science & solutions

Issue #03 | Aquaculture

From feed to immunity:

a focus on fish and shrimp health

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From exposed to protected
In aquaculture, fish and shrimp are constantly exposed to pathogen pressures, environmental fluctuations and other production stressors, negatively impacting survival and productivity.
At dsm-firmenich, we offer solutions to protect aquatic animals, reducing the risk of health and welfare challenges throughout the production cycle.
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In brief

Diseases in aquaculture can significantly reduce production efficiency by more than 30%

Maintaining the health of farmed fish and shrimp is essential to guarantee the sustainable and profitable growth of the aquaculture industry.

Nutritionally balanced and highly digestible feeds are the first essential step towards increasing robustness.

From feed to immunity: a focus on fish and shrimp health

Diseases reduce aquaculture efficiency by over 30%; health maintenance ensures sustainable profitability with optimal feeds

By Sebastien Rider, Senior Scientist Aquaculture, Animal Nutrition and Health at dsm-firmenich

Nucleotide Supplementation: Boosting Immunity and Recovery in Aquaculture

During disease states and injury, the rapid cell proliferation required for cellular immune responses and tissue healing leads to nucleotide depletion. Nucleotides are the basic building blocks for the synthesis of DNA, RNA, ATP, and key coenzymes involved in essential metabolic processes. The cells of the immune system and the gastrointestinal tract are those most affected by shortfalls in the supply of nucleotides. Nucleotide synthesis is an energy intensive process that uses multiple metabolic pathways across different cell compartments and requires a variety of carbon and nitrogen sources. Moreover, nucleotide levels in diets have been declining in recent years due to a shift in feed formulations from marine to vegetable ingredients. To address this, dietary supplementation with nucleotides can be beneficial, particularly under conditions of rapid growth, stress, or disease. Nucleotides are the building blocks for essential cellular processes and their supplementation helps spare energy costs and optimize the function of rapidly dividing tissues like the gut and immune system. A highly purified nucleotide source, such as Rovimax®, has been shown to improve gut health, accelerate healing after injuries, and significantly enhance (up to 30%) both innate and adaptive immune responses in fish and shrimp*. This translates to higher survival rates when faced with pathogens. For example, studies have shown that Rovimax® supplementation increases resistance to bacterial diseases by over 20% in seabass against *Listonella anguillarum* and over 40% in tilapia and shrimp against *Streptococcus iniae* and *Vibrio parahaemolyticus*, respectively*.

How Vitamins Support Optimal Immunity in Aquaculture

Vitamins are essential for the generation of energy reserves necessary to mount immune responses and play specific and vital functions within the immune cell population. To set the best nutritional foundations for optimal aquaculture production we provide our Optimal Vitamin Nutrition™ guidelines (OVN®).

- B vitamins, including thiamine (B1), riboflavin (B2), niacin (B3), and others, act as co-pilots for numerous enzymes and fuel various metabolic pathways, including energy production. This is especially important for the immune system, which can consume a significant portion of an animal's energy reserves – up to 25% under normal conditions and even more when fighting off infections.

- Vitamin D plays a key role in the proliferation, differentiation, and regulation of immune cells and is also implicated in humoral responses. Immunoglobulins, complement proteins and antimicrobial peptides, including lysozyme, are all influenced by the actions of

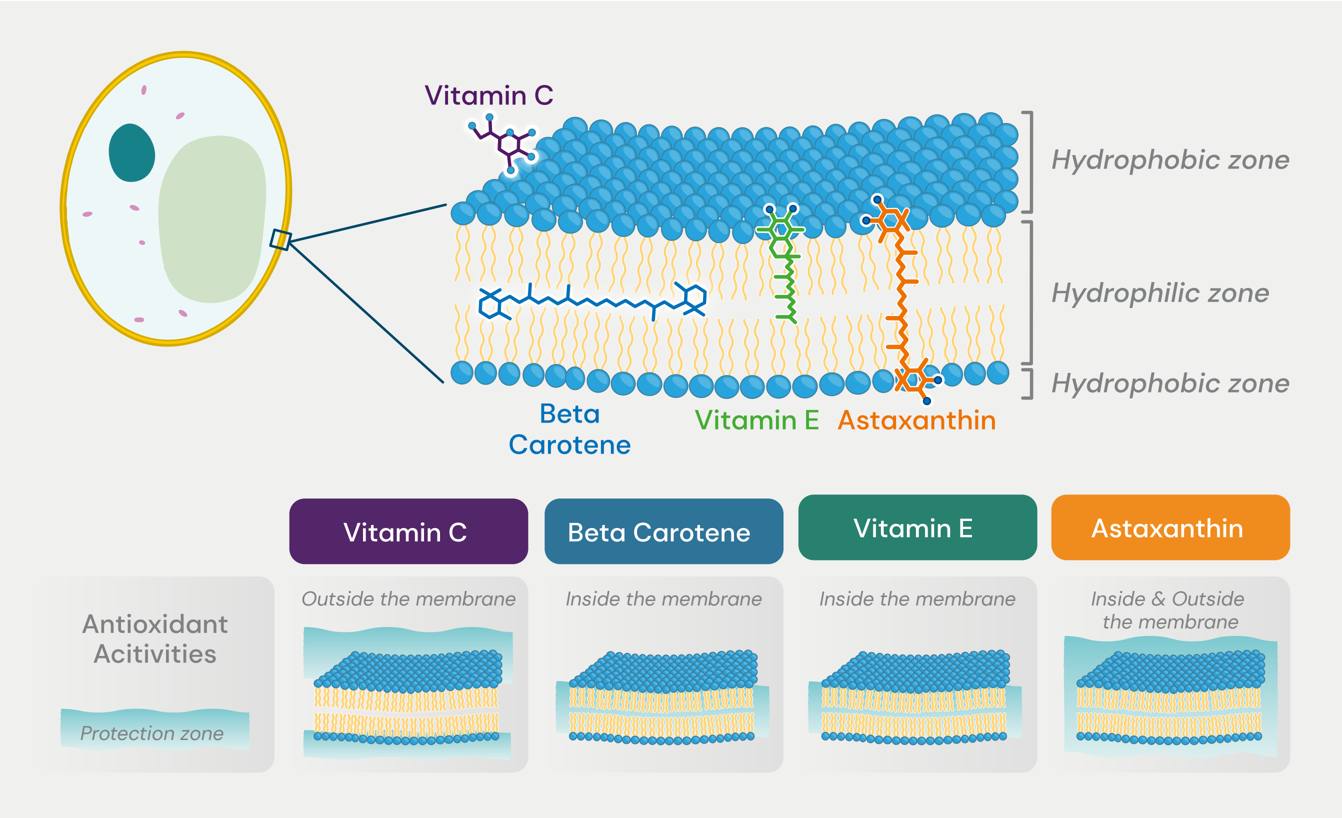


Figure 1. Astaxanthin's Superior Positioning: Hence Better Antioxidant Acitvity Cell membrane protection involves an antioxidant network with individual antioxidants protecting specific niches.

the vitamin D system. The recruitment of neutrophils to sites of infection or injury also depends on vitamin D. Recent *in vitro* studies have shown that D3 reduces the attachment and invasion of gram-negative bacteria to Atlantic salmon macrophages. In shrimp, the increased expression of antimicrobial peptides with D3 reduces the colonisation of *Vibrio parahaemolyticus* in the digestive tract. Recent dsm-firmenich studies showed improved resistance to bacterial pathogens by using ROVIMIX® Hy-D®, a more potent form of vitamin D.

- Vitamin E plays a fundamental role in the cellular component of the immune system by its antioxidant protection of cell membranes against oxidation. The potency of this antioxidant is increased by a synergy with the selenium-containing enzyme glutathione peroxidase. This protective effect is evidenced by the decrease of red blood cell fragility in fish with higher levels of plasma α-tocopherol, the active form of vitamin E in ROVIMIX® E50. Vitamin E also functions in the modulation of cell signalling, particularly those regulating immune antioxidant responses. Humoral responses also depend on dietary supplies of vitamin E. Responses of both the specific and innate immune systems are enhanced by increased supplementation of vitamin E. Several studies across a diversity of aquatic species have demonstrated a reduced disease resistance with vitamin E deficiency. On the contrary, higher levels of dietary vitamin E have been shown to enhance resistance to infectious diseases. Vitamin E supports the production of lysozyme with benefits on survival against bacterial infections. Enhancing feed levels of vitamin E in aquatic species has been shown to increase white blood cell counts, respiratory burst capability, and the activity of the alternative complement pathway.

