Best practices in responsible planning and sustainable management of aquaculture development

REPORT FOR RAUCH FOUNDATION




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Acronyms

MEP	MacAlister Elliott and Partners Limited
AMA	Aquaculture Management Areas
ASC	Aquaculture Stewardship Council
AZA	Allocated Zones for Aquaculture
AZE	Allowable Zone of Effect
BMP	Best Management Practices
EIA	Environmental Impact Assessment
EQO	Environmental Quality Objectives
EU	European Union
FAO	Food and Agriculture Organisation
FCR	Feed Conversion Ratio
GAA	Global Aquaculture Alliance
GFCM	General Fisheries Commission for the Mediterranean
GIS	Geographic Information Systems
ICZM	Integrated Coastal Zone Management
IMTA	Integrated multi-trophic aquaculture
MSP	Marine Spatial Planning
SDG	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SEPA	Scottish Environmental Protection Agency

Executive Summary

Good aquaculture governance is essential for achieving a balance between economic growth and environmental sustainability. A well-structured governance framework, incorporating clear policies, strategic planning, action plans, legislation, and regulations, ensures that aquaculture operations are responsible, resilient, and economically viable. Effective governance promotes innovation, strengthens industry adaptability, takes into consideration the interaction with local communities and other stakeholders, and protects natural resources for future generations. Through adaptive management and continuous policy evaluation, aquaculture governance can evolve to meet emerging challenges and support long-term industry growth.

Planning

Spatial planning plays an important role in ensuring the sustainable expansion of aquaculture. Proper site selection, marine spatial planning, and the application of regulatory frameworks and Geographic Information Systems (GIS) technology help minimise environmental impacts while supporting industry development.

Allocated Zones for Aquaculture (AZAs) provide a structured approach to sustainable aquaculture development by balancing ecological, economic, and social factors. Through strong governance, stakeholder participation, and continuous environmental monitoring, AZAs help ensure sustainable food production, economic prosperity, and marine ecosystem protection.

Socio-economic factors are fundamental to aquaculture planning and management. By incorporating social structures, economic assessments, and environmental impact evaluations, aquaculture can support job creation, enhance local livelihoods, and drive economic development while reducing social conflicts. Ensuring inclusive stakeholder engagement and robust governance frameworks will strengthen the sustainability and social acceptance of aquaculture operations.

The Strategic Environmental Assessment (SEA) Directive plays a vital role in fostering environmentally sustainable decision-making within the European Union. Strengthening the SEA Directive's application will support the EU's broader environmental objectives, including the European Green Deal and UN Sustainable Development Goals (SDGs) as well as ensuring appropriate scale of aquaculture in suitable locations.

Siting

Farm siting and licensing are important in ensuring aquaculture sustainability. Proper site selection minimises environmental risks, maximises production efficiency, and enhances public acceptance. Licensing frameworks regulate aquaculture activities, ensuring compliance with environmental and operational standards. By adopting best management practices, incorporating adaptive strategies, and engaging stakeholders, aquaculture can contribute significantly to food security, economic prosperity, and ecosystem health. Strengthened governance mechanisms and integration with coastal management strategies will support the industry's long-term success.

The Allowable Zone of Effect (AZE) is a key tool in sustainable aquaculture management, defining clear environmental impact boundaries and enforcing monitoring programs.

The Environmental Impact Assessment (EIA) process is a fundamental tool for integrating environmental considerations into development projects. By undertaking a thorough EIA and systematically evaluating and addressing potential impacts, the EIA framework contributes to sustainable decision-making, public participation, and adherence to environmental regulations.

Operation

Aquaculture Management Areas (AMAs) provide a structured approach to harmonising economic productivity with environmental and social responsibility. By designating clear boundaries, establishing governance structures, and implementing coordinated management strategies, AMAs promote sustainability, reduce risks, and facilitate industry growth. Moving forward, strengthening stakeholder engagement, improving regulatory coordination, and investing in monitoring technologies will be key to the success of area-based aquaculture management.

Environmental impact monitoring is necessary for maintaining aquaculture sustainability. Comprehensive monitoring programs, supported by adaptive management and good practice will help to ensure sustainable aquaculture.

Two case studies, Scotland and Turkey, can be found in Appendices 1 and 2, respectively.

1. Introduction

Aquaculture is a rapidly growing sector that plays an important role in global food security, economic development, and environmental sustainability. Effective governance in aquaculture ensures that production is managed responsibly, minimising environmental impacts while optimizing economic and social benefits. Governance in aquaculture encompasses a range of measures, including policy formulation, strategic planning, action planning, legislation, and regulations. A well-defined governance framework helps balance industry growth with ecological preservation and ensures the equitable participation of stakeholders. This essay discusses good practices in aquaculture governance, outlining key components such as policy development, strategic planning, action planning, and regulatory measures to support sustainable aquaculture development.

2. Aquaculture governance framework

Aquaculture governance involves structured policies, strategies, and action plans that provide direction, define objectives and guide implementation. These frameworks help create a sustainable and legally compliant aquaculture industry that can adapt to changing environmental and economic conditions.

2.1 Policy

A well-defined aquaculture policy establishes a comprehensive vision for the sector by setting priorities and development goals across various levels—provincial, national, regional, and international. Effective policies provide clarity and direction for sustainable aquaculture practices and ensure industry stability.

Good aquaculture policies should be evidence-based, relying on scientific research and stakeholder engagement to formulate practical guidelines. They should define roles for key actors, including governmental agencies, private sector players, research institutions, and civil society organisations. Moreover, aquaculture policies should align with global objectives related to food security, economic growth, climate adaptation, and environmental conservation. Policies must also address the growing demand for seafood by supporting sustainable mariculture development and ensuring resource efficiency. Since market forces alone cannot guarantee a balanced and sustainable aquaculture sector, government intervention through well-crafted policies is necessary to regulate the industry effectively.

2.2 Strategy

A strategic plan translates policy objectives into actionable steps. It serves as a roadmap to guide the sustainable development of aquaculture by addressing key challenges and optimizing opportunities.

An effective strategy should identify and mitigate key industry challenges, such as poor spatial planning, limited technological advancements, poor species selection, and the environmental impacts of aquaculture operations. Strategies should also focus on best planning and management practices to improve farm productivity and minimise ecological harm, ensuring that production remains efficient and sustainable.

To enhance governance, strategies should emphasize regulatory improvements to create a streamlined and efficient legal framework. Furthermore, strategies must promote research, development, and capacity-building initiatives to foster innovation in the aquaculture sector. Enhancing technological advancements, such as efficient feeding systems, biosecurity measures, and ecosystem-based management approaches, can significantly contribute to the sector's long-term sustainability.

2.3 Action Plan

An action plan defines the concrete steps required to implement strategies and ensures that governance objectives are achieved. A well-structured action plan is essential for bridging the gap between policy formulation and execution.

A practical action plan should be time-bound, providing clear deadlines for implementation to track progress and evaluate outcomes. It should assign responsibilities to key stakeholders, including government agencies, industry operators, and community organisations. Prioritising actions based on urgency, impact, and available resources is required to achieving targeted objectives. Additionally, action plans should outline financial mechanisms, including government funding, private sector investments, and international financial support, to ensure the successful execution of strategic initiatives.

2.4 Legislation and Regulation

For sustainable and responsible aquaculture development, there should be facilitating and controlling legislation and regulations. Legislation provides an enforceable framework to support policy implementation through the detail specified in such instruments, and through powers relating to enforcement and sanctions for those infringing the law. In addition, legislation formalises the rights and responsibilities of individuals in the sector and helps the implementation of policies.

2.5 Legislative Considerations

Aquaculture legislation plays an important role in defining operational standards and ensuring compliance with environmental and food safety requirements. Effective legislation should establish clear guidelines for resource allocation, site selection, and licensing processes to prevent conflicts over land and water use. Additionally, legislation must define Environmental Quality Standards, including those for water safety, animal welfare, and responsible waste management.

Biosecurity regulations should be enforced to control fish movement, prevent disease outbreaks, and protect both farmed and wild aquatic populations. Waste management policies should mandate the proper treatment of wastewater and regulate emissions to minimise pollution.

Furthermore, integrating aquaculture governance within broader coastal and marine management policies ensures that aquaculture development does not interfere with other marine industries or compromise ecosystem health.

2.6 Regulatory Measures

Regulations serve as instruments to implement legislative frameworks effectively and enforce compliance. They provide operational guidelines for sustainable aquaculture and promote industry accountability.

Effective regulatory measures should include SEA to ensure suitable planning and EIA requirements to evaluate and mitigate the potential risks of individual aquaculture operations. Setting production and stocking limits is essential to prevent resource overexploitation and maintain ecosystem balance. Establishing monitoring systems for water quality, sedimentation, and biodiversity conservation ensures that industry practices align with environmental sustainability goals.

Biosecurity protocols should be strictly implemented to prevent the introduction of invasive species and the spread of aquatic diseases. Furthermore, supporting industry best practices through certification schemes and traceability measures enhances product quality, market competitiveness, and consumer confidence in aquaculture products.

2.7 Codes of practice (COP)

COPs implemented are a practical and economically feasible way to reduce adverse environmental impacts of aquaculture at the farm level and also at a larger scale and so reduce conflicts with fisheries and other users of the aquatic space. Implementing COPs requires action from both the government (in the form of better policy, regulation, enforcement, and planning and management procedures) and industry (through COPs). COPs are generally developed by aquaculture producer organisations to ensure that their members conform to good standards of production.

3. Spatial Planning for Aquaculture

Effective spatial planning ensures that aquaculture operations are located in suitable environments, minimising negative environmental impacts while maximising production efficiency. Poor site selection can lead to environmental degradation, conflicts with other human activities, and economic inefficiencies.

Spatial planning in aquaculture involves the careful allocation of land and water resources to support industry growth while maintaining ecological integrity and social harmony. Effective planning considers multiple factors, including water quality, infrastructure accessibility, environmental sustainability, and economic viability. Without proper spatial planning, aquaculture operations may face challenges such as disease outbreaks, pollution, and conflicts with other industries such as tourism and fisheries.

3.1 Key aspects of marine spatial planning for aquaculture

Selecting an appropriate zone is fundamental to the success of aquaculture planning. Zone selection must consider the other users of the coastline and aquatic space.

MSP is a systematic approach to managing human activities in marine areas to achieve ecological, economic, and social objectives. MSP integrates aquaculture with other marine uses, including fisheries, tourism, and conservation efforts. Characteristics of MSP include.

- **Ecosystem-based approach**. Ensuring that aquaculture activities do not degrade marine ecosystems.
- **Zoning**. Identifying designated zones for aquaculture to minimise conflicts with other marine users.
- **Stakeholder participation**. Involving governments, industry players, and local communities in planning decisions.
- **Adaptive management**. Regularly updating plans based on new research and environmental monitoring.

3.2 Integrated Coastal Zone Management (ICZM)

ICZM provides a holistic approach to spatial planning by considering all economic activities and environmental concerns along coastal areas. ICZM promotes sustainable use of coastal resources and integrates aquaculture planning with land-use, fisheries, tourism, and conservation strategies. Aquaculture spatial planning should align with environmental and socio-economic goals.

Exclusion zones and buffers

A well-planned aquaculture sector must incorporate exclusion zones and buffer areas to prevent conflicts with other marine users and protect environmentally sensitive regions. These spatial management tools help balance economic growth with ecological sustainability, ensuring aquaculture operations coexist harmoniously with other marine activities and conservation efforts.

Exclusion zones are designated areas where aquaculture is prohibited due to conflicts with other users or environmental concerns. One key reason for establishing exclusion zones is to prevent interference with existing marine activities such as navigation routes, commercial fishing zones, or areas reserved for other economic purposes. By restricting aquaculture in these locations, authorities can reduce the risk of competition for space and resources, ensuring that aquaculture does not disrupt essential maritime operations.

In addition to economic and operational considerations, exclusion zones are important for protecting sensitive marine ecosystems. Governments designate marine protected areas (MPAs) to conserve biodiversity, safeguard fragile habitats, and maintain ecological integrity. While MPAs play a necessary role in environmental preservation, they can also limit the available space for aquaculture expansion. The challenge lies in balancing industry growth with conservation priorities, ensuring that aquaculture development does not compromise the health of marine ecosystems.

To effectively implement exclusion zones and buffers, aquaculture governance frameworks should incorporate clear procedures for zone allocation. Strategic Environmental Assessments (SEAs) should be a requirement for new aquaculture zones, ensuring that site selection considers both environmental sustainability and socio-economic factors. Additionally, establishing monitoring systems for aquaculture zones is essential to assess their long-term environmental and social impacts. Regular evaluations will help policymakers adjust regulations as needed, fostering a responsible and adaptive approach to aquaculture development.

Coastal areas are often subject to multiple uses that may create conflicts with aquaculture activities. Therefore, it is crucial to consider existing coastal activities and infrastructure to minimise negative interactions. Important factors include.

- **Port areas and infrastructure.** Overlapping activities with commercial ports may lead to logistical challenges and restrictions.
- **Dumping points and underwater outlets.** Proximity to wastewater discharge areas can lead to water quality deterioration, negatively affecting fish health.
- **Tourism-related areas.** Locations near beaches and residential tourism zones may face opposition due to aesthetic and environmental concerns.
- **Archaeological sites.** The presence of historical sites may impose restrictions on development and activities.
- **Traditional fishing areas.** Conflicts may arise between cage farming operations and traditional fishing communities, necessitating careful planning.
- **Artificial reefs.** These areas are often designated for conservation or recreational activities, making them less suitable for aquaculture.
- **Other aquaculture facilities.** Compatibility with existing aquaculture sites should be assessed to prevent overuse of local resources and environmental degradation.
- **Military zones.** Restrictions on activities in military zones can affect site selection feasibility.

3.3 The Role of GIS

The use of GIS-based mapping enhances decision-making by integrating scientific data with policy frameworks, ensuring that aquaculture developments are both environmentally sustainable and economically viable. GIS technology helps identify optimal sites by assessing factors such as water quality, habitat suitability, regulatory restrictions, and socio-economic considerations, facilitating informed decision-making while complying with environmental regulations.

GIS tools help identify suitable sites by assessing;

- Water quality parameters (e.g., salinity, temperature, oxygen levels).
- Infrastructure accessibility (e.g., proximity to roads and ports).

- Environmental risks (e.g., pollution sources, habitat degradation).

4. Allocated Zones for Aquaculture (AZA)

Aquaculture zoning brings together the criteria for locating aquaculture and other activities to define broad zones suitable for different activities or mixes of activities. The creation of zones facilitates the integration of aquaculture activities into areas that may already be exploited by other users. The effectiveness of zoning depends upon its simplicity, clarity and degree of local support. Zoning is a method to systematically manage the ocean ecosystem and identify appropriate sites.

AZAs are designated marine areas where aquaculture activities take priority over other uses. These zones are identified and managed to ensure sustainable development while minimising environmental and social conflicts. Effective implementation of AZAs contributes to the expansion of the aquaculture sector by providing clear spatial planning, environmental management, and regulatory frameworks.

The establishment of AZAs is necessary for fostering sustainable aquaculture development. By designating specific areas for aquaculture, AZAs help streamline industry operations, reduce spatial conflicts, and improve environmental management.

4.1 Key aspects of AZAs

Aquaculture zones

Effective site selection and zoning are essential to minimising aquaculture’s impact on other marine users and ecosystems. Zoning not only supports sustainable growth but also serves as the foundation for area management plans that promote responsible aquaculture practices.

Unplanned or poorly planned aquaculture expansion has, in some cases, led to environmental and social concerns, contributing to negative public perceptions. To address these issues, spatial planning—including zoning and strategic site selection—is increasingly used to identify suitable areas for aquaculture while preventing overdevelopment. In regions where aquaculture is emerging, zoning helps designate appropriate locations for development. In areas where aquaculture is already established, zoning regulates expansion to maintain ecological balance and prevent overproduction.

The Food and Agriculture Organisation (FAO) and the World Bank have developed guidelines for zoning, site selection, and area management to streamline aquaculture development while maintaining environmental integrity.

A case-by-case site selection approach, where investors identify locations for aquaculture, can lead to scattered developments that complicate monitoring, enforcement, and conflict resolution. To improve governance, regulators should establish aquaculture zones based on carrying capacity assessments. These zones should be designated by the appropriate government agencies, approved by key ministries, and formally allocated for aquaculture use.

Zoning plans should guide the approval or denial of permits, incorporating implementation measures such as enforcement, monitoring, evaluation, research, public participation, and financial planning. A well-designed zoning framework ensures that aquaculture development balances economic growth, environmental sustainability, and social acceptance, fostering long-term industry viability while minimising conflicts with other coastal and marine users.

