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Novel Technologies To Improve

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Novel Technologies To Improve Efficiency and Sustainability in Aquaculture

Introduction

Aquaculture has become an indispensable component of global food production, providing almost 50% of the world's seafood supply. As the demand for seafood continues to rise, so does the pressure on aquaculture operations to meet these demands sustainably, ethically, and economically. Balancing the need for increased production with the imperative to improve animal welfare has long been a challenge for the industry.

There has been increasing pressure from key seafood buyers to improve animal welfare through the value chain, with Western European markets leading the way. In response to this, new advanced technologies have emerged that not only enhance the well-being of aquatic animals but also bolster the economic viability of these enterprises. Many of these technologies cover disease prevention, fish and pen hygiene, and fish slaughtering and processing methods.

The economic consequences of poor fish farming practices are striking, with negative externalities estimated at a staggering $47 billion for salmon alone since 2013[1]. These losses are primarily attributed to high stocking densities that result in greater disease prevalence, unequal feed distribution, and higher mortality rates, emphasizing the need for more sustainable practices. Economic gains are closely linked to improving fish welfare. For example, reducing mortality rates to 5.5% in Norway would represent an annual saving of over $890 million (based on 2019 volumes and prices)[1,2].

Disease outbreaks and fish welfare issues have inflicted substantial economic losses on aquaculture industries worldwide. In Southeast Asia, the acute hepatopancreatic necrosis disease (AHPND) resulted in staggering financial impacts, including US$11.0 billion in China (2009-2016), US$2.5 billion in Vietnam (2010-2016), US$1.2 billion in Malaysia (2010-2016), US$7.9 billion in Thailand (2010-2016), and US$0.7 billion in Mexico (2012-2016)[3]. Meanwhile, sea lice infestations in Scotland have caused persistent challenges, with an average infestation leading to economic damages of US$0.46 per kg of harvested biomass, equivalent to 9% of farm revenues[4]. Furthermore, unplanned mortalities, fish welfare concerns, and sea lice issues have collectively cost the Scottish salmon industry US$177 million in 2019 and 13% of their harvest[1].

The welfare of aquatic organisms is a central concern for the industry, as suboptimal conditions can lead to stress, reduced growth rates, increased disease susceptibility, and, ultimately, decreased product quality. Simultaneously, the economics of aquaculture are under constant scrutiny, with profitability increasingly pressured. To address these challenges, aquaculture is adopting innovative technologies that improve fish welfare, reduce disease prevalence, and enhance farm economics.

Water Quality Management

Water quality management is of paramount importance in aquaculture to ensure the health and productivity of aquatic organisms. Several key contributors to water quality must be closely monitored, including physical parameters such as pH, temperature, salinity, dissolved oxygen, carbon dioxide levels, organic contaminants, biochemical hazards like cyanotoxins, and biological contaminants such as pathogens. Maintaining optimal oxygen concentration in the water, as close to air saturation as possible, is vital for healthy fish growth. Oxygen levels falling below 4 mg/L can lead to fish stress, loss of electrolytes, and even cessation of feeding, ultimately impacting fish yield[5].

Continuous, in-situ monitoring of these critical water quality parameters is essential to create and maintain optimal aquatic conditions. Innovations in water quality monitoring include the development of robotic systems capable of monitoring water quality in fish pens, reducing the need for extensive human labor[6]. These systems can transmit data to mobile devices via the Internet of Things (IoT).

One example is offshore salmon farms in Norway that employ remote monitoring systems that measure temperature, oxygen levels, and currents. The data is transmitted via satellite to onshore control centers, allowing operators to adjust feeding and other processes remotely [7,8].

Controlling feeding systems is another essential lever that can help protect water quality on fish farms. Overfeeding can lead to excess uneaten feed accumulating in the water, which, in turn, triggers bacterial decomposition processes. As the uneaten feed decomposes, it consumes dissolved oxygen in the water, causing oxygen levels to plummet. Insufficient dissolved oxygen can stress fish and other aquatic organisms, impeding their growth and overall health. Additionally, the decomposition of excess feed releases ammonia and other harmful compounds, further deteriorating water quality. Therefore, precise and controlled feeding systems are essential for efficient resource utilization and maintaining the delicate balance of water parameters crucial for the well-being of aquaculture offshore farm species and the sustainability of the operation. Various solutions have been developed to control feeding in aquaculture and protect water quality. These measures include:

1. Feed Modulating Systems: Implementing feed modulating systems is crucial to prevent overfeeding, which can lead to bacterial proliferation.
2. Bionic Fish Observation: Observing the growth status and feeding behavior of fish through bionic fish helps in regulating water quality. Fertilization and chemical spraying on unmanned boats are used for this purpose.
3. Intelligent Bait Feeders: These feeders ensure accurate and automatic feeding, minimizing the risk of overfeeding.
4. Machine Vision and Sonar: Fish movement and feeding information are obtained using machine vision and sonar technologies, allowing for precise feeding control.
5. Net Cage Automatic Feeding System: Norwegian fishery equipment enterprises have developed systems comprising management, online monitoring, and feeding modules. These systems enable real-time control and adjustment of feeding based on environmental parameters.