Astaxanthin (active component in CAROPHYLL® Pink) is well known for its role in the pigmentation of both salmonids and shrimp, but its functions in the immune system are less well recognised. The molecular structure of astaxanthin gives it unique properties that make it the most potent antioxidant known for the protection of cell membranes. It is no surprise that dsm-firmenich studies have detected the presence of astaxanthin in the innate immune cells. The highest concentration of astaxanthin is in the macrophages, which are typically first responder cells performing their functions in highly oxidised tissues. The protection of macrophages by astaxanthin in these challenging environments has positive impacts on their phagocytic capability. The presence of astaxanthin in

immune cells increases resistance to both viral and bacterial disease. In juvenile salmonids, astaxanthin increases resistance to both bacterial and viral pathogens and in *Penaeus vannamei* shrimp astaxanthin improves resistance to Early Mortality Syndrome (EMS) caused by *Vibrio parahaemolyticus*.

- Vitamin C (ascorbic acid) is also known for its role in the immune function of both fish and shrimp. The reduced disease resistance associated with vitamin C deficiency has been documented in several aquatic species. For extruded feeds, ascorbic acid phosphate, the active form in STAY-C® 50 offers the best combination of stability and bioavailability. Vitamin C performs antioxidant functions in hydrophilic cellular environments and is also known for its regeneration of membrane-bound vitamin E. In the innate immune system, vitamin C is involved in the cellular component for leucocyte proliferation, phagocytosis & chemotaxis. Humoral responses including lysozyme & complement proteins also rely on an optimal dietary supply of vitamin C. Vitamin C is also required for immunoglobulin production by the adaptive immune system.

Conclusion

Immunity is a complex topic, but it is key to supporting a robust animal against a range of biological, physiological, and environmental stressors. Ensuring optimum vitamin level with OVN® is fundamental and even suboptimal levels can lead to reduced health, performance, and welfare. During periods of stress or increased disease risk, aquatic animals need additional nutritional support to maximize survival and growth performance. For this extra boost, Rovimax® delivers biologically available nucleotides quickly and directly to the gut with minimal energy investment, for maximum benefits in aquatic animals. Acting in concert, an optimal vitamin intake ensures production animals have a robust immune function that enables performance and survival in challenging conditions.

**Evidenced by dsm-firmenich in vivo feeding trials.*

In brief

Diseases pose a significant threat to the modern aquaculture industry, impacting productivity and animal welfare.

Best practices and animal welfare in aquaculture prioritize protecting animals from infections and subsequent diseases.

The presence of opportunistic pathogens in aquaculture creates a constant risk of disease outbreaks.

Bacterial pathogens are a leading cause of disease in aquaculture, driving antibiotic use. However, viral and parasitic infections also raise significant concerns.

Protecting aquatic species: strategies for pathogen management

Aquaculture faces constant disease threats, requiring best practices to protect productivity and animal welfare

By Benedict Standen, Head of Aqua Marketing Global, Animal Nutrition & Health at dsm-firmenich and Thiago Soligo, Aqua Marketing Manager Latin America, Animal Nutrition & Health at dsm-firmenich

The hidden costs of disease in aquaculture: beyond mortality

Weakened productivity is linked to reduced profitability. Although the exact cost of disease is unknown, it is widely accepted to be in the tens of billions of dollars every year. Mortality is the most obvious loss in profit, but there are also many hidden costs associated with disease, for example:

- Diagnostics & veterinary expertise
- Medicines and chemical treatments
- Time & labor
- Lost growth performance
- Feed losses & increased FCR
- Market access & consumer reputation

Aquaculture practices drive pathogen proliferation

Intensive aquaculture practices such as antibiotic usage, disinfection and even feeding can favor the proliferation of pathogenic bacteria (Figure 2). This is because many pathogens are r-strategists, which means they have high growth rates, especially in non-competitive environments and can dominate in unstable conditions. The opposite, K-strategists, including many probiotics, grow slower but dominate in stable conditions. This means that a disease management plan is required throughout the production cycle. This should include continuous pathogen surveillance and prioritizing proactive strategies to avoid pathogenic outbreaks, or reactive measures such as antibiotics.

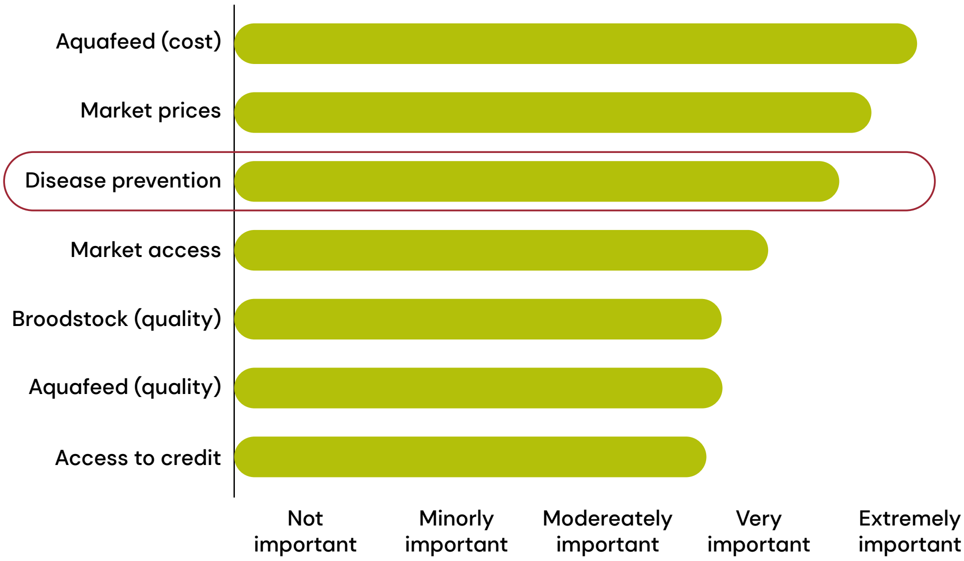


Figure 1: Key challenges faced by the aquaculture industry. Source: GOAL Survey 2022, Rabobank 2022

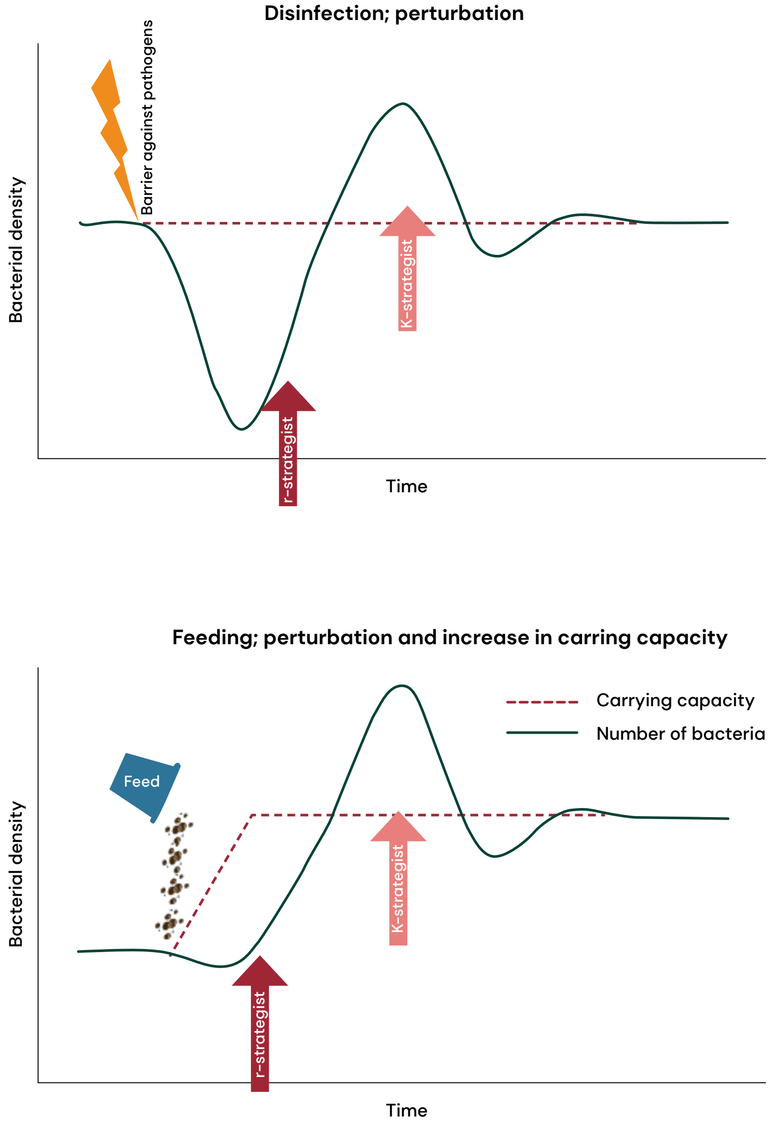


Figure 2: Examples of how current aquaculture practices promote r-selection, increase the probability of opportunistic bacteria (A) Disinfection of intake water. (B) Addition of feed to the system.