Support infrastructure

The availability of infrastructure at potential aquaculture zone locations should be thoroughly assessed to determine the advantages and disadvantages associated with the site. Essential infrastructures that contribute to operational efficiency include.

- **Roads.** Good road connectivity facilitates easier transportation of supplies, harvests, and workforce movements.
- **Piers, harbours, and jetties.** Access to these facilities ensures smooth logistics for fish handling, equipment transport, and emergency responses.
- **Available workspace on land.** Sufficient land-based operational areas are crucial for conducting maintenance activities, handling feed storage, and providing administrative space.
- **Storage or warehouse availability.** Proximity to storage facilities minimises the need for frequent, costly transportation of supplies and finished products.

Zoning process and support tools

- **Identification of high-level objectives.** Establishing clear goals for sustainable aquaculture development, environmental protection, and economic viability.
- **Zone selection criteria.** Using scientific, environmental, and economic criteria to determine suitable sites.
- **Marine spatial planning.** Coordinating aquaculture activities with other marine and coastal uses to ensure harmonious coexistence.
- **Stakeholder consultation.** Engaging local communities, government agencies, and industry representatives to address potential conflicts and concerns.
- **GIS mapping.** Utilising GIS to visualize site conditions, environmental factors, and potential constraints.
- **Strategic environmental assessment.** Evaluating the long-term ecological and social impacts of aquaculture activities within the proposed zones.
- **Estimation of cumulative carrying capacity.** Assessing the ecological limits of a given area to avoid excessive nutrient loads and environmental degradation.
- **Biosecurity and zoning strategies.** Implementing measures to prevent disease transmission and maintain the health of farmed and wild aquatic populations.

- **Legal designation of zones.** Establishing legally recognized aquaculture zones to provide regulatory clarity and long-term stability for the industry.

4.2 Allocation of aquaculture zones

The allocation of aquaculture zones is the final and most critical step in the zoning process. It is a legally binding and regulatory mechanism that designates specific areas for aquaculture, ensuring that all future developments comply with established spatial guidelines. By formalising aquaculture zones, governments can create a structured framework that balances industry growth with environmental sustainability and social equity.

Aquaculture zones should be established within the scope of national or local aquaculture plans and aligned with existing legislative frameworks. The primary objective is to ensure the long-term sustainability of aquaculture while promoting fairness and resilience within interconnected social and ecological systems. Each zone should be assigned regulations and restrictions based on its suitability for aquaculture, carrying capacity, and environmental sensitivity. These zones can be classified into three broad categories:

- **Suitable areas for aquaculture** – Regions where aquaculture activities can be freely developed under standard regulations.
- **Unsuitable areas for aquaculture** – Regions where aquaculture is prohibited due to environmental, economic, or social conflicts.
- **Restricted aquaculture areas –** Regions where aquaculture is permitted under specific conditions, such as limited production scales, seasonal operations, or strict environmental monitoring.

To ensure consistency and effective governance, governments should develop clear guidelines tailored to the specific environmental and socio-economic conditions of each region. These guidelines should outline criteria for zone selection, regulatory requirements, and best management practices to mitigate environmental and social risks.

Zoning plans serve as the foundation for granting or denying individual permits for aquaculture operations. However, effective zoning goes beyond spatial designation; it requires a comprehensive governance structure that includes implementation, enforcement, continuous monitoring, periodic evaluation, research, stakeholder participation, and financial planning.

4.3 Socio-economic considerations

The socio-economic aspects of aquaculture play a vital role in determining its sustainability and success. Understanding the social structure of local communities and the prevailing economic activity in a given region is essential for the effective implementation of AZAs. The integration of aquaculture within local economies has the potential to create employment opportunities, enhance livelihoods, and contribute to food security.

Assessing the socio-economic landscape is essential for identifying potential benefits and challenges associated with aquaculture activities. Social structures define how communities interact, allocate resources, and adapt to new economic opportunities. Economic evaluations, on the other hand, provide insights into market conditions, employment potential, and financial sustainability.

Key socio-economic factors in aquaculture development

- **Employment and livelihood opportunities.** One of the most significant benefits of aquaculture is job creation. The establishment of aquaculture farms can provide direct employment in fish farming, processing, distribution, and supporting industries such as feed production and equipment maintenance. Additionally, aquaculture can indirectly benefit local economies by fostering associated businesses such as transportation, marketing, and trade. Ensuring fair labour practices and equitable employment opportunities is essential for achieving social acceptability and sustainable industry growth.
- **Economic valuation of ecosystem services.** Aquaculture operations rely on various ecosystem services, such as water resources, nutrient cycles, and biodiversity. It is essential to assess the total economic value of these services to understand their contributions to both aquaculture production and broader community benefits. The monetization of ecosystem services helps policymakers and investors determine the feasibility of aquaculture projects and design strategies for sustainable resource utilisation.
- **Environmental externalities and social impact.** Aquaculture activities can have both positive and negative environmental externalities. While they may contribute to economic growth and food security, they can also impact water quality, biodiversity, and traditional livelihoods. Proper site selection, regulatory oversight, and environmentally friendly farming practices are critical in minimising negative externalities. Conducting EIA ensures that aquaculture activities align with social and ecological sustainability goals.
- **Integration with local economic activities.** Aquaculture must be integrated into existing economic activities without causing disruptions. Key considerations include:
    - **Port and coastal infrastructure.** Identifying how aquaculture facilities interact with maritime industries such as fishing, tourism, and shipping.
    - **Protected habitats and conservation areas.** Ensuring that aquaculture activities do not interfere with marine protected areas or critical ecosystems.
    - **Tourism and recreational activities.** Evaluating the potential for aquaculture to coexist with or complement coastal tourism and water sports.
    - **Conflict resolution and community engagement.** Stakeholder engagement is essential in preventing and resolving conflicts between aquaculture and other coastal users. Traditional fishing communities, conservation groups, and tourism operators should be included in decision-making processes to ensure a balanced approach. Establishing clear regulations and transparent communication mechanisms can help address concerns and promote social acceptance.

- **Governance and policy frameworks.** A strong regulatory framework is necessary to balance socio-economic growth with environmental sustainability. Key governance aspects include.
- **Licensing and permitting.** Establishing clear policies for acquiring permits and licenses for aquaculture operations.
- **Zoning and land-use planning.** Defining designated areas for aquaculture while considering ecological and economic factors.
- **Monitoring and compliance.** Implementing monitoring programs to ensure adherence to social and environmental standards.

5. Strategic Environmental Assessment (SEA)

The **SEA Directive** (Directive 2001/42/EC) is a cornerstone of EU environmental legislation designed to assess the potential environmental effects of certain plans and programmes before their implementation. This process integrates environmental considerations into decision-making to promote sustainable development and protect environmental quality.

The SEA Directive applies to a broad range of public plans and programmes in sectors such as land-use, transport, energy, waste, and agriculture. For a plan or programme to fall within the SEA Directive, it must meet the following criteria.

- Be subject to preparation and/or adoption by a national, regional, or local authority.
- Be required by legislative, regulatory, or administrative provisions.
- Be prepared for sectors listed in Article 3(2)(a) of the SEA Directive.
- Set the framework for future development consent of projects listed in Annexes I and II of the EIA Directive.

The SEA Directive aligns with international commitments such as the Protocol on Strategic Environmental Assessment to the convention on EIA in a transboundary context.

5.1 Key stages of the SEA process

The **Strategic Environmental Assessment (SEA)** process is a structured framework designed to integrate environmental considerations into the planning and decision-making process. It ensures that potential environmental and social impacts are identified early in the development of policies, plans, or programs, including aquaculture zoning initiatives. The SEA process typically follows these key stages.

Screening

- The first step in the SEA process determines whether a proposed plan, policy, or program requires an SEA based on its potential environmental significance.

- It applies to decisions regarding new aquaculture zones or modifications of existing plans, particularly when activities may affect sensitive ecosystems or protected areas.

Scoping

- This stage identifies key environmental, social, and economic issues that need to be assessed, ensuring that the SEA remains focused and relevant.
- It involves stakeholder engagement to define the scope of the SEA, including key environmental indicators, geographical boundaries, and alternative aquaculture zoning scenarios.
- Scoping helps determine the necessary level of detail for the environmental report and ensures that relevant cumulative effects, transboundary concerns, and ecosystem services are considered.

Public consultation and participation

- Public engagement is a crucial element of SEA, ensuring that environmental assessments are transparent, inclusive, and participatory.
- The consultation process allows key stakeholders—including local communities, environmental groups, industry representatives, and government authorities—to provide input on the findings of the environmental report.
- It can take various forms, including public hearings, workshops, surveys, and online consultations, ensuring that diverse perspectives are considered in decision-making.

Environmental report preparation

- The environmental report provides a comprehensive assessment of the proposed aquaculture zone, describing baseline environmental conditions such as water quality, biodiversity, and habitat integrity.
- It evaluates the potential direct, indirect, and cumulative effects of the plan on the environment, considering reasonable alternatives to minimise or mitigate negative impacts.
- The report includes recommendations for mitigating adverse effects, enhancing positive environmental outcomes, and integrating sustainability principles into aquaculture development.

Decision-making

- SEA findings are integrated into the final decision-making process to ensure that environmental considerations are adequately addressed before implementation.
- Decision-makers must justify how environmental assessments influenced the final plan, highlighting accepted recommendations and mitigation measures.
- Trade-offs between environmental protection and economic development are carefully weighed.

Monitoring

- Post-implementation monitoring is essential to track the actual environmental impacts of the aquaculture zone and verify whether the predicted effects align with real-world outcomes.
- Monitoring programs should include key environmental indicators such as water quality parameters, ecosystem health, and socio-economic changes within affected communities.
- If unexpected environmental issues arise, adaptive management strategies should be employed to revise or strengthen mitigation measures to prevent long-term ecological degradation.

5.2 Environmental and social factors in SEA

SEA aims to integrate environmental sustainability with social and economic considerations to achieve balanced and informed decision-making in aquaculture development.

Environmental considerations

- **Biodiversity and ecosystems.** Ensuring the protection of local and regional biodiversity by assessing the impact of aquaculture activities on marine and freshwater ecosystems. Identifying and mitigating potential threats such as habitat destruction, invasive species introduction, and overfishing of wild stocks for aquaculture feed. Promoting ecosystem-based management approaches that support ecological resilience and sustainable resource use.
- **Water resources.** Evaluating how aquaculture activities impact water quality, including nutrient loading, eutrophication risks, and chemical contamination from feed and pharmaceuticals. Assessing the sustainability of water extraction for aquaculture and potential conflicts with other water users, such as agriculture or municipal supply. Implementing measures such as water recycling, effluent treatment, and integrated multi-trophic aquaculture (IMTA) to minimise environmental impacts.
- **Air quality.** Addressing emissions from aquaculture facilities, such as ammonia from waste decomposition and greenhouse gas emissions from energy-intensive operations. Encouraging the use of renewable energy sources and energy-efficient practices in aquaculture zone planning.
- **Climate change.** Incorporating climate resilience into aquaculture planning by evaluating potential impacts such as rising sea temperatures, ocean acidification, and extreme weather events. Promoting climate-smart aquaculture practices, including species selection for temperature tolerance, habitat restoration, and carbon sequestration initiatives.
- **Cumulative effects.** Assessing the combined impact of multiple aquaculture operations in a region, considering their long-term and large-scale environmental footprint. Implementing spatial planning approaches to prevent excessive environmental burden and ensure sustainable carrying capacity.

5.3 Social and economic considerations

- **Community Engagement.** Encouraging participatory planning approaches that involve local communities in decision-making, particularly those directly affected by aquaculture development. Addressing concerns related to land and water use conflicts, livelihood changes, and equitable benefit-sharing.
- **Public health.** Assessing potential health risks associated with aquaculture, including waterborne diseases, antibiotic resistance, and contamination of seafood products. Ensuring compliance with food safety regulations and best management practices to protect consumers and workers.
- **Cultural heritage.** Identifying and safeguarding historical, archaeological, and culturally significant sites that may be affected by aquaculture expansion. Engaging with indigenous and local communities to ensure traditional knowledge and cultural values are respected in aquaculture planning.
- **Economic sustainability.** Ensuring that aquaculture zones promote long-term economic viability by balancing environmental sustainability with industry growth. Supporting local economies by providing employment opportunities, fostering innovation, and promoting responsible trade practices.

6. Cumulative environmental impact modelling

To model the cumulative impacts of aquaculture zones on the environmental, several types of models can be used to assess water quality, nutrient dynamics, carrying capacity, and ecological interactions. Below is a brief description of key model types.

- **Mass balance models.** These models estimate the input, output, and accumulation of nutrients (e.g., nitrogen, phosphorus) within an aquaculture system. They are often used to assess nutrient loading and eutrophication risks in receiving waters. Example. Dissolved oxygen balance models for predicting oxygen depletion due to aquaculture activities.
- **Box Models for water quality analysis.** These models divide the waterbody into discrete compartments (or “boxes”) where physical, chemical, and biological processes occur. Useful for predicting water quality changes in coastal and enclosed waters affected by aquaculture. Example. The Delft3D-WAQ model, which simulates nutrient dispersion and algal blooms. The Legović box model to estimate cumulative carrying capacity based on dissolved nutrient thresholds.
- **Hydrodynamic models.** Simulate water movement, mixing, and flushing rates in aquaculture zones. Essential for understanding how aquaculture waste disperses in marine and freshwater environments. Example. MIKE 3 or ROMS (Regional Ocean Modelling System) for simulating water currents and pollutant dispersion.

- **Ecological and biogeochemical models.** Represent interactions between aquaculture, nutrient cycling, plankton, and benthic communities. Used for assessing long-term environmental impacts, including changes in primary productivity and sediment health. Example. EcoWin, ERSEM (European Regional Seas Ecosystem Model) for ecosystem-level impact assessment.

Examples

- **The Equilibrium Concentration equation (ECE) model.** The ECE model works by balancing nutrient inputs against natural dispersion and losses, such as denitrification. It calculates the steady-state enhancement of nutrient levels within a marine system.
- The **Legović box model** is used to estimate the sustainable carrying capacity based on maintaining the dissolved nutrient levels i.e. Phosphorus or Nitrogen (whichever is found to be limiting the primary production) in the water column to below a threshold at which the development of algal bloom becomes a high risk.

7. Allowable zones of effect in aquaculture

The AZE is a designated area within a water body where specific Environmental Quality Standards (EQS) for aquaculture are permitted, without irreversibly compromising the ecosystem's essential services. AZEs are used to balance sustainable aquaculture practices with environmental protection, ensuring that aquaculture activities do not negatively impact surrounding waters and marine biodiversity beyond acceptable thresholds.

An AZE refers to an area of seabed or a specific volume of water where regulatory authorities permit certain deviations from EQS, acknowledging that some localized impacts may occur from aquaculture activities. The primary function of an AZE is to establish clear boundaries for the environmental footprint of responsible aquaculture operations while ensuring that marine space remains available and safe for other stakeholders. Within this zone, aquaculture farms must adhere to strict environmental management protocols to prevent long-term ecological damage.

7.1 Regulation and management of AZEs

The declaration and management of AZEs involve several administrative steps and key stakeholders to ensure environmental sustainability while promoting aquaculture development. The key aspects of AZE regulation and management include.

- **Regulatory authorities and governance.** National and regional regulatory bodies play a fundamental role in the declaration, establishment, and enforcement of AZEs. Their responsibilities include:
  - Defining the legal framework and guidelines governing AZEs based on scientific studies and environmental impact assessments (EIA).
  - Collaborating with marine and environmental agencies to ensure that aquaculture practices align with broader conservation policies.

  - ➢ Enforcing compliance through inspections, licensing, and penalties for non-compliance.

- **Site selection and baseline studies.** Site selection is a critical process to identify suitable locations for AZEs within Aquaculture Zones (AZAs). This involves.
  - ➢ Conducting baseline environmental assessments to understand pre-existing conditions of water quality, sediment composition, and biodiversity.
  - ➢ Utilising Geographic Information Systems (GIS) and remote sensing tools to map and analyse potential AZE locations.
  - ➢ Engaging multidisciplinary research teams to evaluate hydrodynamic models and nutrient dispersion patterns to prevent excessive environmental degradation.
  - ➢ Permit applications and Environmental Impact Assessments (EIA). Aquaculture operators seeking to establish farms within AZEs must undergo a rigorous permitting process, including.
  - ➢ Submitting applications detailing proposed site activities, stocking densities, feed input, and waste management strategies.
  - ➢ Conducting EIAs to evaluate potential impacts on water quality, benthic habitats, and local biodiversity.
  - ➢ Proposing mitigation measures to minimise environmental effects and improve farm sustainability.

The declaration and management of AZEs involve several administrative steps and key stakeholders.

