain) to test the effects of LARVIVA Orbit on the stability of fecal structure, which is key for the effective removal of feces by mechanical filters and for reducing the load on biofilters in RAS. To this end, four diets were provided to seabream and seabass fry, run in quadruplicates (per species and per diet), with standard feed INICIO Plus M as the base formulation and with the addition of varying levels of the Orbit package (0, 0.2, 0.4, or 0.6%). After 60 days, the number of suspended fecal particles <60 µm decreased significantly in the tanks where the Orbit package was used (Fig. 1). In addition, the concentration of suspended fecal particles <30 µm decreased notably, and a higher supplementation of the Orbit package resulted in a more evident decrease. This reduction in the concentration of fecal particles in suspension demonstrated the combined effect of standard INICIO Plus M and Orbit on improving fecal structure stability while maintaining fish performance, thereby supporting the further development and testing of LARVIVA Orbit. After the small-scale R&D trials, BioMar's product development process moved to the BioFarm step wherein large-scale proof-of-concept tests are performed before product launching. A first large-scale trial was performed to validate the effect of LARVIVA Orbit on fecal stability using seabass fry (6 to 15 g body weight) reared on two diets: standard (INICIO Plus M) and LARVIVA Orbit. Three tanks, each containing

165,000 seabass were used per diet to evaluate fecal stability after 15 days. Fecal stability was assessed both visually, using BioMar's scoring system, and numerically, by particle size distribution. Total suspended solids (TSS) and biological oxygen demand (BOD) were also evaluated as a proxy for water quality. In the tanks where fish were fed the standard diet, fecal discharge appeared "dusty" with little to no visible intact fecal casts and with 60% of particles being smaller than 63 µm. In contrast, in the tanks containing fish fed LARVIVA Orbit, fecal casts were clearly visible and intact with 82% of the particles being larger than 63 µm (Fig. 2). In addition to the 35% reduction in fecal particles <63 µm, TSS and BOD also decreased markedly in the tanks where fish were fed LARVIVA Orbit.

LARVIVA Orbit: a specialized feed for improving RAS performance

Additional large-scale trials are currently being conducted to validate LARVIVA Orbit's success in maintaining high fish growth performance and health, optimizing RAS biofilter efficiency and production performance, and ultimately maintaining a stable RAS that drives production predictability, reduces production costs, and increases productivity and the overall profitability of the farmer. Such successful validation is the last step of LARVIVA Orbit product development before product launch, which is planned for the first quarter of 2020. BioMar's development of LARVIVA Orbit – its specialized feed for marine RAS nurseries – clearly illustrates a product development process that relies on multidisciplinary teamwork and expertise and that is *Powered by Partnership and Driven by Innovation.*

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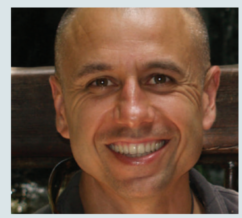

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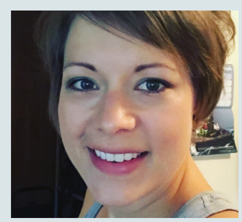

HATCHERY
FEED & MANAGEMENT

NEXT ISSUE
Coming in February

Special topics:

Freshwater fish feed, management and nutrition
Live feed production: systems, enrichments
RAS systems and management

Contact: editor@hatcheryfeed.com

Phytobiotics in hatcheries and nurseries

Carlos Rodríguez, Álvaro Rodríguez, Ewa Sujka, Liptosa

Worldwide, strong growing demand of seafood has been steadily rising over the last few years and has led to aquaculture intensification practices and an increase of stressors.

Aquaculture, as any other animal production system, has several risk factors. According to some stakeholders and the FAIRR report, ten key risk factors can be highlighted in aquaculture such as antibiotic use, disease, animal welfare, working conditions and effluents or discharge (FAIRR report, 2019). Therefore, it is necessary find strategies which mitigate the impact of these factors and ensure aquaculture sustainability and profitability.

Phytobiotics in aquaculture

Nutraceuticals and phytobiotics are effective tools to minimize antibiotic and antimicrobial administration, avoid or reduce the impact of opportunistic bacteria and get the animal strong and healthy. Phytobiotics have several functions such as promoting growth, antiparasitic effect, maintenance of intestine integrity to avoid opportunistic pathogens, and helping cut down the impact of these risk factors.

Larvae and juvenile quality are still a gap in aquaculture industry due to the several factors such as genetics, diseases and stress factors. While nutraceuticals and phytobiotics are widely used in grow-out stages as growth promoters, their usage in the hatchery and nursery stages is still underrated.

In order to fill these gaps, LIPTOSA has designed a new line of products – Liptofry range – for these specific stages in order to provide farmers and feed mills efficient tools for reliable and suitable practices.

Bacteria	MIC
Flavobacterium psichrophilum	0.75 mg/ml
Flavobacterium araucanum	1.25 mg/ml
Flavobacterium piscis	1.25 mg/ml
Vibrio parahaemolyticus	1.25 mg/ml
Vibrio alginolyticus	3 mg/ml
Aeromonas hydrophila	3 mg/ml
Aeromonas salmonicida	0.25 mg/ml
Pseudomona anguilliseptica	3 mg/ml
Lactococcus garviae	3 mg/ml
Tenacibaculum maritimum	0.75 mg/ml
Enterococcus sp.	1.75 mg/ml
Streptococcus agalactiae	0.75 mg/ml

Table 1. Liptofry minimal inhibitory concentration (mg/ml).

Liptofry is a carefully studied combination of essential oils, short and medium fatty acids and plant extracts with multifactorial mechanisms of action against pathogen bacteria based on direct bactericide effect and indirect bacteriostatic properties like quorum sensing or promotion of exclusive competition. Moreover, Liptofry has a specific protection system against extrusion conditions (thermostability) releasing the active components in a specific part of the intestine or hepatopancreas.

	Infective dose *F.psychrophilum* (CFU/fish)	Dead fish/ Innoculated fish (nº)	Mortality (%)
Liptofry	$4{,}2x10^8$	32/120	27
Control	$4{,}2x10^8$	74/120	62

Table 2. *Oncorhynchus mykiss* mortality challenged against *Flavobacterium psychrophilum*. Liptofry group fed on a diet supplemented with Liptofry.

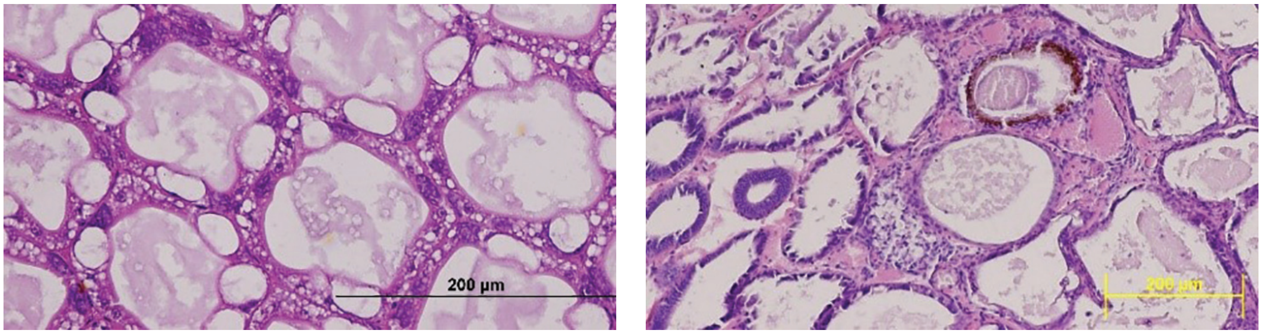

Figure 1. Comparative of hepatopancreas structure Liptofry (left) vs control (right). Challenge against *Vibrio parahaemolyticus* AHPND. Infective dose: 10^5 CFU/mL.

	FCR	Mortality (%)
Liptofry	0.78	15.72
Control	0.92	27.09

Table 3. FCR and mortality rate (%) of rainbow trout field test.

The product development was based on a scientific approach. First, the antibacterial activity efficacy was evaluated *in vitro* by minimal inhibitory concentration test following the microdilution method (Table 1).

Shrimp lab test

To satisfy shrimp's needs, a specific product was designed to control *Vibrio* load and boost hepatopancreas function. Laboratory test achieved important reduction of green colony *Vibrio* count (decrease of 77,96% *vs* control) and lower degree of sloughing of hepatopancreas (Fig. 1).

Rainbow trout lab test

Liptofry was orally administered to rainbow trout fingerlings throughout weaning and nursery stages to check the improvement of disease resistance against *Flavobacterium psychrophilum*. Fingerlings were infected by intraperitoneal injection with *Flavobacterium psychrophilum* RBT4.1.04 (average weight of 5.84±1.29 g). A control group fed on a standard diet was also challenged.

Mortalities started 24 hours post-infection and ceased after 4 days in both groups (Table 2). Mortality rate of control group (62%) was significantly higher than the one fed on phytobiotics (27%, ANOVA p<0,05). The use of feed supplemented with phytobiotics as Liptofry in rainbow trout may contribute to the prevention of diseases caused by *Flavobacterium psychrophilum* due to the combined effect of the high antimicrobial activity of the nutraceutical against *F. psychrophilum* and the ability of nutraceutical-supplemented diets to stimulate parameters of the specific and non-specific immune response of rainbow trout.

Field trials

Several field trials were carried out in shrimp hatcheries and nurseries to control *Vibrio* population. The phytobiotic boosts shrimp's energy consumption making them more resistant to stress and help them to molt.

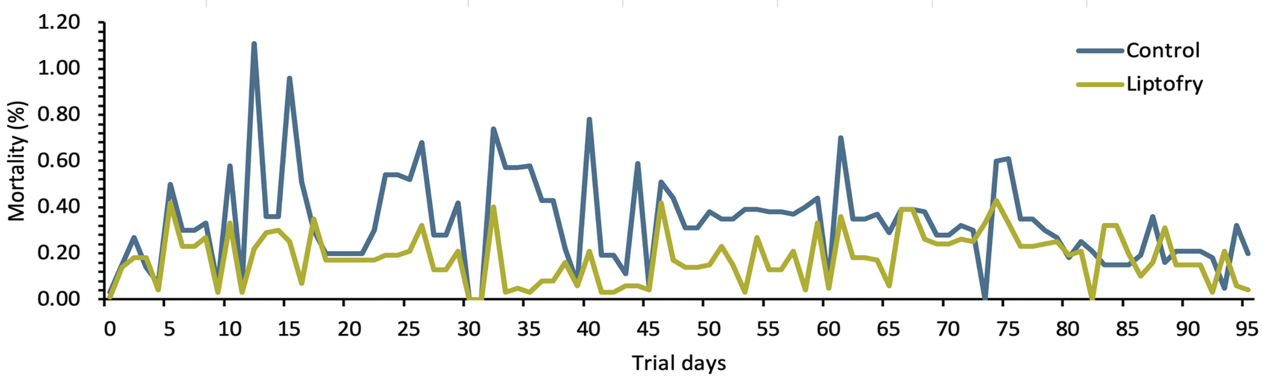

Figure 2. Mortality evolution during the three-month rainbow trout field trial.

