*Perspective*

# A Post-2030 Sustainability Science Framework for Aquaculture as Transformative Rural Development

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## ABSTRACT

Aquaculture is among the fastest-growing food production sectors globally. However, expansion has raised sustainability concerns that large-scale, export-driven aquaculture systems have externalized too many local—mainly rural—environmental and social costs. Post-2030 food systems must operate within planetary boundaries while advancing equity, nutrition, and rural resilience. Sustainability science emphasizes transformation, governance reform, and co-production of knowledge as prerequisites for durable change. Drawing on these principles a Theory of Change (ToC) framework was used to synthesize contemporary evidence and propose a post-2030 transformation agenda for aquaculture with a focus on aquaculture as an important part of sustainable rural development. For aquaculture to expand it need a greater social license in rural areas of its "new geographies" which is nearly everywhere outside of Asia. Well planned ecosystem design, scaling strategies, strategic subsidies, and governance reforms that use scientifically determined carrying capacity limits are required. Rational scaling strategies, multi-sectoral rural development engagement and strategic alignment with and investments in aquaculture tourism are important considerations for systemic, transformative changes. The post-2030 ToC aquaculture framework repositions aquaculture from purely a food production sector to a transformative social–ecological system embedded in governance reform, institutional evolution, innovation and planetary limits.

**KEYWORDS**: theory of change; ecological aquaculture; transformative rural development; strategic subsidies; scaling; social license

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## ABBREVIATIONS

ToC, Theory of Change; SDGs, Sustainable Development Goals

## INTRODUCTION

The 2030 Agenda for Sustainable Development is a global action plan adopted by all United Nations member states in 2015. Its purpose is to guide countries toward a more sustainable, equitable, and prosperous world by the year 2030. At the center of Agenda 2030 are the 17 Sustainable Development Goals (SDGs) which address major global challenges including poverty, hunger, inequality, climate change, environmental degradation, peace, and justice. The agenda is based on the principle of “leaving no one behind.”

Global capture fisheries have plateaued while demands for aquatic foods continue to rise. Aquaculture now provides more than half of human seafood consumption globally, but aquaculture production remains dominated by Asia with few exceptions (e.g., Norway, Chile, Egypt, Brazil, Türkiye) [1,2] (Figure 1).

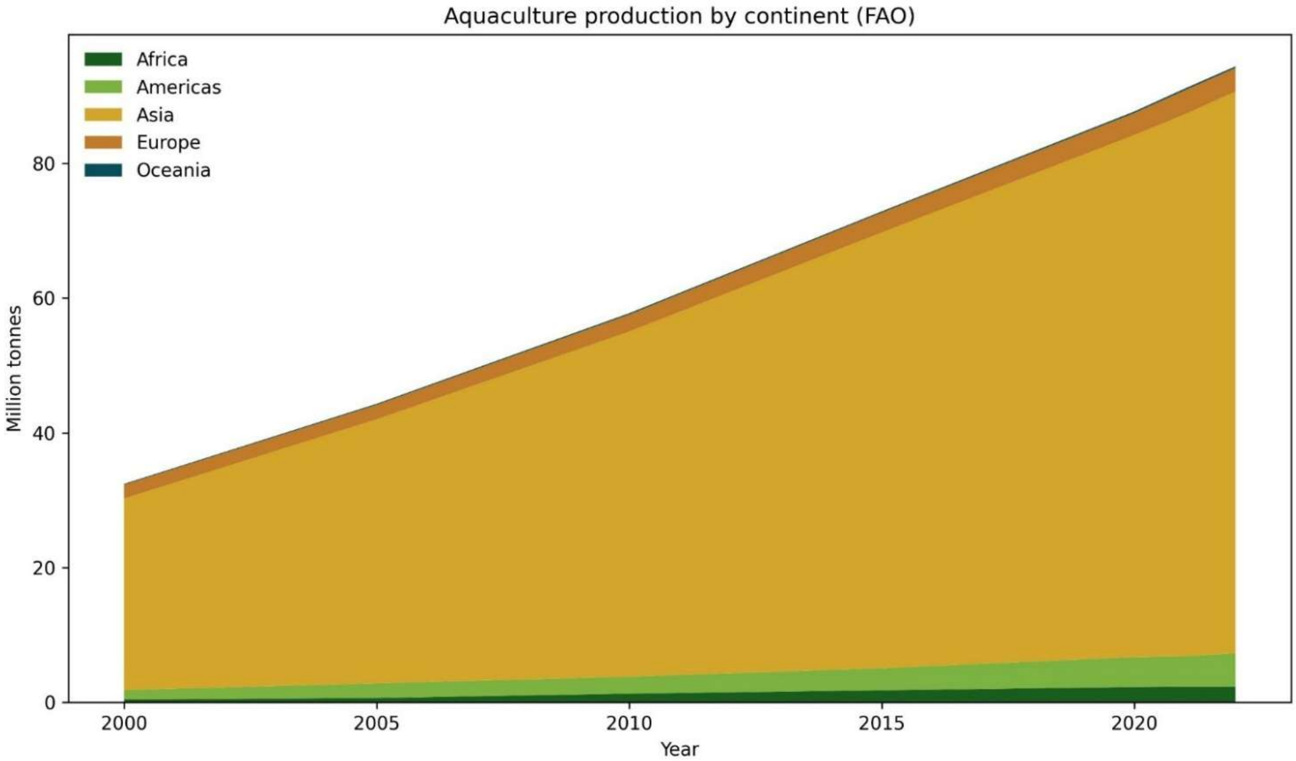


**Figure 1.** Global aquaculture production in millions of metric tonnes (MMT) by continent. Redrawn using the data of FAO [1].

