COMPARATIVE ANALYSIS OF AQUACULTURE FRAMEWORK OF INDIA WITH OTHER COUNTRIES

Nikitha Ann Varghese, B.Com LL.B., LL.M (IPR and Environmental Law), School of Legal Studies, Cochin University of Science and Technology

ABSTRACT

China and Indonesia are ranked the first and second largest coastal aquaculture sector in the world respectively. Norway is leading country in coastal aquaculture and particularly known for its large -scale Atlantic salmon production. They also make a significant stride in sustainable practices. This study provides a comprehensive comparative analysis of coastal aquaculture systems in India, China, Indonesia and Norway, highlighting variations in governance structures, sustainability practices, technology adoption and environmental management strategies. China's transition from a mariculture -centric approach to more diversified and sustainable aquaculture model has been supported by strong policy and regulatory measures. Indonesia prioritizes ecosystem-based aquaculture, community involvement and integrated spatial planning to balance production with environmental conservation efforts. Norway leads in high-tech, regulation -driven aquaculture, particularly in salmon farming, having made significant advancements in disease control and offshore enclosures. While India's aquaculture sector is vital for the rural economy, it faces challenges such as fragmented governance, inadequate enforcement and ecological deterioration. The paper outlines key policy insights actions from international best practices that could be adopted in India to enhance sustainability regulations, and promote inclusive and resilient growth in the aquaculture sector.

Keywords: Aquaculture governance, Coastal aquaculture, Sustainable aquaculture, India, China, Indonesia, Norway, Environmental management, Policy framework, Ecosystem-based management, Technological innovation.

China

China has a long history of aquaculture practices. Since the 1980s, the government has increasingly recognized mariculture as a vital sub sector within aquaculture. Mariculture offers both nutritional and economic advantage while also reducing the pressure on diminishing wild fish stocks. Currently, China leads the world in mariculture output. Between 1967 and 1980, kelp accounted for 50-60% of the total mariculture production in China. By 1980, the production of *Laminaria japonica Aresch* (Kombu Algae), the predominant species has reached 252,907 tons. Following 1981, the proportion of kelp production declined due to a relatively higher output of mollusks, shrimps and finfish. Marine finfish and mollusc production increased sharply after 1990. In 2001, the total mariculture production reached 11,315,000 t from a production area of 1,286,000 ha. The rapid development and changes in mariculture species have aroused increasing concern about mariculture's impact on the coastal environment.[1] The expansion of mariculture will be greatly influenced by the effects of coastal aquaculture, including the deterioration of water quality and presence of contaminants. The cornerstone of enhancing and preserving the long-term viability of mariculture areas is the implementation of sustainable culture practices. It is essential to manage the stocking density of fish and other economically valuable species, such as oysters and scallops, as well as to limit the overall quality of net cages in the mariculture regions. The relocation of cages at regular intervals and the implementation of fallow system, wherein fish farming will be paused foe 1-2 years to allow the polluted sediment to recover is recommended. There are also suggestions to move fish farming to a deeper offshore water. Additionally, it is thought that extensive seaweed farming will help mitigate eutrophication in costal aquaculture areas in China. China's aquaculture sector has seen significant growth, shifting from a mariculture-driven model in the 1989- 2002 period to a freshwater aquaculture- dominated industry between 2003 and 2018.[2] China's evolving aquaculture strategy is increasingly influencing the global seafood industry by promoting sustainability and lessening reliance on capture fisheries from the sea. In the past, China's aquaculture especially in coastal waters put immense pressure on wild fish resources because of the high usage of fishmeal and forage species such as anchovies, sardines and

[1] Feng, Y Y, Hou, LC, Ping, N X, Development of mariculture and its impacts in Chinese coastal waters. Reviews in Fish Biology and Fisheries 14, (2004)
[2] Kangshun Zhao and Min Zhang, Aquaculture Impacts on China's Marine Fisheries Over the Past 30 Years, Frontiers in Marine Science, (2021)

herrings. However, over the past two decades, the nation shifted towards more sustainable practices, reorienting its feed manufacturing and aquaculture operations.

One of the important elements of this shift is decreased dependence on fishmeal. Before, Chinese aquaculture largely relied on fishmeal obtained from marine organisms. Advances in feed technology have significantly reduced dependence on fishmeal and replaced it with plant ingredients and other proteins. Also, greater cultivation of non-fed animals such as mollusks and algae has contributed further to reduced dependence on wild stocks of fish.

The growth of China's coastal aquaculture ponds between 2017 and 2021, based on Sentinel-2 satellite imagery and a multi featured decision tree classification approach is analyzed with 65,332 images through the Google Earth Engine (GEE) platform, scientist attained an extraction accuracy of 90.80% with an average F1 score of 0.91. The results indicate that the overall aquaculture pond area along China's coastal areas in 2021 was around 7,633.83 km², primarily distributed across estuarine bays in Shandong, Jiangsu and Guandong provinces. It revealed a declining trend in coastal pond area foe aquaculture at an annual average of 235.65 km², where old aquaculture pond areas have been changed into wetlands or abandoned aquaculture land. China's coastal aquaculture sector is central to world seafood production, and it provides more than 60% of world aquaculture production.[3]

However, the rapid progress has created environmental concerns, including habitat destruction, pollution of seawater and a decrease in natural wetlands. To combat these issues, China has issued stricter regulations to promote sustainable aquaculture, including the development of demonstration areas and marine pasture programs.