Tilapia producers confirmed the positive impact of Liptofry on their production, improving broodstock performance, sexual reversion and reducing the risk of opportunistic bacteria such as *Aeromonas hidrophyla* and *Flavobacterium columnare*.

Following the rainbow trout's test, a field trail was performed in rainbow trout fingerlings fed on a diet with 5 g/Kg of Liptofry inclusion. The three-month trial was performed in the Titicaca lake, Perú.

Results showed that the phytobiotic reduced mortality rates during disease outbreaks (Fig. 2). Fingerlings fed on a supplemented diet also showed lower FCR (0.78) than control group (0.92). A better performance in terms of zootechnical parameters and mortality rate in the fingerlings fed on the supplemented diet was obtained (Table 3).

Conclusions

Liptofry used as a preventive approach during the nursery stage reduces the severity of *Flavobacterium psicrophylum* outbreaks in trout production. According to our data, not shown in this article, good performance in terms of bactericidal and bacteriostatic properties against other filamentous bacterial such as *Tenacibaculum* sp. was also observed, reducing disease outbreaks in hatcheries.

In shrimp, the product helps to control *Vibrio* load and maintain hepatopancreas structure. It can be used as part of a farm's prophylaxis strategy in order to get antibiotic-free shrimp hatcheries.

Nutraceuticals and phytobiotics are an interesting and useful tool, under a holistic approach, to reduce the impact of diseases throughout the hatchery and nursery stages. Moreover, stronger animals are achieved with better performance throughout the production cycle promoting cost-effective and sustainable aquaculture.

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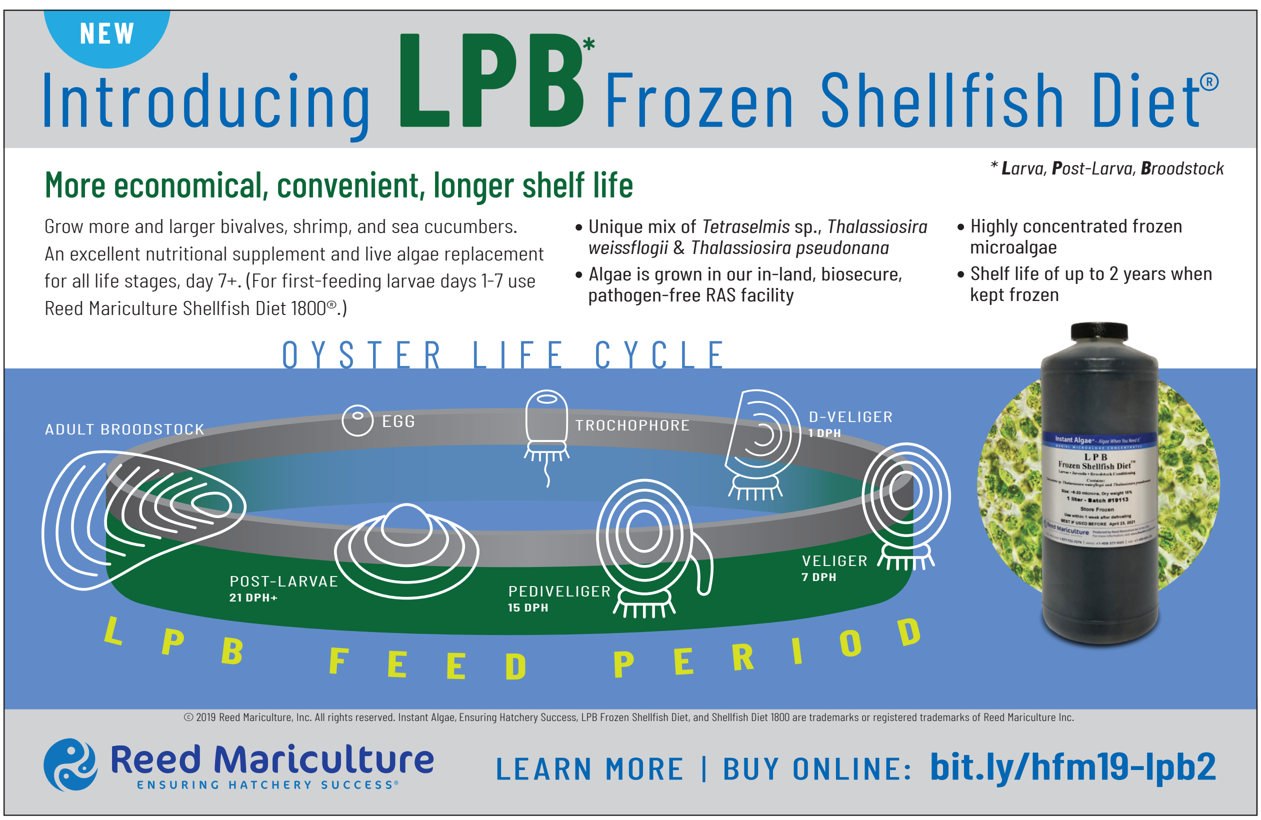

Long-term effects of enhanced dietary micronutrients in early juveniles of gilthead seabream

João Henriques, Filipe Soares, Wilson Pinto, Jorge Dias, Luís Conceição, Sparos

The need for mass production of high quality and healthy larvae and juveniles is one of the main constraints on the future development of the aquaculture industry (FEAP, 2015). In the Mediterranean region alone, the production of marine fish juveniles, in which the dominant species are seabream and seabass, has surpassed one billion in the past few years, accounting for a turnover of €200 million per year. In industrial terms, the first feeding phase of fish larvae is based on live food but in recent years significant advances have been made in the use of microdiets. A main focus has been on the optimization of protein and lipid intake in quantity and quality including hydrolyzed protein sources, essential amino acid contents, essential fatty acids and phospholipid levels (Hamre *et al.*, 2013). Despite recent progress, there are still areas in the nutrition of marine larvae and juveniles where knowledge is very scarce or even non-existent. This is the case with the estimation of nutritional requirements in micronutrients. Micronutrients, such as vitamins and minerals, are essential for a wide range of physiological, metabolic and hormonal processes that critically condition survival, growth, food utilization, skeletal formation, osmoregulation, immune response and susceptibility to pathologies of marine larvae and juveniles. Therefore, it is essential to better understand the effects of different dietary micronutrient levels in the biological performance of marine fish during early stages of development. In this regard, Sparos recently evaluated the effects of a microdiet with an alternative vitamin and mineral profile on the biological performance of seabream early juveniles. In addition, a simulation model (FEEDNETICS™) was used to quantify the long-term outcomes in the production cycle when considering seabream juveniles with different average weights at the beginning of the grow-out phase.

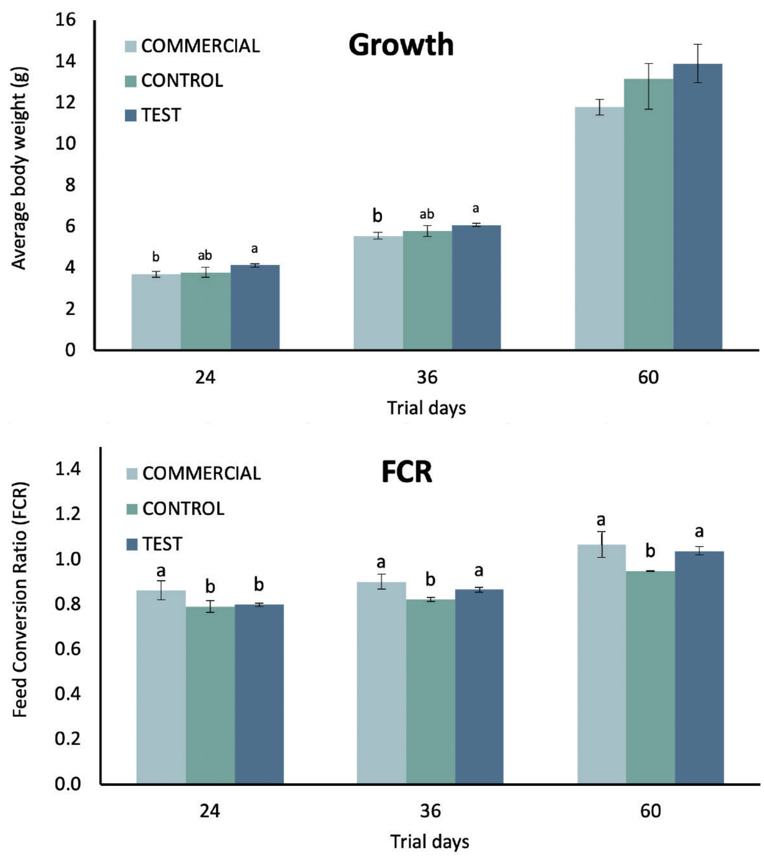

Figure 1. Growth and feed conversion ratio (FCR) of seabream juveniles fed on three different diets (COMMERCIAL, CONTROL and TEST) at three sampling points (day 24, 36 and 60).

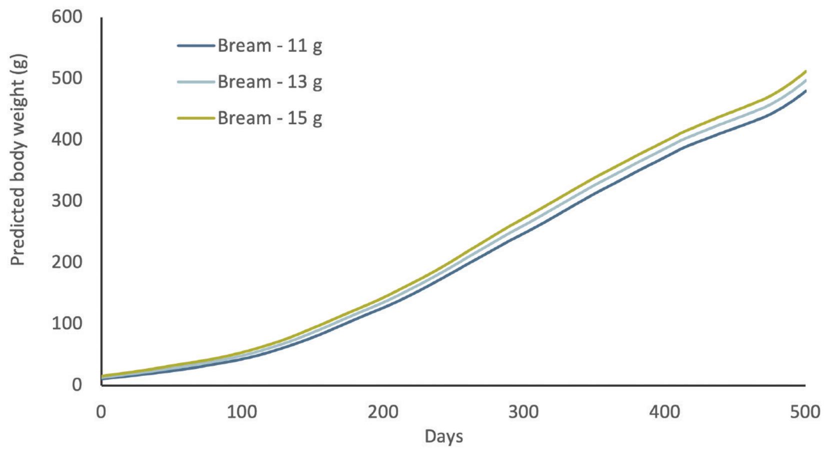

Figure 2. Growth predictions of FEEDNETICS™ considering three scenarios with start weights of 11, 13 and 15 g.

A microfeed with enhanced levels of micronutrients improves growth

The trial was carried out at Riasearch facilities (Murtosa, Portugal) and involved triplicate testing of three different diets: a commercial diet (COMMERCIAL), a Sparos control diet (CONTROL) and a Sparos test diet (TEST), the later with enhanced levels of vitamins (A, C and E), minerals (Mn and Zn), and carotenoids (astaxanthin). Seabream juveniles, with an average initial body weight of 0.86 g, were reared in 200 L tanks for 60 days (photoperiod: 12L/12D, water temperature: 24.1±1.3˚C, salinity: 18.5-19.1 ppt). During the experimental period seabream were hand-fed close to satiation with 4 meals a day, from 9 a.m. to 6 p.m. Sampling procedures involved individual fish weighing at day 24, 36 and 60, in order to assess weight development and posteriorly calculate FCR.

