GOOD AQUACULTURE PRACTICES AND SMART AQUACULTURE

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Introduction

Globally, aquaculture stands out as one of the fastest-growing production sectors, employing water productivity concepts. Aquaculture encompasses the practice of cultivating aquatic organisms- finfish, shellfish, other invertebrates and microscopic and macroscopic plants- in controlled conditions under human management, both in freshwater and saltwater. Farming involves interventions such as breeding, nursery rearing, stocking, feeding, and protection from predators. It also includes aspects of individual or corporate ownership, planning, and development, operation of culture systems, sites, facilities, practices, production, and transport. According to the FAO (2014), aquaculture is the fastest-growing animal food sector worldwide, supplying approximately 50% of the fish consumed by humans. In 2020, global aquaculture production reached 122.6 million tons, with 54.4 million tons from inland waters and 68.1 million tons from marine and coastal aquaculture (mariculture), amounting to a total value of about USD 281.5 billion (FAO, 2022). Notably, the Asian region contributed a substantial 91.6% to this production, positioning India as the world's second-largest aquaculture producer and the third-largest fish producer. The social and financial significance of aquaculture has consistently grown at over 6% in recent years, playing a vital role in global food production and addressing the increasing demand for protein sources, livelihoods, and income. In Afro-Asian countries, where aquaculture plays a vital role in cultural, economic, and nutritional aspects, the adoption of Good Aquaculture Practices and the embrace of Smart Aquaculture technologies become imperative for ensuring long-term food security and sustainable development. Through this lens, this article attempts to uncover the potential of Good Aquaculture Practices and Smart Aquaculture in shaping the future of aquaculture in Afro-Asian countries, striking a balance between economic growth, environmental stewardship, and societal well-being.

Aquaculture systems and their impacts

While aquaculture undeniably contributes significantly to humanity through the provision of food, nutrition, livelihoods, income, and employment, it simultaneously raises global concerns due to its profound environmental and health impacts. The untreated discharge of aquaculture wastewater, indiscriminate use of substances like antimicrobials and growth promoters, nutrient loading from faecal matter and food leftovers, and the release of captive organisms into natural waters pose potential threats to local environments, biodiversity, and human/animal health (Guangjun et al., 2010). As the demand for aquaculture products continues to surge, there is an increasing inclination towards adopting intensive or high-density, high-production aquaculture systems that rely on formulated high-protein feeds, oxygen supply, and the application of drugs and antibiotics. This trend gives rise to significant apprehensions about environmental sustainability and human safety. The global unease regarding these issues has prompted urgent calls for the transformation of aqua-food systems to ensure biosecurity, food security, and the preservation of ecosystems and social equity (FAO, 2022).

Aquaculture systems are categorized based on the degree of human intervention, the density of organisms stocked, and the energy consumption per unit volume of water used/supplied. These classifications include:

- Extensive
- Semi-intensive
- Intensive
- Highly or super-intensive

Extensive aquaculture relies on farming aquatic organisms using natural food sources, while semi-intensive aquaculture utilizes manure and fertilizers with a moderate supply of artificial feeds. Intensive aquaculture involves high stocking densities, and aeration, and relies solely on artificial feeding and the application of chemicals for disease prevention and treatment, resulting in a high unit area or unit of water used. Super-intensive aquaculture systems, on the other hand, demand complete control, featuring extremely high stocking density, water re-circulation, and a substantial input of food materials and chemicals, coupled with very high energy consumption. Depending on the practised aquaculture system and the farmed species, the intensity of impacts varies, ranging from the lowest for extensive systems to the highest for super-intensive setups. These impacts can manifest in visible and invisible, positive and negative ways (Preston et al., 1997; Wang et al., 2005). Effluent discharge, the use of fertilizers, chemicals, medicines, growth promoters, disinfectants, pesticides, and pathogens, and the escape of stocked organisms into the natural environment are among the significant effects of aquaculture. Therefore, the adoption of regulated and monitored aquaculture practices is crucial to achieve sustainability and mitigate risk factors, facilitated by a comprehensive set of assessment tools. In this context, the focus is on "Good Aquaculture Practices" (GAP) and "Smart Aquaculture."