Source: Vadstein et al. 2018

Antibiotic reduction in aquaculture

In line with other protein sectors, antibiotics have traditionally been used to treat bacterial infections in aquaculture. However, their overuse leads to antimicrobial resistance and consequently the industry has many initiatives to reduce its reliance, in favor of preventative healthcare. For example, in addition to meeting Aquaculture Stewardship Council (ASC) criterion, the Sustainable Shrimp Partnership (SSP) in Ecuador also expects its members to use zero antibiotics. Similarly, Norway have grown their salmon production volumes, whilst reducing their consumption of antibiotics by 99%. The Chilean salmon industry has also managed to reduce its antibiotic usage by 50% since 2017, although to a lesser extent. In 2022, Chilean salmon reported to use 458.6 g of antibiotics for every ton of Atlantic salmon produced (CSARP, 2022).

Feed additives as valuable health management tools

Functional feeds are an important part in a robust health management program, but there is no silver bullet. Consequently, multiple active components with complementary modes of action must be explored. Thes include, but are not limited to:

- **Direct inhibition:** Many probiotic bacteria, organic acids and essential oils impact pathogen growth and survival.
- **Competitive exclusion:** Utilizing beneficial bacteria (probiotics) to compete with pathogens for much needed resources e.g., nutrients, adhesion sites.
- **Membrane damage:** Gram-negative pathogens have an outermost layer of lipopolysaccharide. This gives them greater mitigation against antimicrobials and can pump out unwanted substances, like antibiotic metabolites. Breaking this membrane causes stress to the pathogen, disrupting the membrane functionality and reducing overall virulence.`
- **Quorum quenching:** Quorum sensing is a means of bacterial communication and is linked to pathogen virulence. Quorum quenching breaks these channels, disrupting virulence and biofilm formation.
- **Toxin degradation:** Endotoxins can be produced by several pathogens, which cause great damage to the animal. This is the case in Acute Hepatopancreatic Necrosis AHPND (Acute Hepatopancreatic Necrosis Disease), where a number of *Vibrio* spp. produce *pir*AB toxins which attack the hepatopancreas.

Salmon vs salmon rickettsial septicemia disease in the Chilean salmon industry since the 1980's, costing >300 million USD per annum. It is estimated, >95% of all antibiotics used in Chile are used to treat SRS.

In a recent study, Biotronic® Top3, an enhanced acidifier, was able to significantly reduce the mortality of Atlantic salmon after a 65-day *Piscirickettsia salmonsis* cohabitation challenge (55.0 ± 7.9% vs 72.2 ± 13.9%, respectively; P = 0.0064). In the same trial, it was calculated that the enhanced acidifier was able to reduce the probability of a mortality event by nearly 40%.

Interestingly, through *in vitro* investigations, it was demonstrated that the enhanced acidifier was also able to reduce the efflux pump activity in pathogens, which is an important mechanism for antimicrobial resistance. This suggests Biotronic® is also a useful tool in medicated feeds, as well as mitigation prevention.

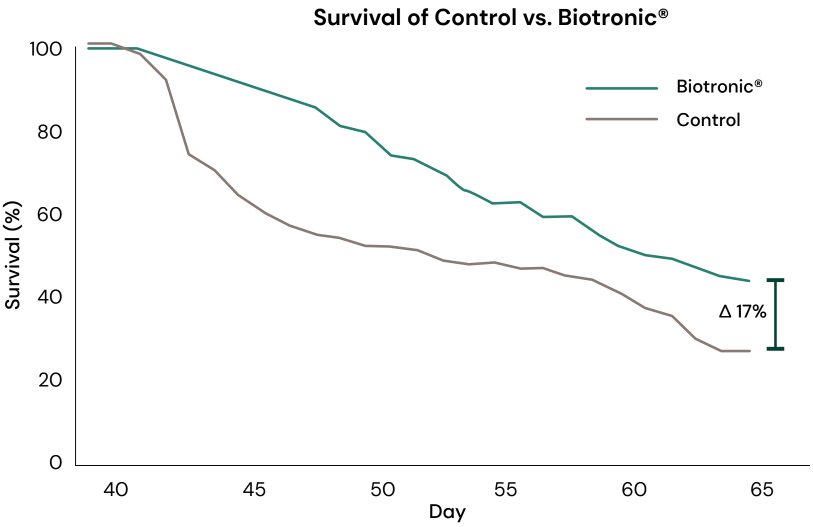
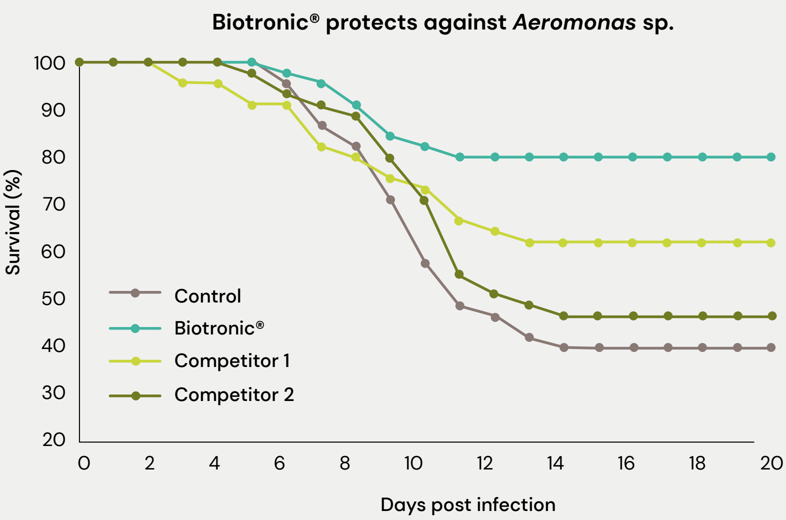


Figure 3: Survival of fish fed a control diet (D1), or supplemented with Biotronic® Top3 at 2 kg/ t, following a 65-day SRS challenge.

Tilapia vs hemorrhagic septicemia

A recent study investigated the effects of Biotronic® on tilapia health and performance when challenged with *Aeromonas hydrophila*. Tilapia 'fingerlings' were divided into 12 tanks and fed one of four diets; control, Biotronic® and two competitor products. The group that received Biotronic® showed improved survival rates and better growth, particularly in terms of feed conversion rate, compared to those given other organic acid products. Overall, the study suggests that Biotronic® may contribute to enhanced tilapia health and production efficiency.



	Final weight (g)	Biomass (g)	SGR	FCR
Control	84.7 ± 1.2	3 322 ± 49	3.30 ± 0.02	1.04 ± 0.02[ab]
Biotronic®	87.0 ± 2.2	3 390 ± 61	3.34 ± 0.04	1.02 ± 0.02[a]
Competitor 1	85.7 ± 1.4	3 342 ± 63	3.32 ± 0.03	1.03 ± 0.02[ab]
Competitor 2	83.0 ± 0.4	3 256 ± 33	3.27 ± 0.01	1.06 ± 0.01[b]

Figure 4: Survival of fish fed different diets, following a 20-day A. hydrophila challenge. The table underneath presents the performance data during the eight-week growth phase of the trial.

AquaStar® GH vs AHPND
Up to 60% higher survival, relative to control

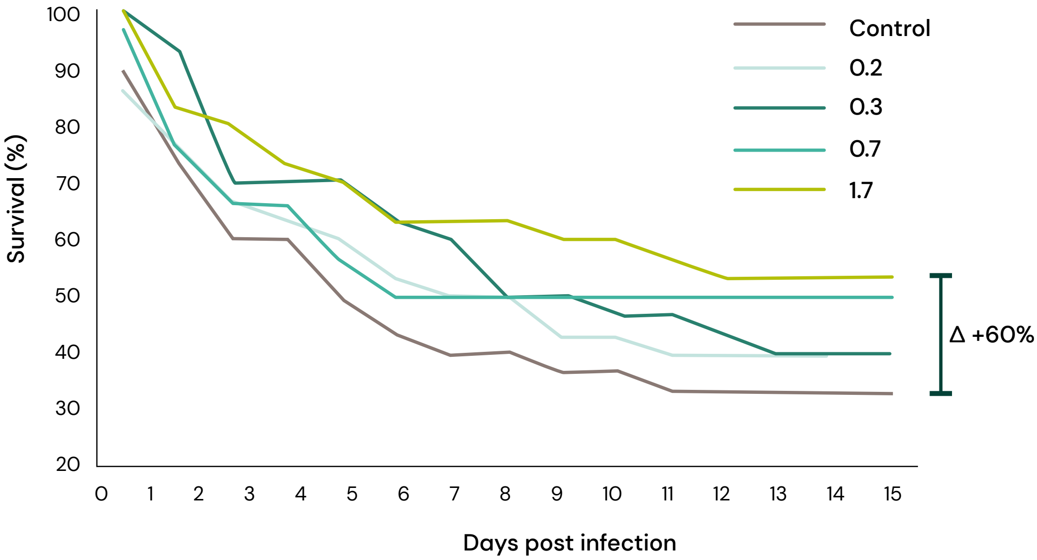


Figure 5: Survival of shrimp fed a control diet, or supplemented with AquaStar® GH in a dose dependent manner, following a *V. parahaemolyticus* challenge.