While aquaculture is among the most resource-efficient animal protein production systems [3], there remain sustainability concerns that some large-scale, export-driven aquaculture expansions have externalized too many environmental and social costs [4–6]. Aquaculture is not new; it has ancient roots. Indigenous aquaculture systems such as rice–fish agriculture in Asia [7,8], Hawaiian *loko i’a* [9,10], and Pacific Northwest clam gardens [11] are just three examples that demonstrate that aquaculture historically evolved as food ecosystems embedded in communal social-ecological governance [12,13]. Modern ecological aquaculture revives these concepts to address some of the concerns of large-scale industrial aquaculture trajectories developed since the 1970’s (Table 1).

**Table 1.** Social-ecological issues arising in current large-scale aquaculture and proposed, alternative ecosystem-based, post-Agenda 2030 transformative approaches [14–16].

| **Social-Ecological Concerns** | Sustainability Challenges | Aquaculture Ecosystems: Transformative Ways Forward Post-2030 |
|---|---|---|
| **Monocultures** | High Inputs; High Waste Discharges | 100% Use; Waste Valorization |
| **Linear Production Designs** | Resource Inefficiencies; Export Economics | Ecosystem Design to Circular Ecosystems; Scaling Out, Not Only Up |
| **Low Direct Job Creation** | Externalized Social Costs; Social Conflicts; Lack of Social License to Operate | Aquaculture as Rural Development; Shortened Value Chains; Participatory Governance Systems |

Theory of Change (ToC) provides both a conceptual and structural account of how and why interventions are expected to generate desired outcomes especially in the context of complex sustainability transformations [17]. Rather than assuming adoption of a production goal or a technical innovation automatically leads to systemic change, ToC approaches can find important causal pathways. These pathways link actions to outcomes by making transparent underlying assumptions, actor coalitions, governance arrangements, incentives, and feasibility constraints. Allen et al. (2026) [17] argue that the Sustainable Development Goals (SDGs) were underpinned by an implicit ToC in which global goal setting was expected to drive national targets, mobilization of resources, implementation, monitoring, and ultimately societal transformation. However, limited progress has been made [18]. A lack of fundamental transformations has highlighted the need to unpack the “black box” of implementation by specifying how barriers will be overcome and by whom, and by assessing both potential impact, political feasibility, and especially the issues of siting and scale.

Applied to aquaculture, ToC thinking similarly shifts attention beyond production growth toward social–ecological transformation. A comprehensive ToC for aquaculture’s future accounts for non-linear technological progress, the importance of scale and place-based pathways, capacity building, adaptive governance, and learning-oriented feedback. Indicators are needed that integrate ecological, social, and economic performance. In this sense, a post-2030 ToC for aquaculture serves as both a design and diagnostic framework for the broader use of sustainability science principles in aquaculture [19] as it clarifies conditions under which aquaculture ecosystems can contribute meaningfully to post-2030 sustainable development transformations.

## METHODS

A three-part synthesis was conducted using a comparative ToC reconstruction methodology grounded in sustainability science and institutional analysis. First, the implicit ToC underpinning the 2030 Agenda was reconstructed following Allen et al. (2026) [17], identifying assumptions linking global goal adoption, localization, implementation, mobilization, and transformation. These assumptions were coded into seven ToC components: assumptions, pathways, actors, incentives, governance, indicators, and feasibility. Second, each component was translated into an aquaculture-specific transformation logic using a normative sustainability framework [20,21], ecosystem-based guidelines for sustainable aquaculture [14,16], governance analyses [22], scaling theory [23], value-chains and institutions [24], and planetary health [25]. Third, a comparative matrix was constructed aligning SDG ToC components with the principles and practices of ecological aquaculture [14,15].

## RESULTS AND DISCUSSION

SDG-based assumptions, diagnosed gaps, and aquaculture-specific institutional and design reforms from the peer-reviewed literature; plus, feasibility assessments that integrated technical, environmental, social, financial, and political economy dimensions were identified and are summarized in Table 2.