Government Policies and Regulatory Framework

Government efforts have been crucial in encouraging sustainable development in the aquaculture sector. The Chinese government has enacted policies to avoid overfishing, maintain ecological protection, and encourage environmentally friendly aquaculture operations. Policies like limiting marine fishery harvests and providing incentives for sustainable practices reflect a sincere commitment to reducing the environment footprint of seafood production. In addition, restructuring of China's aquaculture industry has led to

[3] Weiwei Sun and Tingting Hou, Mapping China's coastal aquaculture ponds expansion with sentinel-2 images during 2017-2021, International Journal of Digital Earth (2023)

improved production efficiency. The sector is shifting towards low input and high output, weighing food security against environmental concerns. This approach enables continuous production of seafood without further decreasing marine fish resources, setting a model of sustainable aquaculture worldwide.

The Fisheries Law of the People's Republic of China (2004 Revision) outlines several provisions related to aquaculture in Chapter II, emphasizing sustainable development and resource management. The law encourages the use of water areas and tidal flats for aquaculture,[4] requiring permits for operations in state-owned waters.[5] It prioritizes local fishery workers in permit allocation and mandates environmental protection measures[6], including restrictions on harmful feed and fertilizers[7]. The law also promotes the breeding of high-quality aquatic species, subjecting new varieties to verification before propagation. Additionally, the law mandates quarantine for imported and exported aquatic species and promotes technological advancements in breeding and disease prevention and also, maintain ecological balance by regulating stocking density, feeding practices and fertilizer application.[8]

China has been actively building marine pasture projects and pilot regions in order to facilitate sustainable aquaculture, restore marine ecosystems, and increase fishery productivity. These initiatives incorporate ecological restoration, technological innovations and policy measures and marine ranching plays an important role in reaching a balance between economic growth and environmental conservation. In southern demonstration sites, research shows that green aquaculture has been impacted positively. In northern areas, however, there are challenges arising from policy misalignments and industrial inefficiencies.

The country has established national pasture demonstration areas to promote sustainable aquaculture and enhance marine ecological conditions. However, these areas have shown mixed results. While there are favorable policies, the efficiency of green aquaculture is low due to institutional obstacles, inefficiencies in the industrial structure and a lack of scientific breakthroughs. Regional variations have also affected the success of these zones: northern demonstration zones have been faced with challenges of policy misalignment, whereas southern zones have experienced more encouraging results. Employing a multi-period

[4] Article 10 of Fisheries Law of the People's Republic of China (2004 Revised)
[5] Article 11 of Fisheries Law of the People's Republic of China (2004 Revised)
[6] Article 12 of Fisheries Law of the People's Republic of China (2004 Revised)
[7] Article 19 of Fisheries Law of the People's Republic of China (2004 Revised)
[8] Article 20 of Fisheries Law of the People's Republic of China (2004 Revised)

Difference -in Difference (DID) model to evaluate, studies have shown that the southern zones have had a positive impact on the development of green aquaculture, while the northern zones have faced a major setback.[9]

Country also has placed marine ranches as apriority measure as a way of increasing ecological efficiency in fisheries. The technique has various major benefits including improve productivity of labor, higher fish species diversity and better management of aquaculture areas. Marine ranching since 2015 has significantly improved eco-friendly, labor productivity and minimized the levels of pollution. It has played a key role in driving technological innovations and promoting efficiency at scale in the fishing sector. In support of these efforts, policy proposals emphasize the need to strengthen marine ecological conservation in addition to aquaculture development, and enhancing fishery technology promotion and resource conservation measures.[10] Despite this institutional barriers, weak regulatory enforcement and the absence of technological innovations hinder broader adoption.

A Case Study in Qingduizi Bay, China [11]

The research performed in Qingduizi Bay, China analyzes the ecological impacts of reclaimed mariculture ponds in the marine environment., presenting a comprehensive framework for assessing ecological damage and proposing mechanisms of compensation to reduce environmental degradation. Th rapid expansion of coastal pond aquaculture, which has led to significant damage to ecosystem services such as marine capture fishery resources depletion as a result of habitat loss, decline in biodiversity, reduced carbon sequestration and oxygen production, increased coastal erosion vulnerability, higher levels of pollution, disturbed nutrient cycling and decline in necessary nursery and habitat functions for marine species. Among the factors considered, nursery and habitat functions suffered the highest, expressed in damage seventy score of 0.74. At an economic scale, the overall ecological cost of damage is calculated at 86,858.48 yuan per hectare per year-29 times more than the current sea usage fee of 3000 yuan. Therefore, it proposes the recalibration of the compensation standards in order to better reflect the real the marine ecosystems. Furthermore, the proposed assessment

[9] Wei Wang and Wei Mao and Renhong Wu, The Effect of Marine Pastures on Green Aquaculture in China Water (2024), 16, 1730. https://doi.org/10.3390/w16121730 https://www.mdpi.com/journal/water

[10] Chen Yusheng and Ma Ye and, Yang Weili and Sun Zhaofa and Han Yang, How to improve fishery eco-efficiency by building marine ranch in China, Frontiers in Sustainable Food Systems (2024)

[11] Anguo Zhang, Ecological damage assessment and compensation for reclaimed coastal pond aquaculture: A case study in Qingduizi Bay, China, Aquaculture Research (2020)

framework can be scaled up and applied to other reclaimed areas of mariculture to assess environment impacts and inform policy.

China's strategic redirection exemplifies how innovation, regulation and sustainability can transform aquaculture to protect oceanic ecosystems yet provide a sustainable seafood supply. Such developments offer crucial lessons for other countries trying to balance seafood requirements with conservation measures.