- **National and regional regulatory bodies** are responsible for declaring AZEs based on scientific studies and environmental assessments.
- **Site selection and baseline studies** are conducted to determine appropriate locations for AZEs within AZAs.
- **Aquaculture operators** must apply for site-specific AZEs and conduct EIA to evaluate potential impacts.
- **Size, species selection, total production levels, and management programs** within an AZE are determined using environmental modelling systems.
- **Monitoring programs** are established to evaluate the effects of aquaculture activities within the AZE and their broader impact on surrounding marine ecosystems.

7.2 Establishing Environmental Quality Standards (EQS) in AZEs

Environmental Quality Standards (EQS) define permissible concentration levels of substances such as nutrients, organic matter, and contaminants within the water column and seabed. The development of EQS within AZEs follows a structured and science-based approach.

- **Consultation with government authorities and scientific experts.** Regulatory agencies and marine scientists collaborate to establish EQS by.
    - Reviewing scientific literature on ecosystem health thresholds.
    - Conducting field and laboratory experiments to determine the tolerances of local marine species.
    - Utilising ecosystem models to predict the long-term effects of aquaculture discharges.
- **Setting Environmental Quality Objectives (EQOs).** Environmental Quality Objectives (EQOs) serve as benchmark goals for maintaining ecosystem sustainability. This involves.
    - Defining acceptable nutrient load limits that prevent eutrophication and algal blooms.
    - Establishing sedimentation thresholds to protect benthic habitats from organic enrichment.
    - Implementing carrying capacity assessments to balance aquaculture expansion with ecological resilience.
- **Independent environmental monitoring and mitigation.** To ensure compliance with EQS, independent environmental monitoring firms conduct regular assessments, which involve.
    - Routine water and sediment sampling to detect deviations from established EQS.
    - Use of remote sensing and real-time data logging for continuous environmental monitoring.
    - Recommending corrective measures such as improved farm management, buffer zones, and technology-based waste treatment solutions.
- **Monitoring and accountability in AZEs.** Ensuring compliance with AZE regulations requires an integrated monitoring approach.
    - Aquaculture operators are responsible for monitoring water quality, sediment conditions, and overall environmental health within and around their sites.
    - Cumulative impact assessments are conducted when multiple aquaculture units are located within the same AZA to measure their combined environmental effects.
    - Monitoring of external influences such as pollution from other industries, climate change impacts, and habitat degradation is also essential.

7.3 Global standards and case studies on AZEs

Different countries have established regulatory frameworks to manage AZEs effectively. For instance.

- **The Scottish Environmental Protection Agency (SEPA)** defines AZEs as areas where certain exceedances of EQS are permitted under strict regulations to control environmental impact. For example, in Scotland, mixing zones are used and we have used 100 m distant from the edge of the floating mooring as impact extending beyond this is generally not acceptable.
- **The Aquaculture Stewardship Council (ASC) Salmon Standard** requires water quality monitoring within and beyond AZEs to prevent negative effects on marine ecosystems.
- **The FAO and GFCM (General Fisheries Commission for the Mediterranean)** emphasize the use of AZEs to balance aquaculture growth with environmental sustainability.

8. Farm siting and licensing for aquaculture

Farm siting and licensing are critical components of aquaculture planning and management. The proper selection of aquaculture sites ensures environmental sustainability, economic viability, and social acceptability. Licensing frameworks regulate the establishment and operation of aquaculture farms, ensuring compliance with environmental standards, biosecurity measures, and industry best practices.

8.1 Farm siting

Proper site selection is essential for the success of aquaculture projects. The suitability of a site depends on various biophysical, socio-economic, and regulatory factors. The key elements in farm siting include.

1. Environmental factors

- **Water quality.** The availability of clean water with appropriate temperature, salinity, and oxygen levels is vital for aquaculture species.
- **Hydrodynamics.** Water currents and depth influence waste dispersion and farm stability.
- **Ecosystem sensitivity.** Avoiding ecologically sensitive areas, such as coral reefs, mangroves, and seagrass beds, to minimise environmental impact.
- **Carrying capacity.** Ensuring that the area can support aquaculture production without exceeding its ecological limits.

2. Socio-economic considerations

- **Community acceptance.** Engaging local communities to address potential conflicts and ensure social acceptance.
- **Infrastructure access.** Proximity to roads, ports, processing facilities, and markets for efficient logistics.

- **Employment opportunities.** The potential to create jobs and support local economies.
- **Coexistence with other activities.** Ensuring compatibility with tourism, fisheries, and marine conservation initiatives.

3. Biosecurity and disease prevention

- **Spacing between farms.** Adequate distance between aquaculture sites to prevent disease transmission.
- **Risk management.** Assessing potential threats such as harmful algal blooms, storms, and pollution sources.
- **Integrated health management.** Implementing biosecurity measures to minimise disease outbreaks.

8.2 Farm permitting, licenses, and registration

The aquaculture licensing system is a legally binding control procedure that allows the authorities to verify the viability of aquaculture at a proposed site and assess the potential environmental and social impacts of the operation. Licenses establish the physical dimensions of the site, acceptable operating conditions (especially production and pollution limits), and the period over which permission to operate is valid. In this way, the location, size, and the number of farms can be controlled to prevent cumulative environmental impact. All permitting and leasing systems should include consideration of distances among existing and planned aquaculture sites and between aquaculture and other potentially conflicting uses. In countries where aquaculture planning and management have been devolved to the local government level, there are problems with capacity and understanding of good and sustainable licensing procedures and problems when one waterbody is under the jurisdiction of more than one local government area.

Permitting. Permits or leases are important to establish the terms and conditions for offshore aquaculture operations, including authorising aquaculture activities and providing legal rights to occupy an area of the ocean. In addition, offshore investors need a legal right—through a permit or lease—to occupy a given area of the ocean. This legal right is important for financing offshore aquaculture operations because it would have market value and, therefore could be used as collateral on a loan to allow investors to secure funding for their projects.

The permits and leases should be valid for a set time frame and renewable if the operator can prove that they have complied with all the terms of the lease and have practised responsible aquaculture without unacceptable impact on the environment. Shorter time frames (say 10 or 20 years) have the advantage of ensuring compliance with regulations and best management practices while longer-term rights allow time for the operation to become profitable and give confidence to lending institutions.

The permit or lease should specify the maximum size of the operation measured biomass production per year based on the estimated carrying capacity of the zone and site.

In some countries, permits are tradable. The ability to trade licences encourages efficiency and consolidation. This is because as the more efficient farms acquire permits the less successful farmers sell their licences and find alternative occupations.

Leasing marine areas. The expansion of offshore aquaculture is dependent on the regulators who determine licence or lease applications. They will need to understand that high fixed and capital costs require that offshore farming is carried out on a large scale with the need for large areas leased for the cages and their moorings.

Good practices for licensing aquaculture farms include.

- To provide a permitting system that is flexible enough to include mitigation practices or new techniques for the management of environmental impacts. Offshore Aquaculture is a young and dynamic industry and technological developments occur relatively quickly.
- To include within any review of consents/licence applications an assessment of the use of mitigation tools or practices (e.g. for effluent water quality) and how these may improve environmental performance.
- National administrations or regulators develop specific good practice guidelines for managing the environmental impacts of offshore cage culture and this is developed in conjunction with the aquaculture industry to ensure that it is directly appropriate.

9. Environmental assessment of aquaculture projects

In the European Union, aquaculture projects are subject to various levels of Environmental Impact Assessment (EIA) depending on their scale, location, and potential environmental impact. The key types of environmental assessments include:

1. **Environmental Impact Assessment (EIA)** – A formal, mandatory assessment required for large-scale aquaculture projects under the **EIA Directive (2011/92/EU, amended by 2014/52/EU)**. It evaluates potential environmental effects before project approval, considering factors such as water quality, biodiversity, and socio-economic impacts. The process includes public consultation and results in an Environmental Statement.
2. **Environmental Statement** – A document produced as part of the EIA process, summarizing findings on environmental impacts, mitigation measures, and monitoring plans. It serves as the basis for regulatory decision-making.
3. **Strategic Environmental Assessment (SEA) –** Conducted at the policy and planning level under the **SEA Directive (2001/42/EC)**. It ensures that broader aquaculture development plans and zoning policies integrate environmental considerations before individual projects are approved.
4. **Appropriate Assessment (AA)** – Required under the **EU Habitats Directive (92/43/EEC)** if an aquaculture project is likely to affect a **Natura 2000 site** (protected habitats and species). It determines whether the project poses risks to conservation objectives and whether mitigation or alternative solutions are needed.

5. **Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD) Assessments –** These assessments ensure aquaculture projects comply with **Directive 2000/60/EC** (WFD) and **Directive 2008/56/EC** (MSFD), which focus on maintaining good ecological and environmental status of freshwater and marine ecosystems.

9.1 Environmental Impact Assessment

EIA is a fundamental tool in environmental policy, ensuring that potential environmental effects of projects are identified and assessed before decisions are made. The EIA process helps to integrate environmental considerations into planning and decision-making, promoting sustainable development. Within the EU, EIA is governed by Directive 2011/92/EU, as amended by Directive 2014/52/EU, which mandates assessments for projects that may have significant environmental effects.

The EIA Directive was first introduced in 1985 through Directive 85/337/EEC and has since evolved through amendments to strengthen its effectiveness. Key amendments include.

- **Directive 97/11/EC**, which expanded project categories requiring EIA.
- **Directive 2003/35/EC**, aligning EIA with public participation principles under the Aarhus Convention.
- **Directive 2009/31/EC**, incorporating carbon capture and storage projects.
- **Directive 2014/52/EU**, which introduced measures for improving the quality and scope of EIAs, reinforcing monitoring obligations, and streamlining procedures.

9.2 Key stages in the EIA process

The EIA process comprises several critical stages, each ensuring a comprehensive evaluation of environmental impacts.

1. Screening

Screening determines whether a project requires an EIA. Projects listed under **Annex I** of the EIA Directive automatically require assessment due to their significant environmental impact, such as nuclear power plants and large industrial developments. Projects under **Annex II** undergo a case-by-case examination or threshold-based assessment by competent authorities to decide if an EIA is necessary.

2. Scoping

Scoping identifies the key environmental aspects to be assessed and determines the necessary level of detail. Developers may seek a scoping opinion from the competent authority, outlining the required information for the EIA report. Although not mandatory in all cases, scoping ensures a focused assessment, preventing unnecessary data collection.

3. Preparation of the EIA report

The developer is responsible for preparing an EIA report that provides a detailed analysis of the project’s potential impacts. As per **Article 5** of the EIA Directive, the report must include.

- A project description, including location, design, and size.
- An assessment of significant environmental effects, including direct, indirect, cumulative, and transboundary impacts.
- An evaluation of reasonable alternatives.
- Proposed measures to prevent, reduce, or compensate for adverse impacts.
- A non-technical summary for public understanding.
- Consideration of monitoring requirements.

4. Public consultation and participation

Public participation is a core principle of the EIA process, ensuring transparency and accountability. The public and relevant authorities are provided access to the EIA report and given opportunities to submit comments. Under **Article 6**, Member States must ensure public involvement through.

- Electronic and public notices about the project and its EIA process.
- Minimum consultation periods (at least 30 days) for public comments.
- Consideration of public input in decision-making.

For projects with potential transboundary impacts, consultation with affected Member States under **Article 7** ensures that concerns from all stakeholders are considered.

5. Decision-making and development consent

Following consultations, the competent authority evaluates the EIA report and public feedback before issuing a **Reasoned Conclusion** on the project's environmental impact. Development consent is granted or refused based on whether the project meets environmental protection standards. The decision, along with justifications, must be made public.

6. Monitoring and compliance

Monitoring is essential to ensure that mitigation and compensation measures are effectively implemented. **Article 8a** mandates that monitoring requirements be included in the development consent conditions. This ensures compliance with predicted impacts and facilitates corrective actions if unforeseen environmental effects arise.

9.3 Environmental factors considered in EIA

The EIA Directive mandates the assessment of various environmental components.

- **Population and human health –** Assessing impacts on local communities and public health.
- **Biodiversity –** Evaluating effects on ecosystems, protected species, and habitats.
- **Land, soil, water, and air –** Understanding changes in land-use, pollution levels, and resource consumption.

- **Climate change –** Examining emissions and resilience to environmental changes.
- **Material assets and cultural heritage** – Identifying impacts on infrastructure and historical sites.

9.4 Mandatory assessment of alternatives

A fundamental requirement of the Environmental Impact Assessment (EIA) process is the systematic evaluation of alternative approaches to minimise environmental harm. This assessment ensures that decision-makers consider multiple options before approving a project, thereby identifying the most environmentally sustainable and least disruptive course of action.

The EIA report must **justify the selection of the proposed project** by comparing its environmental effects with those of reasonable alternatives. These alternatives typically include:

- **Alternative locations** – Evaluating different geographic sites to determine the least environmentally sensitive or most suitable location for the aquaculture project.
- **Alternative technologies –** Considering different aquaculture techniques, infrastructure designs, or operational methods that reduce environmental impact, such as recirculating aquaculture systems (RAS) instead of open-net pens.
- **Alternative project designs** – Modifying aspects such as stocking density, waste management systems, or feed strategies to improve sustainability.
- **Alternative operational scenarios –** Exploring adjustments in farming cycles, seasonal variations, or water management practices to minimise environmental disturbances.
- **The 'do-nothing' scenario** – Assessing the environmental, economic, and social consequences of not proceeding with the proposed project. This baseline scenario helps to establish whether the project delivers enough benefits to justify its impacts.

The assessment of alternatives must be supported by scientific evidence, environmental modelling, and stakeholder input to ensure that the selected option is the most balanced and responsible choice.

9.5 Mitigation and compensation measures

To address potential adverse environmental impacts, the EIA process requires a structured approach to impact mitigation, ensuring that environmental damage is minimised or offset through preventative and restorative measures.

Preventative measures. These strategies focus on avoiding environmental harm at the planning stage by making proactive decisions, including:

- **Site selection** – Choosing locations that minimise habitat disruption, avoid protected areas, and reduce conflicts with other marine users.
- **Best practice design** – Minimising coastal land development or water area usage, minimising use of natural resources and adopting low-impact farming techniques.

Impact minimisation techniques. When impacts cannot be fully avoided, techniques to reduce their severity are implemented:

- **Pollution control technologies** – Implementing water treatment systems, waste collection methods, and sustainable feed practices to reduce nutrient discharge.
- **Habitat protection** – Preventing habitat degradation through protective barriers, vegetation buffers, and responsible land-use practices.
- **Biodiversity safeguards** – Minimising interactions with wildlife and preventing disease transmission to wild populations.

Continuous monitoring and adaptive management. Post-development monitoring is essential to ensure compliance with environmental regulations and to detect unforeseen impacts. This involves:

- **Regular environmental monitoring** – Conducting water quality tests, biodiversity assessments, and ecosystem health evaluations.
- **Adaptive management approaches** – Adjusting operational practices based on monitoring data, new research findings, and stakeholder feedback.
- **Reporting and compliance audits** – Ensuring transparency through public reporting and independent environmental audits to track the project's long-term sustainability.

9.6 Environmental management plan (EMP)

An EMP is normally a requirement of the EIA. An EMP is a site- or project-specific plan developed to ensure that appropriate environmental management practices are followed during the construction and/ or operation of a project to minimise environmental impacts.

The content of an EMP should include the structure and responsibility of the implementation person or team with emergency contact details, the data collection and analysis and the reporting requirements for the activities. The EMP should also contain the environmental training plan and activities for the personnel and the complaints handling protocols for the community and other complaints.

The EMP report requirements can be found in Table 1.

Table 1 EMP report requirements.