Shrimp vs AHPND

Disease outbreaks can disrupt the balance of gut microbiota in shrimp, leading to a loss of microbial diversity. Research suggests a connection between these disruptions and disease severity. This highlights the importance of a healthy gut microbiome for shrimp resilience. This is partly why probiotics are gaining traction in aquaculture. In shrimp farming, probiotics can be used in feed to support gut health and improve the animal's ability to cope with stressful situations, as well as for bioremediation.

However, disease may still occur and since its identification in China in 2009, Acute Hepatopancreatic Necrosis Disease (AHPND) has become a global problem in the shrimp industry, with an estimated loss of >40 billion USD. In a recent trial AquaStar® GH demonstrated positive effects in a dose dependent manner, after shrimp were challenged with *Vibrio parahaemolyticus* (immersion, 1 hour at 1.25 x 10^6 CFU/ ml). In the highest dosage, 1.7 g/ kg, a 60% improvement was observed relative to the control (Figure 5).

Conclusion

Pathogens are a constant threat for the aquaculture sector and a key bottleneck for future growth. The industry must collaborate and innovate together, building partnerships across the value chain to develop a more proactive approach to disease management, including the use of functional feed. This has double benefits, improving the health, welfare and survival of fish and shrimp, but also a key strategy to reduce our reliance on antibiotics – for the good of people, the planet and profit.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Interview

Ivo Lansbergen is the President of Animal Nutrition & Health at dsm-firmenich. He holds a master's in science in Chemical Engineering from the University of Enschede, Netherlands. He joined DSM in 1997 and has held various positions within the company. In 2019, he took over the leadership of the Animal Nutrition & Health business, transforming it into a leading solutions provider. Under his guidance, strategic acquisitions strengthened the firm's expertise in animal health and nutrition. Mr. Lansbergen is committed to driving sustainable animal protein production and reducing on-farm livestock emissions by 2030, aligned with the company's Food System Commitments.

How long have you worked at DSM and has all that time been devoted to Animal Nutrition & Health? Why did you decide that DSM was a career choice for yourself?

I've grown up with DSM, having been with the company now for 26 years. I have a degree in chemical engineering and started my career as a Process Engineer at DSM Resins. I've held a variety of roles in many of the different business lines, including chemicals, materials, human nutrition and most recently Animal Nutrition & Health. One thing that strongly appealed to me is the company's ability to transform itself repeatedly over time, along with a clear dedication to sustainability which is also a core tenet of dsm-firmenich.

The industry in Europe has set high standards when it comes to food safety especially in the area of mycotoxins. Do you believe the rest of the world is capable of reaching these same food safety standards or will we have to settle for various and different requirements from country-to-country?

Mycotoxins jeopardise both animal and human health and pose a direct threat to food safety and food security. Not all mycotoxins are regulated, and even contamination levels below legal limits can still cause problems for farm animals and producers. Food safety standards vary per jurisdiction and continually evolve. Expanding scientific knowledge on mycotoxins and other contaminants contribute to enhancing food safety standards not only in Europe but also on a worldwide basis. Higher standards help ensure that every person has access to safe, healthy, and nutritious food.

Do mycotoxins play a role in food safety for farmed fish species, now that we are using more grain-based proteins in fish diets?

Mycotoxins have a significant impact on feed safety for farmed fish species. Mycotoxin contamination can adversely affect the health, welfare, and performance of aquatic animals, leading to substantial economic losses, estimated at billions of dollars globally each year. Moreover, there is a risk of mycotoxin carryover to human food. Recent data shows that over 90 percent of aquafeed samples contain multiple mycotoxins, with feed materials like corn by-products, rice bran, soy, and wheat being notably contaminated. With the growing use of plant proteins, cheaper raw materials, and the influence of climate change, the mycotoxin threat is expected to increase further in the future.

What are likely to be the future challenges for fish farmers in meeting a demand for protein when competing with land-based livestock production which has had many decades of development and achieving efficiencies? Will farmed fish be competitive with the chicken on the plate in future?

As well as space to grow, future growth of the industry relies on the scale and availability of affordable, low footprint raw materials with the right nutritional profile, and there will be new and continued challenges in health and welfare of farmed aquaculture species.
Production efficiency also drives sustainability of course and a combination of nutritional interventions and data-based decision-making tools can support sustainable growth of aquaculture and accelerate progress in addressing these issues.

Details:

To read the full interview in International Aquafeed, scan the QR code

Latin America aquaculture spotlight

2023 Production:

243,500 mt

Production
- Second-largest shrimp producer in Latin America.
- Key species: White Shrimp, Tilapia, Striped Bass, Seriola, Totoaba.

14 kg
Annual per capita consumption

Costa Rica

Production
- Second in seafood consumption in LATAM.
- Key species: Tilapia, White Shrimp, Snapper, Trout.

Markets
Favorable for exports to US.

Challenges
Higher production costs compared to other countries.

Opportunities
Strong brand for sustainable and quality seafood.

Ecuador

Markets
Major export destinations: China, Europe, U.S.

Challenges
Volatile feed costs and low shrimp prices.

Opportunities
Sustainability efforts and carbon emission reductions

Production
Leading global shrimp producer.
Key species: White Shrimp, Tilapia, Seriola.

1.1 million mt
2022 Production

Peru

Production
- Diverse environments for shrimp, trout, and paiche.
- Fisheries and aquaculture are closely integrated.

Opportunities
Focus on sustainability and quality.

Markets
Significant export growth **in 2003**
$34 million
to over
$300 million
in 2014

50,000 tons

185,000 mt

Markets
Domestic consumption and exports to the U.S.

Challenges
Prices and sanitary issues affecting shrimp.
Inadequate practices affecting tilapia.

Opportunities
Potential for increased production and exports.

Production
Diverse climate supports production of tilapia, trout, and native species.

204,000 mt
2022 Production

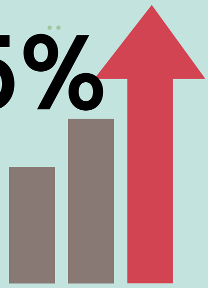
Markets
Exports mainly to North America.

Challenges
Bacterial diseases affecting tilapia.

Opportunities
Focus on native species and new production technologies.

Markets
Export revenue increase by

+15%
in 2022.



Production
- Projected 2024 Production: 1.5 million metric tons.
- Key species: Tilapia (65.3% of output), Shrimp, Native Fish.

Challenges
- Climatic and sanitary issues, fingerling supply.
- Increase internal per capita consumption and export potential

Opportunities
Strong internal consumption and export potential.

Production
- Major global salmon producer.
- Key species: Atlantic Salmon, Coho Salmon, Rainbow Trout, Mussels.

2022 Production:

1,524,149 mt

Markets
Major exports to U.S., Japan, Brazil, Russia, and Mexico.

Challenges
Disease outbreaks and parasite control.

Opportunities
Sustainability efforts and technological advancements.

In brief

The risk of mycotoxin contamination is never zero

A typical tilapia diet comprises soybean meal, sunflower meal, yellow maize, rice bran and wheat middlings – all susceptible to mycotoxin contamination

Disease challenge is at an all-time high, which may mean mycotoxin risk is overlooked

Underwater intrigue:
exploring mycotoxins' impact on fish

The ever-present risk of mycotoxin contamination in animal feed is frequently overlooked due to heightened disease challenges

By Anneliese Müller, Product Manager Mycotoxin Risk Management, Animal Nutrition & Health at dsm-firmenich

Beneath the surface: subclinical impact of dietary imbalance

Typically, a producer's key management concern centers around disease, environment, and cost of feed. Diseases are widespread in aquaculture and pose a high risk to profitability in fish. Environmental fluctuations and stressors add additional pressure. Feed price fluctuate based on global market supply and demand and are one of the biggest costs.

Like all living animals, fish and shrimp have a requirement for certain nutrients. This includes amino-acids, cholesterol, vitamins, and minerals. In commercial fish production, this feed is usually grain and oilseed based. This brings in a sometimes-overlooked challenge: mycotoxins, common contaminants in animal feed.

Clinical symptoms due to mycotoxin contamination levels are rarely observed in aquatic species. More frequently, animals are exposed to moderate levels of mycotoxins over a long time. This chronic exposure leads to unspecific effects typically observed as decreased performance. Poor performance typically manifests as slow growth, increase in feed conversion ratio (FCR), higher susceptibility to disease, and increased medical costs. Nevertheless, these subtle effects often pass unnoticed or are not traced back to the presence of mycotoxins.

Balancing act: nutritional requirement and key feed ingredients

Dietary formulations vary, depending on raw material availability, price, and developmental stage. Production of salmon, trout, tilapia, seabream and seabass through different developmental stages should include crude protein at 20 – 60% and crude lipid at 4-30% (1-5). For vitamin recommendations, dsm-firmenich has developed OVN Optimum Vitamin Nutrition® guidelines.

From a macro-ingredient perspective, fish feeds are following the global trend to reduce reliance on marine ingredients. This is typically delivered through increased usage of plant-based raw materials.