Comparative Insight with Indian Aquaculture Practices

China and India have distinct governance approaches to coastal aquaculture, shaped by their legal frameworks, environmental priorities and economic strategies. China's Fisheries Law integrates aquaculture within broader marine conservation efforts, ensuring resource sustainability and ecosystem protection. The country employs remote sensing and GIS mapping to monitor aquaculture zones, optimizing land-sea interactions. They also provide subsidies and financial support to encourage sustainable aquaculture practices, particularly in provinces like Shandong and Guangdong. China's marine ecological management strategy gives priority to ecological restoration through measures like marine pasture zones and ranching, while India's Coastal Aquaculture Authority Act emphasizes regulatory compliance primarily. China's marine pasture zones' success is tied to the presence of robust liability mechanisms that encourage the compliance with environmental laws. To increase sustainability, it is critical to improve monitoring systems, which can help diminish the ecological risks associated with marine ranching and bolster the long-term health of marine ecosystems. In India the Coastal Aquaculture Authority Act primarily regulates shrimp farming focusing on environmental compliance and coastal zone management. Unlike China's centralized approach India relies on state-level regulations, leading to regional variations in aquaculture governance. India faces coastal pollution, land-use conflicts and climate change impacts, requiring adaptive policy measures. China's model emphasizes technological monitoring and centralized control ensuring efficient resource management. Whereas, India's framework prioritizes regional governance and environmental safeguards, but lacks uniform enforcement across states.

Indonesia

Indonesia is aggressively developing its aquaculture sector with a heavy focus on sustainability

and increased production. The government has launched several programs, such as the establishment of 136 aquaculture villages that are meant to increase exports of key commodities such as shrimp, lobster, crab and seaweed. [12] Ambitious 2030 sustainability targets have been established with the aim of tripling aquaculture production while minimizing environmental footprint. Policy reforms are also being introduced, with emphasis on improved feed conversion ratios, shifting to renewable energy sources, and the greater cultivation of omnivorous finfish species.[13] Major sectors of Indonesian aquaculture are shrimp culture primarily Pacific white shrimp and black tiger shrimp which is facing continuous challenges from diseases like white spot syndrome and Taura syndrome. The nation is also a leader in seaweed cultivation, especially varieties such as Euchema denticulatum and Kappaphycus alvarezii, which are widely utilized in the food, pharmaceutical and cosmetic industries. Cultivation of fish species such as milkfish, barramundi and tilapia are increasing, with a focus on enhancing feed efficiency. Though there has been progress, the industry is still facing environmental issues such as coastal pollution and mangrove loss. To mitigate these issues, Integrated Multi Trophic Aquaculture (IMTA) systems are being considered. Besides, disease management efforts are underway, especially in the fight against ice-ice disease in seaweed and bacterial infections in shrimp. To support these efforts, the government has established broodstock facilities and initiated training programs to improve technical competence among aquaculture personnel. With its long coastline and rich marine biodiversity, Indonesia is poised for sustained development in its aquaculture industry, driven by innovation, sustainability and policy support. [14]

Government Policies and Regulatory Frameworks

Indonesia's Ministry of Marine Affairs and Fisheries has initiated a blue economy framework aimed at encouraging the sustainable use of marine resources while ensuring the protection of ecosystems. Five main initiatives created under this framework are examined:

[12] Luh De Suriyani and M Ambari, Indonesia aims for sustainable farming with aquaculture villages,(2022), Indonesia aims for sustainable fish farming with 'aquaculture villages' Accessed 28th April 2025

[13] The future of aquaculture in Indonesia: A transformation towards increased sustainability, https://digitalarchive.worldfishcenter.org/ Accessed 28th April 2025

[14] Andreas Kunzmann, Gildas Todinanahary, Flower E. Msuya and Yustian Alfiansah. Review: Comparative environmental impacts and development benefits of coastal aquaculture in three tropical countries: Madagascar, Tanzania and Indonesia. (2023) Tropical Life Sciences Research 34(3): 279–302. https://doi.org/10.21315/tlsr2023.34.3.15

1. The expansion of marine conservation areas
2. The imposition of a quota- based fisheries system
3. The observation of coastal and small island territories
4. The development of sustainable agriculture
5. The efforts to address marine plastic pollution

Using participatory tools like focus group discussions, semi -structured interviews, key informant interviews with the stakeholders like government representatives, NGOs and fishing groups, as well as questionnaire surveys, the key findings emphasize the efficiency of quota - based fisheries management system (Penangkapan Ikan Terukur) in improving fisheries management, especially in Fisheries Management Area 718, and reducing dependency on Java for fish transportation. The expansion of marine protected areas has resulted in the creation of 97.5 million hectares of protected spaces, though problems with funding and connectivity persist. Initiatives on sustainable aquaculture have delivered outstanding results, with shrimp aquaculture production increasing from 0.6 to 40 tons per hectare per production cycle. The Marine Smart Platform enhanced the process of licensing and compliance, while the "Month of Loving the Sea" public awareness campaign involved 2,858 volunteers and cleared 172 tons of plastic pollution from the sea. In spite of continued challenges in form of resource constraints and the requirements to adapt to technology, these programs hold much potential for successful sustainable management of the sea's resources. Regular monitoring and assessment will be pivotal to their long- term success.[15]

Additionally, Indonesia's aquaculture governance can be assessed using the **Aquaculture Governance Indicators (AGI)** framework, which evaluates legislation, voluntary codes, collaborative arrangements, and governance capabilities. Aquaculture Governance Indicators (AIG) provide a social-science framework to evaluate the environmental sustainability and governance performance of aquaculture production, tailored to specific countries and species.