**Table 2.** Comparison of ToC components in the post-2030 SDG agenda and proposed aquaculture transformation reforms.

| ToC components | Post-2030 SDG Theory of Change [17] | Aquaculture Transformation Reforms |
|---|---|---|
| Assumptions | Reconstruction of the implicit assumptions underpinning the 2030 Agenda | Reconstruct aquaculture development pathways using ethical and sustainability frameworks [25–27] |
| Pathways | Adoption → localization → implementation → mobilization → transformation | Scale out rural transformation strategies for ecological aquaculture development [23] |
| Actors | Move beyond nation-states toward multi-level actor coalitions and partnerships [18] | Strengthen rural institutions, applied education, and extension systems to support community-based aquaculture [28] |
| Incentives | Recognition of weak incentives and accountability mechanisms for non-state actors | Eliminate perverse subsidies and align incentives with rural development and ecosystem performance [29] |
| Governance | Institutional capacity gaps and weak accountability structures limit transformation | Reform natural resource management agencies to integrate aquaculture within broader food-system governance [30] |
| Indicators | Monitoring, review, and adaptive feedback are central but unevenly implemented | Expand evaluation to environmental, social, economic, and value-chain metrics, including gender and equity indicators [22] |
| Feasibility | Transformation depends on technical, economic, environmental, and social feasibility conditions | Adopt integrated financial–environmental–social performance evaluation models for aquaculture investment and governance [31] |

Search of the sustainability science literature in aquaculture was done to find causal pathways linking actions to outcomes and help evaluate the relevance, limits, and transformation potential of aquaculture systems. Causal relations were explored for temporal precedence, predictable patterns, and alternative explanations to establish causations. The most important casual relations meeting fully these three criteria were not technology related but social, economic and governance features (Table 2). More specific discussion of causal aspects of aquaculture development was: (1) aquaculture as rural economic development and rational scaling, (2) elimination of perverse subsidies, (3) integration of aquaculture within food system governance, and (4) integration of environmental and social performance into financial evaluations.

Aquaculture stands at a historic crossroads. Cage aquaculture in open waters of the African Great Lakes, the Black and Caspian Seas, one of the largest reservoirs in the world (Itaipu, Brazil/Paraguay), Patagonia (Chile/Argentina) are developing or proposed; massive semi-recirculating (~40–50% of the water flow-through) land-based coastal farms have been developed (Norway, Iceland) and have been proposed elsewhere (Canada, USA). The majority of these are proposed in rural areas where the complexity of this rapid evolution of aquaculture has little understanding in governance systems and the public [32]. As the Anthropocene accelerates, defined by climate disruption, biodiversity loss, coastal urbanization, and widening social inequities, capture fisheries can no longer expand to meet global demands for nutritious aquatic foods. Yet the prevailing models of aquaculture have too often mirrored the failures of terrestrial industrial agriculture: ecological simplification, pollution, social exclusion, and loss of public trust [33].

## AQUACULTURE AS RURAL ECONOMIC DEVELOPMENT

Roughly 40% of the world's population lives within 100 km of marine and large lake coastlines, concentrating food demands, infrastructure, markets, and climate risks in coastal regions [34]. The global rural population share has fallen to approximately 20%, reflecting a world increasingly dominated by urban and peri-urban centers and depopulated rural areas. Rural populations have been declining since at least 2015 across Europe, North America, Australia, New Zealand and across large parts of East and Southeast Asia [35,36]. Sub-Saharan Africa remains the only region projected to experience substantial rural population growth in the coming decades.

Aquaculture today is in rural areas in earthen ponds and concrete raceways apart from the few intensive recirculating aquaculture systems (RAS) which remain rare and struggle to be economically viable without subsidies [37]. Asia—home to most of the global aquaculture production—has developed largely as a rural, household-based activity integrated with farming systems, providing livelihoods and food security in rural economies [38–40]. While FAO and other UN bodies do not publish a specific percentage of aquaculture located in the rural areas in Asia, regional reports and national statistics consistently describe aquaculture in the region as predominantly rural, small-scale, and connected to rural livelihoods, transforming rural landscapes, positioning ecological, community-based, and ecosystem-integrated aquaculture as a key bridge between food security, livelihoods, and sustainability transitions. Filipski & Belton (2018) [40] demonstrated that in Myanmar aquaculture stimulated rural employment and local economies, private sector development, and broader economic diversification. Baltic Sea nations developed RAS for environmental reasons; Latin American aquaculture systems were developed to support rural welfare; in Canada, over 90% of aquaculture jobs are in rural and coastal communities; in the U.S., aquaculture farms are widely distributed in rural inland and coastal areas, providing thousands of rural jobs; however, aquaculture development is politically charged in many of these regions [41–44].