Good Aquaculture Practices

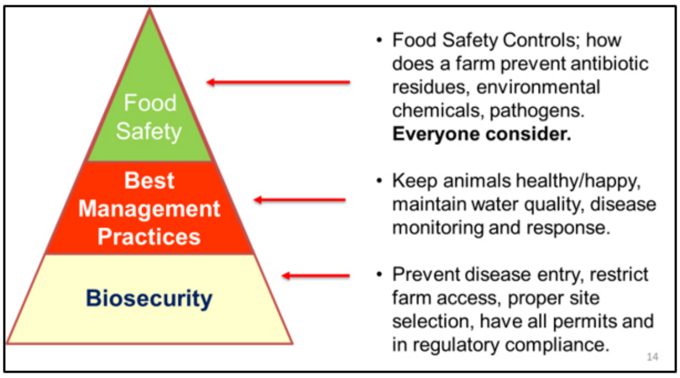
GAP encompasses a comprehensive set of guidelines and principles designed to ensure the responsible and sustainable development of aquaculture. It aims to address environmental concerns, promote animal welfare, and safeguard the health of aquatic ecosystems and the communities dependent on them. To facilitate the promotion of responsible aquaculture practices, generic tools are available for assessment. These tools, including methods, guidelines, and processes, are utilized in planning, development, management, and decision-making in aquaculture (Miao et al., 2013). Their application spans from the farm level to national policy levels, with certain tools guided by international agreements and instruments. Noteworthy examples include the following (Miao et al., 2013).

- Assessing risks in aquaculture (e.g. pathogen risk analysis, food safety risks, genetic and ecological risks)
- Risks in international trade (e.g. IRA)
- For Impact Assessment (e.g. EIA)
- For assessing governance (e.g. codes of practice)
- For management (e.g. BMPs, GAqP, certification)
- Socio-economic assessments

Good Aquaculture Practices (GAqP) constitute a set of operational standards for optimizing aquaculture practices, enhancing product quality and safety, and contributing to environmental integrity and social equity (Miao et al., 2013). GAqPs are preventive protocols designed to address the needs of farmed species, farming methods, end-users, and the local environment. Implemented through Hazard Analysis Critical Control Point (HACCP) principles, these practices involve identifying potential risks and applying preventive and control measures. Seven fundamental principles guide the HACCP approach:

1. Hazard and Risk Analysis
2. Identify Critical Control Points
3. Establish Critical Limits
4. Establish Monitoring Procedures
5. Establish Corrective Actions
6. Establish Verification Procedures
7. Establish Record Keeping Procedures

The Hazard and Risk Analysis involve evaluating potential hazards related to the aquaculture process, determining their likelihood, and assessing severity. From broodstock maturation to harvest and post-harvest, critical control points include water quality, disease outbreaks, and food provision. Identifying these points and setting permissible minimum and maximum levels for monitoring is crucial. Critical limits are established for parameters like stocking density and food ratios to control physical, chemical, or biological hazards. Monitoring procedures ensure accurate tracking of Critical Control Point levels, while corrective actions outline short, medium, and long-term responses to identified hazards. Verification procedures confirm the validity of corrective actions and overall protocol adherence. Record Keeping Procedures document all steps in the process, making records accessible in paper or electronic form. Standard Operating Procedures (SOP) can guide the entire operation, ensuring comprehensive implementation and compliance.