6. Robot Feeding Control System: Developed by Finland's Arvo-Tec company, this system offers remote control of feeding, water quality improvement, and precise feeding through a web interface[7]. It considers factors like water temperature, oxygen content, and biomass to optimize feeding.
7. AI-Powered Feeding Management: Utilizing AI and deep learning techniques, unmanned aerial vehicles (UAVs) capture data on fish feeding intensity by detecting disturbances on the water surface. This information is then analyzed in the cloud, and feeding machines adjust food dispensing accordingly[9].

Efforts to implement these types of technologies at scale are being made, but many challenges remain. The largest challenge is overcoming the cost barrier for implementing this system for small or resource-constrained aquaculture operations and setting up the required infrastructure and data management systems to run these novel feeding systems effectively. Other challenges include training aquaculture workers to operate and maintain the new technology, scaling these solutions to large-scale operations, integrating technologies into existing aquaculture practices, testing the efficacy of the system, and complying with environmental regulations.

Fish Processing and Stunning Technology

The standards for aquaculture killing methods have long been the use of anesthetizing the fish in an ice slurry bath or with blunt force to the head before euthanasia. The first method requires immersing fish in ice water of 1°C temperature until no eye rotation or opercular movement reaction to a painful stimulus is observed, and they are then euthanized. This is a low-cost method and has been employed globally. Percussive stunning uses blunt force trauma to render the fish unconscious before transferring them to the bleeding station. Electrical stunning is a more humane and consistent method that causes the instant insensibility of fish for a short period of time through an applied electrical current. The main producers of the electrical stunning methods are Baader and Optimar. However, there are several challenges with stunning technologies:

Percussive Stunning	**Ice slurry anesthesia**	**Dry electrical stunning**
• Usually, a manual task that is inaccurate / missing the head of the fish or not immediately causing insensibility • If the system is automated, fish are required to be sorted beforehand, which often causes stress to fish • Inaccurate due to differences in fish	• Fish left in an ice slurry result in long inactivity and high stress before they die. • Effectiveness may vary with different types of fish • Not efficient for warm-water species or in tropical climates • Time-consuming method • High stress for fish	• Need specific voltage and duration to ensure effective stunning. • If the voltage is too low, fish can regain consciousness and experience extreme stress during killing or processing procedures.

species, size, and skull morphology	during temperature changes • Product quality issues around skin and tissue freezing	• Too high voltage can result in carcass damage (hemorrhages, blood spotting, or spinal fractures), leading to lower product quality. • Ineffective stunning may leave the fish physically immobilized but conscious • Fish need to enter the machine head-first without any struggling to prevent pre-stun shocks

For all of these stunning technologies, moving fish from holding pens to slaughter locations can affect fish quality due to poor water exchange, long times in the air, low oxygen levels, or fish waste accumulation.

One innovative technology solution is Ace Aquatec's in-water electrical stunning platform. This method pumps fish directly from the sea into the stunning tube, which has electrodes embedded into the interior to pass an electrical current through the water and fish, allowing all fish to be stunned reliably irrespective of size[10–12]. This improves carcass quality and fish processing speed, reduces handling, and allows for a more automated system, reducing labor costs. Solutions that can dramatically improve welfare whilst also driving a notable financial improvement will be highly sought after as legislation and buyer specifications become more stringent.

Feed Supplements

Several strategies can be implemented to improve and optimize fish farming practices, including minimizing the risk of fish loss while improving the FCR. One common strategy is through enriching feed with new feed supplements. Below is a table of recent research on feed supplements that have demonstrated benefits for fish farming.

Feed Additive	Examples	Effects
Essential fatty acids	Arachidonic acid, eicosapentaenoic acid,	Omega-3 polyunsaturated fatty acids are among aquaculture feed's most frequently used

	linolenic acid, and linoleic acid	ingredients. Species have differences in EFA requirements for metabolic adaptation to different habits in aquaculture[13][14]
Essential oils	*Oreganum heracleoticum*, *Sparus aurata*, estergole, and oleoresin	Increase the growth performance and antioxidant effects and enhance the muscle protein activity[15]
Probiotics	*Baciilus pumlis B16, B. mojavensis J7, Streptomyces panacagri, and Streptomyces flocculus, Lactobacillus salivarius UCC118, and Lactobacillus spp. MSU3IR*	Protective against foodborne pathogens, is an alternative to antibiotics, and improves the bacteriocin level of biomolecules[16]
Prebiotics	Mannanoligosaccharide, fructoligosaccharides, and galacto ligosaccharides	Promote innate immune response, increase fish growth, and improve health[17] Improve FCR for fish and trigger the production of glutathione-related enzymes and increased enzymatic activity of GPX, indicating an increased antioxidative process. [18]
Organic Acids	Acetic acid, formic acid, fumaric acid, lactic acid, propionic acid, and citric acid	Act as anesthetics for fish, causes immunosuppression, promotes growth, and induces weight gain[19]
Exogenous enzymes	Protease, amylase, phytase, lipase, and carbohydrase enzymes	Provide a unique ability to grow and increase nutritional value[20]
Herb supplements	Chromolaena Odorata, Allium Sativum	Act as immunostimulants and bolster defense mechanisms and immune responses in fish. Also found to act as growth promoters and boosters of stress resistance. [21]