1	**Structure and responsibility** of the implementation person or team by providing the organisational structure and specific environmental management responsibilities of the team members
2	**Data collection and analysis.**
3	**Reporting requirements** for the activities in terms of frequency and distribution of the results and reports

4	**Environmental training plan** and activities for the personnel detailing the appropriate training and the required skills and qualifications to fulfil their respective roles in a competent manner
5	**Emergency contacts and response plan** to enable it to promptly and effectively deal with emergencies. The emergency response plan will include qualified personnel, specific actions to be undertaken in response to different emergencies, the reporting requirements and regular training.
6	**Complaints handling protocols** for Community and other complaints about the operation of the farm including the recording of the complaints on a register and the method to determine the most appropriate action
7	**Environmental management sub-plans** to be developed to provide guidelines for the operation of the farm.
7a	**Waste Management Plan**. The Waste Management Plan will be developed to ensure responsible waste management and disposal including provisions for recycling materials and the disposal of wastes at approved disposal facilities. The plan will also include procedures on the handling and storage of wastes, including biological waste, and general waste, as well as the provision of appropriate containers for storage and disposal, net cleaning and biofouling management.
7b	**Work Health and Safety Management Plan**. The on-going success of the research trial relies on the competency and safety of farm personnel. Staff training should cover potential Work Health and Safety hazards including SCUBA diving, construction and deployment activities, service and maintenance activities, associated navigation issues, use and storage of chemicals, contamination of feed, stock and the environment, as well as waste disposal.
7c	**Traffic Management Plan**. The Traffic Management Plan will consider the movements of road vehicles and marine vessels. The plan will address potential impacts on marine fauna and other road and waterway users, particularly in relation to navigational safety, the maintenance of navigation buoys, minimising the risk of boat strikes to marine fauna, minimising acoustic pollution, the towing of sea cages and mitigating road congestion issues associated with the transport of products and movement of staff.
7d	**Marine Fauna Interaction Management Plan**. The Marine Fauna Interaction Management Plan will be developed to identify and mitigate potential impacts on marine fauna through direct and indirect interactions
7e	**Disease, Parasite and Pest Management Plan**. The cultured organisms may be exposed to a range of endemic diseases, parasites and pests. The Disease, Parasite and Pest Management Plan will outline preventative measures (e.g. how to minimise stress to stock associated with stocking density, water quality and predatory interactions), inspection schedules (surveillance program), identification

	procedures, contact details of appropriate personnel to assist with the management of pathogens and treatments for stock and infrastructure (e.g. veterinary specialists).

9.7 Farm carrying capacity estimation

Before a farm is established in a certain site, the carrying capacity should be estimated using appropriate models, together with representative observational data from the area and any water quality standards or criteria as well as any of the EQS in force. The carrying capacity for a site can be estimated using such models together with field data and the water quality and Environmental Quality Standards in force. The assessment of ecological carrying capacity uses the assimilative capacity approach which estimates the ability of the ecosystem to deal with inputs of waste wherever they arise to maintain a healthy environment.

Each ecosystem has a different capacity to absorb and assimilate excess loading of organic compounds and nutrients from a farm or to absorb social changes, habitat modifications, and so on, that come with the farm. Therefore, aquaculture production facilities should adjust their production to the carrying capacity of the relevant water body and socio-economic system. Carrying capacity estimation is undertaken as part of aquaculture zoning and or licensing of farms.

Carrying capacity is typically undertaken using depositional models (particle tracking) which predict the particulate outputs from fish cage aquaculture and can be used in local-scale assessment of the effects of fish cages on the organic footprint impact on the sediment and sensitive demersal flora and flora. Particulate tracking models use the output from spatially explicit hydrodynamic-dependent particle tracking models to predict (organic) flux from culture sites to the bottom. At the local scale, screening models may be used to look at aquaculture yields, local impacts of fish farming, and water quality. Government planning departments need to have the capacity to undertake carrying capacity estimations or have access to specialists who can make the calculations. In this way, informed decisions can be made of sustainable production in aquaculture areas.

Carrying capacity models are typically used to estimate maximum allowable production (and therefore nutrient inputs) to a specific site by industrial-intensive farms. Typically, they are undertaken using environmental models based on mathematical algorithms that enable predictions of environmental changes and their consequences. However, the larger the area, the more complex and more difficult becomes to make reliable estimations, therefore for large aquaculture zones/areas it may be necessary to use some indicators or proxies of carrying capacity to determine the maximum allowable production. Such estimation may need to be reassessed periodically through proper monitoring.

Examples of types of models that can be used include.

Farm level Carrying Capacity models. Assess the maximum sustainable aquaculture production a system can support without exceeding environmental thresholds. Often integrate hydrodynamics, biogeochemistry, and farm production models.

- Example. Farm Aquaculture Resource Management (FARM) model, used for site selection and sustainability assessment.

Depositional models. Simulate interactions between organic particles coming from the farm impacting benthic organisms. Useful for predicting biological responses to environmental changes and farming practices.

- Examples. DEPOMOD, MERAMOD, TROPOMOD which model the fate of fish farm waste on the seabed.

9.8 Social responsibility

Fish farms have a responsibility to ensure that their operations contribute positively to the well-being of their employees, the local community, and the broader society. Social responsibility initiatives help create a sustainable and ethical working environment while fostering good relations with stakeholders. These initiatives should include the following key elements.

Staff training scheme. A well-trained workforce is essential for the efficient and responsible operation of a fish farm. Regular training programs should be conducted to enhance technical skills, improve safety awareness, and ensure compliance with biosecurity and environmental standards. Key aspects of staff training should include.

- **Technical training**. Covering fish health management, water quality monitoring, feeding strategies, and harvesting techniques.
- **Safety at sea**. Essential for farms operating in marine environments, ensuring workers are trained in emergency procedures, use of safety equipment, and navigation awareness.
- **First aid**. Staff should be trained in basic and advanced first aid to respond to workplace injuries and health emergencies effectively.
- **Hygiene and food safety**. Ensuring that all employees understand and follow strict hygiene protocols to maintain product safety and prevent contamination.
- **Biosecurity measures**. Training on disease prevention, early detection, and response strategies to protect fish stock and the surrounding environment.

Incentive scheme for workers. Providing fair compensation and incentives is crucial for employee motivation, job satisfaction, and retention. An incentive scheme should be designed to reward staff based on key performance indicators such as.

- **Fish survival rates**. Encouraging best practices in fish handling and disease prevention.
- **Feed conversion ratio (FCR)**. Promoting efficient feeding practices to reduce waste and improve cost-effectiveness.
- **Harvest quality and productivity**. Recognizing contributions to high-quality production and sustainable farming practices.

Other incentives, such as performance bonuses, employee recognition programs, and career progression opportunities, can further motivate staff and improve overall farm efficiency.

Close cooperation with the local community. Maintaining strong relationships with the local community is vital for the long-term sustainability of the fish farm. Proactive engagement helps address community concerns, prevents conflicts, and ensures that the farm's activities contribute positively to the local economy and environment. Key initiatives should include.

- **Employment opportunities**. Prioritising the hiring of local workers and providing skills training to enhance employability.
- **Community development programs**. Supporting local education, infrastructure improvements, or environmental conservation projects.
- **Engagement with stakeholders**. Regularly communicating with local authorities, community leaders, and non-governmental organisations (NGOs) to ensure transparency and address any concerns related to the farm's operations.
- **Responsible resource use**. Implementing sustainable practices to minimise environmental impact and ensure that local water and land resources are not degraded.

Additional social responsibility considerations. Beyond these core initiatives, fish farms can enhance their social responsibility by;

- **Ensuring fair wages and ethical labour practices** in accordance with national and international labour standards.
- **Providing a safe and inclusive workplace** that respects gender equality and prevents discrimination.
- **Supporting education and research** by collaborating with academic institutions, fisheries training centers, and research organisations.
- **Engaging in corporate philanthropy** by donating resources or expertise to local causes related to marine conservation, disaster relief, or food security.

10. Area management in Aquaculture (AMA)

AMAs play an important role in implementing the ecosystem approach to aquaculture. By designating specific management areas, aquaculture operators and regulatory bodies can collaboratively ensure sustainable farm operations while minimising environmental impacts and conflicts with other resource users. Effective area management enhances biosecurity, improves production efficiency, and promotes the long-term viability of aquaculture. This essay explores the principles, benefits, and key components of AMAs, including boundary delineation, governance, environmental monitoring, disease control, and best management practices.

The establishment of AMAs is essential for ensuring sustainable aquaculture development. Managing aquaculture at the area level rather than focusing solely on individual farms allows for coordinated decision-making, better resource management, and enhanced environmental protection. Some key benefits of AMAs include.

- **Enhanced environmental monitoring.** Coordinated oversight of multiple farms within a defined area helps prevent cumulative environmental degradation.
- **Improved disease management.** Synchronisation of treatments and health management practices reduces the spread of diseases among farms.
- **Efficient use of resources.** Collective negotiation for input supplies, waste management, and infrastructure development enhances cost-effectiveness.
- **Stronger stakeholder collaboration.** Engaging local communities, regulators, and industry stakeholders fosters transparency and shared responsibility.
- **Market advantages.** Group certification and branding can improve market access and consumer trust.

10.1 Key components of effective area management

The boundaries of AMAs should be carefully defined based on biophysical, socio-economic, and governance criteria. Effective delineation considers.

- **Hydrodynamic conditions.** Water flow patterns determine disease transfer and waste dispersal, influencing the designation of AMAs.
- **Ecological considerations.** AMAs should exclude sensitive habitats, such as coral reefs and mangroves, to minimise environmental impact.
- **Administrative governance.** Aligning AMAs with existing jurisdictional boundaries (municipal, state, or national) facilitates regulation and oversight.
- **Stakeholder consultation.** Engaging farmers, regulators, and community representatives ensures that boundaries reflect both environmental and economic realities.

10.2 Establishing a management entity

A structured management entity should oversee AMA operations, ensuring compliance with best practices and regulatory frameworks. This entity should.

- Include representation from aquaculture producers, government agencies, and local communities.
- Develop codes of conduct and enforce environmental and operational guidelines.
- Facilitate access to technical and financial support for farmers within the AMA.
- Serve as a liaison between industry stakeholders and regulatory authorities.

Area management agreements include measures to address the common issues and risks to fish farming (including fish health) while improving the profitability of the farmers, minimising impacts on the environment, and ensuring the integration with and acceptance by local communities and other users of the water resource. AMAs can be aquaculture parks, aquaculture neighbourhoods, clusters or any aquaculture area where farms are sharing a common relevant waterbody or source, and that may benefit from a common management system. A large aquaculture zone can also be an AMA, and in many instances, this is the case, but more often smaller units within the aquaculture zone can develop and implement an operative an AMA Management Plan.

Depending on the issues the organisation in AMAs can be on different levels (Figure 1).

- between the aquaculture sites of the AMA
- between all the user's and stakeholders of the area.

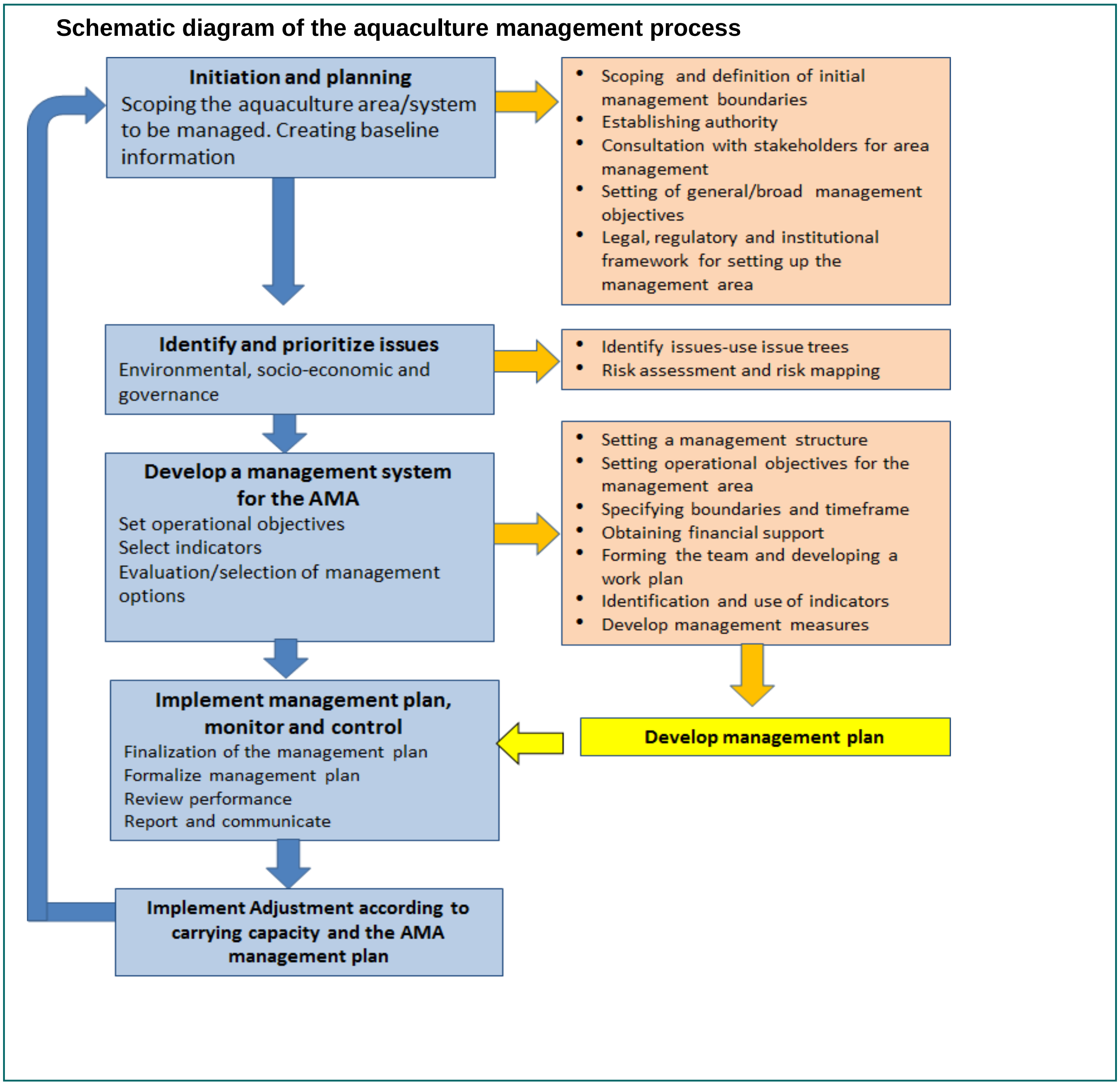

Figure 1 Aquaculture Management Process.

The group of farmers should identify the key management measures to include in the area management plans. The measures should be the most cost-effective set of management arrangements designed to generate acceptable performance in pursuit of the objectives.

The measures can include the area management for each zone should include Good Aquaculture practice that is undertaken by ALL farmers within the zone and health management and biosecurity measures (disease and parasite control).

- **Develop a common aquatic animal health and biosecurity plan for the area**. Defines the approach taken to mitigate all disease risks for the area. Measures to be taken against non-conforming or non-complying farmers.
- **Health status of newly stocked juvenile fish**. There should be agreement on the quality of the juveniles to be stocked into a Management Area which may include. the physiological status of juveniles; use of vaccines; sourcing juveniles from specific pathogen-free (SPF) sources; and tests for specific pathogens
- **Vaccination.** Vaccination of all juveniles prior to stocking.
- **Disease treatments.** Regular disease surveillance and synchronised disease and parasite treatments. Treatment with the same medication. Use of authorised medication only.
- **Regular monitoring and reporting of aquatic animal health status**, regular monitoring of disease within the Management Area.
- **Movements**. Control of movement of gametes/eggs/stock between the farms in the zone and from external sources
- **Disinfection**. Disinfection of equipment, well boats, etc. between different farms and defining the expected disinfection protocols.
- **Fallowing of aquaculture areas**. Synchronised fallowing of aquaculture areas which leaves the whole area empty of cultured fish for a specified time. This is a biosecurity as well as an environmental management measure. It helps to break the disease and parasite cycle and allows the sediments and water quality to recover partially.

10.3 Environmental monitoring and carrying capacity assessment

Regular environmental monitoring is essential for sustainable AMA management. Monitoring programs should.

- Assess water quality, sediment conditions, and biodiversity to detect early signs of environmental stress.
- Establish carrying capacity limits to prevent overstocking and ecological degradation.
- Use GIS and remote sensing technologies for real-time monitoring.
- Ensure transparency by making monitoring data accessible to stakeholders.

10.4 Disease control and biosecurity measures

Disease outbreaks can significantly impact aquaculture production, making disease management a priority within AMAs. Effective measures include.

- **Coordinated health management.** Farms within the same AMA should synchronise disease prevention and treatment efforts.
- **Surveillance and early warning systems.** Routine health checks and diagnostic testing help detect diseases before they spread.
- **Quarantine protocols.** Strict regulations for the introduction of new stock prevent the transmission of pathogens.
- **Fallowing strategies.** Periodic rest periods for production areas help break disease cycles and restore environmental balance.

10.5 Best management practices (BMPs) for sustainable aquaculture

BMPs help ensure responsible farming practices within AMAs. Key BMPs include.

- **Optimized stocking densities.** Avoiding overcrowding reduces disease risks and environmental stress.
- **Efficient feed management.** Using high-quality, eco-friendly feeds minimises nutrient pollution and improves feed conversion ratios.
- **Waste treatment and recycling.** Implementing waste management systems, such as IMTA, enhances sustainability.
- **Responsible chemical use.** Reducing reliance on antibiotics and implementing natural disease control methods supports ecosystem health.

11. Environmental and social impact monitoring

Environmental impact monitoring is a fundamental component of sustainable aquaculture management. Effective monitoring helps in assessing the ecological footprint of aquaculture activities and ensures compliance with environmental regulations. By systematically tracking key indicators, aquaculture managers and policymakers can mitigate risks, optimize resource use, and safeguard aquatic ecosystems.