[15] SW Trenggono and I Meilano , Innovation in the blue economy and environmental sustainability in marine and fisheries strategy, Global J. Environ. Sci. Manage. 11(2): 497-518, Spring 2025, Serial #42

Building upon the Fishery Performance Indicators (FPIs) [16] developed by Anderson and others, AGI employs a mixed- method approach that integrates both quantitative and qualitative data collection and analysis. The methodology consists of five primary steps. The first step is to define the scope and intent of the assessment, focusing on either a specific risk or a comprehensive governance evaluation for a particular species and sector. The second step involves assembling an assessment team, which ideally includes both a social science researcher and aquaculture expert. In the third step, data collection occurs through desk research and semi- structured interviews with key informants, referencing academic publications, and accessible resources such as the FAO's National Aquaculture Legislation Overview. The fourth step entails scoring indicators on a 1–5 Likert scale, assigning a quality category (A–C) to each score based on the reliability of data and the assessor's expertise. These scores are then averaged to depict each governance dimension, while the mode and range are analyzed to assess consistency. Additionally, a narrative synthesis interprets each principle and dimension using both the scores and their rated quality. Finally, the AGI methodology undergoes verification for methodological consistency by members of Wageningen University AGI and empirical accuracy by expert peers. The finalized reports are then uploaded to AGI dashboard at [www.aquaculturegovernance.org], where stakeholders are encouraged to engage in discussions about the results and potential development opportunities through events, webinars and targeted workshops. [17]

Current farming practices threaten coastal ecosystems, necessitating immediate innovative solutions that promote sustainable growth without causing significant environmental harm. The study outlines six key interventions (AqI1–AqI6) designed to boost productivity with minimal environmental impact: achieving a 20% reduction in feed conversion ratios (FCRs) through improved seed, feed, and farming methods (AqI1); implementing sustainable intensification in traditional polyculture systems like milkfish and tiger shrimp (AqI2); transitioning grouper farms from whole fish feed to pelleted feed (AqI3); adopting renewable energy sources widely due to global pressures (AqI4); encouraging consumers to switch from shrimp to omnivorous fish to lessen environmental impact (AqI5); and minimizing food waste while increasing the utilization of by-products in feed (AqI6). Additionally, advancements such as alternative feed

[16] Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur & A. Guttormsen (2015). The Fishery Performance Indicators: A Management Tool for Triple Bottom Line Outcomes.

[17] Hilde M Toonen and Simon R Bush, Aquaculture Governance Indicators: A diagnostic framework for steering towards sustainability (2025), https://doi.org/10.1371/journal.pstr.0000165 Accessed 28th April 2025

ingredients—new single-cell proteins, microalgae, and macroalgae—can help reduce dependence on wild fish stocks. Offshore aquaculture presents further opportunities for mariculture growth without competition from coastal areas, though it requires substantial investment and infrastructure. It is also crucial to implement spatial planning to hinder greenhouse gas emissions resulting from the loss of mangrove forests, with zoning regulations needed to protect ecological hotspots like mangroves, seagrass beds, and tropical forests. Sustainable innovations and reforms enable Indonesia to double its output. This can be accomplished through enhanced farmer education, infrastructure improvements, and increased capital investment, along with a shift in production focus towards domestic species to reduce resource-demanding, export-driven practices. Advancements in processing and market diversification, such as deboned milkfish and value-added seafood, may further improve economic potential and optimize resource use. While Indonesia's aquaculture development offers a strategic path forward, policymakers need to be mindful of the trade-offs between immediate production needs and long-term environmental sustainability.[18]

Indonesian aquaculture faces several significant challenges that must be addressed to achieve sustainable development. A primary issue is spatial conflict, as aquaculture competes with other coastal and marine stakeholders including fisheries, tourism, and maritime transport for limited space, potentially resulting in conflict and inefficient resource use. Another pressing concern is the risk of surpassing the carrying capacity of aquatic ecosystems; intensive farming exerts pressure on water resources, which can lead to worsened water quality, habitat loss, and disruption of ecological balance. Furthermore, disease outbreaks pose a significant danger, often due to inadequate biosecurity measures. These outbreaks can spread pathogens within farmed populations and even between wild aquatic species, resulting in economic losses and environmental harm. Addressing these challenges is essential to harmonize aquaculture growth with environmental preservation.

The Ecosystem Approach to Aquaculture (EAA) presents a conceptual framework aimed at fostering sustainable aquaculture development, grounded in three main principles: aquaculture should coexist with the environment, deliver advantages to local communities, and recognize the shared utilization of marine resources among different sectors. To implement the EAA effectively, the document outlines three primary Best Management Practices (BMPs). The

[18] The future of aquaculture in Indonesia: A transformation towards increased sustainability, https://digitalarchive.worldfishcenter.org/ Accessed 28th April 2025

second BMP focuses on spatial planning and zoning, which includes national-level assessments to determine priorities and feasibility, along with regional-level zoning to allocate space based on ecological, economic, and risk factors. This process entails identifying zones that reduce environmental harm and resource conflicts, as well as creating Aquaculture Management Areas (AMAs) to promote coordination among farms. The second BMP addresses water quality management through the establishment of Allocated Zones for Aquaculture (AZAs), enforcement of assimilative capacity, and the implementation of measures for monitoring water quality, preventing eutrophication, and managing pollution levels. The third BMP pertains to disease management through the recognition of significant disease drivers, coordinated control strategies, and the establishment of stringent biosecurity measures, including pathogen surveillance and emergency response initiatives. As the second-largest aquaculture producer worldwide, Indonesia is expected to experience strong growth in the sector. To support sustainable development, the report recommends integrating EAA principles into Indonesia's National Medium-Term Development Plan (RPJMN), enhancing policy frameworks, and boosting stakeholder engagement through workshops and intersectoral collaboration.[19]

Brackish Water Pond Polyculture in Mangrove Areas in the Marine Protected Area of Derawan Islands and Surrounding Waters[20]

