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Review Article

Spatial planning: an ecosystem-based approach to aquaculture

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Abstract

The demand of fish is increasing day by day with increasing global population. The Ecosystem Approach for Aquaculture develops spatial planning to integrate aquaculture in the wider ecosystem. A good spatial management is a key factor of "Blue economy" to increase the profit along with the environmental sustainability with proper biosecurity management. The selection of proper spatial area must consider about the environmental, biological, social, economic and regulatory issues to allocate proper zone for aquaculture practices within the ecosystem. This management process follows three steps which include allocation of suitable zones for different activities, identification of most appropriate location within the zone and management of the farms collectively with best water and disease management practices within that Aquaculture Management Areas (AMAs). There must be a common goal within AMAs to achieve in collaboration based on the opinion of the stakeholders including local communities by implementing common practices with better standards. Recently, in Australia, Chile, New Zealand, Brazil, China, Indonesia spatial planning has been implementedfor selection of suitable spaces for different aquaculture activities like coastal and marine cage culture, freshwater cage and pen culture, seaweed culture, pond culture and hatchery practices based on the ecological and social carrying capacity. The cooperative action of all farmers in this process improves aquatic health management aspects, controls environmental impacts, increases economic performance of the farmers, minimizes conflicts among the users of the resources etc. Thus, the cluster management of the zoning improves production potential than the individual effort under ecosystem perspective.

Keywords: AMAs, Aquaculture zoning, Biosecurity, Carrying capacity, Cluster management

Highlights

- Ecosystem-based spatial planning is essential for sustainable aquaculture
- Aquaculture Management Areas (AMAs) promote collective farm management
- Global adoption in countries like Australia and China enhances production, and supports the blue economy
- Aligns environmental, social and economic factors through proper zoning

INTRODUCTION

Global demand for animal-based foods is expanding in tandem with population expansion and shifting dietary preferences toward meat, dairy, and fish products. However, this increased demand presents considerable difficulties to environmental sustainability, food safety, and resource efficiency. To solve these difficulties, resource-based methods that optimize inputs, increase efficiency, and reduce environmental effect are required. The multifaceted role of fisheries sector in building a sustainable and equitable food system for the future is well acknowledged. With an overall annual growth rate of around 10% in the fisheries sector in India, demand for fish as an important and inexpensive animal protein source is increasing on a daily basis. Between 1950 and 1970, aquaculture's share of total production was roughly 4 to 5 percent; in the 1990s, it increased to 20 percent, and in the 2010s, it reached 44 percent. For the first time ever, the production of aquatic animal aquaculture surpassed that of catch fisheries in 2022. Fifty one percent (94 million tonnes) of the 185 million tonnes of aquatic animals produced in 2022 came from aquaculture, while 49 percent (91 million tonnes) came from capture fisheries.(FAO, 2024) As the capture fishery production is now stagnant and even in declining phase, the whole demand relies mainly on culture fishery. For sustainable and successful aquaculture along with social and economic benefits, selection of proper area for different culture activities is an essential step as poor space management reduces the viability of aquaculture production.

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Ecosystem Approach to Aquaculture (EAA) was developed to implement plan to improve the potentiality of a sector without harming environment (O'Brien, 2012). It ensures both ecosystem and human well-being with effective management within that ecosystem (Waylen *et al*., 2014). Spatial planning (SP) is mainly the plan related to management of spaces. It allocates different activities in suitable zone to augment production potential without any negative impact to environment. Mainly it is a technical process to handle both environmental and social factors within an ecosystem. It also helps to solve many transboundary issues and develops a climate-resilient aquaculture practice (Ehler, 2014). The high return for investor along with reduction of environmental and social risk help to increase the acceptability of spatial planning worldwide. Thus, a sustainable, efficient, and equitable expansion of the aquaculture highly depends on careful spatial planning. This article deals with a newer approach named spatial planning, so that the aquaculture can be developed in a manner that benefits both people and the earth by integrating science, policy, and stakeholder engagement.

What is spatial planning?