**Rational Scaling: Scaling Out, Not Only Up**

In contemporary aquaculture discourses, some ambitious proposals envision rapid expansion to unprecedented industrial scales. These visions, often framed as economies of scale, technologically inevitable and socially necessary, promise to reconcile some of aquaculture's glaring problems with the SDGs, namely food security, socio-economic justice, healthy foods, education, rural development, and climate change mitigation by economic growth through permitting ever-larger production systems. Such scaling up through increasing farm size and spatial occupation has become one of the most contentious elements of aquaculture development in its new geographies. Some of these have been characterized as scaling fantasies that cannot be bioeconomically viable without large, fail-safe biofilter systems technologies and consistent, massive influxes of new investor funding, government subsidies (external donor funding, grants, etc.) [4,37,43]. Among the most striking examples are proposals for mega-scale land-based RAS designed to produce >100,000 MT/year from single sites. Examples include Atlantic Sapphire, USA which targets ~220,000 MT annual production by 2031 and Norway's World Heritage Salmon project which proposes converting a former mine into an underground RAS facility producing 100,000 MT/year [45,46].

Similarly, some marine aquaculture (both coastal and water-based) expansions have proposed large farm footprints in or adjacent to nature reserves or busy, common-property coastal systems. Some of these projects are framed as the next big thing in aquaculture innovation and justified based on technological control, biosecurity, proximity to markets and social benefits (jobs, increases to incomes).

Aquaculture facilities of capital intensity and large demands for space have a risk of disconnection from communities, especially in rural areas. Here, scale becomes not merely technical and economic variables but social-political ones, as scaling is not fully considered. However, it is too simplistic to conclude that social licenses erode with increasing farm size. Export-oriented aquaculture development at scale can co-exist within broader contexts of rural development, decrease political polarization, reorient subsidies, and contribute more broadly to the SDGs if a proper ToC lens is applied to the future of aquaculture. Large-scale, capital-intensive aquaculture can be aligned with the SDGs if more rational scaling options are fully considered.

There are at least three significant concerns about how scaling up is typically practiced in modern aquaculture development. First, there is the illusion of linear expansion. Woltering et al. (2019) [23] critiques this linear, technology-transfer mindset, stating it ignores institutional and policy barriers, neglects robust market developments, and financial viability assessments. Most importantly for this analysis, scaling up proposals often overlook the deeply local, mostly rural, social-ecological conditions where most of aquaculture is being planned. A singular scaling up pathway often produces fragile growth that collapses when external support and subsidies are withdrawn. Moreover, social-ecological carrying capacities are often incompletely integrated into expansion planning, and the absence of clearly defined, stakeholder-informed thresholds can precipitate environmental degradation and social conflicts. Woltering et al. (2019) [23] caution against the overreliance on scaling up as the silver bullet narrative: the belief that this single development pathway/intervention/innovation will change the world.

Scaling requires recognizing the complexities involved in facilitating a transition to a new normal. Aquaculture, as a new intervention in most of the world outside of Asia, requires systemic, not simplistic, scaling strategies. Overhyped scaling-up narratives can attract capital prematurely, ignore ecosystem and social limits, and undermine credibility if failures occur. Controlled, pilot project environments don’t always scale up. Pilot projects often rely on external funding, high-level technical, often-imported, leadership, and temporary incentives (subsidies). Such conditions do not represent real-world complexity. Many pilots fail because markets are not ready, governance is not aligned, and producers lose sustained incentives (subsidies). Developers too often do not spend enough time and money investigating consumers, local and regional markets, trade (especially price and volume competition), supply chain logistics and infrastructures as critical elements in scaling. Production may increase, but distribution systems fail, market access is constrained, and imports outcompete local producers. Scaling up production without scaling value chains is unstable.

As a result, scaling up alone risks reinforcing industrial path dependencies and “productionist” narratives rather than catalyzing the systemic transformations required under post-2030 sustainability frameworks, now recognized by some agriculture scientists [47,48]. The risk is that improper planning for scaling up can increase ecological impacts, concentrate economic power leading to even greater income disparities, marginalize small-scale producers, outpace governance capacity, and create social opposition. Without ecosystem-based management and participatory governance, scaling up can intensify conflicts and externalities. These suggest that aquaculture development must not only transform scaling up to growth in size or output but also consider all scaling options and help industry move toward strategies that embed ecological limits, social legitimacy, participatory governance, capacity building in rural areas and institutional learning as core elements of sectoral expansion.

There is a path of rational scaling rarely considered in aquaculture development in governance systems or by investors—scaling out—not only scaling up (Table 3). Scaling out strategies emphasize replication, institutional diffusion, and governance alignment rather than simple production expansion.

**Table 3.** Scaling Up vs. Scaling Out in Aquaculture Development.

| Scaling Up: The Conventional Approach [23] | Scaling Out: A Sustainable Systems Change Approach |
|---|---|
| Focuses primarily on increasing production volume | Focus on transforming the entire aquaculture system [30] |
| Assumes a linear pathway: pilot → replicate → commercialize | Build long-term change through strategic subsidies in institutions, governance, and markets [29] |
| Measures success by numbers reached (e.g., adopters, farms, tons produced) | Measures success by whether the system sustains adoption and spreads beyond pilot projects [23] |
| Often technology-driven (“best practice transfer”) | Social-ecological systems-driven, adapting innovations to context [44] |
| Rely heavily on external funding and project support | Embedded in a social ecological system of actors (public, private, community) [28] |
| Short-term project timelines often end when grants close | Long-term programmatic strategy designed for durability and ownership [42] |
| Frequently ignores “soft” constraints: politics, incentives, norms | Explicitly address rules, incentives, power relations, and institutions [19] |
| Vulnerable to collapse when pilots leave the “glasshouse” | Creates a new normal that perpetuates solutions beyond interventions [48] |
| Risks hype, oversimplification, and premature investment | Emphasizes responsible scale, legitimacy, and adaptive governance [49] |
| Can intensify ecological/social conflicts if governance lags growth | Builds participatory governance, evidence-led policy, and social license [22,28] |