11.1 Regular environmental monitoring surveys

Monitoring is often designed at the end of the Environmental Impact Assessment (EIA) and is part of the EIA statement. The monitoring protocol proposes what type of indicators should be used to monitor the impact of the farm at various points in time. It usually focuses on environmental parameters.

Environmental monitoring results support decision makers as well as the producer himself with an estimation of the size of the impacts (extent and severity) and ways to improve management and regulate the activity. The input of phosphate and nitrate to the environment and the environmental impact of a farm will depend on three factors, namely.

- The frequency, direction and strength of water currents in the area, indicating the rate at which the water mass is renewed around the installation. A 1000-tonne fish farm can have less impact than a 100-tonne fish farm if placed in a position where currents and depth provide better dispersion in the environment.
- The phase of the production cycle. In summer, Mediterranean species develop their greatest need for feed during the year; hence the spillage at this time will be greater than in January.
- The management practices. Good feeding and disease prophylaxis procedures have low impacts on the environment.

In monitoring the environmental effects of aquaculture, as in all studies on environmental change, data are collected at various points in time and are compared with original, pre-development data as well as with contemporary reference data. This will show changes over time due to the impacts, and natural environmental change will also be taken into consideration. Survey techniques vary but generally require the following (adapted from Telfer and Beveridge, 2001).

- **A baseline definition**. based on data collected before development. Baseline monitoring refers to the measurement of environmental parameters during a pre-project period for the purpose of determining the nature and ranges of natural variation and establish, where appropriate, the nature of change. This provides essential background ecosystem data for subsequent comparison. The survey may be both spatial and temporal, providing pre-development data on the natural environment and its changes throughout the proposed development area. Such data can aid in the design of an appropriate monitoring study, focusing, for example, on the areas which are most relevant for investigating change in a particular environment. The survey will also answer important management questions for the developer. in this case, will the site support aquaculture?
- **A monitoring survey**. The collection of post-development data provides information on the actual impacts, in relation to the contemporary reference and baseline data. Once interpreted, the results may be used directly for management decisions by both fish farmers and environmental regulators by ensuring adherence to Environmental Quality Standards (EQSs) and acceptable zones of effect. Care should be taken in designing the monitoring study so that data is generated to answer the questions posed by all users of the data.
- **Compliance monitoring** takes the form of periodic sampling and/or continuous measurement of environmental parameters, levels of waste discharge or process emissions to ensure that specific regulatory requirements are observed and standards met.

In general, the protocol for monitoring is based on previous knowledge of the existing zone and will be taken into consideration.

- Frequency of sampling,
- Position of sampling stations,
- Method of sampling water or sediments,
- Method of analysis of the samples taken to measure the determinants.

Sampling strategies usually attempt to maximize data collection per expended effort, which normally entails the use of transects aligned with the direction of principal current flow rather than a less efficient but more statistically rigorous random sample or grid approach.

Transects and specific station protocols are particularly good at allowing the detailed investigation of gradients from a discharge point, as illustrated in Figure 2.

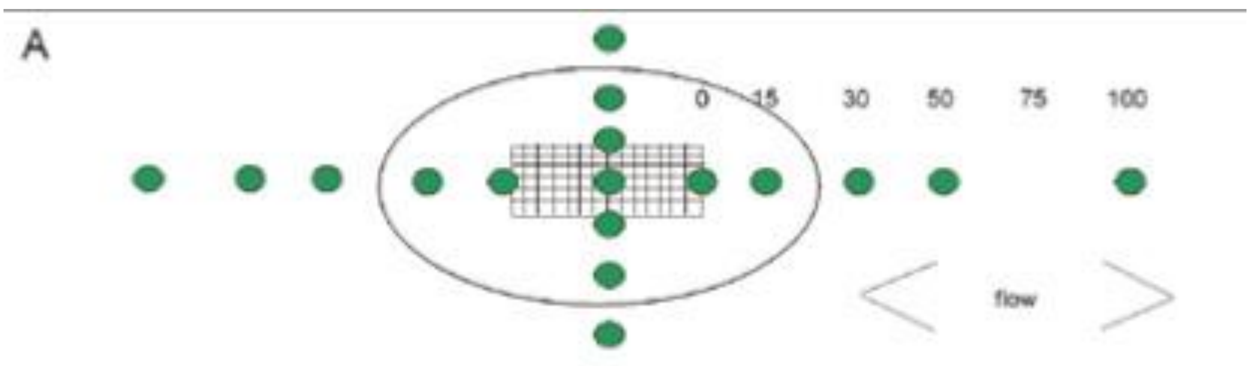

Figure 2. ***Potential locations for sampling station to detect gradients from a marine fish cage. (from Telfer and Beveridge, 2001)***

The various parameters monitored are similar to those measured during the EIA. They usually consist of the following.

11.2 Implementation of monitoring programs

To be effective, environmental monitoring programs must be systematic, transparent, and based on scientific methodologies. Key steps in the implementation process include:

- **Establishing baseline data.** Baseline environmental assessments are conducted before the establishment of aquaculture operations to determine natural conditions and identify potential risks. This data provides a reference point for future comparisons.
- **Continuous data collection and analysis.** Monitoring programs require regular data collection on selected indicators. Advanced technologies such as GIS, remote sensing, and automated water quality sensors can enhance real-time data accuracy.

- **Regulatory compliance and benchmarking.** Monitoring indicators should align with environmental policies and industry benchmarks to ensure regulatory compliance. International standards such as those developed by the FAO and the Global Aquaculture Alliance (GAA) provide frameworks for sustainable aquaculture monitoring.
- **Adaptive management and reporting.** Findings from environmental monitoring programs should be used to refine aquaculture management practices. Regular reporting and stakeholder engagement ensure transparency and accountability in decision-making.

The monitoring survey comprises of the following parameters

- **Visual observations.** Based on special in situ transect sections and/or video transect analysis, these observations describe the following.
  - Real distance of sedimentation impacts (from faeces, remnants of feed pellets or trash fish)
  - Superficial state of the sediment due to organic concentration below or around the cages
  - Signs of ecosystem changes below or around the farm due to the presence or absence of Beggiatoa bacteria on anoxic sediments, the number and type of wild species below and around the cages (e.g. fishes, octopus, pelagic/benthic fishes and detrital invertebrates), or a reduction of macroscopic life
  - Status of corals and seagrass beds (in terms of quality and extent).
  - **Water column measurements.** Maintenance of water quality is critical to the health of the cultured stock so important culture parameters such as water temperature, salinity, pH and dissolved oxygen, levels inside sea cages will be monitored regularly, usually daily. Parameters such as total dissolved solids and concentrations of nitrogen and phosphorus will be monitored as required by the monitoring program.

Measurements are taken of temperature, salinity, dissolved oxygen, optical properties (turbidity, suspended solids, Secchi disk transparency), nutrients (phosphorus, ammonium and nitrogen) and chlorophyll-a. Various studies show that the follow-up of dissolved oxygen and other elements in the water is not very useful since no measurable change is identifiable beyond 50m from the cage and the high dispersion capacity of the water does not reflect the impact of the farm on the Mediterranean.

  - **Sediment and bottom community measurements.** Particulate wastes tend to settle to the sediments creating a ‘footprint’ effect usually distributed in the direction of the main current flow (Beveridge, 1996). The benthic environment beneath and surrounding the sea cages or close to the effluent outflow point should be monitored biologically (e.g. macrofauna abundance and species diversity), chemically (i.e. the composition of elements in sediment) and physically (e.g. the particle size of sediment and video footage/photo comparisons).

Distribution of the soft substrate in the area should be measured, with data on granulometry, redox potential, organic and mineral content, free sulphides and Beggiatoa percentage, and the presence or absence of pellets and food. Where appropriate, pollutants may be studied, based on the EIA results. In addition, seagrass quality and density should be described, based on specific transect protocols.

Benthic communities are usually described using bioindicators as key elements in the analysis of the bottom reactivity of the farm since they are the species or groups of species that provide evidence for a specific environmental factor. Besides identification, data on species richness, abundance, biomass and diversity (using the Shannon index) should also be produced.

Measurements of sediment and bottom community species are highly relevant since they incorporate all the elements from the production farm, such as impact on photosynthesis, transformation in the sediment or trends towards anoxia. Because of this, it is also the topic that has been most studied up to now (FAO/GFCM, 2004).

- **Control sites.** The water quality and benthic quality at the farm should be compared to unimpacted sites (control sites). The control sites will be located approximately 500 metres from the farm boundary.
- **Interference with other users.** A small section concerns monitoring of conflicts and relations with other users. In general, this section is not very complete or well researched by the monitoring consultancy or researchers.

11.3 Categories of environmental monitoring indicators

Environmental monitoring indicators in aquaculture can be broadly categorized into economic, environmental, and social indicators. Each category serves a specific function in assessing the sustainability of aquaculture practices.

1. Environmental indicators

Environmental indicators assess the impact of aquaculture activities on ecosystems and natural resources. Important environmental indicators include.

- **Feed Conversion Ratio (FCR).** Measures the efficiency of feed use in producing fish biomass.
- **Water quality parameters.** Tracks changes in dissolved oxygen, nitrogen, phosphorus, and other critical water quality components.
- **Sediment quality parameters.** The quality of the sediment in terms of organic matter, REDOX, benthic diversity, etc.
- **Waste and nutrient discharge levels.** Evaluates the amount of organic waste released into surrounding water bodies.
- **Biodiversity and habitat conservation.** Monitors the effects of aquaculture on native species and ecosystems.

2. Social indicators

Social indicators evaluate the interaction between aquaculture activities and local communities. These indicators include.

- **Employment opportunities in aquaculture.** Measures job creation and the livelihoods supported by the industry.
- **Community engagement and acceptance.** Assesses local perceptions and involvement in aquaculture operations.
- **Certifications and regulatory compliance.** Examines adherence to sustainable production standards and national regulations.

12. Product certification

The growth in product certification (sustainability standards or eco-labelling) is increasing, led by sustainability requirements by mainly Western retailers. Today, virtually all retailers in developed nations have some form of 'sustainable procurement policy' which covers the purchasing of aquaculture products globally. The need for this sustainable procurement has been strongly promoted by the very active environmental NGOs in the Western world (the WWF, PEW Charitable Trusts and Greenpeace to name a few) and at first, retailers were responding to criticism from this sector. In the past five years, this has changed somewhat with retailers now actively promoting their sustainability credentials to customers with the hope of increasing sales. In summary, sustainability is now a key part of most Western retailers' buying and marketing approaches for aquaculture products.

Proving that the aquaculture supply chains are sustainable has mainly been done through third-party certification schemes. These are programs which use an independent auditor to verify the sustainability of your product against a set of pre-defined rules. Several different schemes exist in the aquaculture sector with the main ones being as follows;

- **Aquaculture Stewardship Council (ASC).** The ASC was first founded in 2004 through a series of aquaculture dialogues (multi-stakeholder roundtables for best production practices in aquaculture species). It was founded directly on the back of the successful wild fisheries eco-label, the Marine Stewardship Council (MSC). Due to its importance as a sector, salmon was one of the first species to be targeted and a standard was developed and became live in June 2012.
- **Global G.A.P aquaculture.** Global G.A.P. was set up by European retailers in 1997 to develop independent certification systems for Good Agricultural Practice (G.A.P.). It has now developed into the world's leading farm assurance program with certificates in over 135 countries. It expanded into aquaculture in 2004 and now runs a third-party certification program like the ASC but with one difference being it has a single standard which covers all finfish species (salmon included).

- **Global Aquaculture Alliance (GAA) Best Aquaculture Practices (BAP).** The GAA was founded in 1997 in the United States and was dedicated to the advocacy, education, and leadership of responsible aquaculture. As part of this process, they developed the BAP standards which include a Salmon Farm standard, and which has proven especially popular in North America.
- **Friend of the Sea (FoS).** FoS was founded in the 1990s commencing with the creation of standards for wild capture fisheries. In 2013, they released a marine aquaculture standard which has limited uptake in the salmon industry (proving more popular for the bass and bream, industry).

13. Challenges in responsible planning and sustainable management of aquaculture

Conflicts with other marine users.

- **Challenge.** Competition for marine space with industries such as fisheries, tourism, and conservation efforts often lead to conflicts. These disputes can delay aquaculture projects, limit expansion opportunities, and create tensions between stakeholders. The lack of a coordinated approach may result in inefficient resource use and environmental degradation.
- **Potential solution.** Multi-stakeholder engagement, integrated MSP, and participatory decision-making can help balance competing interests and foster collaboration. Establishing marine protected areas and clear zoning regulations can also facilitate coexistence by designating specific zones for aquaculture activities while safeguarding critical marine ecosystems.

Environmental and regulatory challenges.

- **Challenge.** Aquaculture activities must operate within strict environmental regulations to prevent pollution, habitat degradation, and loss of biodiversity. However, fragmented policies, overlapping jurisdictions, and inconsistent enforcement of environmental laws can hinder effective governance. Additionally, cumbersome licensing procedures may discourage investment and slow down sectoral development.
- **Potential solution.** Strengthening regulatory frameworks, streamlining permitting procedures, and enhancing inter-agency coordination can improve compliance and efficiency. Implementing standardized EIAs and fostering cross-sectoral collaboration among regulatory bodies can ensure a more coherent approach to aquaculture governance.

Data gaps and monitoring limitations.

- **Challenge.** Inconsistent data collection and limited monitoring capacity pose challenges to assessing environmental impacts and ensuring sustainability. Without reliable data, it becomes difficult to make informed decisions regarding site selection, resource allocation, and environmental mitigation measures.

- **Potential solution**. Investing in real-time data collection technologies, standardizing monitoring protocols, and integrating GIS for site assessments can enhance data-driven decision-making. Encouraging public-private partnerships to support research and data-sharing initiatives will further improve aquaculture monitoring systems.

Socio-economic challenges.

- **Challenge.** Aquaculture can create employment and economic growth but also faces market competition, uneven resource distribution, and resistance from coastal communities. In some cases, large-scale aquaculture projects can lead to the displacement of traditional fishing communities and exacerbate social inequalities.
- **Potential solution.** Strengthening market access, supporting small-scale fishers, and implementing community-driven aquaculture initiatives can ensure equitable benefits. Providing financial support and technical training to marginalized groups can promote inclusive economic development while minimising socio-economic disparities.

Public awareness and stakeholder engagement.

- **Challenge.** Lack of public understanding about aquaculture's benefits and misconceptions about its environmental impact can create resistance. Misinformation about aquaculture's sustainability, food safety, and ecological footprint may lead to public opposition and regulatory delays.
- **Potential solution.** Enhancing transparency, promoting awareness campaigns, and engaging stakeholders in aquaculture decision-making can improve public acceptance and policy support. Developing educational programs and fostering community engagement can help build trust and dispel myths surrounding aquaculture practices.

Overcoming these challenges requires a comprehensive approach that integrates strategic governance, technological advancements, and inclusive stakeholder participation. Strengthening regulatory coordination, enhancing data collection, and adopting adaptive management practices will be key to ensuring aquaculture remains a sustainable and responsible industry. By fostering resilience, supporting local communities, and leveraging innovative solutions, the aquaculture sector can address emerging challenges while promoting long-term sustainability.

Appendices

Appendix 1: Regulatory case study - Scotland

Table of Abbreviations

ECE	Equilibrium Concentration Enhancement
EIA	Environmental Impact Assessment
GIS	Geographic Information Systems
MPA	Marine Protected Areas
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency

1. Introduction

Scotland is one of the leading regions for aquaculture in Europe, primarily in the farming of Atlantic salmon. The industry plays a significant role in Scotland's economy, generating substantial export revenues and supporting thousands of jobs in coastal communities.

The industry is a major contributor to Scotland's economy, with significant export revenues. Farms are based in the West and Northwest coasts due to Scottish Planning Policy restrictions[1]. Scotland has faced challenges related to environmental sustainability, particularly concerning the impact of salmon lice on wild fish populations.