The Ecosystem Approach to Aquaculture (EAA) develops spatial planning to integrate aquaculture in the wider ecosystem. A good spatial management is one of the key factors of "Blue economy" to increase the profit along with the environmental sustainability with proper biosecurity management. It is a 'public process of analyzing and allocating the spatial and temporal distribution of human activities in water areas to achieve ecological, social, economic and sustainable aquaculture through a political process' (Aguilar-Manjarrez *et al*., 2017a). The whole process is carried out following the regulations of Code of Conduct for Responsible Fisheries (CCRF). Specific steps are involved to make a framework to implement the management aspects in the spatial planning. It is mainly the distribution of activities in proper spaces. It works on four components like suitable zone selection, estimation of carrying capacity, biosecurity planning and authorization. The main view of this planning is to achieve higher yield by clustering the farmers which can't be obtained by individual effort without harming the ecosystem.

Need of spatial planning in aquaculture

Different biological, social, and environmental factors are responsible for proper space selection in aquaculture. Spatial planning (SP) helps to identify appropriate zones, select suitable sites, and define management areas for different practices. Thus, it supports sustainable development and better expansion of this sector (Gimpel *et al*., 2015). Firstly, some specific conditions must be fulfilled, such as water quality parameters, stocking density, and other biological needs of specific species, to achieve better production and reduce disease and stress (Aguilar-Manjarrez *et al*., 2017a; Wickliffe *et al*., 2024). Farm locations often coexist with other activities; therefore, farms require proper access to shared resources. SP reduces the confused perception among people regarding the use of coastal and marine resources, facilitating clearer governance and decision-making (Soto *et al*., 2008). Various financing agencies are associated with spatial planning to enhance economic benefits and social outcomes. Thus, SP links different components of the 'Blue Economy' program to enhance the overall economic aspects of aquaculture through better coordination (FAO, 2021). It also improves the understanding of cumulative environmental effects from interactions among multiple users (Ospina-Alvarez *et al*., 2020). Risk-sharing models help to augment yield in area-based frameworks, and joint access to common facilities improves coordination and confidence among cluster farmers. Promising aquaculture zones can be managed through national-level implementation strategies. Ultimately, SP helps to integrate aquaculture practices into the broader ecosystem and marine spatial management frameworks (Ewig *et al*., 2024). For aquaculture to flourish in India in a way that is sustainable, conflict-free, and climate-resilient, spatial planning is essential. Zonenization is emphasized by policies such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY), but more robust execution is required. Mangrove loss, water contamination, and the salinization of freshwater resources have all resulted from unregulated aquaculture, particularly shrimp farming (Primavera, 2006). By identifying appropriate zones, spatial planning reduces ecological harm. While, clustering of farms increases disease risks (e.g., White Spot Syndrome Virus in shrimp), spatial planning ensures adequate spacing and buffer zones (MPEDA, 2020).

Problems without spatial planning

Among the common problems enlisted in Table 1 with benefits, some need special mention. When there are too many farms in close contact, risk of disease arises due to lack of proper biosecurity and disease prevention measures at farm level (Bondad-Reantaso

Table 1. Benefits of spatial planning vs. problems without it

Aspect	With Spatial Planning	Without Spatial Planning	Reference
Environmental Impact	Managed eutrophication, waste, and biodiversity conservation	Pollution, habitat loss, and biodiversity decline	Hambrey *et al*., 2000
Disease Risk	Coordinated biosecurity, reduced disease transfer	Higher risk due to farm proximity and lack of protocols	Sanchez-Jerez *et al*., 2016
Economic Performance	Shared market access, inputs, and certifications	Poor access to market and post-harvest services, especially for smallholders	Corner *et al*., 2006
Social Conflict	Reduced conflicts through stakeholder involvement and zoning	Increased resource-use conflict and poor public perception	FAO, 2013
Disaster Resilience	Integrated planning increases adaptive capacity	Vulnerability to floods, droughts, and storms	Ehler, 2014