At day 24 and 36 gilthead seabream juveniles fed on the TEST diet showed significantly higher body weight when compared to seabream fed on the COMMERCIAL diet (Fig. 1). This trend was kept until the end of the experiment (day 60) with seabream fed on the TEST diet showing 5% and 15% higher body weight in comparison with seabream fed on the CONTROL and COMMERCIAL diets, respectively. At day 24, both fish fed on the CONTROL and TEST diets showed significantly lower feed conversion ratio (FCR) when compared to fish fed the COMMERCIAL diet (Fig. 1). At day 60 fish fed on the TEST diet showed lower FCR than the group fed on the COMMERCIAL diet.

Overall, early gilthead seabream juveniles fed on the TEST diet showed the best growth performance when compared to the other treatment groups and a good feed conversion ratio, according to industry standards. These results suggest that the enhanced levels of dietary vitamins, minerals and carotenoids can possibly improve the biological performance of gilthead seabream juveniles. Moreover, studies have shown that increased levels of vitamins C and E seem to stimulate immunity and stress-resistance both in fish larvae and juveniles (Hamre, 2011). Although not directly related to growth, a good health status can increase seabream juveniles' robustness and potentially contribute towards improved biological performances. However, the knowledge on dose response of specific vitamins and minerals on fish larvae and juveniles is still scarce (Hamre *et al*., 2013) and further studies need to be carried out to in order continuously optimize the nutritional content of microdiets and ultimately improve biological performances in commercial environments.

Start weight affects long-term performance in farm operations

Unlocking the full growth potential of marine larvae and juveniles still remains one of the primarily goals of commercial aquaculture. Optimized microdiets are contributing to improve biological performances at early life stages, despite the difficulty in accurately

Scenarios	Days to reach 450g	FCR	Feed price	Total feed cost	ECR
	-	-	(€/Kg)	(€)	(€/Kg)
Bream - 11 g	481	1.62	1.10	73,122.00	1.78
Bream - 13 g	467	1.58	1.10	75,795.00	1.74
Bream - 15 g	453	1.53	1.10	78,093.00	1.68

Table 1. Feed conversion ratio (FCR), total feed cost, and economic conversion ratio (ECR) predicted by FEEDNETICS™ for a harvest size of 450 g, considering three scenarios with start weights of 11, 13 and 15 g.

predicting long-term results when using grower diets. To help overcoming this challenge, modelling tools can be applied, allowing fish farmers to compare the effects of different production strategies and rearing practices on the fish growth performance. In this context, FEEDNETICS™ software was used to predict the growth patterns of seabream juveniles with different initial weights (11, 13 and 15 g), as obtained in the trial described above until harvest size (450 g). Apart from the initial fish weight, all simulations were carried out under the same rearing conditions (initial number of fish: 100,000 bream; temperature profile: Chios, Greece; feeding regime: commercial standard). The main objective of this approach was to predict how small improvements in the biological performance at early life stages can significantly influence the long-term outcomes in a commercial production.

The results presented in Figure 2 and Table 1 suggest that starting the grow-out phase with higher initial weights can bring long-term benefits in terms of biological and economic performance. In this case, juveniles with initial weight of 15 g reach the harvest size (450 g) faster, ultimately allowing the production cycle to be shortened by up to 14 days and 28 days when comparing to the 13 g and 11 g scenario, respectively. Furthermore, the shorter production cycle in the 15 g scenario allows reducing the economic conversion rate (ECR) by 3% and 6% when comparing with the 13 g and 11 g scenarios, respectively. In turn, these differences can ultimately translate into feed savings of €60 and €100 per ton of fish produced. By bringing the above-mentioned trial outcomes into the context of the FEEDNETICS™ simulations, we can conclude that the 2 g relative increase in body weight between seabream juveniles fed on the TEST diet (13 g FBW) and the group fed on the COMMERCIAL diet (11 g FBW) can result in substantial long-term gains in fish farming commercial productions.

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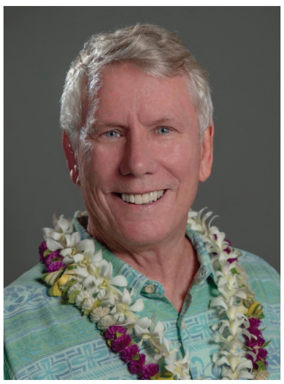
SPF shrimp technology: past, present & future

Jim Wyban, Marine Genetics LLC, Hawaii, USA

SPF shrimp technology past

This is the first of a series of articles titled "SPF Shrimp Technology: past, present and future." This article will describe the past including development and adoption of SPF shrimp technologies and examples of how the introduction of SPF *P. vannamei* rapidly expanded industry production.



The development of SPF *P. vannamei* in the U.S. in the early 1990s resulted in a doubling of U.S. industry production. Subsequent introduction of SPF *P. vannamei* to Asia in the late 1990s produced dramatic increases in shrimp production and rapidly spread throughout Asia. *P. vannamei*'s widespread adoption in Asia increased global shrimp production five times between 2000 and 2012. By 2012, *P. vannamei* production accounted for 80% of total world production and was the dominant species farmed in China, Vietnam and Indonesia – three of the world's leading production countries. India subsequently adopted *P. vannamei* for farming which resulted in a significant increase in farmed shrimp production in that country.

Domestication of SPF *P. vannamei*

In the late 1980s, U.S. shrimp farmers dealt with a variety of serious disease problems. Our research group at Oceanic Institute set out to develop a disease-free shrimp to help alleviate these problems. Our SPF program was based on developing shrimp that were certifiably free of "listed pathogens" which are disease-causing microbes that can be diagnosed and can be physically excluded from a facility. The listed pathogens used in the original SPF certification are shown in Table 1. It is interesting that those listed shrimp pathogens in 1990 were quite limited and did not include White Spot, EMS, Taura or EHP. At that time, there were no

Pathogen type	Pathogen acronym/name
Virus	IHHNV - Infectious Hematopoietic Necrosis Virus
Virus	HPV, BPV
Protozoa	Microsporidians, Haplosporidians
Protozoa	Gregarines
Metazoan parasites	Larval nematodes, trematodes, cestodes

Table 1. SPF listed pathogens used to establish the first SPF shrimp stock in 1990.

PCR systems available for shrimp diagnostics. All diagnostics to establish the first SPF stocks were done by histopathology.

Impact of SPF *P. vannamei* in the U.S. industry

Commercial production trials comparing SPF and non-SPF stocks were undertaken in cooperation with the U.S. industry. In 1991, 2,000 SPF broodstock were produced in and shipped from Kona, Hawaii to shrimp hatcheries in Hawaii, Texas and South Carolina. Biosecurity protocols for the hatcheries were developed to prevent disease introduction and produce SPF postlarvae. More than 50 million SPF postlarvae were produced and stocked into commercial U.S.

ponds for field trials. SPF ponds were run side by side with non-SPF ponds in commercial farms in all three U.S. farming regions.

Production results in SPF ponds were significantly better than in non-SPF ponds in all three regions. A typical result is illustrated by data in Table 2 comparing SPF and non-SPF shrimp in an intensive commercial pond in Hawaii. Harvest weight, size distribution (CV), feed conversion rate (FCR), total crop and crop value were all greater in the SPF crop. Subtracting feed costs from crop value in both trials, the SPF crop was more than twice as profitable as the non-SPF crop.

Based on the excellent results of pond trials in 1991, more than 5,000 SPF broodstock were produced in Kona, Hawaii in 1992 and supplied to U.S. hatcheries. From these, more than 200 million SPF postlarvae were produced from the SPF broodstock and stocked into commercial ponds in the three shrimp culture regions of the U.S. Virtually all shrimp ponds in the U.S. were stocked with SPF PL in 1992. Total production of the U.S. industry doubled as a direct result of this innovation.

These dramatic gains in production from use of SPF shrimp were experienced in all three shrimp production regions of the U.S. in many different environments and using a variety of technologies and stocking densities. Use of SPF shrimp in commercial farms increased production and survival, improved FCR and narrowed harvest size distribution. Each of these improvements contributed to increased profitability. In addition to increased production, use of SPF shrimp reduced incidence of shrimp disease. There was unanimous opinion among U.S. farmers that the tremendous profitability experienced in 1992 was due to use of SPF stocks!

	NON-SPF	SPF
Stocking density (#/m²)	97	90
Duration (days)	101	104
Survival (%)	86	90
Mean weight (g)	8.5	11.8
CV (%)	38	9
FCR	3.37:1	2.1:1
Total crop (kg)	1,424	1,937
Crop value ($)	12,507	20,326
Crop less feed costs ($)	7,228	15,852

Table 2. Comparison of SPF *vs* non-SPF shrimp in a commercial intensive system in Hawaii (1991).

Globalization of SPF *P. vannamei*

SPF *P. vannamei* broodstock were first shipped to Taiwan in 1996. By 1997, the receiving hatchery was producing substantial quantities of PL and distributing them throughout Taiwan. By August, farmers who stocked *P. vannamei* PL had great harvests – they made lots of money and news of the *P. vannamei* jackpot reached the front page of the national newspaper. Urgent demands for *P. vannamei* broodstock deluged Hawaii shrimp farmers. The Taiwan *P. vannamei* craze

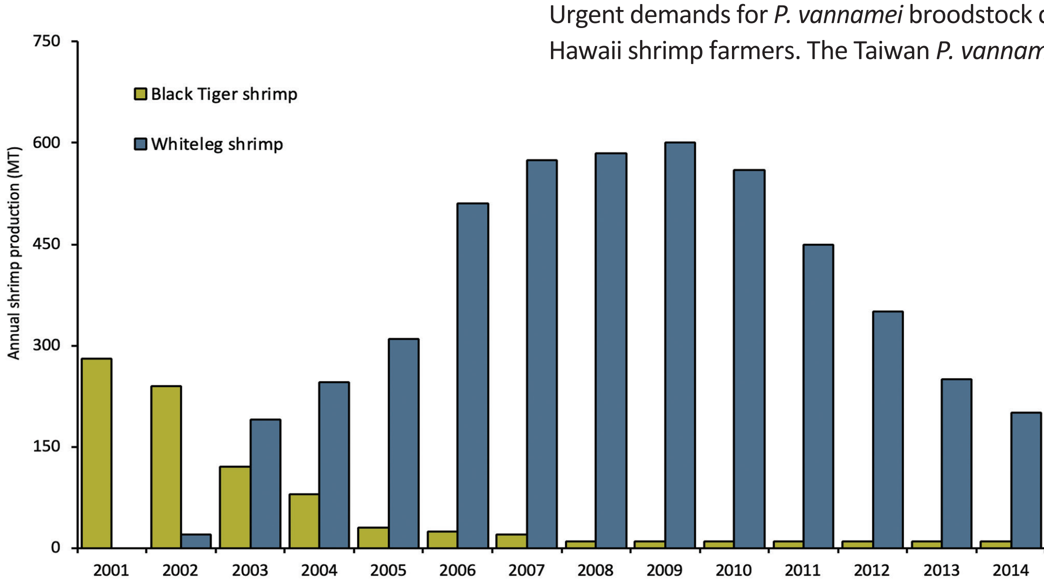


Figure 1. Annual shrimp production in Thailand comparing Black Tiger and *P. vannamei*.