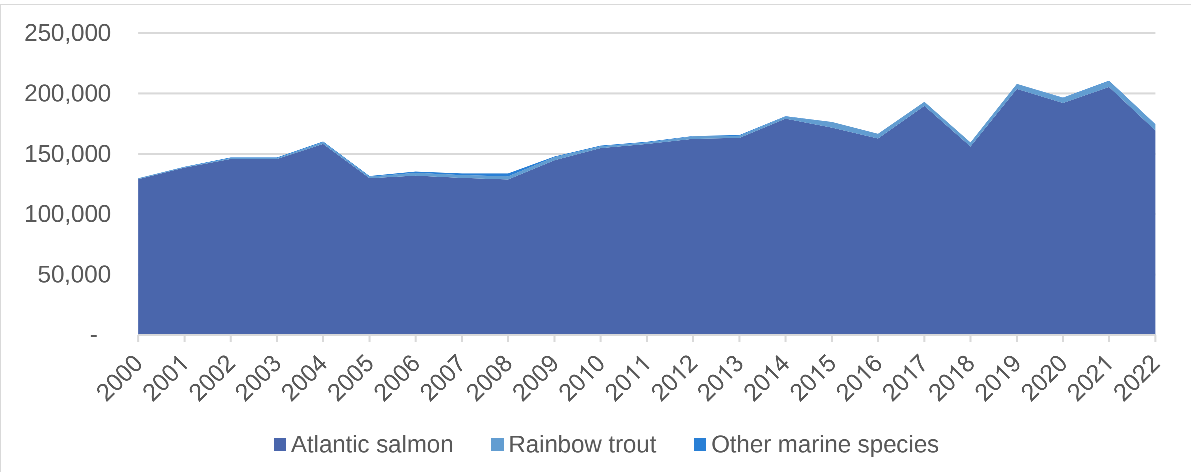

Figure 1. Marine fish culture in the United Kingdom (t)

Scotland's salmon farming industry has undergone significant regulatory and environmental scrutiny in recent years. Following two major parliamentary inquiries in 2018[2,3] the Scottish Government initiated a comprehensive review of its aquaculture regulatory processes[4]. This led to the formation of the Scottish Aquaculture Committee and the subsequent publication of the "Vision for Sustainable Aquaculture" in July 2023, which outlines a framework to guide the industry until 2045[5]. This vision emphasises sustainable growth, environmental stewardship, and the balancing of industry interests with those of local communities and environmental groups.

The majority of aquaculture activities are concentrated along the West and Northwest coasts due to Scottish Planning Policy restrictions, which ensure that fish farms are located in areas with suitable environmental conditions. However, the industry faces significant challenges related to

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[1] Scottish Government (2020) Scotland's Marine Assessment 2020. Aquaculture. Available at https://marine.gov.scot/sma/assessment/aquaculture

[2] The Scottish Parliament (2018a) Environment, Climate Change and Land Reform (ECCLR) Committee report on the environmental impacts of salmon farming. Available at: https://archive2021.parliament.scot/S5_Environment/Inquiries/20180305_GD_to_Rec_salmon_farming.pdf

[3] The Scottish Government (2018b) Rural Economy and Connectivity Committee - Salmon farming in Scotland. Available at: https://bprcdn.parliament.scot/published/REC/2018/11/27/Salmon-farming-inScotland/REC-S5-18-09.pdf

[4] Griggs, R. (2022) A Review of the Aquaculture Regulatory Process of Scotland. Scottish Government. ISBN: 978-1-80435-022-5 (web only). Available at https://www.gov.scot/publications/review-aquacultureregulatory-process-scotland/

[5] Scottish Government (2023) Vision for Sustainable Aquaculture. ISBN: 978-1-83521-148-9 (web only). Available at https://www.gov.scot/publications/vision-sustainable-aquaculture/

environmental sustainability, particularly concerning the impact of salmon lice on wild fish populations, waste management, and habitat conservation.

1. Regulatory framework

Scotland's salmon farming industry operates under a complex regulatory system that requires multiple approvals from various authorities. The regulation framework ensures compliance with environmental protection standards, sustainable growth, and biosecurity measures.

1.1 Regulatory bodies

- **Scottish Environment Protection Agency (SEPA) –** Regulates environmental impacts, including waste emissions, chemical use, and water quality.
- **Marine Directorate Fish Health Inspectorate –** Oversees disease control, biosecurity measures, and health monitoring of farmed fish.
- **Scottish Natural Heritage (SNH) –** Ensures aquaculture activities align with environmental conservation policies.
- **Local Authorities –** Provide planning guidance, assess development proposals, and oversee regulatory compliance.
- **The Crown Estate –** Issues seabed leases for fish farming operations and ensures compliance with leasing conditions.

1.2 Key Legislative Acts

- **Aquaculture and Fisheries Act (2007) –** Governs the management of fish farms and disease control.
- **Aquatic Animal Health Regulations (2009) –** Establishes health monitoring and biosecurity measures.
- **Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations (1999) –** Requires environmental assessments for new or modified aquaculture projects.
- **Water Environment (Controlled Activities) (Scotland) Regulations (2005) –** Sets out requirements for controlling pollution and ensuring water quality.
- **Marine Scotland Act (2010) –** Governs marine planning and licensing processes.

2. Identification of Marine Scotland aquaculture Management Areas

Marine Scotland plays a major role in the identification and allocation of distinct Management Areas. These areas serve multiple purposes, including conservation, fisheries regulation, renewable energy development, and marine spatial planning. The process of designating these Management Areas involves scientific assessments, regulatory frameworks, stakeholder consultations, and continuous monitoring to ensure sustainable use of marine resources while balancing economic and environmental priorities.

Data collection and environmental assessment. Marine Scotland employs a range of scientific and socio-economic research methods to assess the condition and use of marine environments. Environmental surveys are conducted to gather information on seabed habitats, water quality, marine biodiversity, and ecological interactions. These surveys often involve advanced technologies such as remote sensing, underwater mapping, and species monitoring programs. Socio-economic data on fishing communities, aquaculture activities, shipping routes, and tourism is considered to balance economic needs with conservation goals. Stakeholder input is actively sought from industry representatives, coastal communities, environmental organisations, and scientists to incorporate a broad range of perspectives in decision-making.

Defining management objectives. Once data has been collected and analysed, Marine Scotland defines the objectives of each management area. These objectives vary depending on ecological, economic, and social priorities. Common objectives include.

- **Marine conservation.** Some areas are designated to protect critical habitats and species, such as coral reefs, seagrass beds, or marine mammals.
- **Sustainable fisheries management.** Certain zones are allocated for regulated fishing activities to prevent overexploitation of fish stocks and maintain a balanced marine ecosystem.
- **Renewable energy development.** With the growing importance of sustainable energy, specific marine areas are allocated for offshore wind farms, tidal energy projects, and wave energy installations.
- **Coastal and Marine Spatial Planning.** Management areas are also identified for activities such as maritime transport, aquaculture, and tourism to ensure compatibility with environmental protection policies.

Zoning and designation of Management Areas. Once objectives have been set, the next step is to establish the geographic boundaries of the Management Areas. Marine Scotland utilizes Geographic Information Systems (GIS), satellite imagery, and modelling tools to map and zone the marine environment. These tools help in determining the most suitable locations for conservation efforts, fisheries regulation, renewable energy projects, and other activities. Management areas are categorized into various zones, including.

- **Marine Protected Areas (MPAs).** Designed to safeguard ecologically significant habitats and species by restricting certain activities such as trawling and industrial development.
- **Fisheries management zones.** These areas implement specific rules for fishing activities, such as seasonal closures, catch limits, and restrictions on fishing gear.
- **Renewable energy zones.** Allocated for offshore wind, wave, and tidal energy projects, ensuring that they do not interfere with marine ecosystems or other maritime activities.
- **Aquaculture zones.** Designated for fish farming and shellfish cultivation, ensuring that these activities are carried out in a manner that minimizes environmental impact.
- **Shipping and harbour zones.** Areas assigned for maritime transportation, navigation, and port infrastructure development.

Regulatory framework and compliance measures. Following the designation of Management Areas, Marine Scotland enforces a regulatory framework to govern activities within these zones. Various legal instruments and policies are implemented to ensure compliance with marine conservation and resource management objectives. Licensing requirements are established for activities such as commercial fishing, aquaculture, renewable energy projects, and maritime operations. These licenses stipulate conditions related to environmental impact assessments, sustainability criteria, and operational guidelines. Additionally, conservation measures such as seasonal fishing bans, gear restrictions, and marine habitat restoration projects are enforced to protect biodiversity. To ensure compliance, Marine Scotland employs monitoring and enforcement mechanisms, including vessel tracking systems, satellite surveillance, and on-site inspections. Violations of regulations, such as illegal fishing or unauthorized industrial activities, can result in penalties, fines, or restrictions on operations. This regulatory framework plays a vital role in maintaining the long-term health and productivity of Scotland's marine resources.

Stakeholder consultation and governance. The effective management of marine areas requires the involvement of multiple stakeholders, including government agencies, local communities, industry representatives, and environmental groups. Marine Scotland facilitates public consultations and collaborative decision-making processes to ensure that all perspectives are considered.

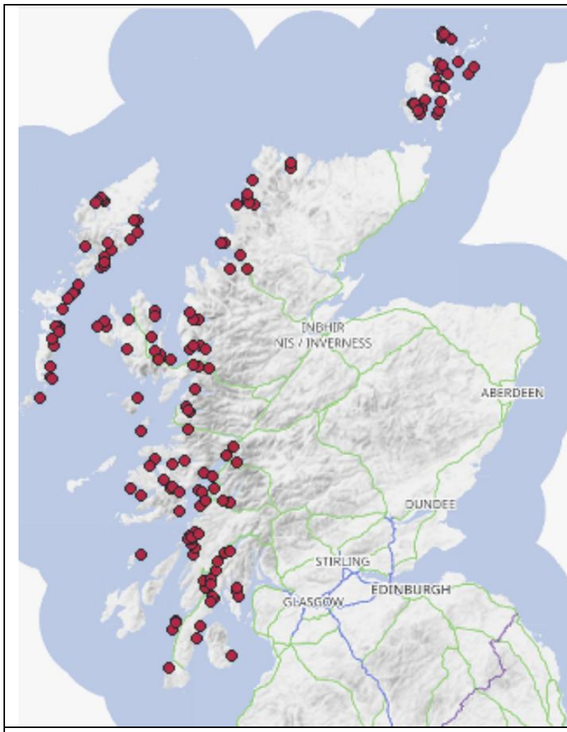


Figure 1. Active seawater finfish sites

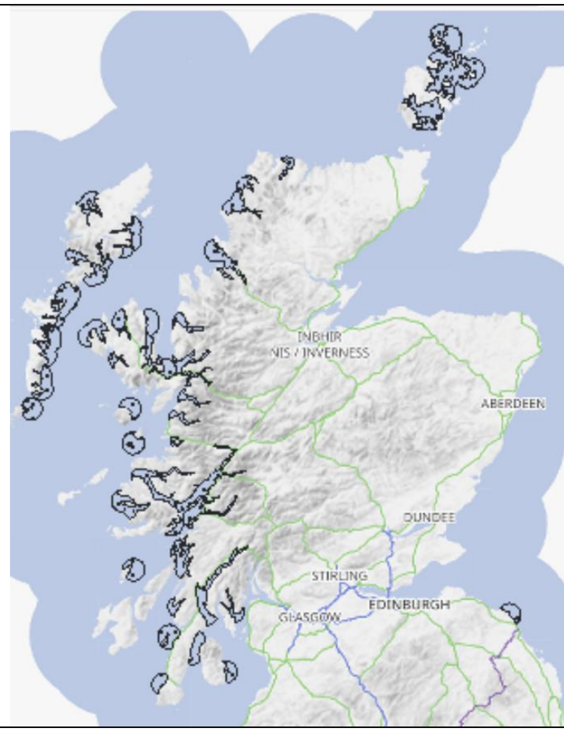


Figure 2. Marine Scotland Management Areas.

3. Aquaculture licensing and compliance process

Scotland's aquaculture licensing system involves multiple regulatory approvals to ensure environmental and economic sustainability.

3.1 Licensing requirements

- **Planning permission (Local Authority).** Approval is required for new aquaculture developments.
- **Marine licenses (Marine Scotland).** Ensures compliance with marine conservation laws.
- **Seabed lease (Crown Estate).** Grants access to marine areas for aquaculture.
- **Consent to discharge (SEPA).** Regulates emissions and waste management.

3.2 Environmental Impact Assessment (EIA) Criteria

- All proposals in **sensitive environmental areas** must undergo an EIA.
- Projects exceeding **100 tonnes of biomass** or **1,000m² cage area** require an EIA.
- Local Authorities, SEPA, and Marine Scotland assess EIAs before granting approvals.

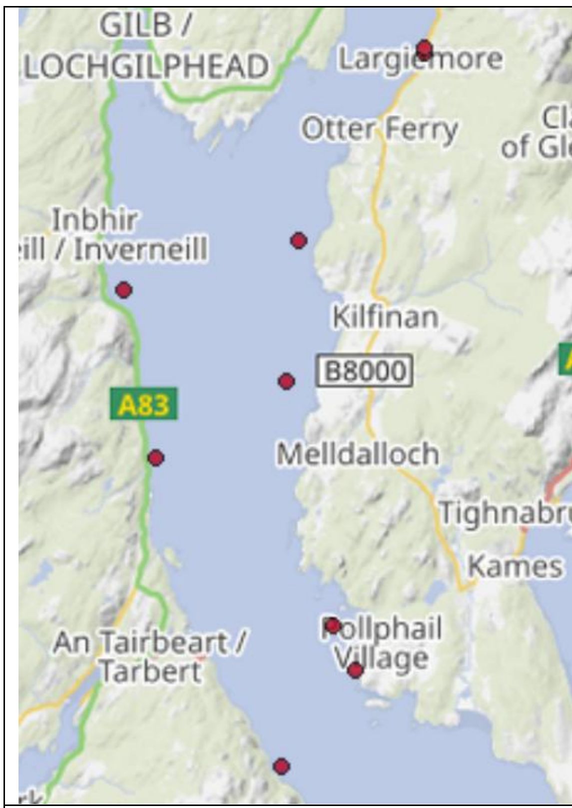


Figure 3. Active seawater finfish sites in Lochgilphead	Figure 4. actual location of seawater finfish sites in Lochgilphead

3.3 Process of EIA for site licensing.

- **Screening.** Determines whether an EIA is required for the proposed project.
- **Scoping.** Identifies key environmental concerns that need to be addressed.
- **Impact assessment.** Evaluates potential impacts on water quality, biodiversity, and socio-economic factors.
- **Mitigation measures.** Proposes actions to minimize negative environmental effects.
- **Public consultation.** Engages stakeholders, including local communities and conservation groups.
- **Approval or rejection.** Regulatory authorities review the EIA report and decide whether to grant or deny the license.

4. Environmental monitoring and management

Environmental monitoring ensures compliance with regulatory standards. Various agencies conduct regular assessments to track water quality, seabed conditions, and fish health.

- **SEPA monitors** waste emissions, nutrient levels, and benthic (seabed) health to assess the impact of fish farming.
- **The Marine Directorate Fish Health Inspectorate** carries out routine fish health inspections and ensures biosecurity compliance.
- **Scottish Natural Heritage (SNH)** evaluates aquaculture developments in protected areas to prevent habitat degradation.
- **Local authorities** oversee planning applications and enforce conditions related to farm locations and operations.

4.1 Key environmental concerns

- **Waste management.** Fish farming generates organic waste, including uneaten feed and fish excreta, which can impact water quality and seabed health. SEPA enforces waste management guidelines, requiring farms to adhere to site-specific **Depomod** modelling predictions for waste dispersion. Recent regulations restrict the use of **Acoustic Deterrent Devices (ADDs)** to prevent harm to marine mammals.
- **Water quality & habitat protection.** Fish farms discharge excess nutrients (e.g., nitrogen and phosphorus) into the marine environment, which can lead to algal blooms and oxygen depletion. SEPA conducts water sampling to assess compliance with the **Water Environment and Water Services Act (2003)**. EIAs evaluate potential risks before the approval of new sites.
- **Impact on local communities.** Aquaculture supports economic development in rural coastal areas by creating jobs and business opportunities. Local authorities require developers to engage with communities to address concerns related to visual impact,

noise pollution, and environmental sustainability. Community benefit programs aim to ensure that local residents share in the economic gains from fish farming operations.

One of the primary issues is the conflict between profitability and sustainability. Salmon farming is a high-revenue industry, with much of Scotland's production catering to international markets. As a result, companies prioritise high production levels to meet demand, making it difficult to implement measures that may reduce environmental impact. For example, lowering stocking densities—one of the most effective ways to reduce sea lice outbreaks—is often seen as financially unfeasible unless strong incentives or penalties are in place. Similarly, investing in advanced treatment technologies, such as semi-closed containment systems or offshore farms, requires substantial capital that smaller operators may struggle to afford.

The industry also faces significant international market pressures. Any regulatory action that significantly raises production costs could reduce Scotland's competitiveness in the global seafood market, leading to reluctance from both companies and policymakers to introduce stricter environmental measures.