Vaccines and Alternatives

In aquaculture, vaccination is commonly employed, and there are currently 24 licensed fish vaccines available for various fish species, ranging from whole killed and peptide subunit to recombinant protein, DNA, and live attenuated vaccines[22]. However, challenges persist, such as the predominant use of intraperitoneal injection for vaccine administration, which may not be suitable for all vaccines. Challenges include the need for effective adjuvants, limited knowledge of immune responses, and cost concerns that sometimes lead countries to prioritize disease treatment over prevention.

Despite these challenges, there are promising opportunities in the field. Advancements in technology, changing regulations like the authorization of DNA vaccines in Europe, and the availability of fully-sequenced fish species genomes have opened new avenues for vaccine development. One promising alternative to intraperitoneal injection vaccines is mucosal-based vaccines. Optimizing mucosal vaccines for delivery through the skin, gills, gut, and nasal mucosae holds potential, especially in low- and middle-income countries[23]. However, challenges with mucosal vaccines include efficacy issues, uncertainty regarding optimal protective doses, the potential for oral tolerance, the risk of denaturation in the stomach, and the need for antigens to cross mucosal barriers to reach antigen-presenting cells (APCs).

Emergency (autogenous) vaccines can address emerging disease challenges, and the ability to measure vaccine-induced responses is crucial for both new vaccine development and evaluation of existing vaccines[24]. While options like live attenuated vaccines, mRNA vaccines, and nanoparticle vaccine delivery methods exist, their adoption hinges on striking the right balance between price and efficacy in aquaculture[22].

Lice Treatment Technologies

Sea lice pose a significant economic cost and health challenge to the aquaculture industry, particularly in salmonid aquaculture. Recent studies have indicated that parasites, including sea lice, contribute to an annual loss of 5.8–16.5% of UK aquaculture production, encompassing both freshwater and marine species[25].

Addressing the sea lice problem in aquaculture is critical, and there is a need to transition from reactive approaches to proactive prevention measures. While technologies for sea lice treatment have existed for some time, there is an ongoing effort to develop more cost-effective and efficient methods. The most common approaches have been chemical therapeutics and physical management methods, such as brushing lice off of fish, jet spraying fish with strong streams of water, or putting fish in warm baths to kill lice, which are heat resistant. While chemical treatments are available, they often negatively affect both fish and the environment. These treatments include organophosphates, pyrethroids, hydrogen peroxide, emamectin benzoate, and diflubenzuron. Bath treatments using these chemicals involve immersing fish in a solution containing the treatment agent or incorporating them into fish feed as additives. Some chemicals can curb salmon appetite and reduce growth, potentially worsening the economic impact. More importantly, sea lice have developed resistance to many of these chemical substances, leading to higher concentrations and ineffective treatments.[26,27]

Some innovative technologies and approaches include:

1. Ultrasound Technology: Companies like Giga AS have developed ultrasound technology capable of reducing lice infestations by up to 95% in salmon lice larvae within closed containment aquaculture systems. This proactive approach targets sea lice early in their life-cycle[28].
2. Physical Restraints: Nets placed at depths where sea lice do not inhabit can act as a barrier. These nets are preventive measures since young infectious sea lice tend to stay in upper water layers.

3. Bacterial Strains: Some innovative approaches involve using bacterial strains in fish feed to stimulate the formation of natural bioactive compounds in fish intestines, potentially enhancing their resistance to sea lice[30].

Despite these technological advancements, challenges around regulatory approval of new treatments and the cost of implementing them at large scales remain.

Conclusion

The aquaculture industry is set to come under increasing pressure from consumers, governments and buyers to improve welfare. This creates a dual challenge of meeting growing seafood demand while improving fish welfare and sector economics. This will require innovation through the value chain from farm inputs and technologies to fish processing. Companies targeting water quality management, novel feed supplements & vaccines, sustainable lice treatment technologies, and stunning & processing technologies that enhance fish welfare and improve operational efficiency represent key areas of opportunity for investors. The most promising among them offer the potential for economic improvements while addressing critical industry concerns. Overcoming cost barriers, navigating regulations, and ensuring scalability will be essential for startups and investors aiming to make a lasting impact on aquaculture sustainability and profitability.

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