### An Example “Scaling Out” Strategy—Aquaculture Ecotourism

Scaling out requires partnerships who develop at first economically viable, smaller scale aquaculture models that can be distributed widely over diversified local/regional networks and investments in place-based branding. Marine and coastal tourism has the highest employment and economic returns of any sector of the ocean economy [50]. Aquaculture ecotourism is a practical way to add value to aquaculture without necessarily scaling production volume, as scaling out development works through diversification, network-building, and branding. Aquaculture ecotourism is most compatible with experiential, nature-based tourism. Aquaculture ecotourism through farm visits, participatory monitoring, food experiences, and place-based narratives creates new interfaces among producers, communities, scientists, educators, policymakers, conservation NGOs, and consumers [51–54].

Its main benefits are: (1) Income diversification and creation of local, mostly rural, jobs via farm tours, tastings, festivals, snorkeling/diving, and education experiences that diversify and create new revenue streams and employment that can buffer farmers from commodity price swings and create multiplier economies for communities. (2) Strengthened local food systems (shorter value chains) by creating "eat local" demands and premium pricing for traceable seafood, helping farmers and communities capture more value locally rather than exporting it. This aligns with broader evidence that culinary/food tourism can strengthen inter-sector linkages and local economic development. (3) Increased social license and environmental stewardship in rural areas by making production visible and accessible, improving understanding and acceptance (when farms are well-managed), and providing an educational and partnership platform for monitoring, biodiversity, and conservation practices, as research has shown that increasing and diversifying stakeholder engagement is central to aquaculture's social acceptability [54]. Partnerships with local academia and technology providers to develop, for example, transparent, accessible monitoring platforms, can turn farms into living labs and field classrooms—another way to scale out benefits beyond production.

There has been a rapid expansion of sea bream (*Sparus aurata*) and bass (*Dicentrarchus labrax*) cage aquaculture in Greece and community opposition has increased [55]. In the Greek Strongyli-Rhodes islands, a Natura 2000 region, an aquaculture company produces sea bass, bream, and meagre (*Argyrosomus regius*) for island markets [56]. They have strategic partnerships with local tourism, culinary, technology, education and research institutions with data sharing, and cooperate with a local telecommunications company on monitoring/management to optimize farming conditions, ensure fish health, and mitigate risks. Farm owners aim to designate their farm as a marine protected area. In the Nordic countries, typical tourism concerns are due to impacts on fjords and mountains bringing emissions, garbage, and sewage. Helgadóttir et al. (2021) [57] call for the expansion of Nordic eco-tourism with the growing aquaculture industry to promote Arctic Charr (*Salvelinus alpinus*) as an iconic, traditional Nordic food in the growing tourist market that craves local, sustainably produced, healthy food. The Farmed Catfish Trail (USA) mixes rural catfish aquaculture with culinary culture, music, and accommodations. In Scotland, Budhathoki et al. (2025) [58] found that integration of tourism with aquaculture had a significant impact on consumer attitudes towards aquaculture. They found that aquaculture sites could be key centers for aquaculture knowledge development, stating that aquaculture ecotourism "presents exciting opportunities for sustainable development in coastal communities, where achieving a balance between economic growth and environmental conservation is often a complex challenge" [58]. Empirical cases of aquaculture tourism globally are shown in Table 4.