Plant proteins may be the largest protein contributor, but their increased inclusion is not without risk. Even when diets are nutritionally balanced any increase in plant ingredients means a greater chance of introducing unwanted contaminants. These include anti-nutritional factors (ANFs), including mycotoxins. Ultimately, this will impact health and performance.

Table 1: Example of a typical nile tilapia diet in the Middle East:

Tilapia raw material	Tilapia inclusion (%)
Soybean meal, 46% CP	44
Poultry meal 55%	7.15
Sunflower Meal 36% CP	4.5
Yellow maize, 7.5%	12.80
Fish premix, 0.5%	0.5
Limestone (CaCO^3)	1.3
Rice bran, full fat	11
Salt (NaCl)	1.5
Wheat middlings - 14-15	15
DL-Methionine	0.14
Antioxidant	0.05
Mono calcium phosphate (MCP)	0.41
Soybean oil	1.3
Mycotoxin binder, Mycofix®	0.1
Fish oil	0.5

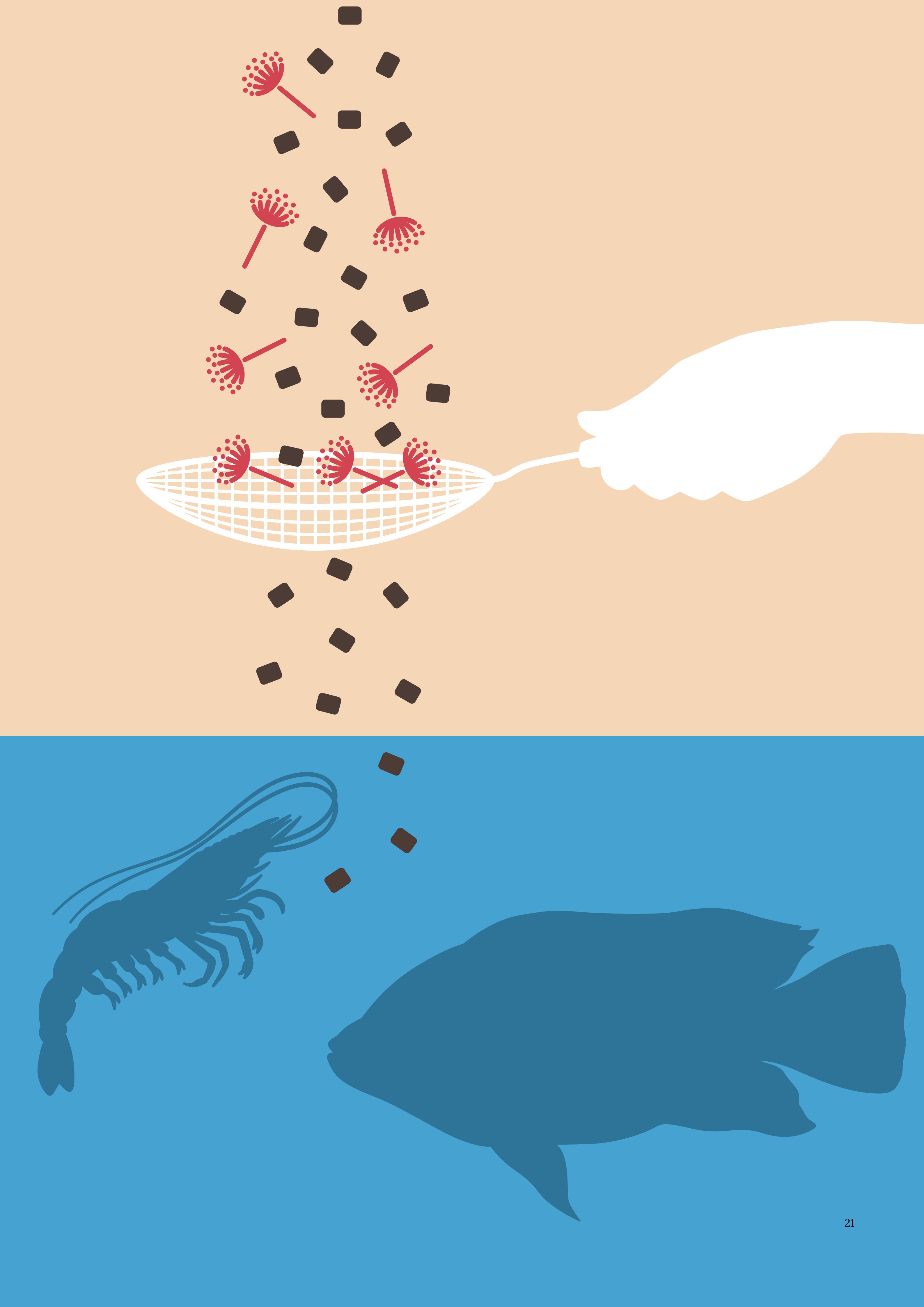
Deep dive: impact of mycotoxins on salmonid health

There has been quite some research done on effects of mycotoxins in salmonids. Most studies however are limited to rainbow trout (*Oncorhynchus mykiss*). Aflatoxins have been shown to lead to lesions in liver tissue at a high

Table 2: Summary of observed detrimental effects of mycotoxins on liver, intestine and immune system, performance, and reproductive tract (selected studies):

	Liver	Intestine and immune system	Performance	Else	Reproductive Tract
DON	Affected hepatosomatic index (1 200 ppb; 4 700 ppb) (8) (9) Histopathological changes (1 200 – 2 800 ppb) (10), (11), (12), (13) Increased liver enzyme activities in serum (1 200–2700 ppb) (10) Increased relative liver weight (dose-dep., 500 -6000 ppb; Salmo salar) (14)	Biomarkers of oxidative stress in liver, kidneys, and gill (1 960 ppb) (15) Dose-dependent decrease in antibody response to Aeromonas salmonicidae vaccination. (500– 600 ppb; *Salmo salar*) (14) Histopathological changes intestine (2 800 ppb) (13) Decreased mucosal fold width and enterocyte width in the midgut (1 329 ppb) (9)	Decreased body weight (370 ppb) (10), (>4 700 ppb) (8), plus ZEN (16), (9), (12), (13) Decreased weight gain (>4 700 ppb) (8), (start 300 ppb) (17), (2 100 ppb) (20), (11), (18), (9), (12), (13) Decreased feed intake (>4 700 ppb) (8), (2 700 ppb) (10), plus ZEN (16), (11), (18) Increased feed intake (370 ppb) (10), (2 100 ppb) (20), Decreased feed efficiency (370 ppb) (10), plus ZEN (19), (start 300 ppb) (17), (2 100 ppb) (20), (11), (18), (9), (12), (13) Decreased crude protein content, retained nitrogen (retention) (start 300 ppb) (17), (2 100 ppb) (20), (11), (18)	Altered body composition (8), (2 100 ppb; 10), (20) Abnormal body confirmation and anal papilla (2 700 ppb) (10) Decreased blood levels of hemoglobin, glucose, cholesterol, ammonia, histopathological changes in the caudal kidney (1 960 ppb) (25) Increase in whole body water content (start 300 ppb) (18)	
ZEN	Histopathological changes (1 800 ppb) (21)	Effects on immunological parameters and oxidative stress biomarkers in serum and intestines (300-600 ppb) (22) Affected hematological parameters (e.g., decreased B lymphocyte concentration) and cytokine expression in different organs (2 000 ppb) (23)	Reduced feed intake and weight gain (500 ppb + 3 300 ppb DON) (500 ppb + 4 100 ppb DON) (16) (19) Reduced final body weight, weight gain, specific growth rate, increased FCR (300-600 ppb) (22) Increased growth, decreased FCR (23) inhibited growth, reduced final body weight and feed conversion ratio (~8 800 ppb) (13)	Effects on digestive enzymes (300-600 ppb) (22) Inflammation of the trunk kidney (2000 ppb) (23)	Advanced ovarian development (1 800 ppb) (21) Increased mortality of offspring, morphological anomalies in gonads, increased vitellogenin concentration in plasma of male fish (2 000 ppb) (24)
FUM	Histopathological changes, affected hepatosomatic index (~8 800 ppb) (13)	Histopathological changes in intestines (~8 800 ppb) (13)	Inhibited growth, reduced final body weight and feed conversion ratio (~8 800 ppb) (13)		

DON = deoxynivalenol; ZEN = zearalenone; FUM = fumonisins



dosage of 80 ppm (6). Dose-dependent increase in liver tumor incidence was also observed at 4-64 ppb (7). Although Aflatoxins are the most toxic mycotoxins, focus of research has been on the more frequently occurring *Fusarium* mycotoxins DON and ZEN, with less investigations for FUM (see table below).