Another major challenge is the increasing resistance of sea lice to chemical treatments. Overuse of chemical treatments such as emamectin benzoate, hydrogen peroxide, and azamethiphos has led to resistant lice populations, reducing the effectiveness of these methods. This issue is compounded by environmental concerns, as excessive chemical use can harm other marine life. Alternative, non-chemical methods, such as cleaner fish (e.g., lumpfish and wrasse) and mechanical treatments (e.g., thermolicers, freshwater baths), have shown promise but come with their own limitations. High mortality rates of cleaner fish and the logistical difficulties in sourcing and breeding them at scale limit their widespread adoption. Meanwhile, mechanical treatments can cause stress, injuries, and mortality among farmed salmon, making their use a less-than-ideal solution.

Beyond the direct impacts of sea lice, salmon escapes pose another serious ecological concern. Escaped farmed salmon can interbreed with wild populations, reducing genetic diversity and overall survival rates. Despite this risk, Scotland lacks legally binding escape prevention standards, with industry-led voluntary measures often proving insufficient.

Regulatory approvals for farm sites typically focus on the carrying capacity of individual operations New Depomod). A very simple formula is used to calculate the carrying capacity of water bodies based on water quality (ECE formula), but this formula is over simplified, and this can lead to high organic waste loads.

Although regulations exist to manage sea lice at the farm level, they do not fully account for cumulative environmental impacts. Farms are often approved without considering the broader effects of multiple operations in the same region. Additionally, collaboration between salmon farming companies and wild fish conservation groups remains limited. Some proposed solutions, such as relocating farms away from wild salmon migration routes, face resistance due to logistical and economic constraints.

Weaknesses in the quality of environmental monitoring and result data transparency hinder effective management of salmon farming's environmental impact. Unlike Norway, Scotland does not require real-time public reporting of sea lice levels, farm escapes, environmental quality or chemical use. Limited access to environmental data makes it difficult to assess the true extent of the problem and hold companies accountable. Furthermore, environmental impact assessments (EIAs) are often conducted by industry-funded consultants, raising concerns about bias and reducing the credibility of the assessments. Without independent oversight and transparent data reporting, environmental non-compliance can go undetected, allowing problems to persist.

5. Decision-Support Tools for planning

A range of analytical and modelling tools are used to support impact prediction, environmental monitoring, and regulatory compliance. These modelling tools enable decision-makers to evaluate proposed aquaculture sites before granting operational permits and ensure that farms comply with environmental regulations by simulating different scenarios and management strategies. This allows adjustments in farm layout, stocking densities, and feeding practices to minimize environmental harm and supports adaptive management by predicting long-term seabed recovery periods after farm operations cease.

Depositional Modelling

Depomod provides regulators, scientists, and aquaculture operators with a scientifically validated tool for sustainable site selection and management, minimizing negative impacts on Scotland's marine environment.

- **Predicting organic waste deposition.** Models the distribution and accumulation of organic waste from fish farms on the seabed. Assists in determining the dispersal patterns of waste based on water currents, depth, and farm configuration.
- **Assessing benthic (seabed) Impact.** Estimates the level of oxygen depletion and changes in seabed chemistry due to organic deposition. Helps regulators set limits on the biomass that can be farmed without harming the local ecosystem.

The Depomod model has developed and become more sophisticated as Scottish aquaculture has developed.

- **Depomod (Early 2000s).** Developed as the first depositional model used to predict waste deposition from fish farms onto the seabed. Simulated the dispersal and accumulation of uneaten feed and fish faeces, helping regulators assess the benthic (seabed) impact of aquaculture activities. Provided a basic tool for assessing whether proposed sites were suitable for fish farming based on their depositional footprint.
- **AutoDEPOMOD (Mid-2000s - 2015).** An enhanced version of Depomod with automated calibration and validation features. Allowed for site-specific impact modelling, improving accuracy by incorporating hydrodynamic data (e.g., currents, depth, and flushing rates). Became the standard tool used by SEPA to regulate fish farm licenses and ensure compliance with environmental standards.
- **New Depomod (2015 - Present).** A fully updated and refined version, integrating improved hydrodynamic modelling and real-world validation to enhance predictions. Includes dynamic modelling capabilities, allowing it to assess the long-term impact of fish farms under different operational scenarios. Offers greater regulatory confidence, helping

authorities set biomass limits, enforce compliance, and monitor cumulative impacts in sensitive marine environments.

Box Modelling

The Equilibrium Concentration Enhancement (ECE) model offers a powerful tool for understanding and managing the potential impact of nutrient discharges from salmon cage production. The ECE model was developed to quantify the concentration of nutrients added to a body of water as a result of fish farming activities. It is particularly effective in environments where aquaculture contributes to nutrient loading, such as nitrogenous compounds from fish excretion and feed waste. The model works by balancing nutrient inputs against natural dispersion and losses, such as denitrification. It calculates the steady-state enhancement of nutrient levels within a marine system. The ECE model provides a practical, scientifically grounded approach to managing nutrient inputs from aquaculture. Its simplicity and reliance on measurable parameters make it accessible for regulatory and operational use. However, the model has limitations. It assumes that tidal flushing is the primary mechanism for water exchange, potentially underestimating the influence of wind and river inputs.

6. Challenges in the current regulatory framework

- **Fragmented regulatory process.** Multiple agencies regulate different aspects of aquaculture without a unified approval system.
- **Prolonged licensing procedures.** Sequential approval requirements lead to delays in project development.
- **Limited enforcement capacity.** Regulatory bodies often lack the necessary resources for frequent inspections.
- **Inconsistent decision-making.** Interpretation of regulations varies among local authorities, creating uncertainty for businesses.

Strengthening environmental governance and operational strategies

While existing regulations provide a foundation for sustainable aquaculture, their enforcement and scope require significant improvements. A key step toward better management is the introduction of mandatory real-time public reporting of sea lice levels, farm escapes, and chemical use. By requiring farms to publish real-time environmental data, policymakers, researchers, and the public would have access to timely information, allowing for more immediate interventions when lice outbreaks occur. This transparency would also help hold companies accountable and foster greater public trust in the industry.

1. Strengthening enforcement and compliance

Farms exceeding pollution or lice thresholds should face immediate and meaningful penalties, such as mandatory reductions in production or temporary closures. Repeat offenders should risk losing their licenses. Additionally, third-party, independent environmental monitoring should be introduced to ensure compliance with regulations.

- Mandatory real-time public reporting of sea lice levels, escapes, and chemical use.

- Require farms to publish real-time environmental data.
- This would improve transparency and allow for more immediate intervention when lice outbreaks occur.

- Harsher penalties for non-compliance.
  - Farms exceeding pollution limits should face mandatory reductions in production or temporary closures.
  - Repeat offenders should risk losing their licenses.
- Independent third-party environmental monitoring.
  - Require independent audits of sea lice levels, farm escapes, and chemical use.

2. Improving environmental planning and management

Improving environmental planning and management practices should be improved. Instead of assessing farm sites individually, a more sophisticated regional carrying capacity approach should be adopted. This would involve setting environmental thresholds at the regional level, considering stocking densities, waste emissions, and sea lice loads across entire farming zones. Implementing better site selection and zoning policies would also help mitigate environmental risks. Farms should be strategically located away from wild salmon migration routes where possible, and the density of farms in sensitive ecological areas should be limited to prevent cumulative impacts.

- Strengthening regional carrying capacity assessments.
  - Shift from individual farm approvals to region-wide ecosystem-based management.
  - Establish regional environmental thresholds for stocking densities, waste emissions, and sea lice loads.
- Better site selection and zoning.
  - Move farms away from wild salmon migration routes where possible.
  - Limit the density of farms in sensitive areas to prevent cumulative lice outbreaks.

3. Promoting and adoption of sustainable operational practices

Fish farmers in Scotland should invest in sustainable farming methods, such as semi-closed or offshore systems. Semi-closed containment systems filter water before it reaches the surrounding environment, significantly reducing lice transmission and pollution. Offshore farms, located in deeper waters, expose salmon to stronger currents, reducing lice infestations compared to inshore farms. To encourage the adoption of these technologies, the government should offer financial incentives, such as tax breaks or subsidies, for farms that transition to more sustainable practices.

- Investing in semi-closed or offshore farming.

- Semi-closed systems (where water is filtered before reaching the surrounding environment) significantly reduce lice transmission.
- Offshore farms in deeper waters reduce lice exposure compared to inshore sites.

- Financial incentives for sustainable practices.
  - Provide subsidies or tax incentives for farms that adopt sustainable methods (e.g., lower stocking densities, better waste management).

4. Addressing major environmental concerns.

Implementation of coordinated lice treatment strategies across farming regions. Currently, farms operate on independent treatment schedules, allowing resistant lice strains to develop. A mandatory, synchronised lice treatment program should be introduced, requiring all farms within a region to treat infestations simultaneously. Additionally, farms should be required to use a combination of lice control methods to prevent the overreliance on any single treatment and reduce the risk of resistance.

- Mandating coordinated lice treatment strategies.
  - Enforce synchronised lice treatments across entire farming zones to prevent reinfestation.
  - Require companies to use a mix of treatment methods to reduce resistance build-up.

5. Enhancing community and stakeholder engagement

Greater community engagement and collaboration between stakeholders are needed to improve salmon farming's sustainability and social acceptability. Increasing public participation in aquaculture planning and decision-making would foster greater trust and accountability. Establishing industry-government-science partnerships could also drive innovation in sustainable practices, helping to bridge the gap between industry needs and environmental conservation efforts.

- Transparent decision-making and public consultations.
  - Increase public participation in aquaculture planning.
  - Provide clear reporting on environmental performance and regulatory enforcement actions.
- Industry-government-science partnerships.
  - Foster joint research programs between universities, government agencies, and industry to develop sustainable solutions.

Conclusion

Scotland’s aquaculture industry is a vital economic sector with significant global exports. However, ensuring long-term sustainability requires effective regulation, improved environmental monitoring, and community engagement. By streamlining regulatory processes, enhancing enforcement capacity, and fostering innovation in environmental management, Scotland can maintain its position as a leader in sustainable aquaculture.

SEPA conditions for farm operation

SEPA have developed a draft permit template which provides standard conditions of use which are often included for the farm's operation (although others may also be added if required). These standard conditions are set out in the table below with a description of the justification behind each.

Fish species: Only one species may be farmed at the site at one time (with exceptions for cleaner fish) *Justification: Although not common to mix species on site it is commonly a requirement that this is not allowed. The only exception to this is in the use of cleaner fish.*
***Maximum weight of fish*: A maximum weight of fish to be held at the site at one time will be set.** *Justification: This is a standard licence requirement for any fish farm pretty much anywhere. A maximum biomass is agreed for the farm based on the outcome of all the other investigative work and as determined as suitable by SEPA. This biomass is the amount that cannot be exceeded on the farm (i.e., a maximum biomass not an average one).*
Fallow period: A minimum period of 42 consecutive days fallow period must be used between every production cycle during which no fish shall be kept on the site. SEPA must be notified within 14 days of a site being stocked and fallowed. *Justification: The use of a fallow period has become a more and more common regulatory requirement in salmon farming. The aim of it is to break the life cycle of the sea lice and help in reducing infection rates. The 42-day period is considered a minimum time to allow this to happen and is used as a standard fallow period. However, SEPA can increase or decrease this as they see fit.*
Pen configuration: An agreed configuration of pens is agreed in the licence and specific locational points are stated (National Grid References). A maximum distance is specific from which the pens can deviate from these NGRs (taking account of tide, currents etc…). *Justification: This condition is added to ensure the farmer cannot add or move the cages from the agreed locations. With the NGRs set in the licence it is easy for a SEPA official to check the location using a handheld GPS unit.*
Medicine minimisation: All reasonable steps must be taken to minimise the discharge of medicine residues *Justification*: This condition helps to ensure the protection of the water environment through sustainable water use.

<u>Medicines & chemical use:</u> **Only medicines and chemicals specifically authorised in this permit may be discharged into the water environment.** *<u>Justification</u>*: This condition ensures that only permitted and authorised chemicals are allowed to be discharged by the farm (and specifically lists what these are as part of the permit).
<u>PSL and PSWP</u>: All medicines named in the Permitted Substance List (PSL) or Permitted Substance Working Plan (PSWP) must be used in accordance with the limits specified. *<u>Justification:</u> Ensures that farms only administer approves substances at approved levels and using approved techniques.*
<u>Notification of medicines use</u>: Requires SEPA to be informed at least two (2) working days prior to a treatment being carried out (for bath medicines) or five (5) working days for in-feed medicines. *<u>Justification:</u> Required to ensure strict environmental levels are not likely to be exceed by the farms use.*
<u>Biological seabed standards</u>: Requires the seabed at any point immediately under the outer edge of any pen to contain a minimum of two (2) species of re-worker polychaete worms with a combined abundance of more than 1,000 individuals per square metre. *<u>Justification:</u> Required to ensure strict environmental levels are not likely to be exceed by the farms use.*
<u>Chemical seabed standards</u>: Requires Emamectin benzoate concentrations to not exceed 12 ng/kg (dry weight) in the seabed at the boundary of the mixing zone *<u>Justification:</u> Chemical used in in-feed treatments and aims to ensure that excreted quantities do not build up to toxic levels in the seabed around the farm.*
<u>Seabed and water monitoring plan</u>: Monitoring to be carried out against the approved SWMP (submitted at the CAR application stage). Monitoring activities should be notified to SEPA fourteen (14) days in advance *<u>Justification:</u> Ensures that the farm is meeting its SWMP requirements properly.*
<u>Notification of environmental event</u>: SEPA to be informed of any event which could cause an adverse impact to the water environment or human health or is a breach of the CAR permit within 24 hours of identification. *<u>Justification:</u> Pretty clear justification.*
<u>Management of environmental event</u>: All reasonably practicable measures should be taken to stop an event and to minimise and/or mitigate its effects. *<u>Justification:</u> Clearly important that the farm attempts to deal with an event to the best degree possible.*

<u>Reporting of environmental event</u>: Within fourteen (14) days of any event a report must be submitted to SEPA setting out the reasons for the event, actions taken to minimise its impacts and actions taken to prevent it recurring. *<u>Justification:</u> Important to learn lessons from incidents as and when they occur.*
<u>Data recording & reporting:</u> All key records must be maintained for six (6) years and key information (as specified by SEPA) should be submitted every quarter. *<u>Justification:</u> Record keeping is a vital part of monitoring, so it is important that the farm maintains the records and submits important data regularly to the authorities.*

Appendix 2: Regulatory case study – Turkey

Table of Abbreviations

AZA	Allocated Zone for Aquaculture
EIA	Environmental Impact Assessment
GFCM	General Fisheries Commission for the Mediterranean
GIS	Geographic Information Systems
SEA	Strategic Environmental Assessment
TRIX	Trophic Index

1. Introduction

Turkey has experienced rapid growth in marine aquaculture over the past few decades, becoming one of Europe's leading producers of farmed fish. The industry began in the 1980s with small-scale mussel farming, later expanding to species such as sea bream and sea bass. Driven by increasing global seafood demand and concerns over wild fish stock depletion, the industry has faced environmental and regulatory challenges over time.

Turkey's aquaculture industry primarily focuses on.

- **European seabass** *(Dicentrarchus labrax)* and **Gilthead seabream** *(Sparus aurata),* valued in international markets.
- **Meagre and rainbow trout**, though the latter is predominantly farmed in freshwater.
- **Tuna farming**, governed by specific regulatory articles.

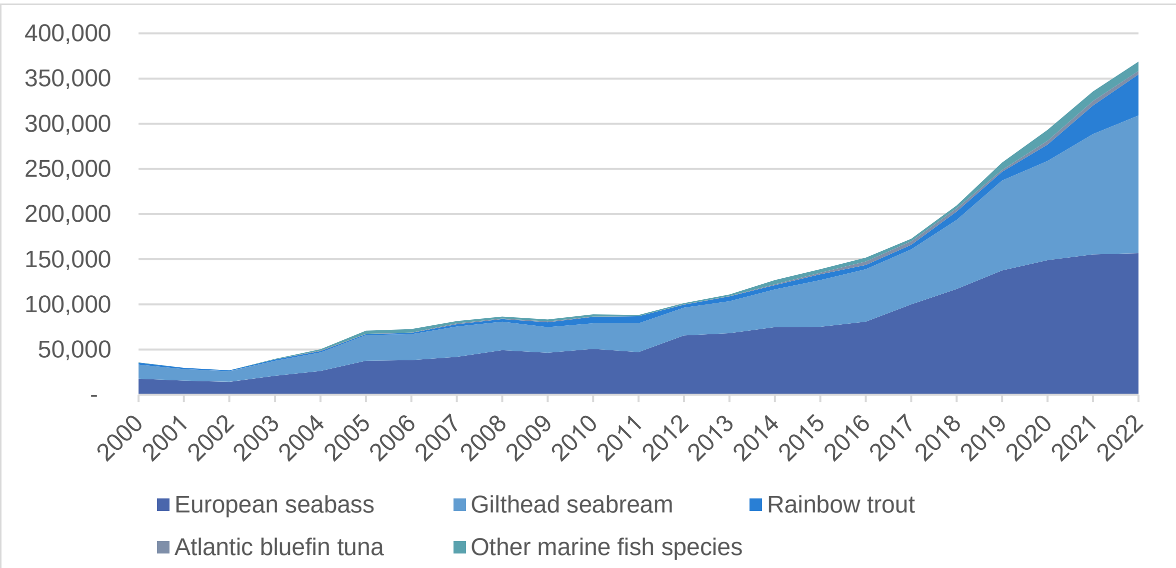


Figure 1. Marine fish culture in Turkey (t)

As the sector expanded, concerns over the environmental impact, including pollution, habitat degradation, and the effect on coastal tourism, grew as the industry expanded.