**Table 4**. Aquaculture Tourism as Community-Based "Scaling-Out" Strategy: Global Examples.

| Countries | Examples | Tourism Products | Community-Based Scaling-Out Mechanisms | References |
|---|---|---|---|---|
| Canada | Prince Edward Island Aquaculture Tourism (mussels, oysters) | Farm tours, oyster shucking, culinary tourism | Small-scale growers linked with culinary tourism; regional "merroir" branding | Martineau [59] |
| Ghana | F3 Aquaculture Tourism Centre (tilapia) | Farm visits, biodiversity education, cultural programming | Community identity-building; livelihood diversification; education outreach | F3 Aquaculture Tourism [60] |
| Greece | Rhodes Fish Farm (sea bream, sea bass) | Snorkeling/diving near cages; farm interpretation | Multi-use partnerships; education outreach | Waycott [56] |
| Iceland | Culinary Tourism (Arctic charr) | Culinary tourism; destination seafood branding | Sustainable farmed seafood supporting tourism identity and rural resilience | Helgadóttir et al. (2021) [57] |
| Japan | Ama Divers (shellfish & seaweed) | Farm visits; traditional diving; tasting | Integration of aquaculture with women-led cultural heritage tourism | FAO [61] |
| Norway | Salmon Aquaculture Visitor Centres (Hardangerfjord) | Visitor centers; fjord tours; educational exhibits | Corporate–community partnerships; technology transparency; education outreach | Salmon Eye [62] |
| Sweden | Oyster and seaweed safaris; Mussel adventures | Farm visits; culinary tourism; aquaculture education | University–corporate–community partnerships; consumer food diversification | Armbrecht & Skallerud (2019) [63]; Sutherland & Armbrecht (2024) [64] |
| Scotland | Salmon | Tours near salmon farms | Motivational tourism; education, outreach | Budhathoki et al. (2025) [58] |
| South Africa | Knysna Farm (abalone, oysters) | Facility tours; seafood festivals | High-value niche branding in coastal tourism | Troell et al. (2006) [65] |
| Tanzania (Zanzibar) | Seaweed Farming Tours | Farm visits; cultural interpretation; product demonstrations | Women's cooperatives; aquaculture economy diversification | Msuya (2011) [66] |
| United States | Mississippi Catfish Trail | Culinary tourism linking farms and restaurants | Regional branding; producer–restaurant networks | The Catfish Institute (n.d.) [67] |

### Elimination of Perverse Subsidies

Strategic subsidies are justified by positive externalities, innovation needs or transition support, and advances in innovation and competitiveness. However, even well-placed subsidies can generate significant design and implementation problems. Segerson et al. (2024) [68] argue subsidies are justified when subsidized activities generate uncompensated positive spillovers, i.e., knowledge, positive contributions to the environment, ecosystem services, technology learning curves, etc. Segerson et al. (2024) [68] stress that subsidies are not cost-free and create social costs through taxation or debt.

Perverse subsidies are those that directly or indirectly increase environmental harm or reduce economic efficiency. Some aspects of perverse subsidies are those that increase production and expand market size but do not shift value chains and market composition; subsidies that pay for costs of increased social and environmental externalities; and subsidies that pay for investments that would have occurred anyway. These subsidies risk becoming income transfers rather than drivers of transformation. Unlike taxes or cap-based systems, perverse subsidies can stimulate growth without social and ecological limits. Perverse subsidies increase fiscal opportunity costs to society by diverting public funds from R&D, infrastructure, ecosystem restoration and incentive-based environmental regulation. Segerson et al. (2024) [68] identify a principal issue with perverse subsidies is that they too often persist even when net societal benefits are unclear.

Guillen et al. (2019) [29] conducted one of the most in-depth examinations of aquaculture subsidies in the European Union (EU). EU aquaculture production is small [1] and has stagnated for almost a decade. Their study is instructive to other countries and regions that are advancing proposals to increase aquaculture to multi-lateral (World Bank, Asian Development, African Development Banks, etc.) and bi-lateral donor agencies and investors, where plans include a range of proposed subsidies. The European Court of Auditors concluded that support to aquaculture did not yield a growth in production and that subsidies had not led to sustainable aquaculture development [69]. There was no clear link between subsidies and productivity improvements despite approximately €1.2 billion in funding from 2000 to 2014. In some EU countries public funding exceeded 40–300% of production value and taxpayers paid €6–€17 per kg of production, an extraordinary high subsidy-to-value ratio [69].

EU aquaculture stagnation was linked to administrative, command and control regulation and environmental permitting barriers. EU aquaculture was found to be highly fragmented and dominated by many small projects and micro-enterprises; thus, evaluation of subsidies was difficult, but the overall finding was that they were weakly linked to structural transformation, and that the opportunity costs of subsidies were high relative to public benefit. Aquaculture subsidies did not provide incentive for regulatory reform, and unwieldy command-and-control governance systems remained.

Not much has changed in EU aquaculture after 2015. EU aquaculture policy has increasingly emphasized sustainability and blue growth, but aquaculture production has remained largely stagnant despite substantial public investments. The 2023 European Court of Auditors report concluded that EU aquaculture showed little production growth, weak sustainability monitoring, and unclear outcomes from increased subsidies [70]. Segerson et al. (2024) [68] highlight that subsidies create concentrated beneficiaries and political resistance to removal. In aquaculture this can lock in suboptimal economic species, inefficient production systems, protect marginal producers, stifle innovation, and reduce pressure for consolidation. Once companies become subsidy-dependent, reforms become politically costly. Subsidies cannot solve structural constraints like regulatory bottlenecks. Instead, they increase capital intensity while leaving institutional constraints unchanged [68] This creates capital deepening without growth. The strategic failure is that funds are not concentrated where technological scaling options are possible, and production gains are sustained primarily by funding transfers rather than market viabilities.