Parameter	*Black Tiger*	*P.vannamei*	% Difference
Density (PL/m2)	40-50	120-200	300%
Crop duration (days)	110-140	105-120	27%
Harvest size (g) (#/kg)	22-28 (40/kg)	21-25 (42/kg)	5%
Yield MT/ha/crop	8	24	300%
Crop value ($/ha)	45,000	96,000	220%
Crop costs ($/ha)	32,000	60,000	
Production profit ($/ha)	13,000	36,000	280%

Table 3. Comparison of production parameters and profits between typical Black Tiger and *P. vannamei* production systems in Thailand (in US$).

continued at a fevered pitch through the winter and spring of 1998. It was widely agreed that introduction and success with SPF *P. vannamei* was the most exciting news in Taiwan shrimp farming since the collapse of their *P. monodon* industry in 1989 (Liao, pers. com.).

Thailand's shrimp revolution

Thailand started farming shrimp in the 1970s using locally available *P. monodon* broodstock captured from the sea to produce PL in land-based hatcheries for pond stocking. By the early 1990s, the country emerged as the world's leading farmed shrimp producer and exporter based on *P. monodon* production.

In the 1990s, disease problems increased risks and slowed industry expansion. Yellow head and white spot viruses severely impacted production. Government-sponsored research and extension helped the industry adjust and manage around these diseases. These viruses were most often introduced through the wild broodstock supply. Despite these problems, the Thai industry maintained its position as the first shrimp producer. In 2001, Thailand's *P. monodon* production peaked at 280,000 MT (Fig. 1).

By 2001, Thai farmers faced a new disease called Monodon Slow Growth Syndrome (MSGS), characterized by slow growth leading to smaller harvest size and lower prices. The cause of MSGS is still unknown. This slow growth problem with *P. monodon* set the stage for SPF *P. vannamei* introduction. Farmers were looking for a lower risk, more reliable way to make money farming shrimp.

Limited SPF *P. vannamei* broodstock imports were first tested in 2001. Results were impressive with stable, consistent results; high survival rates and fast growth to 20 g in 100 days with uniform size distribution at harvest (2-3 size classes). The SPF shrimp were tolerant to higher densities than *P. monodon* – up to 2.5 kg/m^2 and there were lower incidences of mass mortalities. The industry lobbied to allow more broodstock imports in 2002. More farm trials followed and 2002 also saw tests of "homegrown" or "F1 broodstock". Farmers soon found that most growth and production advantages of true SPF *P. vannamei* were lost using "home grown" or F1 broodstock. Slower growth and large size variation and more disease events were typically experienced with F1 stocks. *P. vannamei* production in 2002 jumped to 20,000 MT. Figure 1 illustrates the rapid increase in *P. vannamei* production (blue bars) between 2002 and 2006 while *P. monodon* production (green bars) rapidly declined. By 2009, *P. vannamei* represented over 98% of the total production of 600,000 MT, which was more than double the previous peak in Black Tiger production. In 2010, Thailand closed its border to broodstock imports and in 2012 EMS arrived causing precipitous loss in industry output which illustrates the EMS effects (Fig. 1).

Progressive Thai farmers were producing 20-30 MT/Ha/crop using SPF *P. vannamei*. Table 3 compares the relative production numbers and profits between species in Thai shrimp farms. These data clearly show the driving force of Thailand's change from farming Black Tiger to *P. vannamei* and the superior production economics with *P. vannamei*. Crop value and profits ($/ha) with *P. vannamei* are two to three times greater than with Black Tiger. Reliability of production (avoidance of disease) is also higher with SPF *P. vannamei*.

		Annual production (MT)			Growth rate
Era Name	**Years**	**Start**	**Finish**	**Gain**	**(%/yr)**
Wild PL	1982-88	84	604	520	103%
Hatchery PL	1988-96	604	693	89	2%
SPF P. *vannamei*	1996-2011	693	4,100	3,407	20%
EMS	2011-	4,100	3,900	-200	-3%

Table 4. Shrimp farming eras.

P. vannamei advantages

A key issue in understanding the rapid spread of SPF *P. vannamei* through Asia is to understand the specific advantages *P. vannamei* enjoys compared to Black Tiger in shrimp farming. Several important biological factors strongly favor *P. vannamei* for farming. Nutritional requirements are less expensive to satisfy so lower protein feed can be used with *P. vannamei*. Further, *P. vannamei* greatly benefits from pond ecosystem-generated food. While not well understood, *P. vannamei's* feeding behavior and waste metabolism generates a healthy "nutritious" ecosystem that actually supplements *P. vannamei* growth. This ecosystem effect is the basis of biofloc technology.

A third key factor is *P. vannamei* is amenable to high stocking densities. This is somewhat dependent on the ecosystem factor but is also a result of *P. vannamei's* behavior. Domestication has played a role in this behavior – as domestication proceeds, *P. vannamei* are amenable to higher densities. Trials in super-intensive culture have successfully reared *P. vannamei* at stocking densities over 800 PL/m^2.

Shrimp farming eras

Shrimp farming's long and colorful history can be divided into four distinct eras (Table 4, Fig.2). During the "Wild PL Era" nearly all stocking material was wild PL gathered from the sea. In each hemisphere, shrimp

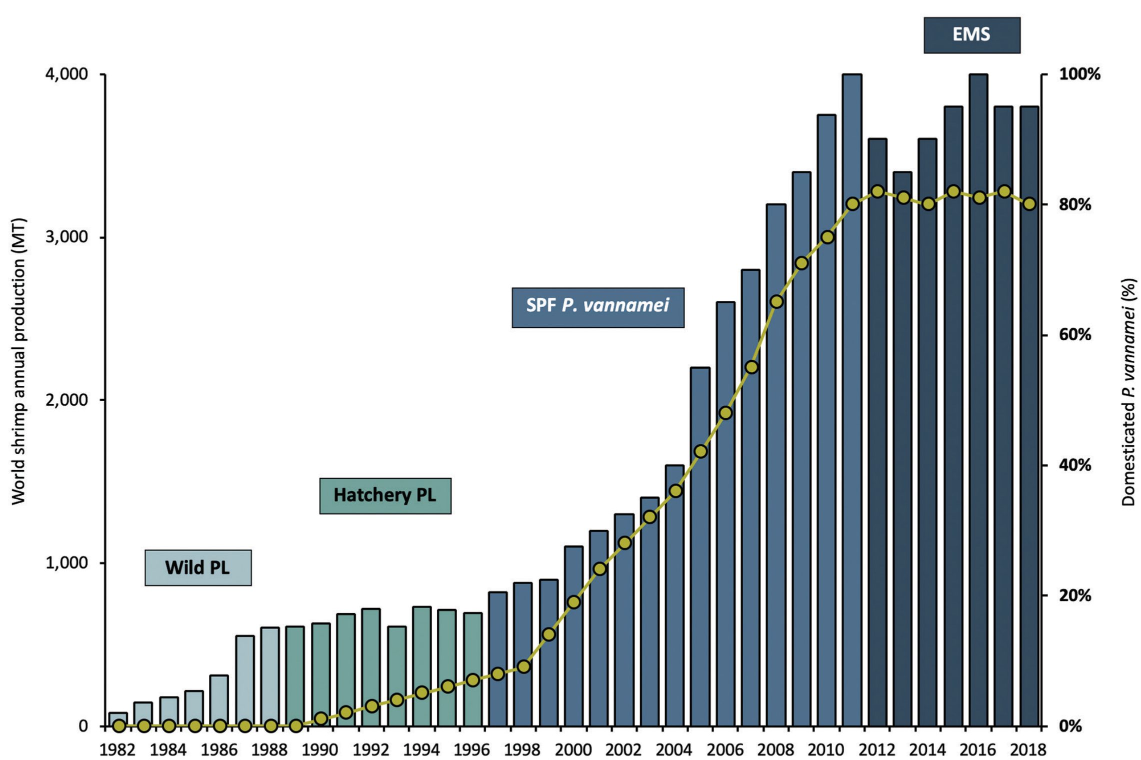


Figure 2. World shrimp farming annual production (left axis) and percent contribution to total by domesticated *P. vannamei* (right axis).

farming was based on the use of native species. In Asia, the industry was dominated by Black Tiger while in the West, the industry used *P. vannamei*. During this era, annual production increased rapidly (~100% per year). Growth was driven by very strong market acceptance and demand for farmed shrimp and a relative absence of disease which allowed simple pond culture methods to succeed.

The second era in shrimp farming is the "Hatchery PL Era" (1988-96). In this phase, post larvae were produced in land-based hatcheries. While cultured, these PL were genetically wild animals because the parents were wild caught broodstock gathered from the sea. During this era, shrimp farming in each hemisphere continued to use their native species. Asian shrimp production was at least five times greater than Western production throughout this era so global production statistics in this era were dominated by *P. monodon*. During the hatchery PL era, total world production only increased from 604 to 693 thousand MT resulting in an average annual gain of just 2% per year. The main obstacle to growth in the hatchery era was widespread shrimp disease. Diseases were spread through the industry with the hatchery-produced PL because the hatcheries paid little or no attention to animal biosecurity. Wild broodstock carried disease into the hatchery where it passed to the PL and then out to the farms.

The other obstacle to growth in this era was the continued use of wild animals. Shrimp farming production during the hatchery PL era reached a "carrying capacity" for use of wild, non-domesticated, non-SPF animals. While farmers tried increasing stocking densities to increase yields and profits, their use of wild animals precluded these attempts and prevented industry growth.

The third era of shrimp farming is the "SPF *P. vannamei* Era". From 1996 to 2011, industry production grew from about 700,000 MT to 4 MMT with sustained annual growth of more than 20% per year. This SPF era is characterized by the use of domesticated SPF *P. vannamei* bred for faster growth and disease resistance. As domesticated animals, they are far more accommodated to culture systems. The single biggest factor contributing to the rapid increase in production is the domestication, breeding and widespread use of *P. vannamei* as species of choice for farming.

The fourth era is the "EMS era." This *Vibrio*-caused disease has wreaked havoc throughout the Asian industry with heavy losses in Vietnam, China and Thailand. Figure 1 clearly illustrates the devastating impact EMS had on Thailand's shrimp production after 2012. This disease continues to limit industry production but there are developing strategies that reduce its impact. While SPF stocks are part of the solution to the EMS problem, system biosecurity and ecosystem management need upgrading to overcome this problem.

Economic impact

Widespread adoption of SPF *P. vannamei* in Asia significantly improved the economics and reliability of shrimp farming. The driving force in Asia's switch to *P. vannamei* was based on the higher profit achieved with *P. vannamei* compared to Black Tigers (Table 3).

Domestication, breeding and globalization of *P. vannamei* added tremendous value to the world shrimp industry. In the mid-90s, global farmed shrimp production was 700,000 MT per year with a total crop value of about $3.5 billion. Current crop value is more than $25 billion with production at 4.1 MMT. This 6-fold increase in industry production and value resulted from the domestication, breeding and widespread use of *P. vannamei*. The cumulative value added to the shrimp industry crop value from the introduction of SPF *P. vannamei* to Asia is about $225 B. This industry transformation was driven by SPF *P. vannamei's* lower production costs and reduced disease risks which derive from their disease-free status, advancing domestication and *P. vannamei's* natural growth traits. The biggest opportunity to lower costs in shrimp farming is through continual advanced breeding SPF *P. vannamei* for improved performance and providing farmers with top quality, disease free (SPF) postlarvae with high performance genetics cultured under optimum, controlled conditions to maximize their growth potential.