This case study explores the integration of brackish water pond aquaculture with marine conservation efforts in Indonesia's Derawan Islands Coastal and Small Islands Conservation Area (KKP3K KDPS), illustrating how traditional local aquaculture methods can coexist with marine protection initiatives while promoting biodiversity and supporting local economies. The marine protected area (MPA), which was established in 2016, spans 285,549 hectares in Berau Regency, East Kalimantan, and is managed through a zoning approach that includes core, restricted use, and sustainable economic activity zones. This area boasts significant biodiversity, featuring hundreds of species of reef fish, manta rays, marine mammals, and seagrass habitats. Within this MPA, indigenous polyculture aquaculture in brackish water ponds, which includes milkfish, tiger shrimp, mud crabs, and mullets, was revived in 2013

[19] Jennifer Bone and Tyler and Joao G. Ferreira and Jon Grant and Ian Ladner and Anton Immink and Jenna Stoner and Nick G.H. Taylor, Best Practices for Aquaculture Management Guidance for implementing the ecosystem approach in Indonesia and beyond, Conservation International, Sustainable Fisheries Partnership, University of California Santa Barbara, (2018)

[20] IUCN (2021). INDONESIA CASE STUDY. Brackish Water Pond Polyculture in Mangrove Areas in the Marine Protected Area of Derawan Islands and Surrounding Waters. Case study Worldwide Catalogue of Case Studies on Aquaculture and Marine Conservation. Gland, Switzerland: IUCN.

after a previous decline linked to disease, providing a vital income source for 34 small-scale farmers. Despite generating significant revenue, the industry faces several environmental challenges, including mangrove deforestation, water quality concerns, and the historical use of illegal pesticides. As a result, sustainable practices have been implemented, such as using natural pest control, reforesting mangroves, and adopting low-impact farming methods. Socioeconomic issues remain pressing, particularly regarding land ownership, since most ponds are situated on government land; the TORA program aims to address this through land certification. The market dynamics are complex, with shrimp primarily exported through intermediaries and milkfish sold locally. Women play a vital role in marketing, processing, and other income-generating activities. The East Kalimantan Marine and Fisheries Agency, with support from NGOs, manages the MPA, although community decision-making authority remains limited. Government and NGO funding sources are predominant, while research efforts focus on ecosystem health and sustainable aquaculture practices. A SWOT analysis reveals strengths such as governmental and community backing, alongside weaknesses like mangrove encroachment and low productivity levels. Opportunities exist to expand sustainable practices and achieve eco-certification, whereas threats include illegal fishing, climate change, and pressures from tourism. The case study concludes that ecosystem-based aquaculture approaches, combined with enhanced land rights, research extension, better market frameworks, and inclusive governance, can promote a balanced pathway towards conservation and economic development in marine protected areas.

Community - Based Shrimp Aquaculture in Sumatra[21]

The World Bank/NACA/WWF/FAO Consortium Programme on Shrimp Farming and the Environment examines the community-led management of shrimp aquaculture in Pematang Pasir, Lampung Province, Sumatra, Indonesia, offering valuable information on effective practices, obstacles, and approaches for environmentally responsible shrimp farming along the coastline. The rapid growth of shrimp aquaculture in Lampung poses significant environmental threats, including mangrove deforestation, coastal erosion, and water contamination. The pilot project in Pematang Pasir aims to assess and enhance sustainable farming methods that could be adapted in other coastal regions, focusing on semi-intensive and traditional extensive

[21] Tobey, J., H. Poespitasari and B. Wiryawan 2002: "Good Practices for Community-based Planning and Management of Shrimp Aquaculture in Sumatra, Indonesia" Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. p18

practices. Key challenges encountered so far include the destruction of mangrove areas due to the transformation of ponds for aquaculture, deteriorating water quality from aquaculture waste, insecure land tenure resulting from the leasing of government common lands for many farms, the prevalence of the white spot virus, and difficulties in enforcing environmental regulations. In response, the report emphasizes community-oriented approaches, such as Integrated Coastal Management (ICM), replanting mangroves, zoning regulations, and sustainable measures like polyculture systems (combining shrimp and milkfish), monitoring of water quality, and eco-certification. Institutional reforms aim to secure land tenure, enhance licensing and compliance systems, and establish shrimp farmer cooperatives to boost market access and negotiating power. The implementation of public-private partnerships, improved regulatory enforcement, community involvement, and innovations in water management and disease control are essential for achieving sustainability. It offers valuable insights into the governance of shrimp aquaculture and resonates with recent efforts to improve aquaculture policy frameworks in coastal regions.

Comparative Insight with Indian Aquaculture Practices

Indonesia has embraced a coastal aquaculture ecosystem management strategy focused on protecting the environment in a sustainable manner. The strategy emphasizes judicious site selection to avoid habitat destruction, uses spatial planning to minimize aquaculture activity conflicts with indigenous fishing trades, and encourages stakeholders' participation to assure fair resource use. Contrarily, as India fortifies its coastal zoning law, the use of integrated coastal zone management would ease environmental degradation due to intensive shrimp aquaculture. Indonesia is also a leader in seaweed farming, especially using Eucheuma and Gracilaria varieties, with the support of the government to cooperative societies, investment in processing and export plants, and sustainable farming practices. India, with great potential for seaweed farming in Tamil Nadu and Gujarat, stands to learn from Indonesia's cooperative approach in growing its seaweed industry and enhancing local livelihoods. In the fisheries sector, Indonesia successfully maintains aquaculture alongside wild fisheries by strictly enforcing licensing, adopting biosecurity strategies to minimize disease outbreaks, and encouraging multi-trophic aquaculture, where several species are cultivated together to maximize resource utilization. India can improve its coastal aquaculture industry by emulating such practices particularly multi-trophic systems and better disease management to increase biodiversity and productivity. In general, India can improve its coastal aquaculture industry

substantially by incorporating Indonesia's ecosystem-based management, cooperative seaweed culture, and resource-saving aquaculture approaches to enhance sustainability and support rural communities.