In aquaculture strategic subsidies may include technological innovations via R&D (new feeds, vaccines, genetics, biofilter technologies for RAS) that improve market competitiveness, improve value chains, improve environmental performances via environmental mitigation technologies and provide positive impacts on ecosystem services, and biosecurity. Subsidies in aquaculture development become problematic when they: (1) expand capacity without correcting environmental and social externalities (where no environmental and social pricing is introduced, these externalities remain unpriced while capital is subsidized), and (2) lack additionality, lock in inefficient production, and create fiscal transfers without measurable value transformations. Perverse aquaculture subsidies distort competitiveness by artificially lowering production costs, distorting prices, reducing pressure to improve efficiency, and crowding out innovation.

Segerson et al. (2024) [68] argue that when negative externalities exist, taxes are more efficient than subsidies. Subsidies cannot compensate for regulatory rigidity. Capacity subsidies to industry risk advancing poorly planned intensification, leading to a fragmentation of subsidies that dilute impacts, and high subsidy-to-output ratios that create structural inefficiencies. Long term, poorly analyzed and reviewed subsidies entrench low productivity structures. But subsidies are politically easier to create than remove.

Key implications of subsidies for aquaculture development are that they: (1) be time-bound, regularly reviewed and stopped if found to be perverse; (2) target R&D and innovation, not capacity expansion; (3) be tied to measurable environmental and social performance improvements; (3) avoid fragmentation across small projects; (4) be paired with incentive-based environmental regulations (taxes, tradable permits); and (5) be focused on transformation of markets, value chains and creation of value, not just volume expansion. The EU aquaculture reviews [69,70] demonstrate how even large financial support can fail to produce growth when structural, regulatory, and economic fundamentals are not addressed. A post-2030 ToC for aquaculture must clearly identify strategic vs. perverse subsidies (Table 5).

**Table 5.** Conceptual distinction between strategic and perverse subsidies in aquaculture development.

| Dimensions | Strategic Subsidies (ideal) | Perverse Subsidies (risky) |
|---|---|---|
| Economic logic | Corrects and monetizes externalities (e.g., innovation, ecosystem services); Invests in R&D | Supports activities with unpriced negative externalities |
| Additionality | Induces investment or innovation that would not occur otherwise | Finances activities that would occur in absence of subsidy |
| Market effects | Improves productivity and competitiveness | Expands output and environmental pressure |
| Environmental impacts | Reduces ecological footprint or enhances environmental performance | Increases nutrient loading, disease/parasite risks, or habitat pressures |
| Political economy | Time-bound; includes sunset or review mechanisms | Creates vested interests and policy lock-in |
| Evidence | Limited sectoral innovation gains | High expenditure with weak production growth |

**Integration of Aquaculture within Food System Governance**

Aquaculture globally is insufficiently coordinated and governed within cohesive food system strategies and must be integrated into broader food-system governance and implementation if it is to realize its full contribution to sustainable development [30,71,72]. There are, however, recent social-ecological, legal and regulatory developments of global importance in Norway, Chile and Scotland. An aquaculture food systems perspective recognizes that aquaculture's impacts and benefits are shaped by basal political, economic, and environmental framing conditions, as well as by globalized value chains, and, for fed aquaculture, by distant resource dependencies. Troell et al. (2023) [30] in their assessment of aquaculture's role in achieving the SDGs emphasize the diversity of aquaculture across water and terrestrial systems, and state that the acknowledgement of aquaculture as an integral part of food systems governance, planning, research and development is vital. Aquatic foods risk being overlooked in global food dialogues which remain largely terrestrial in orientation thereby limiting their recognized and actual contributions to food security, nutrition, and environmental sustainability.

Troell et al. (2023) [30] propose an "iterative process" in which aquaculture outcomes are benchmarked against SDG indicators and fed back into more comprehensive political and institutional decision-making. Thus, integration is not merely administrative but requires adaptive governance that links production systems, markets, value chains, climate stressors, and sustainability targets. Integrated governance can help evaluate environmental performance, climate implications, feed dependencies, and biodiversity effects from a broader social–ecological systems perspective. By situating aquaculture within comprehensive food-system planning, rather than treating it as a stand-alone sector, political jurisdictions can better leverage aquatic foods to enhance resilience, reduce environmental pressures relative to some terrestrial livestock systems, and advance the interconnected goals of food security, sustainability, and human health. Export-oriented or production-driven aquaculture may limit food-security and equity gains if multi-sectoral governance, scaling, and rural benefits are not more broadly distributed. Aquaculture production growth alone does not guarantee SDG outcomes.

**Integration of Environmental and Social Performance into Aquaculture Financial Evaluations**

There are dubious financial practices within the aquaculture industry, particularly at the medium to large commercial scales. Some have exaggerated financial performance, production prospects, sustainability, and profitability to attract investment and unsecured loans [73,74]. Wide overuse of incomplete financial assessments such as EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization), which exclude major costs can make financially questionable operations appear financially healthier to investors and can secure capital under dubious pretenses. Such practices can manifest promises of unrealistic production timelines, inflated sales prices, and unrealistic revenue forecasts. Some aquaculture firms may take on excessive debt to stay operational while high executive compensation is kept, effectively rewarding insiders while risking collapse for outsiders and investors. Capitalism’s structural incentives can reward these deceptive practices, especially in complex, capital-intensive sectors like large scale aquaculture where long gestation periods and technical uncertainty already create high financial risks.