The next article in this series will discuss the present situation in SPF technology. The complete manuscript will be presented as the keynote address by Dr. Wyban at Aquaculture America 2020 in Honolulu, USA.

Performance of European lobster *Homarus gammarus* larvae and postlarvae reared on dry feeds: insights into cannibalism, post molt death syndrome and sustainability

James Hinchcliffe, Adam Powell, Linda Svanberg, University of Gothenburg

In the EU, the production of crustaceans originates mainly from wild decapod fisheries such as lobsters, crabs and prawns. Landings of European lobster (*Homarus gammarus*) rarely exceed the average of ca. 5,000 tons per annum (FAO 2014). In contrast, live imports of American lobster (*Homarus americanus*) average ca. 13,000 tons annually, to make up for the shortage in supply of the native species (Swedish agency for Marine and Water management, 2016). With a high global demand that exceeds supply, in addition to concerns about conservation of native stocks, the culture of the European lobster is increasingly viewed as a method to increase production and assist conservation efforts (release and restocking of young juveniles for remediation). However, the cultivation of the European lobster currently operates at modest scales.

With the precedent long set by the Penaeid shrimp industry, the testing, production and use of a dry formulated feed specifically designed for *Homarus* sp. could prove very beneficial for farming operations, with feeds that could be tailored to meet the different nutritional requirements of various life stages. Additionally, dry feeds have a consistent nutritional value, are easy to store, transport and handle and therefore permit easier and standardized hygiene and quality from feed practices. With the global challenge to reduce fishmeal usage in aquaculture operations, there is a need to identify local alternative protein sources that can reduce the environmental footprint and increase the sustainability of farming operations.

Juvenile European lobster produced at Swedish first pilot scale lobster hatchery, Kristineberg.

A current Swedish Project has created test quantities of feeds using raw ingredients - off-cuts from herring fisheries, flocculated protein from waste water in local shrimp fisheries and mussel meal produced from local farm discards - to investigate if this could yield further benefits in terms of growth and survival of European lobster juveniles. This article will summarize the main findings of the project and how this can optimize European lobster aquaculture in Europe.

Life stages tested	Feeds tested	Survival (%) performances	Growth performances
I-IV[1]	"PAS"	Average survival	Average performance
	Otohime B1	Average survival	Average performance
	Otohime B2	Average survival	Longer development time
	Otohime C1	Average survival	Average performance
	Conspecifics	Optimal survival	Optimal growth
IV-V[2]	Wet shrimp	Optimal survival	Optimal growth
	Fishmeal based	Poor survival	Longer development and poor growth
	Herringmeal based	Optimal survival	Molting problems
	Musselmeal based	Poor survival	Longer development and poor growth
	Shrimpmeal based	Optimal survival	Optimal growth

Table 1. Survival and growth performances of lobster larvae reared on different feeds.
[1]Powell *et al.*, 2017. [2]Hinchcliffe *et al.*, 2020.

Importance of cannibalism

Currently, in European lobster hatcheries, there is a large degree of cannibalism during larval stages, which are pelagic and consist of three stages prior to metamorphosis. Recently, Powell *et al.* (2017) investigated the effects of cannibalism in communal (conventionally reared) and experimental (individually reared) *H. gammarus* larvae. Communally reared larvae, fed dry feed, showed significantly improved survival and development rate (compared with experimentally unfed larvae). While this is unsurprising, some individuals in unfed groups nevertheless survived, developed and grew larger. Larvae were also reared individually in suspended perforated cells to eliminate cannibalism between live larvae and to allow full control of a rearing diet.

Larvae fed only dry feed showed the highest mortality rates and poorest development of any experimental group. The group fed humanely culled conspecifics only (cannibal treatment), showed significantly higher survival throughout the experiment (ca. 84% survival compared with 40%–52%, respectively). This finding represents the highest growth and survival of *H. gammarus* larvae in the literature and shows that individual rearing, using an appropriate feed and feeding protocol, could theoretically reduce larval losses due to cannibalism by over 60%, although not commercially viable at larval stages.

Individual rearing of lobster larvae should be targeted at lobster juveniles after metamorphosis, i.e. from stage IV onwards. Ultimately, the importance of cannibalism for the survival and growth of larvae indicate the benchmark that formulators should aim for when designing a novel feed, and the results provide a basis to design a species-specific feed formulation that supports optimum growth and development.

Crustaceans are a high source of phospholipids (Conklin *et al.*, 1980), n-3 PUFA (Haché *et al.*, 2015), astaxanthin (Lim *et al.*, 2018) and essential amino acids (Barrento *et al.*, 2009), all of which could play a crucial part in the increased survival rates observed from cannibalism.

Dry feeds for European lobster hatcheries and prevalence of molt death syndrome

Recently, a commercially available fishmeal-based dry feed (Otohime, grade B1, Marubeni Nisshin feed company, Tokyo Japan) has been used to successfully rear *H. gammarus* larvae from stage I to stage IV (Powell *et al.*, 2017). However, it is challenging to understand the nutritional requirements via observations, and changes in biochemical composition, which occur during periods of environmental stress and molting, cause changes in nutrient demand (Anger, 1998; Torres *et al.*, 2002).

Suboptimal feed can cause a variety of challenges when rearing lobsters, for example *Molt death syndrome* (MDS) which causes mortality by entrapment in the exuviae (Conklin, 1995). Conklin *et al.* (1980) stated that the inclusion of soy lecithin in the purified diet of crustaceans is critical for survival and prevention of MDS, and that its absence can reduce survival dramatically. This was supported by Coutteau *et al.*

Hatchery set up in Kristineberg showing 100 L tanks used to contain European lobster larvae.

Selection of dry feeds that have been used to grow stage IV of European lobsters.

(1997) who highlighted the need to understand the interaction between protein sources and phospholipids in diets of crustaceans, although, to the best of our knowledge, no further work has followed this in Homarid lobsters specifically.

Recently, Hinchcliffe *et al*. (2020) assessed the suitability of alternative protein sources, the effect of drying and the effect of added supplements in dry feeds on European lobster stage IV individual survival and growth performance and concluded that feeds containing a portion of freeze-dried crustacean sources improve growth and survival and reduce the prevalence of MDS. While current hatchery practices yield survival many orders of magnitude higher than in the wild, there is still room for improvement on the typical survival to stage IV and beyond (perhaps 25%). This may be achieved by embracing a dry formulated feed designed for the species according to life stage.

Sustainability potential of local protein sources

Overall, the results of the present work suggest that the shrimp processing sector represents an undervalued resource that can be upgraded to feed ingredients, which may not require the addition of valuable supplements. In conclusion, the present work confirms the usefulness of the method of Tlusty *et al*. (2005) to screen an array of candidate feeds relatively quickly, studying young American lobsters.

The work involved in the present project also provides a breakdown of lobster feed composition and a method to make satisfactory dry feed (e.g. freeze-dried crustacean based feed, see Hinchcliffe *et al*., 2020) that may assist home aquarists and the restocking subsector. Although it is challenging to understand the ecological and nutritional needs of juvenile *H. gammarus*, the results of the project show that a diet containing a proportion of shrimp, created from local industry by-products, has potential to produce a satisfactory dry feed for European lobster larvae, utilizing a circular economy concept to reduce dependence on fishmeal.

This work has led to Sweden's first pilot scale lobster hatchery in Kristineberg, Sweden, which is now using optimized feeding techniques to produce and release lobster juveniles into local waters, in association with Sotenäs Municipality and funded by the Swedish Board of Agriculture. Coupled with this, a number of interactive workshops intended to inform and assist Swedish companies in aquaculture technologies have been organized, this activity could further support a nascent Swedish lobster production and restocking program.

References available on request

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Developments in aquaculture

Ruben Props & Jasmine Heyse, Center for Microbial Ecology and Technology (CMET), Ghent University, Belgium

Microbiome insights: few and far between

Microorganisms represent by far the most abundant life form in all aquaculture systems. While farmers have a strong commitment to the health, well-being and overall performance of the animal stock, the invisible microbial majority usually receives far less compassion. This is caused by the limited knowledge on the role of the microbiome in animal health and the inherent difficulty in timely observing and diagnosing dysbiosis in the (host) microbiome. Microbial communities inhabit all compartments of aquaculture farms, have both sessile and planktonic niches, can change metabolism within minutes to hours, and generally consist of up to thousands of unique populations, each with their own metabolic potential.

With these aspects in mind, understanding the role of the aquaculture microbiome demands analytical methods that enable the measurement of all microbes and that can provide a temporally resolved view of the microbiome. Case-in-point: opportunistic pathogenic bacteria, such as *Vibrio* spp., are often detected in both "healthy" and "diseased" aquaculture systems. This finding alone challenges the notion that monitoring the presence of pathogens is sufficient to guide management and ensure biosecurity. Unfortunately, our knowledge on the aquaculture microbiome has largely been derived from cultivation-based methods (e.g., plate counts). These methods not only retrieve a small fraction of the microbiome (e.g. < 0.1 - 1 %), they are also often accompanied by sparse and irregular sampling that mismatches with the underlying microbiome dynamics. As mentioned in a previous edition of this column, it is surprisingly difficult to find an estimate on even the most basic microbial parameters, such as the dynamics of the bacterial load in the rearing water. High-resolution monitoring campaigns that unveil the structure, interactions and dynamics of the microbes in these systems are scarce, yet, they are the key to furthering our understanding of the role of the microbiome in disease outbreaks. Despite the advent of more "high-tech" technologies, such as next-generation sequencing and flow cytometry, the cost and required technical and (bio-)informatic skill set has prohibited them from becoming widely adopted in the field of aquaculture. Significant progress has recently been made in making targeted diagnostic services miniaturized and accessible to the farmer, but these have not yet proven to sufficiently guarantee biosecurity.

A key aspect to enable effective microbiome management is understanding the sources and processes that shape the structure of the rearing water and larval microbiomes. The rearing water tanks are complex systems with many inputs that vary over time. One could expect the rearing water microbiomes to be very dynamic as there are constant disturbances through the addition of live and dry feeds, water exchanges, and the addition of probiotics. Many of these disturbances are associated with an active addition of microbes to the rearing water. To what extent the introduced microbes can survive, or even grow, in the system is not well known. During disturbances, the community assembly will be driven by both stochastic and deterministic processes. The relative importance of these two will likely be dependent on the rearing technology, which dictates the intensity and frequency of the disturbances, as well as the selective pressures that are imposed on the microbes. The importance of stochasticity is illustrated through the large variability in performance that is often observed across replicate tanks or even across individual animals from the same tank. Associating both assembly processes with aquaculture operation requires a commitment to longitudinal studies in order to gather sufficiently rich datasets. These big data may then inform management through, for example, optimal and timely probiotic dosing, or predicting the risk of invasion by opportunistic pathogens. The establishment of effective and sustainable microbial management strategies would be greatly accelerated by increasing our knowledge regarding the microbial ecology of these systems. A concerted effort among both industrial stakeholders, who have access to diverse aquaculture platforms, and academic partners, who have access to the know-how of next-generation technologies, is paramount to revolutionize the fundamental basis on which aquaculture microbiome management must be based.