Norway

Norway is recognized globally for its leadership in sustainable aquaculture, particularly in the field of salmon farming, which operates within a highly regulated framework focused on environmental stewardship and fish welfare. As the foremost producer of Atlantic salmon worldwide, Norway achieves an annual output exceeding 1.3 million tons, supported by cutting-edge facilities and a commitment to innovation and technology. The aquaculture sector provides employment for over 20,000 individuals and significantly contributes to the nation's economy, with salmon exports representing a substantial part of Norway's total export activities. This practice adheres to sustainable methods with stringent regulations governing fish feed, water quality, and disease management. Norway's aquaculture output continues to grow, encompassing a variety of seafood products such as salmon, trout, and shellfish, all developed with a strong emphasis on sustainability and responsible practices to meet the rising global demand.

New technologies are playing a crucial role in addressing significant challenges in aquaculture, with Norway at the forefront of this innovation. Leveraging its vast coastline, rich marine life, and longstanding fishing traditions, Norway is harnessing its knowledge to develop advanced approaches for sustainable fish farming. One of the most urgent challenges is sea lice—parasites that lay eggs in the water, which then hatch into larvae that attach themselves to fish, hindering their growth, salt balance, and overall health. Initially controlled through chemicals and medicines, sea lice have developed resistance to many of these treatments. As a result, Norwegian companies are pioneering non-chemical, tech-driven solutions.

For instance, Harbor has created the Harbor Fence, which sends out electrical pulses to incapacitate sea lice before they can adhere to fish, thus preventing infestations without harming the fish or the ecosystem. Stingray Marine Solutions employs a laser-based method, utilizing AI-powered technology to detect and remove lice from individual fish continually and non-invasively. Fishency Innovation's SmartFunnel combines underwater hardware with machine learning to identify sea lice using high-resolution imaging, streamlining what was

previously a labor-intensive task. Conversely, Blue Lice tackles sea lice before they reach fish cages by implementing a system similar to a mosquito trap to attract and trap the parasites.

Beyond managing sea lice, Norway is also innovating offshore and closed containment systems to improve fish welfare and environmental performance. Environmental Vision Norway (EVN) introduced an Autonomous Offshore Fish Farming Vessel that features new current deflectors to protect smaller fish from ocean currents while allowing larger fish to swim deeper. Closed containment systems like Bluegreen Technologies' Marine Donut and FishGLOBE's globe-shaped farming unit offer additional benefits such as reducing fish escapes, capturing waste, and drawing in clean water from deeper layers to avoid lice-infested areas. These systems not only enhance environmental management but also significantly lower the risk of sea lice, setting new benchmarks for sustainable aquaculture globally.[22]

Government Policies and Regulatory Frameworks

In Norway Act No. 79 of 2005 relating to aquaculture (Aquaculture Act) establishes the legal foundation foe aquaculture operations. It regulates licensing, environmental sustainability, and compliance measures for aquaculture activities in inland and marine waters. The legislation went into effect on January 1, 2006. A consolidated version in Norwegian of Act No. 79 from 2005, which was last amended by Act No. 67 of 2019, governs the breeding of anadromous salmonids and freshwater fish for cultivation purposes according to the Act of May 15, 1992, No. 47. This Act does not apply to Svalbard and Jan Mayen. It establishes a legal framework for the aquaculture industry in both marine and inland waters, including Norway's territorial sea, Continental shelf, and Exclusive Economic Zone (EEZ). The Act consists of 34 sections divided into 8 chapters. The Ministry of Trade, Industry and Fisheries may issue a license ("aquaculture license") for the production of specified species in designated geographical areas, subject to specified terms. The conditions required for issuing the license are outlined in the Act. The issuance of aquaculture licenses for salmon, trout, and rainbow trout will be based on the Regulations established by the Ministry. Additionally, the Act: (a) sets forth environmental sustainability requirements for aquaculture operations, including the obligation to restore the aquaculture site and adjacent areas if production is halted; (b) clarifies how licensed aquaculture operations relate to land-use planning and conservation of nature or cultural

[22] Norwegian technology for sustainable aquaculture (2023) , https://businessnorway.com/articles/norwegian-technology-for-sustainable-aquaculture, Accessed on 29th April 2025

heritage; (c) provides for the registration, transfer, and mortgaging of aquaculture licenses; (d) establishes the framework for administrative oversight and regulation; and (e) outlines penalties for violations of the provisions of this Act or those prescribed under it.[23]

Norway's regulations for aquaculture are centered on sustainability, ensuring a balance between economic feasibility, environmental health, and social acceptability. The country has developed a comprehensive regulatory framework that promotes aquaculture production that is competitive, market-oriented, and environmentally responsible. The key principles of governance include accountability, efficiency, fairness, and predictability, providing stability for investors while safeguarding ecosystems. Through the maximum allowable biomass (MAB) limits, Norway's licensing system manages production, ensuring responsible growth. An innovative aspect is the traffic light system, which uses environmental indicators to determine whether aquaculture expansion is permitted in specific regions. Engaging stakeholders, including industry groups and NGOs, plays a crucial role in monitoring compliance and making decisions on site approvals. Norway's governance model has enabled profitable growth in aquaculture by implementing strict environmental standards, establishing it as a leader in sustainable aquaculture management.[24]