Research shows that negative effects on the liver can not only be the result of a contamination with Aflatoxin, but also with DON, ZEN and FUM. These mycotoxins show a negative effect on performance of salmonids, as reduced final body weight, reduced feed intake and increased FCR. First studies highlight the negative impact of the estrogenic mycotoxin ZEN on the reproductive tract in rainbow trout with a concentration at EU guidance value of 2,000 ppb.
An impact on the immune system and intestine of salmonids is indicated as well. The immune system of fish

Table 3: Summary of observed detrimental effects of mycotoxins on liver, intestine and immune system, performance, and reproductive tract (selected studies):

	Liver	Performance	else	Reproductive Tract
Afla	Chronic liver manifestations (yellowing, enlargement, necrosis, inflammation, cellular swelling) (5-39 ppb) (43) Hepatic disorder (245 ppb) (28) Hepatosomatic index (150-245 ppb) (28) (27) Residues in liver (200 ppb) (29), (28) Histopathological changes (200 ppb) (29)	Decreased growth rate and increased FCR (40 – 20 000 ppb) (40), (34), (41), (42), (37), (39), (27), (28), (29)	Increased mortality (5-200 ppb) (34) (29) (43) No significant effect on mortality (30 000 ppb) (40), (37) Kidney-somatic index (150 ppb) (27) Impaired spleen (27) (29) Blood parameters (27) Fish carcass (27) Residues (whole body) (27)	Gonads-somatic index (27)
DON	Histopathological changes (1 600 + ZEN 340 ppb, 1 000 ppb FUM)) (30) Increased hepatosomatic index (1 600 + ZEN 340 ppb, 1 000 ppb FUM) (30)	Reduced weight gain, feed intake and efficiency (dose-dependent effect with ZEN (310 ppb and 90 ppb) (33) Decreased biomass gain (1 600 + ZEN 340 ppb, 1 000 ppb FUM) (30) No effect (100 – 1 100 ppb) (17)	Increase in mortality (dose-dependent effect with ZEN (310 ppb and 90 ppb) (33)	
ZEN		Reduced weight gain, feed intake and feed efficiency (dose-dependent effect with ZEN (start 70 ppb and 10 ppb) (33)	Increase in mortality (dose-dependent effect with ZEN (310 ppb and 90 ppb) (33)	
FUM	May promote liver tumors when co-contamination with Afla (32)	Weight gain, feed efficiency (50 000 ppb) (31)	mRNA expression reduced (growth hormone receptor, insulin growth) (50 000 ppb) (31) Decreased hematocrit (38)	

Afla = aflatoxins; DON = deoxynivalenol; ZEN = zearalenone; FUM = fumonisins

is quite complex, and similar to the immune systems of mammals, including innate and adaptive immunity (35). Important for the fish immune system are also specialized organs and cell types as the thyme, head kidney and spleen, as well as the mucosa-associated lymphoid tissue; skin, gill, and gut-associated (35).
Several detrimental effects were described on the intestine and immune system. Studies found histopathological lesions in the intestine, a negative effect on gut mucosa, hematological parameters, oxidative stress biomarkers in the liver, kidneys, and gill. Conversely, some studies describe no increased mortality in the presence of mycotoxins and challenge to *Yersinia ruckeri* and *Flavobacterium psychrophilum* (10, 19, 36).
Decreased antibody response to vaccination to *Aeromonas salmonicida* was described in *Salmo salar*. Fish are constantly challenged by pathogens due to their environment, so a negative impact of mycotoxins on different parts of the immune system would add further challenge. For ochratoxin (OTA) research results are limited. A high dose intra-peritoneal study at 2,000 ppb resulted in degeneration and necrosis of liver and kidney, swollen liver as well as pale kidney and increased mortality (26).

Closer look: mycotoxin impact on tilapia health

Fewer studies are available for research on the effects of mycotoxins in tilapia. High focus rests on aflatoxins, confirming their toxic effects in animals especially on the liver. Contamination with aflatoxin amongst others, also increased mortality of tilapia in several studies. Aflatoxin also impacted kidney and spleen as well as fish carcass. Although residues in the liver have been described at high contamination levels, one study indicated residues in the whole body. Negative effects on liver health have been also observed in the presence of DON, and one study suggests a co-contamination of aflatoxin with FUM might promote liver tumors. For all toxins described in the table below, an impairment of performance can be observed.
A study with co-contamination of DON and ZEN showed a dose-dependent decrease of performance and an increase in mortality.

What's next?

The risk of mycotoxin contamination is never zero. Even with the best quality control procedures, mycotoxins are a constant threat. So how do producers manage this, alongside the demands of disease challenge? A robust mycotoxin risk management program is essential. Part of the toolbox is using mycotoxin deactivator in the feed formulation. Mycofix® is a state-of-the-art mycotoxin deactivator comprising three modes of action for the ultimate insurance policy against a wide range of known, and emerging mycotoxins. Adsorption to bind adsorbable mycotoxins, biotransformation to detoxify non-adsorbable mycotoxins and bioprotection-natural ingredients supporting liver and hepatopancreas, immune system and intestinal barrier.
A proper mycotoxin risk management is key to protect fish from the adverse effects of mycotoxins, thus supporting business profitability.

In brief

Filling the Protein Gap: Aquaculture is crucial for meeting future protein demands, needing an extra 30-40 million tons of fish and shrimp by 2030

Health and Welfare Impact: Health and welfare drive sustainability, influencing production efficiency, environmental footprint, antimicrobial resistance, and food waste

Economic and Environmental Benefits: Better health and welfare in aquaculture reduce mortality and increase profitability, lowering CO_2 emissions significantly and improving overall sustainability

Supercharged:

health and welfare results in sustainability performance in aquaculture

Aquaculture requires 30-40 million more tons by 2030, enhancing health, efficiency, and lowering CO_2 emissions for sustainability

By Louise Buttle , Key Accounts Aqua Global, Animal Nutrition & Health at dsm-firmenich

Hungry: Aquaculture's Role in Filling the Protein Gap

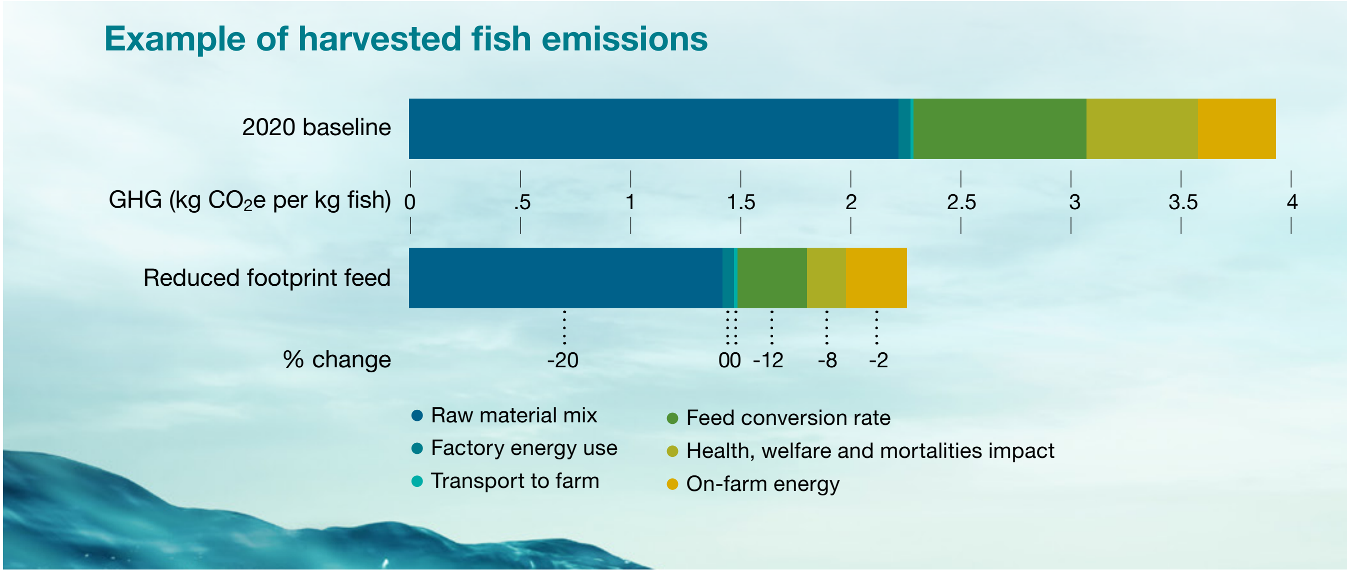
Aquaculture plays an important part when it comes to filling the protein gap for the generations to come. To make this happen, the world will require another 30 to 40 million tons of fish and shrimp by 2030, which must be produced within planetary boundaries. Health and welfare are key drivers for sustainable aquaculture and depend on biotic and abiotic factors. Production efficiencies and profitability, the environmental footprint, antimicrobial resistance and food loss and waste all impact overall sustainability performance.

Health and welfare challenges are present in all aquaculture systems. Poor results are often linked to industry reputational issues, as stakeholders across the value chain demand increased transparency. Sustainability reports play a pivotal role when it comes to company profiling. Factors such as mortality, welfare indicators, antibiotic treatment and sealice infestation levels are key sustainability metrics.