Storage of seawater before use can prevent losses by pathogens in finfish and shellfish hatcheries

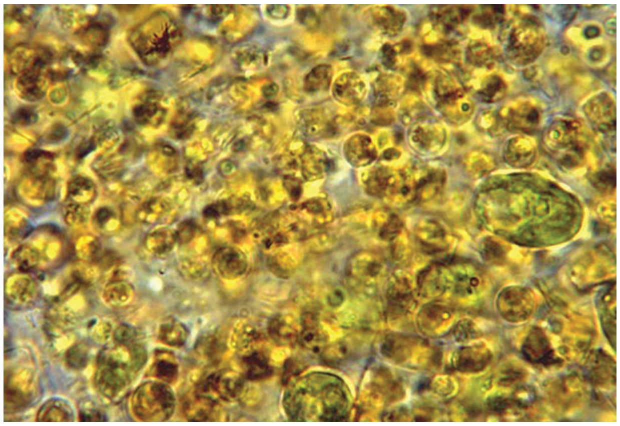
Eric C. Henry, Reed Mariculture

In recent years, there have been anecdotal accounts of reduced pathogen problems in both shellfish and finfish hatcheries when a diverse bacterial population is allowed to develop.

For example, the Auburn University Shellfish Laboratory experienced frequent larviculture failures attributable to *Vibrio* outbreaks after installation of a new seawater system with powerful UV treatment. These problems continued for two years until they adopted the practice of first storing the water for 24 hours before use and stopping UV treatment, whereupon the larviculture failures ceased (see Scott Rikard's talk on oyster hatcheries in the South ~ 2017 Oyster South Symposium). This contradicts the conventional wisdom that the best defense against *Vibrio* pathogens is stringent sanitary precautions to reduce the number of bacteria present with the hope of preventing invasion by pathogens. But it can be difficult to impossible to prevent invasion of a hatchery by all pathogenic *Vibrios*, because all seawater entering the hatchery must be sanitized, broodstock and algae cultures must be kept free of pathogens, airborne transport of pathogens must be prevented (very difficult in a shoreline location), and all these measures must work without breaches all the time.

Vibrio Predatory Bacteria mechanism

Now, there are published experimental studies that demonstrate how water storage can prevent *Vibrio* pathogens from causing problems in hatcheries. The preventive mechanism is the activity of *Vibrio* Predatory Bacteria (VPB), which appear to be ubiquitous in raw seawater. As shown by the very comprehensive study of Richards *et al*. (2012), and more recent studies by this lab, when raw seawater is stored for several days, during the first 24 hours pathogenic *Vibrios* bloom



Shellfish Diet 1800®: a unique mix of *Isochrysis*, *Pavlova*, *Tetraselmis*, *Chaetoceros calcitrans*, *Thalassiosira weissflogii* and *Thalassiosira pseudonana*.

to very high numbers, but by 48 hours VPB bloom and progressively reduce the numbers of pathogenic *Vibrios* and at 72 hours they are virtually undetectable. This pattern of VPB activity was shown to consistently occur in seawater samples from multiple sites in Delaware, Alabama, Oregon and Hawaii.

These findings support the recognition by many operators of RAS (Recirculating Aquaculture Systems) facilities that the health of their animals improves when the hatchery "biofilter," which harbors a bacterial consortium designed to remove nitrogenous wastes, has sufficient time to develop a diverse bacterial community. This concept is supported by the findings of a recent study (Kandel *et al*., 2014) that showed by molecular genetic analysis that biofilters in both freshwater and saline finfish RAS facilities also harbor diverse populations of VPB.

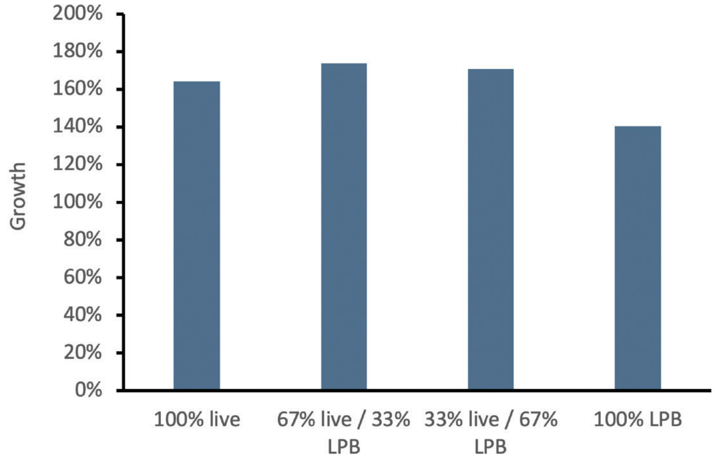


Figure 1. *Crassostrea gigas* growth (end weight/strat weight, as %). Carlsbad Aquafarms (August 13, 2019 to September 3, 2019). Fed 0.15mL/g per day. Live feed: *Isochrysis*/*Pavlova* mix.

Low-cost measures

Fortunately, only simple and low-cost measures are required for hatcheries to take advantage of this phenomenon:

- All seawater entering the aquaculture facility should be stored before use, preferably for three days.
- Storage for less than three days may be effective if the seawater storage tank already contains a concentrated population of predatory bacteria. Such populations can be created by allowing a residue of settled material to accumulate in the storage tank. Therefore, the tank should not be completely emptied or cleaned when water is removed for use.
- Seawater should not be sanitized, e.g. by UV. This can kill *Vibrios*, but it also kills predatory bacteria. Storage of seawater establishes active populations of VPB that may continue to protect larvae and later stages in the hatchery.
- Broodstock used in the hatchery should be *Vibrio*-free and maintained in stored seawater.
- Water storage for 2-3 days will remove most of the phytoplankton from seawater, so in bivalve hatcheries algae must be added to feed broodstock, larval and spat cultures.
- All food algae should be free of *Vibrios*, and so must be cultured using only stored seawater or commercial algae concentrates should be used.

After storage has allowed VPB to eliminate *Vibrios*, the seawater can be filtered (commonly to five or one micron) to remove larger organisms (zooplankton) and then used as usual.

Protection against oyster herpesvirus

Storage of seawater before use has been shown to also provide reliable protection against infection by oyster herpesvirus (Whittington *et al.*, 2015). Although oyster herpesvirus has not yet proved to be a significant concern to bivalve hatcheries in North America and some other parts of the world, it is important to consider that this virus was not a significant problem for *C. gigas* hatcheries until relatively recently, when it struck whole production regions in distant parts of the world. It appears that all kinds of bivalves are susceptible to infection by herpesviruses, so the potential for a newly virulent strain to arise and spread worldwide should remain a concern for all shellfish producers.

When seawater is stored and even relatively coarsely filtered before use, most of the resident plankton will be removed, requiring that hatcheries and bivalve nurseries add algae to the water to feed their animals. Fortunately, it is no longer necessary for hatcheries to make the substantial investments in infrastructure, personnel training, labor and energy costs required to produce large amounts of algae themselves. Reed Mariculture's Instant Algae® concentrates are effective feeds for culture of rotifers and for greenwater applications in finfish hatcheries.

In bivalve hatcheries, Instant Algae feeds can supplement or completely replace natural phytoplankton or algae cultured on-site, eliminating the risk of toxic phytoplankton blooms or algae culture crashes. Reed Mariculture now introduces LPB Frozen Shellfish Diet®, formulated with a larger cell-size distribution than Shellfish Diet 1800®, for more efficient feeding by larger larvae and spat. Results from this feed trial demonstrate the efficacy of LPB with spat of *Crassostrea gigas*.

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Importance of astaxanthin as a dietary supplement in aquaculture

Terry W. Snell, Stacy E. Harder, Matthew Carberry, John Carberry, Sustainable Nutrition

What is astaxanthin and what are its uses in aquaculture?

Astaxanthin is a carotenoid, comprising a diverse group of lipid-soluble pigments synthesized by a variety of organisms including yeast, bacteria and microalgae (Higuera-Ciapara *et al.*, 2006). Astaxanthin (3,30-dihydroxy-b,b0-carotene-4,40-dione) is a vitamin A precursor and a form of β-carotene widely distributed in nature (Torrissen & Christiansen, 1995). It is commonly used in a variety of commercial applications (Lorenz & Cysewski, 2000; Li *et al.*, 2011; Markou & Nerantzis, 2013; Zhang *et al.*, 2014). Carotenoids are best known for their contribution to the wide array of pigmented colors found in many aquatic species. Astaxanthin has marked effects on pigmentation, and is widely used as a colorant in formulated diets in the aquaculture industry. In addition to this widely appreciated role as a colorant, diets including astaxanthin also produce better survival, growth and reproductive rates, stress tolerance and disease resistance in fish, for reasons that are poorly understood (Torrissen & Christiansen, 1995). Despite its importance, aquatic animals are generally unable to synthesize astaxanthin, and thus require a dietary source of astaxanthin to realize its benefits (Nakano *et al.*, 1995; Lorenz & Cysewski, 2000; Moriel *et al.*, 2005; Liu et al., 2006; Kim *et al.*, 2006). It is well-known that astaxanthin contains conjugated double bonds at the center of its 28 carbon backbone that allow it to act as a powerful antioxidant with significant and broad biological effects (Yang *et al.*, 2013). The wide range of physiological benefits that astaxanthin confers to aquatic species is discussed below.

Benefits of astaxanthin for rotifer mass culture

As animals in closed system aquaculture do not have access to natural astaxanthin, it is necessary to supplement astaxanthin in their diets (Higuera-Ciapara *et al.*, 2006). Rotifers are easy to culture and enrich; therefore, developing an effective method for astaxanthin enrichment improves the nutritional value of rotifers for fish larvae, thus improving survival, accelerating growth and increasing reproductive rates. Johnston *et al.*, 2018 used the rotifer *Brachionus manjavacus* to demonstrate how supplementation of rotifer diets with astaxanthin extracted from the green alga *Haematococcus pluvialis* positively affects rotifer population growth and mass culture performance. Not only did this study demonstrate that rotifers are capable of absorbing and incorporating astaxanthin, but they also showed that supplementation of the rotifer *B. manjavacas* with astaxanthin yielded up to 43% faster reproductive rates, higher population densities and more stable mass cultures. As a powerful antioxidant, astaxanthin also markedly enhanced rotifer resistance to oxidative stress, a common cause of collapse in rotifer mass cultures, allowing rotifer populations to reach and sustain higher densities (Johnston *et al.*, 2018). Similarly, astaxanthin dietary

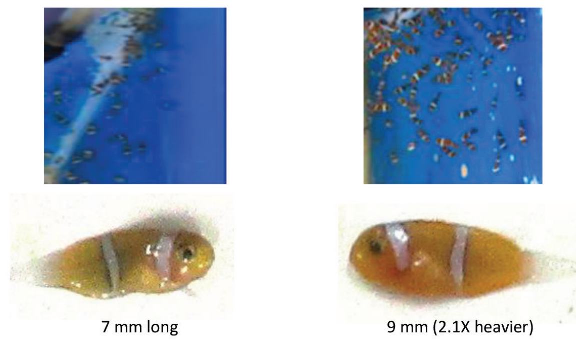

Figure 1. Comparison of clownfish juveniles (14 dph). Clownfish on left was fed rotifers cultured solely on the green microalga *Tetraselmis suecica*. Clownfish on right was fed rotifers cultured on *T. suecica* and enriched with Amplifeed Replete. The latter clownfish were 2.1 times heavier than the controls on day 14. Also note the deeper orange coloration of this fish.