Norwegian Minister of Fisheries and the Oceans, Marianne Sivertsen Næss, recently introduced a White Paper entitled "The Future of Aquaculture – Sustainable Growth and Food for the World," which outlines a fresh regulatory strategy aimed at ensuring sustainable advancement for Norway's aquaculture industry. Minister Næss emphasized that while aquaculture has become Norway's second-largest export sector and a key component of the coastal economy, it also presents significant environmental and animal welfare challenges. She highlighted those current laws do not sufficiently promote responsible practices. To address this, the government has proposed a new management framework that prioritizes a low environmental impact and high welfare standards for fish, aiming to make these practices financially feasible for producers. The core of the White Paper involves transitioning from regulating production volume to regulating environmental impact, specifically concerning sea lice control. Instead of company-level production controls, the government will set up a tradable sea lice emission quota system based on regional environmental capacity. This

[23] Act No. 79 of 2005 relating to aquaculture (Aquaculture Act). | UNEP Law and Environment Assistance Platform, Accessed on 29th April 2025

[24] Nathanael Hishamunda and Neil Ridler and Elisabetta Martone, Policy and governance in aquaculture: lessons learnt and way forward , FAO of UN (2014)

approach will encourage flexibility and cost-effective solutions while holding producers accountable for their environmental impact. Additionally, the government is contemplating a fee on sea lice emissions to further incentivize sustainable practices. Furthermore, the plan includes the removal of production volume limits from aquaculture licenses. Licenses will remain necessary and linked to specific geographic areas under the new framework, but they will no longer impose restrictions on production volume or farmed species. New licenses will be allocated through auctions to ensure fair access to marine resources, and existing licenses will be consolidated to one license per site. Site-specific volume regulations will continue to be managed under different regulations. To address fish mortality, particularly from sea lice treatments, the government plans to introduce a "lost fish" fee. This fee will start low but has the potential to increase over time to encourage producers to enhance fish welfare and prevent escapes. The objective is to lower fish mortality to around 5%, in line with the standards set in Norway's Animal Welfare Report. The proposed system is technology-neutral, allowing producers to choose the most effective methods to meet welfare and environmental standards. The government will also enhance marine spatial planning through national guidelines and by establishing a robust knowledge base for designating suitable farming areas. In summary, the new regulations aim to foster sustainable value creation, prioritize the welfare of fish and the environment, eliminate traditional volume-based restrictions, and enable producers to advance responsibly through innovative and effective approaches.[25]

A government-appointed committee (Havbruksutvalget) has been tasked with reviewing Norway's aquaculture licensing system, aiming to create a systematic and progressive framework over the past two years. On 28 September 2023, it released its findings in the Official Norwegian Report (NOU), which, while not legislative at this stage, includes various recommendations that could significantly influence future regulations for sea-based aquaculture in Norway, pending government approval. Key proposals encompass modifications to the existing "traffic light system"—which is rooted in the environmental impact of production—and incentives for the adoption of sustainable technologies. The report mainly focuses on the coastal farming of salmon, trout, and rainbow trout, advocating for considerable changes to their oversight. It also proposes an auction-based licensing approach for other species such as cod instead of the current open application system. While there is a brief discussion on land and offshore aquaculture, those regulatory developments are being

[25] Norway unveils new aquaculture strategy, https://www.aquafeed.com/newsroom/news/norway-unveils-new-aquaculture-strategy/, Accessed on 29th April 2025

addressed separately. Alongside its principal recommendations, the committee suggests enhancing central government authority over spatial planning, refining the traffic light system to encourage sustainable technologies, implementing environmental impact charges, and abolishing special license types like viewing licenses. It also proposes that all licenses, including those for species beyond salmonids, be allocated through auctions and have maximum allowed biomass (MAB) limits. Although the committee generally supports time-limited licenses, it does not advocate for such restrictions on salmon, trout, and rainbow trout due to their established role in the industry. Other suggestions include creating buffer zones to improve biosecurity and promoting collaboration among fish farmers. The document is currently undergoing public consultation until 2 January 2024, and the implementation of its proposals will require further regulatory development and additional rounds of consultation.[26]

Catch-based aquaculture (CBA) plays a significant role in global fish production, particularly in developing countries. In Norway, CBA involves capturing and then storing or raising mature North-east Atlantic (NEA) cod (Gadus morhua), aiming to lessen seasonal fluctuations and increase value by selling the fish during periods of higher prices. However, despite various development attempts and financial incentives, progress toward making CBA a viable business model has been limited. Many operators do not retain fish long enough to benefit from off-season price increases. One issue is that CBA exists at the intersection of two distinct sectors—fisheries and aquaculture—each governed by vastly different regulatory frameworks, resulting in cumbersome regulations and significant entry barriers. Additionally, CBA raises questions regarding its legitimacy as it disrupts traditional fisheries' resource allocation systems.[27]

Comparative Insight with Indian Aquaculture Practices

Norway and India adopt different approaches to coastal aquaculture, shaped by their environmental contexts, regulatory systems, and levels of technological advancement. Norway implements a stringent environmental governance policy, particularly through the traffic light system, which regulates aquaculture growth based on sustainability metrics. In contrast, India relies on the Coastal Aquaculture Authority Act (2005), which prioritizes licensing, environmental regulations, and sustainable practices in aquaculture. In terms of technology,

[26] OCEAN I NOU 2023:23 – New report on Norweigan aquaculture for sustainable value creation, OCEAN | NOU 2023:23 - New report on Norwegian aquaculture for sustainable value creation — Advokatfirmaet BAHR, Accessed on 29th April 2025

[27] Signe A Sonvisen and Dag Standal, Catch -based aquaculture in Norway- Institutional challenges in the development of a new marine industry, Marine Policy 104 (2019) 118-124

Norway is at the forefront with advanced digital monitoring, automated feeding systems, and sustainable feed innovations, while India continues to modernize its methods alongside traditional farming practices, increasingly focusing on biosecurity. Regarding environmental sustainability, Norway favors ecosystem-based management to tackle issues like sea lice, fish health, and ecological impacts. In comparison, India grapples with problems such as coastal pollution, habitat loss, and disease outbreaks, although efforts are being made to enhance sustainability. Economically, Norway's aquaculture sector is primarily export-driven and industrialized, whereas in India, it serves as a critical socio-economic support system for rural populations and small-scale farmers.