Table 2. Key components of spatial planning

Component	Description	Reference
Aquaculture Zoning	Allocation of zones based on hydrological, biophysical, social, and economic factors. Uses GIS/remote sensing for identifying suitable areas.	Aguilar-Manjarrez *et al*., 2017
Site Selection	Farm-level location planning based on water quality, disease risk, and environmental indicators. Requires legal licensing and permits.	Scarfe *et al*., 2009; Cubillo *et al*., 2016
Aquaculture Management Areas (AMAs)	Designated zones for cluster farming practices. Focus oncooperative biosecurity, monitoring, certification, and stakeholder coordination.	Kassam *et al*., 2011; FAO, 2015
Carrying Capacity	Assesses ecological and social thresholds for sustainable production. Supports stocking density decisions.	Soto *et al*., 2007; Tett *et al*., 2011
Biosecurity Measures	Zonal disease management through isolation, quarantine, and common aquatic health codes.	Scarfe *et al*., 2009

et al., 2005). Environmental deteriorations like loss of biodiversity, eutrophication, carrying capacity, reduce the productivity of the particular area (Holmer, 2010). Parallelly, different problems emerge when a poor individual farmer want to access market, post-harvest services and quality assurance approaches and conflicts arise where aquaculture practices co-exist with other resource users (Bush *et al*., 2010). Climate threats and disasters like drought, flood, tsunami, hurricane etc reduce the capacity of the particular area regarding the production potential (FAO, 2018).

Steps involved in spatial planning

With the help of spatial planning, aquaculture can be developed in a way that is both economically viable and socially and environmentally equitable. Steps involved in spatial planning (Table 2) assures proper implementations and thus reduces negative effects on the environment, maximizes efficient use of resources, and avoids conflicts with other marine and coastal activities by designating appropriate zones for aquaculture operations.

Aquaculture zoning: Aquaculture zoning is mainly the allocation of zones in a hydrological system according to their uses. A task team is made with stakeholders, farmers with sufficient political background, local people, tour guide, scientist, entrepreneur, environmentalist etc at the beginning. This team find out a suitable zone based on the available information regarding that area to reduce conflict, monitor development, minimize risk and maximize sharing of land and water resources. Different criteria like biophysical (water quality parameter, hydrodynamics, water source etc), environmental (habitat, buffer zone, benthic population, predators etc) are studied to understand the current situation of that particular zone (Waylen *et al*., 2014). Concentrated development of zones is prohibited to reduce pollution and disease related issues (Hambrey *et al*., 2000). Physical parameters of environment are monitored to select the zone for specific aquaculture activities. Decisions are made depending on the adopted culture system, selected species, selected technology and interaction of the whole system individually before tenure application (O'Brien, 2012). Identification of areas suitable for aquaculture is done by GIS mapping or remote sensing based on social, economic, environmental and biophysical criteria. Potential species & culture system are then selected after observing the overall parameters of that ecosystem. As a production process, aquaculture is vulnerable to some climatic disturbances, predation, theft, pollution, algal bloom, oil spills etc so strategic environmental assessment is done to find out issues and risks associated with the system (Stockwell *et al.*, 2006; Nunes *et al.*, 2011). Ecological and social carrying capacity are estimated by mass balance equation model for proper stocking density estimation in that culture system. Ecological carrying capacity is estimated to know the highest production that does not have any negative impact on environment. Whereas, social carrying capacity helps to get the license of the level of development that does not cause harm to local economy (Soto *et al.*, 2007). As disease is the main disaster in aquaculture, proper biosecurity management is necessary to monitor it. According to world organization of Animal Health, a zone must have a specific health status based on its geographical boundaries against specific disease. The final step of zoning is the allocation of proper area for specific activities following some legal process. Each zone must have specific regulations and restriction for easy management. Zones are divided in three classes like suitable zone, unsuitable zone and zone with particular regulations (Tett *et al.*, 2011). Finally, individual permit is necessary within the zone for effective management of the space.

Site selection: Site selection is done by mapping for suitability of aquaculture practices. It ensures that farms must be allocated in specific location to get adequate production with very less negative impact on environment. Though sites are selected by the stakeholders after monitoring biophysical, environmental and social parameters, the licensing is provided by the government. For site selection, first area is assessed as a suitable site for aquaculture. Space between the selected site and other farms must be maintained to reduce the risk of disease transfer, pollution, waste disposal problems etc. (Stigebrandt, 2011). Carrying capacity of that site should be calculated properly to estimate the nutrients input, their effect on sediment and accepted level of production in that particular site (Cubillo et al., 2016). In case of coastal zone, fluctuation of tide or water flow is also one of the important factors to be considered for site selection. Disease is controlled following 'Aquatic Animal Health Code' by establishing the basic components of biosecurity in that site like screening, isolation, quarantine, proper handling and effective monitoring. Different environmental indicators as benthic diversity, water qualities etc. are chosen for observing the level of fluctuation in the ecosystem (Scarfe et al., 2009). To get secure right of a specific site for aquaculture practices for a specific period of time, proper leasing, permitting and licensing is necessary.