Science-based Targets: Health, Welfare and Sustainability Ambition

Bacterial and viral diseases, external parasites, melanosis, skin wounds and environmental challenges are among many factors that can reduce productivity, profitability and the overall sustainability performance.

In Norway, it is estimated that the lost value due to a 20% mortality would be in excess of €2.7m for an average farm (Biomar Sustainability Report 2022). The total industry annual cost of €5.6b would be the financial loss for European salmon by mid-century (DNV, 2021). In addition,



Cargill Aqua Nutrition Sustainability Report 2023

these costs do not cover the reduced growth, resource utilisation and compromised fish when grown in suboptimal conditions.
Even when mortality is avoided, skin wounds can affect product quality and drive losses. For example, skin wounds have an estimated cost to the Norwegian salmon industry of €700m annually (John Harald Pettersen, Lofotenseminar June 2023). Biological issues remain a challenge for the salmon industry, and sea lice still represents the biggest issue to date. Other diseases are prevalent, such as pancreas disease (PD), infectious salmon anemia (ISA) and heart and skeletal muscle inflammation (HSMI). In the most recent Fish Health report from Norway (Veterinaerinstituttet, 2023) fish health professionals revealed that damage from sealice treatment and gill diseases were of the top concerns in the Norwegian industry.

1 in 5: Mortality and LCA Impact

Farmed fish is recognised as one of the most environmentally efficient and sustainable form of protein production. However, mortality rates of up to 20% can be referenced in commercial aquaculture systems, meaning that 1 in 5 animals does not make it to the end of the production cycle. The carbon footprint, as part of the full life cycle analysis (LCA) is an essential metric of environmental sustainability in animal production systems.
LCA considers the resource use for an output of animal production, and therefore mortality lowers the output. Calculations have been done to highlight the savings in greenhouse gases (GHG) emissions when mortalities are reduced or avoided. For example, if an average Norwegian salmon farm could avoid a 20% fish loss, 2100 tonnes of CO2e would be saved (Biomar Sustainability report 2022). This 2100 tonnes CO_2e saving is equivalent to the annual GHG emissions of 450 cars. Recent examples also include Cargill Aqua Nutrition SeaFurther initiative. Using 2020 baseline, health, welfare and mortality had a 12.5% contribution to the overall carbon footprint, while interventions lowered GHG emissions (kg CO_2e per kg fish) by 8%.

dsm-firmenich's strategic initiative We Make It Possible helps the industry to build a robust and achievable transformation worldwide, toward more sustainable animal protein production, and to accelerate science-based solutions to foster a brighter future for everyone. A win-win for the whole value chain from farmers to consumers, and future generations.

Robust: Data and Analytics

Global Salmon Initiative reported annually mortality as one of the sustainability indicators. The industry is also accelerating the adoption of new technologies focusing on fish welfare. For example, technologies available to monitor live fish in cages and quantify the level of some biological indicators, such as skin wounds. At the same time, there is increased focus on the environmental footprint, and the importance of measuring, knowing and reducing your own footprint.
In recent years, many salmon companies have made public commitments towards decarbonization and have signed up to science-based targets (SBTi) to reduce GHG emissions by 2030 in line with the Paris Agreement on climate change. Sustell™ is a robust, user-friendly,

secure, cloud-based intelligent platform for data input, calculation & visualization of aquaculture environmental footprints results. It measures the full LCA of the animal protein production and has modules available today for salmon, marine fish and coming soon, shrimp.

Global Threat: Antimicrobial Resistance

The World Health Organization cites Antimicrobial Resistance (AMR) as an increasingly serious threat to global public health, and implementation of coordinated action plans across all levels of society is vital. Antibiotic use in animal protein production is recognized as one of the drivers in AMR and a risk factor to human and environmental health (FAO, 2019). If no action is taken, AMR could lead to 10 million deaths each year by 2050 and force up to 24 million people into extreme poverty by 2030 (WHO, 2019).
The aquaculture sector has developed rapidly over the past decades, and within the sustainability dialogue the reduced use of antibiotics is a key development focus. The Norwegian salmon industry, which in 2023 produced 1.4M tons of salmon, has almost eliminated the use of antibiotics in the last two decades.
However, in other aquaculture species, where there has been less success of vaccines and biosecurity measures for specific diseases, the use of antibiotics is still a necessity.

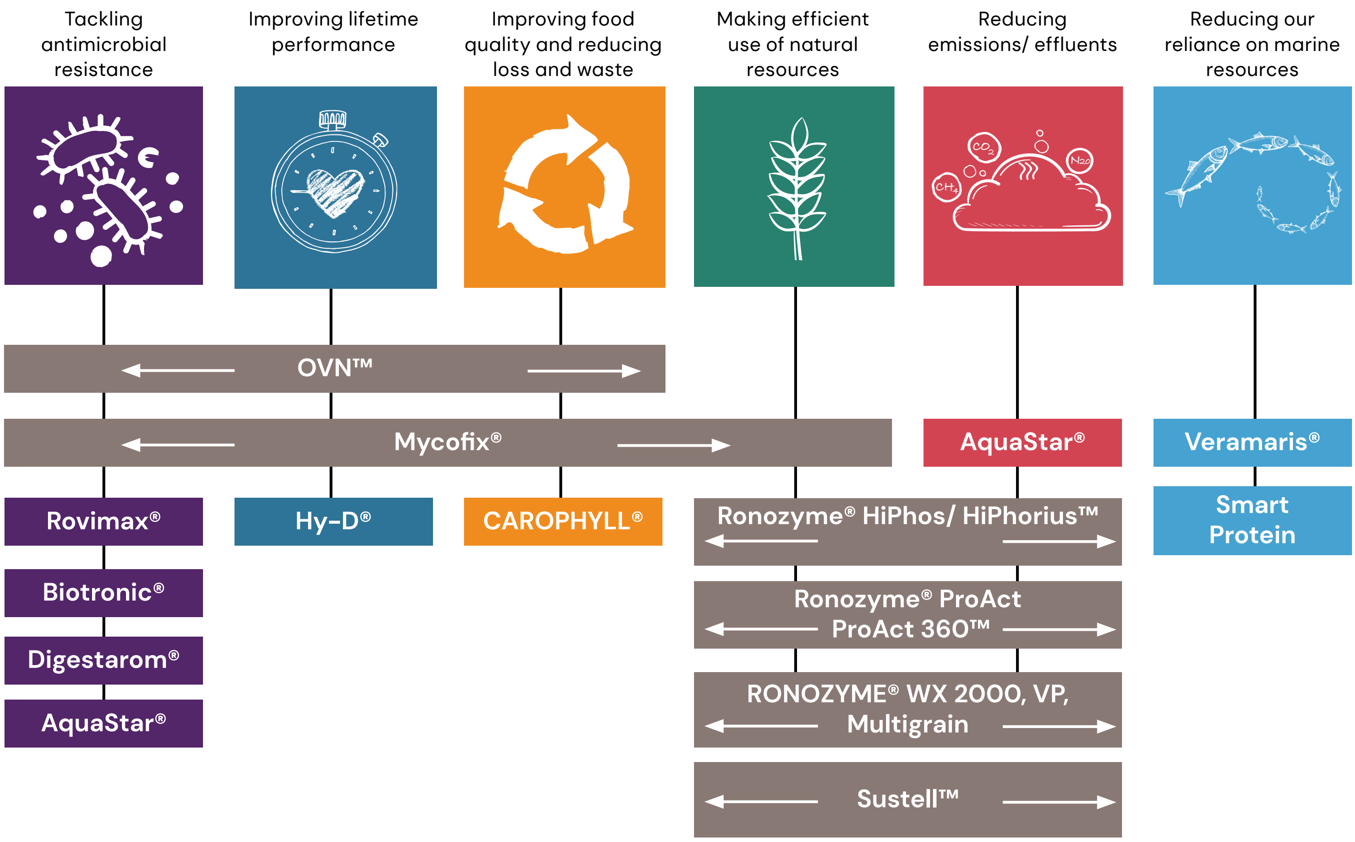
Intervention: Nutrition to Improve Footprint

dsm-firmenich plays a key role in providing solutions for animal production that deliver optimum health and welfare and mitigate the risk of AMR.

Examples include the concept of OVN Optimum Vitamin Nutrition® and eubiotic portfolio. OVN Optimum Vitamin Nutrition® targets feeding animals high quality vitamins in the right amounts and ratios appropriate to their life stage and growing conditions.
Our eubiotic solutions improve gut health and strengthen the immune system in both fish and shrimp. By increasing immune defense, disease resistance and supporting the animal through adverse environmental conditions, we help the industry to reduce the need to use antibiotics and improve survival by up to 30%. Extensive documentation has been generated for our Rovimax® (nucleotides), Biotronic® (organic acids), Digestarom® (essential oils) and AquaStar® (probiotics) product lines, enabling consistent improvement in survival and performance in both cold water and warm water species.