Conclusion

Ultimately, a comparative analysis of aquaculture systems in China, Indonesia, Norway, and India provides valuable insights into how differing governance structures, technological advancements, and environmental priorities shape the future of sustainable aquaculture. While China emphasizes large-scale production and is gradually integrating sustainability practices, Indonesia promotes ecosystem-based strategies with substantial community involvement. In contrast, Norway exemplifies a technology-centric, highly regulated, and ecologically mindful approach. India, despite its significant aquaculture potential, continues to face challenges such as regulatory fragmentation, weak enforcement, and environmental concerns. However, with recent policy shifts and growing awareness, India has considerable opportunity to learn from international best practices. By adopting ecosystem-based management, fostering technological innovation, strengthening enforcement, and ensuring inclusive governance, India can enhance the resilience and sustainability of its coastal aquaculture sector. A proactive, flexible, and locally focused policy will be essential to reconcile the growth of aquaculture with environmental protection and socio-economic development.

References

1. Exploring the Underbelly of Chile's Salmon Farming Industry, Yale School of the Environment, (May 06, 2024) https://environment.yale.edu/news/article/exploring-underbelly-chiles-salmon-farming-industry, Accessed on 3rd April,2025

2. The future of aquaculture in Indonesia: A transformation towards increased sustainability, https://digitalarchive.worldfishcenter.org/ Accessed 28th April 2025

3. Norwegian technology for sustainable aquaculture (2023), https://businessnorway.com/articles/norwegian-technology-for-sustainable-aquaculture, Accessed on 29th April 2025

4. Norway unveils new aquaculture strategy, https://www.aquafeed.com/newsroom/news/norway-unveils-new-aquaculture-strategy/, Accessed on 29th April 2025

5. Asha J, Repressed Coastal Population- An Analysis of Rights of Coastal Communities And Ineffective Intricacies Of Coastal Law Regime in India, International Journal of Law and Social Sciences (IJLS), Vol6(2020)

6. Anirudh Rajesh Warrier, Arundathi Vimal and S. Sneha Dutt, Balancing Development and Conservation: An Analysis of the Coastal Regulation Zone Regime in India, International Journal of Law Management and Humanities Vol 7 (2024)

7. Feng, Y Y, Hou, LC, Ping, N X, Development of mariculture and its impacts in Chinese coastal waters. Reviews in Fish Biology and Fisheries 14, (2004)

8. Kangshun Zhao and Min Zhang, Aquaculture Impacts on China's Marine Fisheries Over the Past 30 Years, Frontiers in Marine Science, (2021)

9. Weiwei Sun and Tingting Hou, Mapping China's coastal aquaculture ponds expansion with sentinel-2 images during 2017-2021, International Journal of Digital Earth (2023)

10. Wei Wang and Wei Mao and Renhong Wu, The Effect of Marine Pastures on Green Aquaculture in China Water (2024), 16, 1730

11. Chen Yusheng and Ma Ye and, Yang Weili and Sun Zhaofa and Han Yang, How to improve fishery eco- efficiency by building marine ranch in China, Frontiers in Sustainable Food Systems (2024)

12. Anguo Zhang, Ecological damage assessment and compensation for reclaimed coastal pond aquaculture: A case study in Qingduizi Bay, China, Aquaculture Research (2020)

13. Luh De Suriyani and M Ambari, Indonesia aims for sustainable farming with aquaculture villages,(2022),

14. Andreas Kunzmann, Gildas Todinanahary, Flower E. Msuya and Yustian Alfiansah. Review: Comparative environmental impacts and development benefits of coastal aquaculture in three tropical countries: Madagascar, Tanzania and Indonesia. (2023) Tropical Life Sciences Research 34(3): 279–302

15. SW Trenggono and I Meilano , Innovation in the blue economy and environmental sustainability in marine and fisheries strategy, Global J. Environ. Sci. Manage. 11(2): 497-518, Spring 2025

16. Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur & A. Guttormsen (2015). The Fishery Performance Indicators: A Management Tool for Triple Bottom Line Outcomes.

17. Hilde M Toonen and Simon R Bush, Aquaculture Governance Indicators: A diagnostic framework for steering towards sustainability (2025),

18. Jennifer Bone and Tyler and Joao G. Ferreira and Jon Grant and Ian Ladner and Anton Immink and Jenna Stoner and Nick G.H. Taylor, Best Practices for Aquaculture Management Guidance for implementing the ecosystem approach in Indonesia and beyond, Conservation International, Sustainable Fisheries Partnership, University of California Santa Barbara, (2018)

19. Tobey, J., H. Poespitasari and B. Wiryawan : “Good Practices for Community-based Planning and Management of Shrimp Aquaculture in Sumatra, Indonesia” Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on

Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. (2002)

20. Nathanael Hishamunda and Neil Ridler and Elisabetta Martone, Policy and governance in aquaculture: lessons learnt and way forward , FAO of UN (2014)

21. Signe A Sonvisen and Dag Standal, Catch -based aquaculture in Norway- Institutional challenges in the development of a new marine industry, Marine Policy 104 (2019) 118-124