Aquaculture Management Areas (AMAs): Aquaculture management areas are the centre of attraction in the spatial planning process. 'AMAs are shared water bodies, or parts, where all the aquaculture operators agree (coordinate and cooperate) to certain management practices or codes of conduct that act to minimize the overall impacts from their collective activities (Dow, 2004). Sometimes area management activities like cropping cycle coordination, marketing, post-harvest, certification process etc are not effective properly for the individual farm but it is effective in case of multiple farms. AMAs are divided with boundaries with stakeholder consultation for ease of regulation based on environmental and socio-economic criteria (Aguilar-Manjarrez et al., 2017b). It may be also divided by water supply that is shared by farms within that area. After dividing the area, the government must frame a formal structure to engage farmers' association within management aspects. Though the framework varies in different area but it helps to coordinate farmers to implement different management practices and reduce conflicts among them (Kassam et al., 2011). Number of farms that are incorporated within the planning must be decided after observing all parameters. During clustering the farms some problems like eutrophication, habitat loss, predators, diseases, disasters must be kept in mind (Sanchez-Jerez et al., 2016). A common aquatic animal health code and biosecurity plan should be developed for that specific area to mitigate against disease. Regular surveillance is necessary to understand the little fluctuation within the area based on different parameters. Proper environmental monitoring is also done with better management practices (BMP) following standard operating procedures. Implementation of HACCP and traceability is necessary to obtain better quality final product which is safe for consumption. Formation of area management entity is necessary with local community to ensure commonality in operations (FAO, 2015). Overall, a

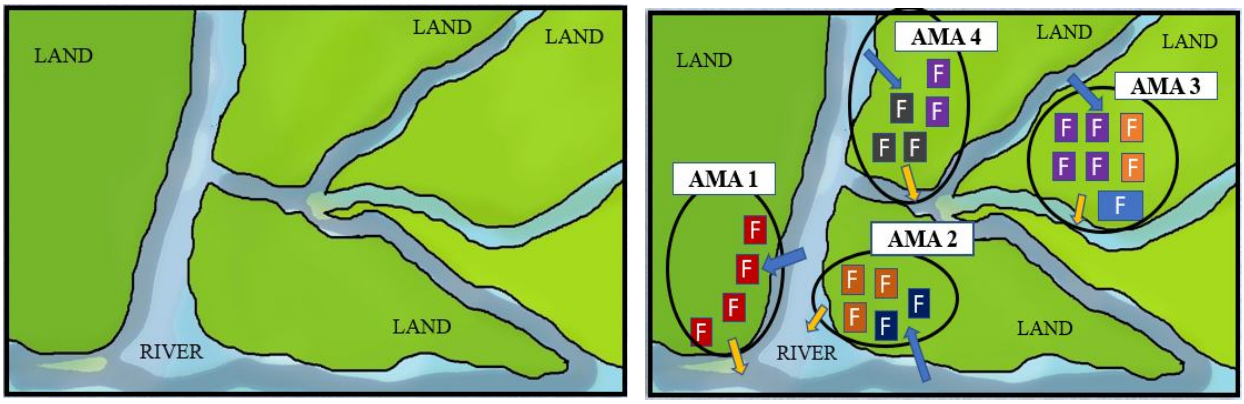

Fig. 1. Different culture systems are represented by different colours for inland aquaculture system