Layered preventative controls in GAqP (source: Brett Koonse, JIFSAN)

Standard Operating Procedure (SOP)

An SOP, a crucial manual for farm managers, offers a user-friendly guide through each step of the HACCP process. Prepared before the farming operation starts, the SOP encompasses facility design, flow diagrams, husbandry procedures, waste management, pest control, staff rules, and more. It extends to encompass animal welfare, environmental protection, and social responsibility, incorporating details on stock, diagnostics, disinfection, pathogen eradication, and more. The principles of HACCP provide a systematic approach to prevent contamination, pathogen entry, and disease outbreaks, enabling farm managers to identify essential process steps and select appropriate Critical Control Points and Measures. GAqPs play a vital role in minimizing animal and human diseases, antimicrobial resistance (AMR), import violations, and in enhancing the perception of aquaculture. It streamlines planning, risk identification, control implementation, and documentation, ensuring effectiveness through verification.

Smart Aquaculture

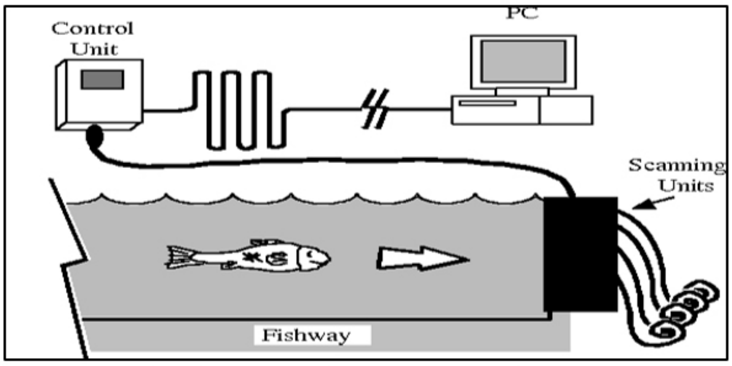
Smart Aquaculture integrates advanced technologies and innovative approaches to boost productivity, efficiency, and resource management in aquaculture. From precision farming to automation and artificial intelligence, it promises to make the industry more resilient, environmentally friendly, and economically viable. The key goals include minimizing effluents, and input and labour costs while maximizing human health and environmental benefits. Applying digital and electronic knowledge such as computer vision, machine learning, information and communication technologies (ICT), Internet of Things (IoT), cloud-based computing, and automation, Smart Aquaculture shows immense potential for sustainable management and enhanced production. This article discusses the current developments and explores avenues for smart mariculture. Artificial Intelligence, Machine Learning, Virtual Reality, and Augmented Virtual Reality are major components of smart aquaculture systems. Complex algorithms analyse data from sensors, creating mathematical models for performance monitoring and activating specific amelioration actions. These intelligent systems can oversee breeding, nursery, grow-out, water quality, feeding, effluent management, growth and health monitoring, size-based sorting, and counting. As current traditional or semi-intensive farming practices may struggle to meet all demands, interventions through smart aquaculture, integrating electronics, instrumentation, computer programming, IoT, etc., can substantially boost growth and the economy of the sector. Some of the growing modules applicable in smart aquaculture and mariculture are the following.

Water quality monitoring

Water quality monitoring, often facilitated in real-time, is a widely employed module. AI advancements enable self-contained systems, minimizing human interventions. Integrated sensors continuously monitor water quality, triggering alerts to farm managers and prompting automated remedial measures through connected actuators.

Counting and sizing/ weighing of fishes

Counting and sizing/weighing cultured species, crucial in aquaculture/mariculture for stocking decisions, feeding adjustments, growth monitoring, and harvest advisories, can enhance operational efficiency and profitability while minimizing stress on the fish. Automation, facilitated by computer vision technology, involves video analysis and image processing. Existing systems in modern hatcheries use this technology to detect and count larvae and juveniles. Integrated modules can measure fish dimensions, model corresponding weight, and estimate biomass. Pixel size and number in an image can also be modelled to estimate fish size and biomass.