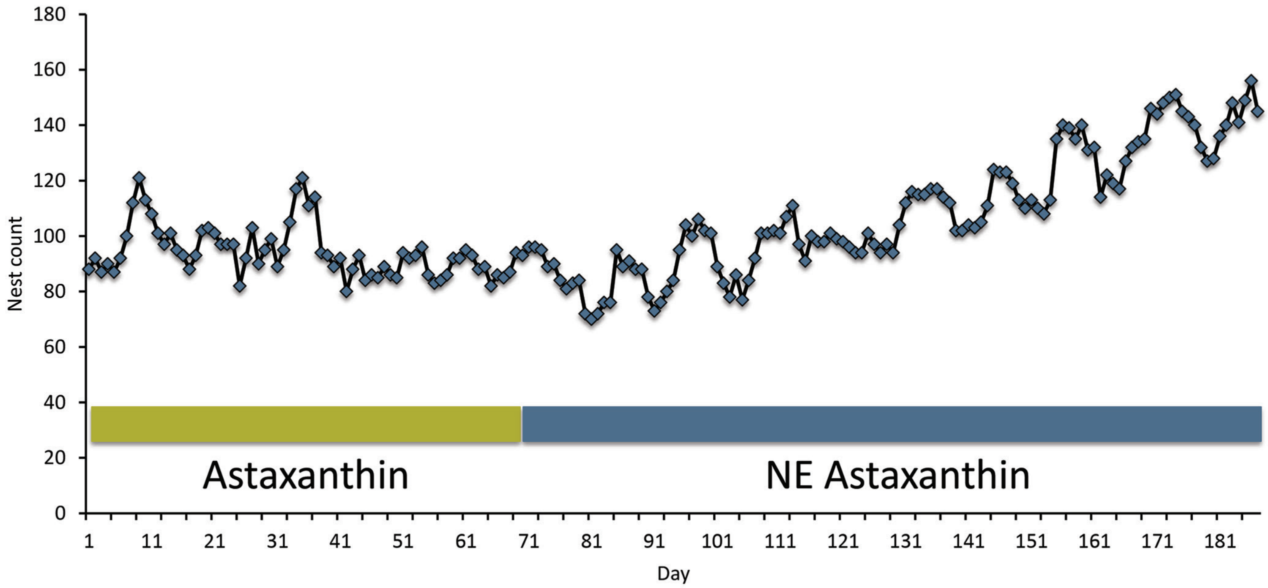

Figure 2. Nest counts from all clownfish broodstock in Sustainable Aquatics hatchery. Broodstock were fed a diet containing nano-emulsified astaxanthin beginning on day 69. Nest counts gradually increased over the next 112 days from a mean of about 90 to about 150.

supplements of 10-40 mg kg^{-1} had comparable effects on the resistance to ammonia stress of the characid ornamental fish, *Hyphessobrycon eques* (Pan *et al.*, 2011).

Benefits of astaxanthin for fish larviculture

When astaxanthin is included in the diets of larval fish, they grow faster, mature faster and achieve darker coloration than controls lacking astaxanthin. For example, a dose of as little as 20 ppm astaxanthin in the diet enhanced red hue in clownfish after 5 weeks (Yasir & Qin, 2010). Another example for clownfish was observed in the Sustainable Aquatics hatchery and can be seen in Figure 1. We found better survival rates in clownfish larvae fed rotifers enriched with Amplifeed Replete, a rotifer enrichment dietary supplement containing astaxanthin.

Several studies indicate that diets supplemented with astaxanthin also significantly improve reproductive performance, egg production and egg quality of aquatic animals (Vassallo-Agius *et al.*, 2001; Ahmadi *et al.*, 2006; Paibulkichakul *et al.*, 2008; Tizkar *et al.*, 2013, 2015; Palma *et al.*, 2016). Moreover, aquatic animal species supplemented with astaxanthin often have higher survival rates and accelerated growth rates.
For example, Atlantic cod broodstock fed diets containing higher astaxanthin (100 ppm) had higher egg production and efficiency of egg output, lower egg mortality, and higher larval growth and survival (Hanssen *et al.*, 2016). Broodstock fed more astaxanthin also had significantly higher fertilization success. These authors concluded that increasing astaxanthin content in broodstock diets improved Atlantic cod health and fecundity. Likewise, rainbow trout specific growth rates were 33% higher in the offspring of females fed diets supplemented with 12.5 – 92.9 mg astaxanthin kg^{-1} than in offspring of control females fed a non-supplemented diet (Bazyar *et al.*, 2009). Regrettably, the biological mechanisms which mediate these desirable effects are still poorly understood.

Issues of astaxanthin bioavailability

The lipophilic character of carotenoids and their association with biological membranes limits their bioavailability (Viera *et al.*, 2018). Carotenoids act as antioxidants in cells, reducing cellular damage and strengthening disease resistance. Bioavailability of carotenoids is determined by their isomerization (there is selective absorption of cis-isomers), their source as natural or synthetic, whether they are dispersed in lipid-based formulations, or administered with *H. pluvialis* biomass (Viera *et al.*, 2018).

All biological processes are very vulnerable to reactive oxygen species (ROS) and oxidative stress. Having abundant intracellular antioxidants can mitigate oxidative damage. Astaxanthin takes up residence in cell plasma membranes and in the mitochondria themselves. This is where much of the ROS in cells is generated and resides.

Studies of astaxanthin have shown that bioavailable astaxanthin imbedded in plasma membranes is protective of ROS damage (Viera *et al*., 2018).

One of the biggest challenges in formulating diets with astaxanthin is maintaining its bioavailability. Many studies have explored natural sources of astaxanthin, settling on the freshwater green alga *Haematococcus pluvialis* as the most commercially viable source (Torrissen & Christiansen, 1995). However, several studies have shown comparatively poorer efficiency in pigmentation of salmonids when using *H. pluvialis* as a source of astaxanthin, compared to a synthetic form of astaxanthin (Sommer *et al*., 1991; Sommer *et al*., 1992; Choubert & Heinrich, 1993). In all cases, it was suggested that poorer pigmentation was a result of reduced bioavailability of astaxanthin from *H. pluvialis*, due to astaxanthin being sequestered within encysted cell walls. Scientists at Sustainable Nutrition determined that to make astaxanthin bioavailable, a nano-emulsion was necessary, as reported by Affandi *et al*. (2011). Thus, a patented technology was developed, providing a nano-emulsified form of astaxanthin that allowed elimination of antibiotic use, doubled fish growth rates and increased egg production by 300%. This technology uses high energy in warm ethanol to not only extract the astaxanthin, but to break the encysted cells containing astaxanthin into nano-sized molecular complexes, making Sustainable Nutrition astaxanthin the most bioavailable form available. Future investigations will explore additional means of increasing the bioavailability of astaxanthin and improving its resistance to degradation in fish feeds in order to further enhance its usefulness in aquaculture.

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Improving feed efficiency, a priority in aquaculture

Benjamin J. Renquist, Genetirate Inc.

Feed efficiency in aquaculture far exceeds that in land-based agriculture species. In fact, the feed conversion ratio (gain (kg)/feed (kg)) is 6-10 in beef cattle, 3-5 in pigs, 1.7-2 in chicken and 1 to 1.5 in fish species (Fry *et al*., 2018). This improved efficiency is primarily associated with the efficiency gained from adapting body temperature to the environmental temperature (ectotherm) rather than maintaining a constant body temperature (endotherm). In support of this key role of ectothermy in feed efficiency, when insects (ectotherms) are fed a high-quality diet feed conversion ratio is near 1 (Nakagaki *et al*., 1991). Moreover, insects are efficient when provided a diet of food by-products (Oonincx *et al*., 2015).

Although the feed conversion ratio in fish species is low, the conversion of the protein and calories in fish feed into human consumable product is not significantly better in fish than in many land-based agriculture species (Fry *et al*., 2018). To improve the conversion of animal feed into consumable production, aquaculture must work to improve the yield (percent of consumable production relative to whole animal mass) or improve feed efficiency.

Genetic selection for yield

Genetic selection in chicken has dramatically improved both whole carcass (12.4%) and breast (97.7%) yield (Havenstein *et al*., 2003), with heritability estimated to be 0.24 (Gaya *et al*., 2006). In cattle, percent lean yield is highly heritable (0.42 ± 0.17) (Crews *et al*., 2001). Filet yield is highly to moderately heritable in tilapia (h^2 = 0.38) and carp (h^2 = 0.50) (Garcia *et al*., 2017; Prchal *et al*., 2018). However, selection based on filet yield requires sacrificing the animal on which yield is measured. Accordingly, selection for yield has been limited. Still, new technologies that indirectly assess yield including SNP and ultrasound analyses are moving

this selection forward and will be key to improving the conversion of animal feed into consumable products for humans (Tsai *et al*., 2015; Vandeputte *et al*., 2019).

Financial benefit of selection for feed efficiency

Selection to improve feed efficiency has the potential to address producer costs and expand upon sustainability. With feed costs constituting 40-70% of total expenses, improvements in feed efficiency have the potential to dramatically decrease cost of production. At current market values (Table 1), with a set 10% profit margin, and feed costs constituting 50% of production costs, a 2.5% improvement in feed efficiency would increase profitability by 1.13%, while a 10% improvement in feed efficiency would increase profitability by 4.5%. This equates to an added profit per fish of $1.20, $0.07, and $0.20 for Atlantic salmon, rainbow trout and tilapia. Alternatively, an added profit per one million kg of fish exceeding $300,000, $115,000, and $198,000 for Atlantic salmon, rainbow trout and tilapia, respectively.

Environmental benefit of selection for feed efficiency

Improving feed efficiency will limit the environmental impact of aquaculture production. In carnivorous fish species fishmeal is integral to production. This fish meal is highly dependent on the catch of wild fish (Naylor *et al*., 2000; Papatryphon *et al*., 2004).