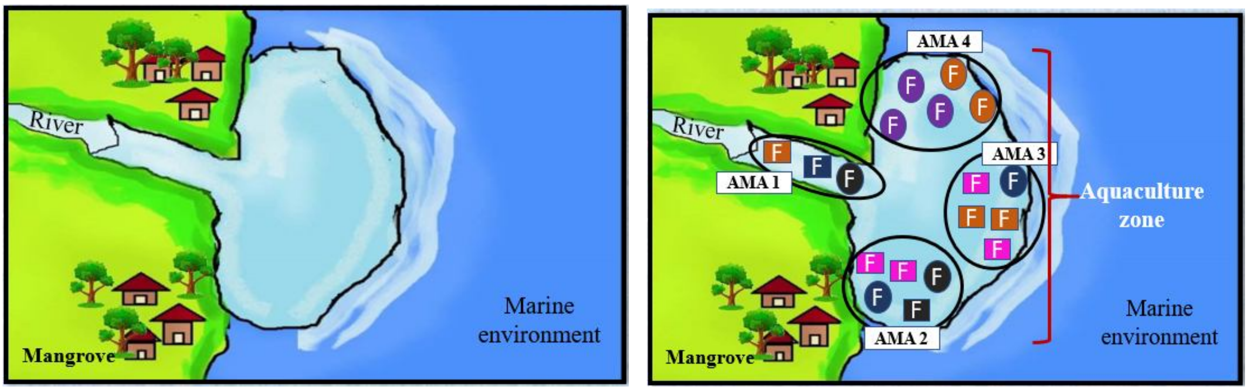

Fig. 2. Different culture systems are represented by different colours for marine aquaculture system

baseline conditions must be implemented to achieve the goal through joint venture.

Spatial planning in aquaculture

Inland aquaculture: Here we can see an existing aquaculture zone containing land-based farms like catfish, tilapia etc. This zone is divided into 4 AMAs with common water flow (Fig. 1). The areas are divided to reduce disease transmission and environmental risks. We can see that every AMA has its specific inflow and outflow of water and it is completely separated from other AMAs. The number of farms in every AMAs are decided according to space, species combination, water availability, stocking density etc (Aguilar-Manjarrez, 2017b).

Marine aquaculture: An estuary and its adjacent coastal-marine area are represented in the Fig. 2. The AMAs are divided accounting the tidal and water movements in that particular area. The number of farms in every AMAs are decided according to selected species and farming systems (Ehler, 2014; Turner *et al*., 2014).

Ecosystem based management plans for spatial planning

Spatial planning mainly focuses on sustainable development of local community in every aspect by managing the usage of resources by proper sharing. To minimize the negative impact on environment and society, the development activity must be designed through proper planning (Costanza *et al*., 1999). Transboundary issues are solved early to implement spatial planning in local and national level (Aguilar-Manjarrez *et al*., 2017a). To integrate spatially planned aquaculture with the Ecosystem Approach to Aquaculture (EAA), several guiding principles are followed, as approved by the Code of Conduct for Responsible Fisheries (FAO, 2009). This approach ensures that aquaculture management does not cause any form of ecosystem degradation, such as biodiversity loss or a reduction in carrying capacity. It also emphasizes equity among all stakeholders, ensuring fair access to resources and equitable income sharing (Brugère *et al*., 2019; Alexander *et al*., 2021). Aquaculture activities are developed in alignment with established policies and broader developmental goals

(FAO, 2010; FAO, 2024). Furthermore, there is a clear understanding of the roles and involvement of both local and national governments, along with other stakeholders, to achieve effective and sustainable aquaculture management (Soto *et al*., 2020).

The EAA provides a planning and management framework to effectively integrate aquaculture into local planning and engage producers and the government in effective and sustainable aquaculture operations (FAO, 2013; Joffre *et al*., 2023). There are some procedures which are to be followed to maintain the whole system as given below-

2007). This planning helps to prevent environmental deterioration in the water body, implement biosecurity measures, reduce negative interactions between environment and society, improve carrying capacity of the ecosystem, reduce conflicts among shareholders of the resources and regulates farmers' interaction and behaviours.

Advanced planning

Some advanced planning strategies can be introduced when spatial planning is implemented, which helps to enhance the production potential of aquaculture systems. Such planning not only increases efficiency but also reduces the risk of disease transmission, thereby supporting higher and more sustainable yields. For example, using the same canal for both inlet and outlet purposes should be avoided to prevent contamination and disease spread. Specific areas can be designated for other domesticated activities to ensure compatibility and reduce conflict. Additionally, integrated farming practices can be incorporated within the designated zones to maximize resource use and promote ecological balance. Advanced culture systems, such as aquaponics, may also be adopted to enhance resource recycling and improve overall productivity (Aguilar-Manjarrez *et al*., 2017a; FAO, 2021).