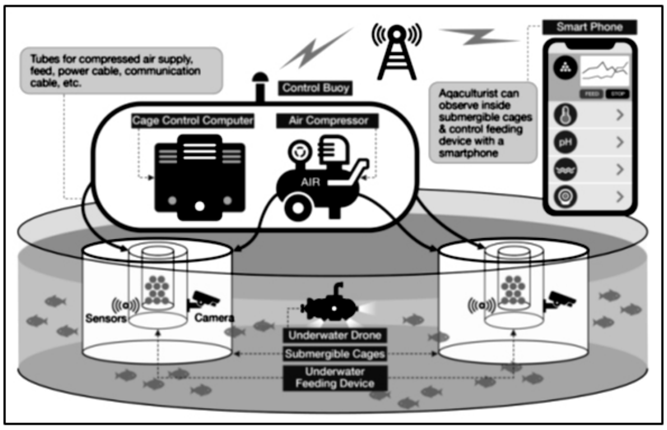


A scheme of an automatic fish counting system.
Source: Cadieux et al. (2000)

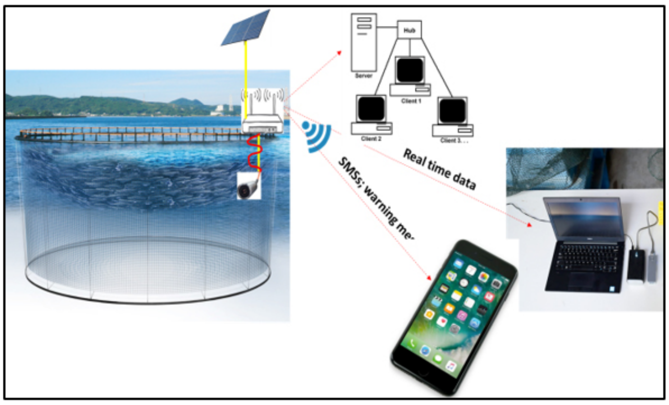
Disease and health management

In aquaculture, diseases result from imbalances in factors like pathogens, nutrition, and the environment, falling into infectious (parasitic, fungal, bacterial, viral) and non-infectious (environmental, nutritional, genetic) categories. Timely diagnosis and treatment are essential for disease management. Machine learning, with feature identification algorithms, can detect and alert farmers to real-time external symptoms of fish diseases, facilitating prompt interventions. Automated applications of antibiotics and medicated feeds are possible through seamless integration. Utilizing vision-based image processing to track fish movement in aquaculture systems aids in identifying unhealthy fish based on their movement patterns, compared to stored healthy trajectories. This information is crucial for different health conditions, deficiencies, or water quality changes, allowing timely alerts to managers. Species-specific data must populate digital reference libraries for aquaculture/mariculture, either locally or in cloud storage systems. Modern science and technology have significantly benefited aquaculture by reducing labour, enhancing production, and promoting environmental friendliness. Smart mariculture, or intelligent mariculture, seeks to apply smart principles and systems to manage saltwater aquaculture through intelligent technology, electronics, machine computation, internet and communication technologies, and automation with robotics. The goal is to ensure sustainability, increase production, and boost profits while addressing challenges in conventional mariculture practices. Smart mariculture offers solutions to various issues, such as making real-time informed decisions in offshore cage farms using sensor data and applying quick remedial actions through actuators or alerts to managers. The system can be operated remotely using IoT, big data, artificial intelligence, 5G, cloud computing, and robotics. AI and IoT have proven effective in solving problems present in traditional mariculture.

Smart systems find application in various setups, including oceanic cage farms, coastal ponds, hatcheries, raceways, and re-circulatory aquaculture systems. They are used for water quality monitoring and adjustments, health and growth monitoring of stocked fishes and larval stages, optimizing feed ration and schedule, reducing labour, and ensuring human safety, especially in offshore culture installations. The future of smart mariculture lies in cloud-based monitoring and control systems, with web and Android applications aiding in determining ideal conditions in culture ponds. Notably, in India, the recent adoption of feed dispensing sensors and mechanisms represents a step forward in this direction.