Atlantic salmon (farm gate price: $6.68/Kg) 4 Kg harvest fish	Feed costs as % of total costs			
Improvement in feed efficiency (%)	70%	60%	50%	40%
2.50%	$0.421	$0.361	$0.301	$0.240
5.00%	$0.842	$0.721	$0.601	$0.481
7.50%	$1.263	$1.082	$0.902	$0.721
10.00%	$1.683	$1.443	$1.202	$0.962

Rainbow trout (farm gate price: $2.57/Kg) 600 g harvest fish	Feed costs as % of total costs			
Improvement in feed efficiency (%)	70%	60%	50%	40%
2.50%	$0.024	$0.021	$0.017	$0.014
5.00%	$0.049	$0.042	$0.035	$0.028
7.50%	$0.073	$0.062	$0.052	$0.042
10.00%	$0.097	$0.083	$0.069	$0.056

Tilapia (farm gate price: $4.40/Kg) 1 Kg harvest fish	Feed costs as % of total costs			
Improvement in feed efficiency (%)	70%	60%	50%	40%
2.50%	$0.069	$0.059	$0.050	$0.040
5.00%	$0.139	$0.119	$0.099	$0.079
7.50%	$0.208	$0.178	$0.149	$0.119
10.00%	$0.277	$0.238	$0.198	$0.158

Table 1. Increase in profitability (USD$)/fish.

New farmed protein and fat sources are working to limit this pressure on wild fish populations, but with the high costs of production they have done little to address feed costs.

By limiting the feed per pound of product, improvements in feed efficiency can also limit water quality and effluent concerns. Notably, aquaculture production in many areas is being limited by phosphorus or nitrogen release into the environment (Papatryphon *et al.*, 2004). Improved feed efficiency decreases the phosphorus and nitrogen inputs required to produce product. Accordingly, there is less pass through into the environment and more production can be sustained per unit of these elements released.

Finally, aquaculture has taken an active role in limiting the carbon release per unit of animal protein production. In fact, total greenhouse gases are 15.5 CO_2 equivalents/kg beef and less than 5 CO_2 equivalents/kg salmon (Ziegler *et al.*, 2013; Phetteplace *et al.*, 2001). Still, there is room for improvement. Since feed production is the primary source of greenhouse gas emissions in aquaculture, improvement in feed efficiency will further establish aquaculture as the green source of animal protein (Ziegler *et al.*, 2013; Hasan & Soto, 2017).

Methods to select for feed efficient animals

Although the benefits of improved feed efficiency in limiting costs and improving sustainability are clear, the methods by which to select for improved feed efficiency are limited. The best-established method to identify fish that are more feed efficient is to measure weight loss in response to an extended fast. By eliminating feed intake, assessing weight loss during a fast is an indirect measure of basal metabolic rate, the energy an animal expends to maintain life. Mass lost during a fast is inversely related to basal metabolic rate. Accordingly, fish that lose less mass during a fast expend less energy maintaining basal function and can put more dietary energy toward growth. Although effective, this method is limited in that it is difficult to apply across a production system and may lack sensitivity. We have recently shown that by measuring NADH production in skeletal muscle biopsies we can identify feed efficient animals (Beckett *et al.*, 2019). This relatively non-invasive and scalable measure of skeletal muscle metabolism provides a unique tool to advance feed efficiency in aquaculture.

With the opportunity to increase profitability while meeting consumer demands for sustainability, it is essential that aquaculture researchers develop and aquaculture producers adapt production systems, diets, and genetic selection tools to improve feed efficiency.

References available on request

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Developing an operational welfare index for lumpfish

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Stakeholder focus groups set up to test some of the welfare metrics and discuss potential solutions for improving lumpfish welfare.

Parasitic sea lice (*Lepeoptheirus salmonis*) represent one of the major challenges threatening the salmon farming industry. Sea lice affects the health and welfare of salmon, compromises their survival and growth and has a huge environmental and economic impact in terms of lost revenue and negative publicity. Sea lice have developed widespread resistance against most chemotherapeutants (Aaen *et al*., 2015), and the use of lumpfish has become a popular alternative to control sea lice. However, lumpfish survival is often poor in sea cages and little is known about their welfare under farm conditions.

Lumpfish operational welfare indicators

A practical approach to measure fish welfare is through the use of welfare indicators (Treasurer *et al*., 2018) which need to be developed and validated for novel species in aquaculture. Funded by the EC–KESSII program, and in collaboration with Ocean Matters Ltd (the leading UK lumpfish producer), we have developed a Lumpfish Operational Welfare Index (LOWI) to monitor welfare in farm environments, reduce mortalities and ultimately enhance delousing efficiency.

Juveniles were screened at two different stages of development (pre-deployment in the hatchery and post-deployment in sea cages) and the following metrics were used to develop an operational welfare index: (1) external condition, (2) fin damage, (3) eye condition, (4) eye darkening and (5) suction disc deformities (Fig. 1). Plasma cortisol and relative weight were used to validate the welfare metrics, and their repeatability was assessed by the Intraclass Correlation Coefficient (ICC), both within and among observers.

Results

Principal Component Analysis (PCA) was performed on the welfare indicators to obtain an aggregated welfare score. The first component accounted for 39% of the variation and was mostly associated with suction disc deformity, eye darkening and external condition. The second component accounted for 21% of the variation in welfare scores and was negatively affected by eye condition and fin damage, and positively associated with plasma cortisol levels (R^2=0.4, $p<0.01$).

Welfare indicators were affected by age (Fig. 2) suggesting that they should be tailor-made depending on the life stage (pre- or post-deployment). Fin damage and eye condition were the most important determinants of lumpfish welfare at post-deployment stage (sea cages) while suction disc deformities were more important at the hatchery stage. Fin damage and eye condition tend to deteriorate in sea cages and are

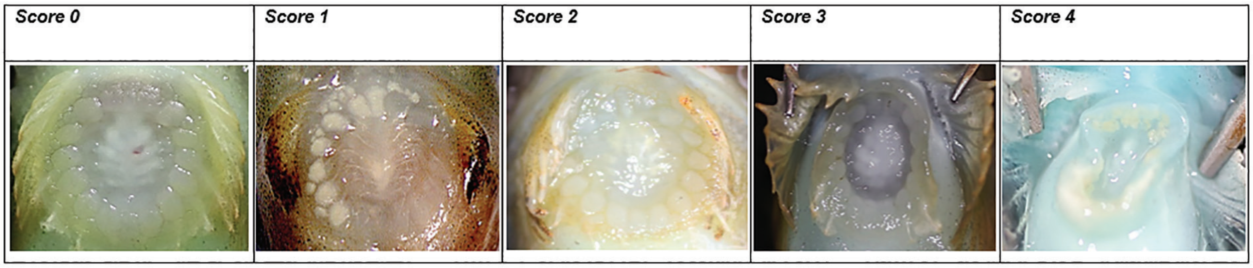

Figure 1. Suction disc deformity scoring chart on a 5-point scale (0-4) used on the development of welfare indicators, based on the severity and extent of area affected. 0: Perfect and functional suction disc. 4: Deformed and non-functional suction disc.

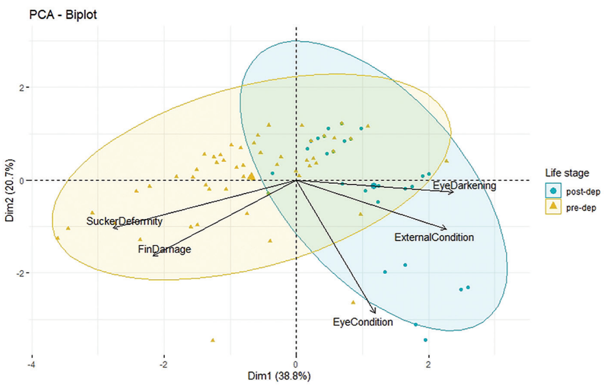

Figure 2. Principal Component Analysis (PCA) showing the strength of the welfare metrics and differences between pre-deployment (hatchery) and post-deployment (sea cages) lumpfish.

particularly important for welfare and also delousing efficiency, as lumpfish are visual feeders and need to chase salmon to feed on sea lice (Jonassen *et al.*, 2017).

The refined Operational Welfare Index, which consisted in the assessment of (1) skin damage, (2) caudal fin damage, (3) eye condition, (4) suction disc deformities and (5) relative weight, was tested by ten fish farmers and was found to be repeatable (R_{OWI}=0.826, 0.767-0.871, p<0.01). All fish farmers found the Lumpfish OWI useful and said they would be willing to train their staff and implement it in their farms.

Promoting research on fish welfare

Fish welfare has increasingly gained public awareness over the last few decades. Swansea University's Centre for Sustainable Aquatic Research (CSAR) has been working with lumpfish since 2005 and fish welfare has always been a research priority. Hosted by the ERDF SMARTAQUA project, CSAR hosted the "First Symposium on Welfare in Aquaculture - Welfare Indicators for novel species" (https://www.youtube.com/watch?v=dSEb735jR5U) on May 14, 2019 with contributions by seven international speakers who gave talks on metrics of fish welfare, the effects of stress on welfare, the use of fish behavior as a welfare indicator and development of operational welfare indicators for farmed lumpfish, and public perceptions on fish welfare.

During an afternoon workshop on lumpfish welfare, focus groups were formed and asked to test and validate some of the welfare metrics and discuss potential solutions for improving lumpfish welfare.

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Industry Events

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JANUARY

15 – 16:	European Fish Mariculture Conference, London, UK	EU.MaricultureConference.com
29 – 30:	AquaExpo Santa Elena, Santa Elena, Ecuador	aquaexposantaelena.cna-ecuador.com

FEBRUARY

6 - 8:	Aquaex India, Bhimavaram, India	www.aquaexindia.com
9 – 12:	Aquaculture America 2020, Hawaii, USA	was.org
13 - 14:	Design of Food Extrusion Dies, Sion, Switzerland	www.fie.com.au
19 – 20:	Aquafarm, Pordenone, Italy	www.aquafarm.show

MARCH

16 - 17:	International Conference on Aquaculture, Bangkok, Thailand	aemconferences.com/aqua/
17 - 19:	AFIA Purchasing & Ingredient Suppliers, Seattle, USA	www.afia.org
24:	Aquafeed Horizons Asia 2020, Bangkok, Thailand	feedconferences.com
24 - 26:	VICTAM and Animal Health and Nutrition Asia, Bangkok, Thailand	victamasia.com
March 30 - April 1:	Aquafeed Extrusion Technology Course, Temuco, Chile	www.fie.com.au

APRIL

22 - 24:	International Genomics in Aquaculture Symposium, Granada, Spain	www.gia2020.es

MAY

7 - 9:	Guatemala Aquaculture Symposium, Antigua Guatemala, Guatemala	acuiculturaypescaenguatemala.com
17 - 19:	ONE: The Alltech Ideas Conference, Lexington, KY, USA	one.alltech.com
19 - 21:	Aquaculture UK, Scotland, UK	aquacultureuk.com
20 - 21:	World Aquaculture and Fisheries Conference, Tokyo, Japan	worldaquacultureconference.com

JUNE

8 - 12:	World Aquaculture 2020, Singapore	was.org
17 - 18:	EnhanceMicroAlgae Conference, Manchester, UK	lfc44.uconn.edu
21 - 26:	44th Larval Fish Conference, Mystic, CT, USA	enhancemicroalgae.eu

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www.prochaete.com

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Sparos Lda
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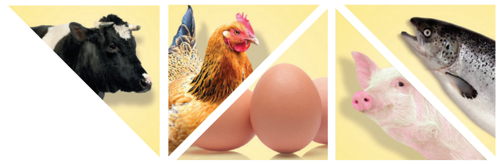

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