Initiation:	• Scoping and baseline data collection
	• Stakeholder agreement
	• Selection of general objectives of management area
Issue selection:	• Issues and problems identified and prioritized after discussion
	• Risk assessment
System management:	• Set objectives for each problem
	• Indicators identified
	• Evaluation of management option among stakeholders
Implementation:	• Finalizing and formalizing management plans
	• Joint access to feed, seed, market, post-harvest services
Monitoring:	• Integrated monitoring for the area as a whole
	• Remedial action plans for environmental, social and financial parameters
Final production:	• Cluster management
	• Collective certification of product under ecosystem perspective
	• Group certification after 3rd party auditing

Common issues to be addressed

Spatial planning helps to improve the quality of culture by reducing the common issues and risks associated with the farming practices. Some environmental issues like eutrophication problems, waste disposal, disease transmission, biodiversity loss, habitat destruction, impact of applied chemicals, poor water management etc are addressed in this planning (Brugère *et al*., 2019). Some indicators like critical habitat, biodiversity, sediment dwellers etc are followed to know the ecological fluctuation levels in this management. Loss in production due to mortality, theft etc and limited access to market, post-harvest services, seed, feed and capitals are easily accessed collaborate to reduce the economic issues (Corner *et al*., 2006; Gentry *et al*., 2017). Social issues like conflict among resource users, lack of training, lack of proper services, lack of labour, lack of women opportunities, food safety problems etc are solved during planning of the system. Some governance issues are also solved like inadequate monitoring, absence of biosecurity, lack of political support, damages of farm due to climatic variability and disasters etc (FAO,

GIS based spatial planning

GIS (Geographic Information Systems) plays a critical role in aquaculture spatial planning by combining diverse data sources to support well-informed decision-making in modern days. By analyzing key factors such as water quality, environmental conditions, infrastructure access, and land availability, GIS helps pinpoint suitable sites for aquaculture operations while minimizing environmental impact. This technology enhances stakeholder participation and transparency, especially in areas where resource use conflicts may arise (Hasankhani *et al*., 2024). Innovations like the integration of GIS with AI-driven models and satellite imagery have further increased the accuracy of zone identification and environmental monitoring (Wickliffe *et al*., 2024). Additionally, GIS supports ecosystem-based planning by visualizing the collective influence of various activities, which is crucial for adapting to climate change and maintaining resource sustainability (López-Angarita *et al*., 2018). GIS and remote sensing tools were used to identify suitable zones for brackishwater aquaculture in Kollam (Gopakumar *et al*., 2018) and shrimp farming in Nagapattinam District, Tamil Nadu (Rao *et al*., 2013) ensuring minimal conflict with agriculture, human settlements, and ecologically sensitive zones. In a study (Nayak *et al*, 2014) appropriate sites for aquaculture development in the mid/high Himalayan region of Uttarakhand was identified and quantified using remote sensing and geographical information system (GIS). In order to identify potential conflicts in land uses and take conservation concerns into account early in the planning process for brackish water aquaculture, mathematical models such as fuzzy sets and GIS are currently being used (Tarunamulia and Sammut, 2023). These capabilities make GIS a foundational tool along with other mathematical and computer model in advancing resilient and sustainable aquaculture development.

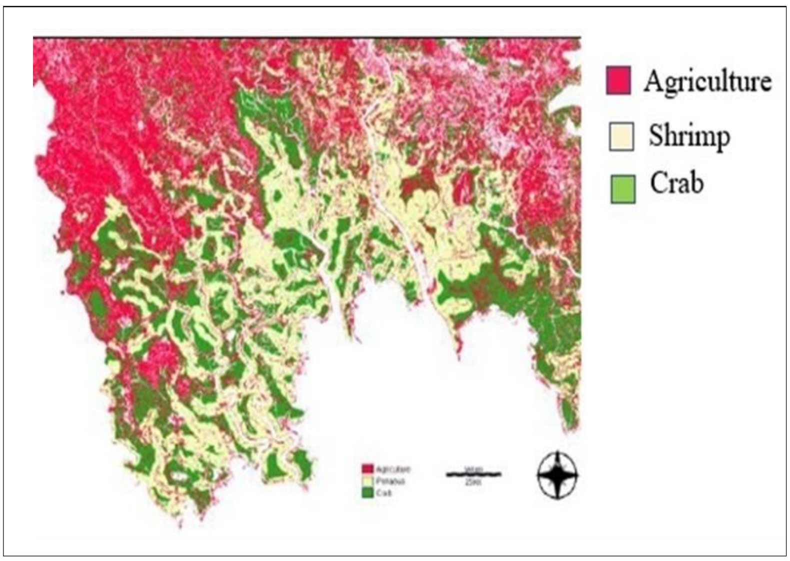

Fig. 3. Marine spatial planning in Bangladesh (Salam, 2010)