In response, the Turkish government introduced regulations in the early 2000s, mandating that all fish farms be moved further offshore to mitigate environmental damage. This initiative aimed to reduce nutrient pollution and its impact on local ecosystems. The move was controversial at the time, particularly among smaller farms, which faced increased operational costs and logistical challenges. Many resisted the change, fearing that relocation would threaten their businesses.

Despite the opposition, the government stood firm, enforcing the relocation as part of a broader strategy to promote more sustainable aquaculture practices. Over time, this policy strengthened the sector, allowing for more environmentally responsible growth. Today, Turkey's aquaculture industry has expanded significantly, becoming one of the leading producers of farmed fish in

Europe, particularly for species like sea bass and sea bream. The move offshore ultimately improved environmental management and enhanced the industry's long-term sustainability.

Turkey's marine aquaculture industry is largely dominated by the production of European seabass and gilthead seabream, both of which are highly valued in international markets, particularly in Europe.

Advancements in hatchery technologies and feed production have supported industry growth, allowing Turkey to become a top exporter to the European Union and beyond.

2. Regulatory framework

The Turkish aquaculture sector is governed by the Ministry of Agriculture and Forestry, specifically the Directorate General of Fisheries and Aquaculture. Other relevant authorities include.

- **Ministry of Environment and Urbanization** – Oversees environmental protection policies and enforcement.
- **Ministry of Health** – Ensures food safety and public health related to aquaculture products.
- **Ministry of Culture and Tourism** – Regulates aquaculture's impact on coastal tourism.

2.1 Key laws and regulations.

Law/regulation	Key provisions
Fishery Law No. 1380 (1971, amended 1986, 2003)	Governs fisheries and aquaculture activities.
Environmental Law No. 2872 (1983, amended 2006)	Mandates EIAs and relocation of marine aquaculture offshore.
Aquaculture Regulation No. 25507 (2004, amended 2005, 2006)	Defines licensing, site selection, and monitoring requirements.
Water Pollution Control Regulations (2004, amended 2008)	Sets marine environmental quality criteria.
Monitoring Regulations for Fish Farms (2009, revised 2010)	Establishes sediment and water sampling techniques.

Key regulations include.

- **Environmental Impact Assessments (EIA).** Mandatory for all new aquaculture projects to evaluate potential marine ecosystem impacts.
- **Aquaculture production areas.** Strategically designated zones with strict density and environmental guidelines to prevent overcrowding and disease outbreaks.
- **Sustainability measures.** Adoption of environmentally friendly feeds and waste management policies.

3. Environmental monitoring and management

Environmental oversight involves.

- **Water quality monitoring.** Conducted by the Ministry of Agriculture and the Ministry of Environment and Forestry.
- **Waste management.** Strict controls on effluent discharge to prevent eutrophication.
- **Periodic assessments.** Annual monitoring programs with data submission to authorities.
- **Marine Protected Areas compliance.** Adherence to international environmental conventions such as the Ramsar and Barcelona Conventions.

4. Aquaculture and coastal planning

4.1 Allocated Zones for Aquaculture (AZAs)

To minimize conflicts with tourism, fisheries, and maritime activities, the **General Fisheries Commission for the Mediterranean (GFCM)** recommends the establishment of **AZAs**. These designated areas prioritize aquaculture development while reducing environmental and spatial conflicts.

The process of identifying and allocating aquaculture zones in Turkey is a structured and multi-phase procedure designed to balance economic growth with environmental sustainability. This process integrates scientific assessments, regulatory requirements, and stakeholder engagement to ensure that aquaculture activities are placed in locations that minimize conflicts and environmental degradation.

Figure 2. Identified aquaculture marine aquaculture zones in Turkey

Identification of suitable areas

The first step in establishing aquaculture zones involves **Strategic Environmental Assessment (SEA)**, which is used to identify potential sites based on large-scale environmental and socio-economic factors. This phase includes.

- **Geospatial Analysis.** Use of Geographic Information Systems (GIS) and Remote Sensing to map coastal areas, assess water quality, depth, and hydrodynamic characteristics.
- **Environmental Constraints Analysis.** Evaluating biodiversity, water currents, pollution levels, and sensitive marine habitats.
- **Conflict Assessment.** Identifying potential conflicts with tourism, fisheries, shipping routes, and protected marine areas.

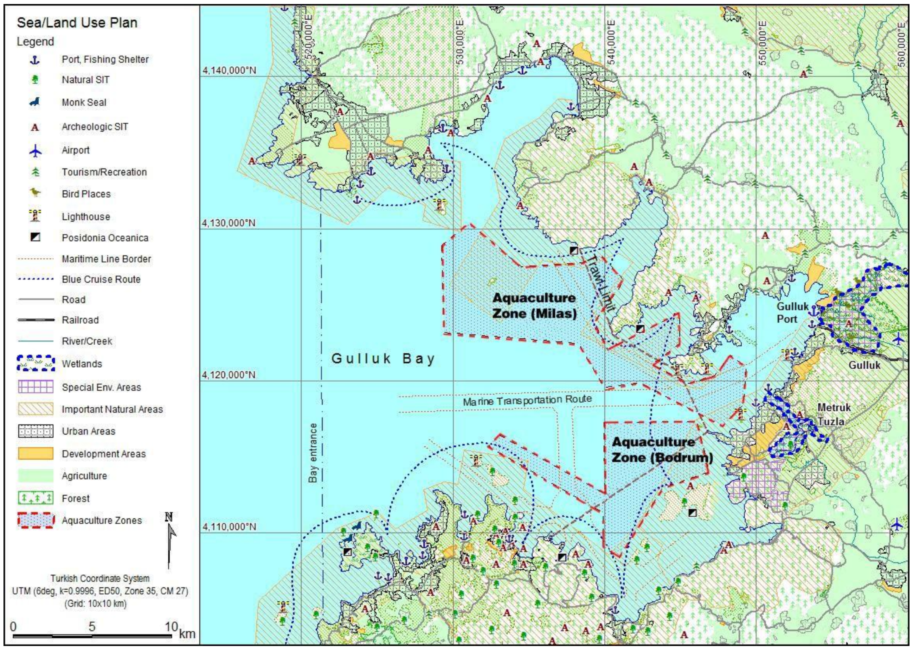


Figure 3. Identified aquaculture zones in Gulluk Bay

Establishment of Allocated Aquaculture Zones (AZAs)

Once suitable locations are identified, the government designates **Allocated Aquaculture Zones (AZAs)** where aquaculture is prioritized. This process involves.

- **Hydrodynamic modelling.** Simulating nutrient dispersion and water flow to assess the carrying capacity of the area.
- **Application of the TRIX Index.** The **Trophic Index (TRIX)** is used to evaluate water quality by assessing the level of eutrophication in marine environments. It measures parameters such as dissolved oxygen, total nitrogen, total phosphorus, and chlorophyll-a concentration. A lower TRIX value indicates better water quality, while higher values signal increased nutrient loads and potential environmental stress. This tool plays a critical role in monitoring aquaculture impacts and guiding regulatory decisions.
- **Regulatory screening.** Ensuring compliance with national and international marine conservation regulations.

Stakeholder engagement and zoning approval

Before finalising the allocation of aquaculture zones, a **stakeholder consultation process** is conducted to gather input from;

- **Government Agencies.** Ministries of Agriculture, Environment, Tourism, and Transport.
- **Local communities & fishery cooperatives.** Ensuring aquaculture does not adversely impact traditional fisheries.

- **Environmental organizations.** Addressing ecological concerns and conservation measures.

The zoning plan is then subject to governmental approval and integrated into national Coastal Zone Management Plans.

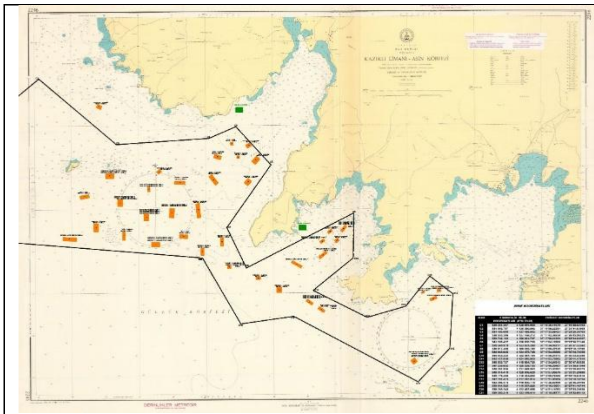
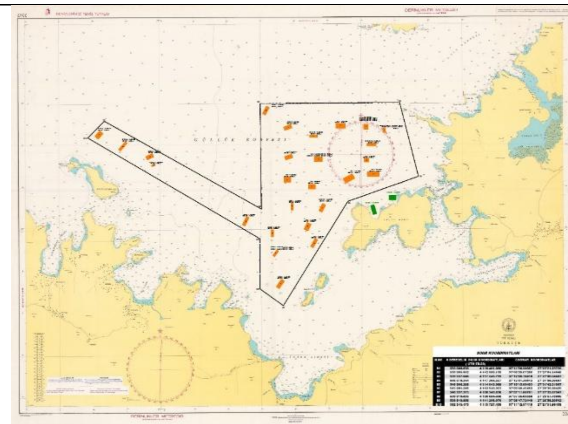
	

Figure 4. Allocated site licences in Milas zone, Gulluk Bay	Figure 5. Allocated site licences in Bodrum zone, Gulluk Bay

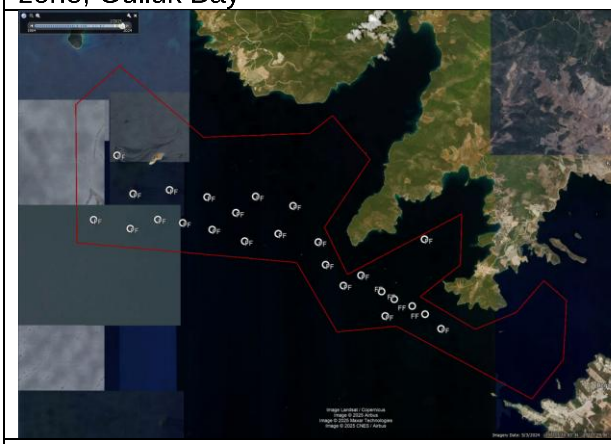
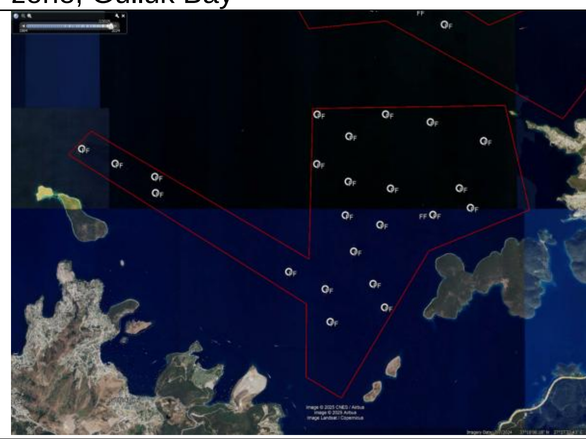
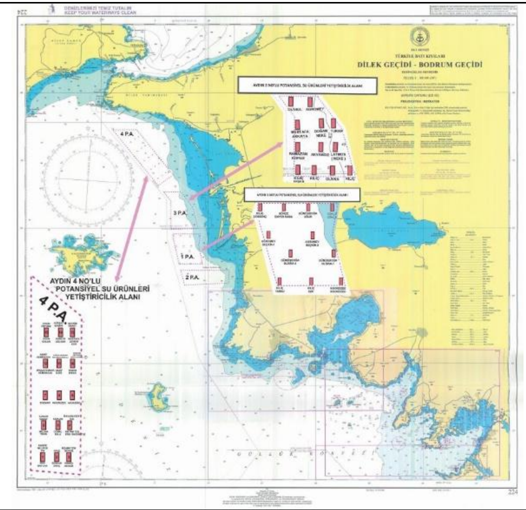
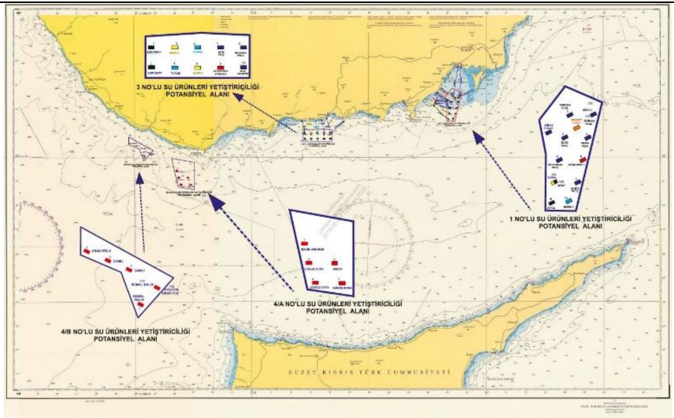

	

Figure 6. Actual farm site locations in Milas zone, Gulluk Bay 02/2025	Figure 7. Actual farm site locations in Bodrum zone, Gulluk Bay 02/2025

4.2 Allocated Zones for future aquaculture development





5. Aquaculture licensing and compliance process

5.1 Licensing requirements

Licenses for marine cage farms exceeding 250 tons per year are issued by the Ministry of Agriculture and Rural Affairs. The application process includes.

1. Submission of a site map and water quality report.
2. Preliminary survey and clearance from the Maritime Affairs authority.
3. Approval from multiple ministries including Health, Environment, and Forestry.
4. Final license issuance after feasibility studies and compliance checks.

5.2 Site selection criteria

Key considerations include.

- Minimum 40m water depth for offshore farms.
- 1-2km distance between farms to prevent disease spread.
- Restrictions on placement near sensitive ecological areas, cultural sites, and tourism zones.

Investors or aquaculture operators must conduct a site-specific **EIA** before obtaining a license. This process includes.

- **Site-specific analysis.** Assessing water quality, benthic habitats, and species diversity at the exact farm location.

- **Project feasibility studies.** Evaluating the scale of operations, infrastructure, and technology used.
- **Impact mitigation plans.** Developing strategies to minimize environmental risks, such as waste management and disease control.
- **Government review & approval.** The EIA report is submitted for approval, and if accepted, a license is granted.

5.3 Tools supporting the decision process

To support SEA and EIA, various technological and analytical tools are employed.

- **GIS.** Used to map aquaculture zones and assess environmental constraints.
- **Remote sensing.** Helps in monitoring coastal changes and detecting environmental impacts.
- **Hydrodynamic models.** Simulate water currents and nutrient dispersal to evaluate potential pollution risks.
- **Biodiversity assessments.** Examine the impact of aquaculture on marine life and sensitive ecosystems.
- **TRIX index.** Evaluating the eutrophication potential of the zone to ensure minimal environmental degradation. Assessment using the **Trophic Index (TRIX)** for eutrophication risk.
- **Stakeholder consultation platforms.** Facilitate dialogue between government agencies, fish farmers, and conservation groups to ensure balanced decision-making.

6. Strengths and weaknesses of the processes

Aspect	Strengths	Weaknesses
AZA	- Provides a comprehensive framework for aquaculture development. - Reduces conflicts with other maritime sectors. - Enhances long-term sustainability planning.	- Requires extensive data collection and stakeholder involvement. - Implementation may be slow due to bureaucratic processes.
EIA	- Ensures site-specific environmental protection. - Provides a legal basis for rejecting unsustainable projects. - Encourages responsible farm management.	- Can be costly and time-consuming for investors. - Effectiveness depends on the quality of environmental monitoring and enforcement.

7. Key Challenges

- **Regulatory gaps.** Inconsistencies in inter-ministerial coordination for licensing and monitoring.
- **Environmental concerns.** Balancing economic growth with ecological sustainability.
- **Conflicts with other sectors.** Managing space for aquaculture, tourism, and maritime activities.

Conclusion

Turkey's marine aquaculture industry has evolved from small-scale coastal operations to a leading global producer through strategic regulatory reforms, offshore expansion, and sustainable practices. While challenges persist, continued investment in technological advancements, environmental protection, and stakeholder collaboration will shape the industry's future.