Conceptual framework of a smart aquaculture system (Source: Vo et al., 2021)

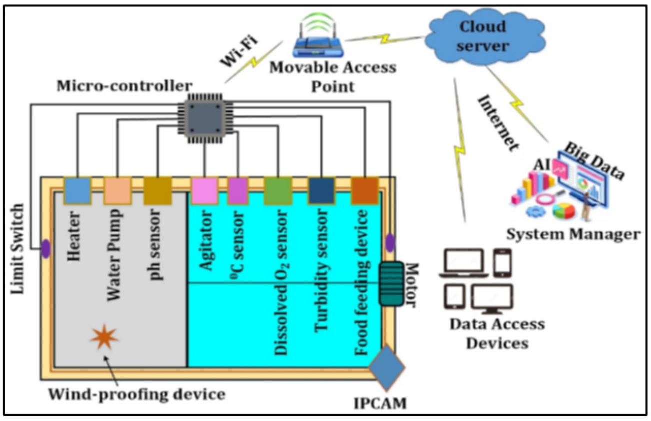


A conceptual model for computer vision-based monitoring of fish stocked in marine cages

Intelligent devices and analytics frameworks are being produced every day throughout the world. For example, salmon cage farming currently resorts to smart systems for daily management in Norway.

Integrating IoT in the aquaculture industry offers significant advantages. It enables effective monitoring with extensive data coverage from multiple locations, facilitating real-time remedial actions. Through the utilization of artificial intelligence (AI) and machine learning (ML) technologies, collected data over time contributes to creating large predictive models for accurate decision-making, process automation, and timely warnings. This is particularly crucial for offshore installations in mariculture, where human labour-based management is both expensive and poses risks to human health and life. Automation and smart mariculture systems are more impactful in offshore settings than on land.

The increasing use of remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and autonomous surface vehicles (ASVs) has become prominent in marine explorations and monitoring. Specifically in mariculture, ROVs, including underwater robotics, are being developed for tasks like inspecting offshore installations, cleaning cage farm mesh nets, and monitoring water quality. Challenges such as reliability, safety, endurance, human-machine interface, real-time dynamic process tracking, and event detection and classification need addressing (Betancourt et al., 2000). Researchers like Rodriguez et al. (2015) explore the use of a non-invasive 3D optical stereo system and computer vision techniques to study biological variables in fish. Betancourt et al. (2020) developed a novel robotic architecture with an RGB camera for real-time video capturing and integrated sensors for hydro-climatic data, aiming to inspect net cages in fish farms. Recent studies have focused on smart and intelligent systems for fish feeding and monitoring (An et al., 2020). Cisar et al. (2021) propose a precision fish farming concept for fully automatic Atlantic salmon individual identification. Various tracking algorithms, such as Minami et al. (1999) and Chen et al. (2015), are explored, with considerations for accuracy and limitations. Chuang et al. (2017) developed an algorithm for underwater fish tracking based on multiple deformable kernels, demonstrating effectiveness in low-illumination underwater videos. While machine learning and computer vision concepts have been utilized in smart agriculture, the Indian context is in the early stages of research and development. Significant investment and interdisciplinary collaboration are crucial to developing self-reliant smart aquaculture/mariculture systems.



A scheme of multiple sensor-based automatic monitoring and control in a fish pond (Source: Min-Chie et al., 2022)

In conclusion, the integration of advanced technologies and intelligent systems in aquaculture represents a transformative shift towards sustainable, efficient, and economically viable practices. From the adoption of Good Aquaculture Practices to the implementation of Smart Aquaculture, the sector is poised to address environmental concerns, enhance animal welfare, and optimize resource management. The application of the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), and robotics in monitoring, disease management, and automated processes offers unprecedented possibilities for real-time decision-making and proactive interventions. However, challenges such as reliability, safety, and interdisciplinary collaboration remain, emphasizing the need for continued research, development, and investment. As the industry navigates towards self-reliant Good Aquaculture Practices and Smart Aquaculture systems, a holistic approach is essential to ensure the long-term success and implementation of these practices.

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