Example of AMAs

Several Aquaculture Management Areas (AMAs) have been initiated around the world to enhance sustainable aquaculture through spatial planning and advanced monitoring systems (Ross *et al*., 2013). In the Canary Islands, fish cage culture has been integrated with tourism development using GIS-based spatial models to ensure minimal ecological disruption and optimal resource use. Offshore cage farming in Tenerife utilizes wave mapping to determine safe and productive farming zones. In Argentina, floodplain aquaculture is managed using MODIS satellite data to understand and align operations with natural flood cycles. In Chile, different spatial standards have been applied to reduce environmental and health risks, including extensive culture systems maintaining 200 meters between farms, intensive systems with 400 meters of separation, and microalgae suspended farming with 50 meters between units. Similarly, Turkey has adopted tuna cage farming practices with 1 km spacing to reduce overcrowding and water pollution. Shrimp aquaculture in Mexico, zonal culture practices in China, and the development of mariculture parks in Indonesia are additional examples of spatially managed aquaculture systems that aim to balance productivity with environmental sustainability (Soto *et al*., 2008; FAO, 2021).

Depending on the mass balance model, an approach was raised to make AMAs in marine water in Bangladesh. Strength and direction of tidal movement was collected based on the bathymetry data (Fig. 3). Multi-objective land allocation tool was used to reduce conflict as the water body was commonly shared with agriculture. Both shrimp and crab culture were done there. Waste disposal system was monitored so that waste could be settled down immediate at vicinity of cages (Salam, 2000).

Proposed AMAs

Several Aquaculture Management Areas (AMAs) have been proposed globally to promote sustainable aquaculture development through spatial planning and integrated ecosystem management. These initiatives aim to balance aquaculture production with environmental conservation and socio-economic benefits. For instance, integrating marine cage and pen farming with eco-tourism has been suggested to enhance local economies while minimizing ecological footprints (Weitzman *et al*., 2023). Island-based offshore cage culture, complemented by wave monitoring systems, offers a method to optimize site selection and ensure the structural integrity of aquaculture installations in dynamic marine environments (Sclodnick *et al*., 2024). The establishment of aquaculture emergency zones has been proposed to allow for the short-term relocation of operations in response to environmental hazards or disease outbreaks, thereby enhancing the resilience of aquaculture systems (NOAA, 2024). Off-bottom bivalve and seaweed culture practices are being considered for their potential to improve water quality and provide ecosystem services, while coastal cage culture continues to be a focal point for expanding marine aquaculture in suitable near shore areas (Soto *et al*., 2018; Weitzman *et al*., 2023). Additionally, the development of freshwater farms and hatcheries is essential for supporting inland aquaculture and ensuring a steady supply of seed stock for various aquaculture ventures (Debnath *et al*., 2023). These proposals align with the principles outlined in the FAO's guidelines on aquaculture zoning and area management, which emphasize the importance of ecosystem-based approaches and stakeholder involvement in aquaculture planning and development (FAO, 2024).

Conclusion

Management areas show common plan to minimize risks by proper coordination. Space and resources of aquaculture are easily influenced by surrounding environment and other activities. So, we have to monitor a little fluctuation in the system and its surrounding to mitigate any possible risks in the system. Surrounding catchment areas must be included within the planning along with stakeholders' consultation. Thus, zoning and clustering of farms help to achieve bigger than the individual effort under ecosystem perspective.

Conflict of interest: There is no conflict of interest among the authors.

Data availability statement: The data that support this study are available from the corresponding author upon reasonable request.

Author's contribution: PB: Concept and design, collection of data and preparation of original draft along with illustrations; HSM, SKS: Reviewing of the draft and addition; SD: Reviewing and overall supervision.

Use of artificial intelligence tools: During the preparation of this work only Microsoft Power Point presentation (2019) was used for making the illustration.

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