What's next?

Health and welfare challenges not only drive financial results but impact the environmental footprint of animal production. As always, the need for data transparency and aligned methodology, also extends to monitoring environmental footprint.



Willem van der Pijl's favorite recipe

Ixta Belfrage's Prawn Lasagne with Habanero Oil

by Ixta Belfrage from MEZCLA: Recipes to Excite

Serves 4

250 g	fresh lasagne sheets
130 g	double cream, plus 1 tablespoon to serve
100 g	Parmesan, finely grated
10 g	fresh chives, finely chopped

For the prawn ragù:

6 tbsp	olive oil
½	onion, finely chopped
5	cloves of garlic, crushed
200 g	sweet, ripe cherry tomatoes, such as Datterini, finely chopped
1 tsp	fine salt
500 g	raw peeled king prawns, very finely chopped to mince consistency (about 1kg if you're starting with shell-on prawns – use the shells to make a stock)
1	dried habanero chilli (or chilli flakes if you prefer less heat)
80g	tomato purée/paste
2 tsp	white miso paste

About 50 twists of freshly ground black pepper

100 g	white wine
500 g	fish, shellfish or chicken stock (unsalted liquid stock, not cubes)

For the Habanero oil:

120 g	olive oil
2 tsp	tomato purée/paste
½ tsp	chipotle flakes
1	dried habanero chilli, seeds discarded, finely chopped (use less habanero or a pinch of regular chilli flakes if you prefer)
½ tsp	sweet paprika
¼ tsp	fine salt

©GettyImages

Method

For the ragù, put 4 tablespoons of the oil into a large sauté pan on a medium heat with the onion, garlic, cherry tomatoes and fine salt. Fry, stirring often, for 8–10 minutes or until the onions are soft and golden and the tomatoes have broken down.

Increase the heat to high, add the chopped prawns and fry for another 8 minutes, stirring every now and then, until the prawn mince has taken on some colour.

If you don't have a food processor, very finely chop all the vegetables and prawns by hand.

Add the habanero (or chilli flakes), tomato purée/paste, miso and plenty of pepper. Continue to fry for 3 minutes, stirring every now and then. Turn the heat down if the mixture starts to catch or burn.

Pour over the wine and let it bubble away for 30 seconds. Add the stock (or water) and the remaining 2 tablespoons of oil, bring to a simmer, then reduce the heat to medium-low and simmer gently for about 18–20 minutes. Remove the habanero, squeezing it into the sauce first if you like heat.

Meanwhile, put all the ingredients for the habanero oil into a small saucepan and place on a medium heat. Mix well and heat until gently bubbling, about 1½ minutes. Remove from the heat and set aside. Once cool, transfer to a clean jar (you'll only need a couple of tablespoons for this recipe).

Preheat the oven to 200°C fan/220°C.

To assemble the lasagne, cover the bottom of a small baking dish with lasagne sheets, about 20 x 20cm or a similar size, then spread over a fifth of the ragù. Follow with a fifth each of the cream, Parmesan and chives. Continue layering in the same way until you've used up all the ingredients. Drizzle over ½ tablespoon of the habanero oil, cover tightly with foil and bake for 20 minutes.

Increase the oven heat to 230°C fan/250°C, remove the foil and bake for another 12 minutes, or until the edges are crisp and the pasta is cooked through.

Leave to cool for 10 minutes. Finish with the remaining 1 tablespoon of cream and a good drizzle of the habanero oil, and serve.

Interview: Navigating the Shrimp Industry:

Name
Willem van der Pijl

Title
Co-founder of The Global Shrimp Forum

You are an advisor to the newly established Global Shrimp Council. Why now, and what is the main objective?

It's a privilege to serve as an advisor to the newly formed Global Shrimp Council. The timing for this initiative couldn't be better, and its primary goal is clear: to boost shrimp consumption worldwide. The Council wouldn't exist without the vision of Gabriel Luna and David Castro. They approached me last year with a bold idea – a collaborative marketing effort for shrimp, something the industry had never attempted. Previously, discussions stalled on funding mechanisms, often relying on voluntary contributions that wouldn't be universally adopted. We launched the concept at last year's Global Shrimp Forum, where it resonated with major producers. Many committed to initial research funding. By the Boston Seafood Show in March 2023, membership reached 50 companies and the inaugural board was elected – 13 representatives from across the global shrimp industry united to drive shrimp consumption. The Council's sole focus is to boost shrimp consumption. This initiative comes at a critical time, as the industry faces an oversupply situation that has not been seen before. Production is outpacing consumption, and this imbalance necessitates two primary responses: increasing efficiency to reduce costs and enhancing demand for shrimp. Promoting shrimp as a healthy, fun, and sustainable protein option can help it compete more effectively with other popular protein sources worldwide.

In what way does disease shape the shrimp industry?

Disease remains a significant factor in the shrimp industry, particularly in Asia, more so than in Latin America currently. For instance, in India, a farmer can achieve substantial profits if there is no disease on their farm. However, if disease strikes, it can lead to significant financial losses. This highlights the substantial impact dis-

Interview: Innovating for Sustainability:

Name
Esteban Ramírez

Title
CEO of INTESAL

Esteban, you have extensive experience in the Chilean salmon industry. What is your highlight?

I have spent six years in the Chilean salmon industry, leading INTESAL. The most significant highlight is witnessing the industry's potential to address global issues like climate change while contributing to sustainable food production. Over time, we have made significant strides in improving socio-environmental practices, enhancing community relations, and promoting good farming practices. At INTESAL, we support these efforts, aiming to bridge gaps and foster collaboration. My focus is on ensuring the industry's continued progress and the well-being of the 70,000 families dependent on it.

Can you share a bit more about INTESAL, what is the ambition of the company?

INTESAL, the Salmon Technological Institute, is part of the Chilean Salmon Association (Salmonchile) and was established in 1992 with support from CORFO to drive research and innovation in Chilean salmon farming. Our ambition is to generate key scientific knowledge and advance sustainability in the industry. We focus on promoting good practices in sanitary and aquaculture health issues. Recently, we launched a five-year Science Plan to address new socio-environmental challenges and establish the real impact of salmon farming on biodiversity, oceanography, water resources, and coastal governance, all within the context of climate change adaptation.

Insights from Willem van der Pijl

ease can have. There are numerous opportunities to help the industry better manage disease pressure on farms. However, there's no one-size-fits-all solution—it involves a combination of biosecurity, preventative healthcare, and quality seed, among other factors. Slow growth is another issue that can be more challenging to address. When shrimp experience stunted growth, but farmers continue feeding them, hidden costs can accumulate. Feed expenses make up 60-70% of total production costs, and continuing to spend on shrimp that aren't growing effectively can lead to further financial difficulties.

We often talk about animal welfare in vertebrates, with fewer discussions for invertebrates. How important is shrimp welfare?
Shrimp welfare is becoming increasingly significant, particularly in Europe, where there is considerable focus on the practice of ablation—removing one of the eyes of the female shrimp to accelerate the spawning cycle. This practice is seeing a swift shift away in Latin America and may eventually occur in Asia as well, due to growing media attention and evolving scientific views. The prevailing belief is that not performing ablation enhances the female's quality of life, prolongs its lifespan, and improves the quality of its eggs. Since avoiding ablation isn't more costly and results in better farming outcomes, this shift is expected to happen quickly, influenced by Northern European retailers and subsequently spreading across the industry. Another area of growing interest is electrical stunning. This process involves stunning the shrimp after harvest before placing them on ice. While the science supporting its benefits for shrimp welfare is less convincing, the method also requires significant investment and changes to harvesting procedures, making widespread adoption less certain. Nevertheless, there is momentum for change. For instance, one Dutch supermarket has recently banned shrimp produced using ablation, and others are following suit. This is part of a broader trend toward improving sustainability in the industry, which includes initiatives such as sustainable feeds and enhanced traceability across the supply chain.

Read the full interview with Willem van der Pijl

Discover the guide to the Indian shrimp industry

A Conversation with Esteban Ramírez

What solutions is the industry implementing to reduce its reliance on antibiotics?
Chile's salmon industry is actively reducing antibiotic use through a multi-pronged approach. Public-private partnerships like Yelcho are leading the charge, fostering collaboration to develop new disease prevention solutions and vaccines. This initiative mirrors successful public-private efforts in human health, like the rapid development of COVID-19 vaccines. Additionally, programs like Pincoy and Proa support best practices in fish health management and disease prevention. These efforts aim to emulate Norway's success in minimizing antibiotic use through robust research and preventative measures.

How important is it to reduce the risk of AMR? And what role does aquaculture have?
Aquaculture, particularly salmon farming, plays a significant role in preventing AMR as we still rely on antibiotics to control certain diseases. In the case of Chile, we have few antibiotic alternatives, and part of this scenario is related to a joint effort between salmon producers and authorities to eliminate the use of critically important antibiotics for human health in salmon production.

Read the full interview with Esteban Ramírez