A lack of economic rigor to evaluate aquaculture undermines genuine sustainable development goals. Misleading investors and overstating prospects can divert capital away from practical, ecology-integrated enterprises, reinforce systemic risks, and erode trust in efforts to grow ecologically sustainable aquatic food systems. Economic misrepresentation and poor governance can have ripple effects on industry reputation, investment patterns, and ultimately undermine the social license of aquaculture development

Financial indicators, especially metrics such as EBITDA, can be misleading or incomplete when assessing a company’s performance in the context of environmental and social sustainability, especially where environmental and social performances can show neutral or negative relationships with complete financial returns assessed over longer horizons. In addition, metrics focused only on financial results do not account for sustainability dimensions unless they are paired with explicit ESG (Environmental, Social, Governance) indicators, reflecting a major shortcoming of current aquaculture investments [75–77].

What is needed is: (1) Clear, honest financial reporting. Companies must move away from misleading metrics—such as those that hide actual costs or inflate profitability—and instead adopt transparent accounting practices that reflect true performance and risk. This includes avoiding selective use of EBITDA; showing full cost structures instead of glossing over liabilities and reporting realistic production and revenue projections rather than optimistic forecasts that cannot be justified. (2) Full accountability for executives and promoters. There are concerns regarding misaligned incentives, where executives and promoters are rewarded for raising capital regardless of actual aquaculture economic and social progress. To counter this executive compensation and bonuses should be tied to verified not only to production/economic outcomes, but also social ones, not just fundraising success. Firms should face real consequences for misrepresentation. There is a need to reduce the the reward for hype. (3) Better due diligence by investors. Investors need to conduct deeper, independent due diligence rather than relying solely on company-provided figures. This includes verifying production claims and business plans by third-parties of professional business auditors, engaging experienced aquaculture technical experts early in investment reviews, scrutinizing financing structures and debt loads realistically, and making structural changes to incentives and governance.

Aquaculture industry norms must shift toward valuing sustainable performance and long-term viability, encouraging regulatory frameworks that emphasize disclosure, third-party verification, investor protection, and foster industry associations and standards bodies requiring best practices for reporting and accountability [78]. A lack of economic transparency in aquaculture around inflated financial claims, opaque reporting, and misaligned executive incentives emphasize the need for stronger governance in aquaculture. Outcomes are shaped by framing conditions and institutional rules that influence incentives, accountability, and transparency across value chains. Weak policy coherence, fragmented regulations, and limited monitoring capacities create environments in which opportunistic behavior and misrepresentation flourish. From a systems perspective, aquaculture governance must embed transparency, predictable rule-of-law, and cross-sector coordination to ensure that production growth translates into equitable and sustainable outcomes rather than short-term financial gains. Governance elements most directly linked to reducing economic risks are summarized in Table 6.

**Table 6.** Governance elements most directly linked to reducing economic fraud risk in aquaculture.

| Governance Elements | References |
| --- | --- |
| Full cost accounting, environmental and social performance reporting | [19,31,75] |
| Policy coherence across sectors, especially alignment of aquaculture with food, environmental and rural development policies; coordination (land–water–sea integration) to better manage systemic risks and externalities | [30] |
| Monitoring and enforcement capacity with credible oversight and compliance mechanisms | [31] |
| Equity and benefit-sharing frameworks that prevent value capture by elites at expense of food security that aligns incentives with sustainability metrics | [77] |

**CONCLUSIONS**

Expanding large scale aquaculture production by conventional scaling up could significantly improve cost competitiveness but will not automatically deliver food security or equitable development outcomes. Aquaculture is fundamentally rural. Rural areas of many countries are facing severe outmigration, lack of jobs, and disinvestment, all contributing to political polarization. Overemphasis on production growth without attention to benefit distribution and equity will undermine aquaculture's contributions to the SDGs. Strategic subsidies can be built directly into governance frameworks so that aquaculture contributes not only healthy products and increased values but also meets broader societal goals. Aquaculture development must move beyond growth in size or output toward rational scaling strategies including scaling out that embed ecological limits, social legitimacy, participatory governance, and investments in capacity building especially in rural areas. Institutional learning such as aquaculture education for municipal officials as done for co-management of small-scale fisheries can be at the core of aquaculture scaling decisions.

Designing and applying strategic subsidies that create successful transformative spaces for aquaculture are an important endeavor for our humanity which has exceeded planetary boundaries. When embedded within planetary boundaries and adaptive governance systems, aquaculture can advance transformative sustainable development while restoring ecosystems and strengthening communities.

Scaling up in aquaculture is often naïve, linear, technology-centered, and insufficiently attentive to governance, markets, and social-ecological systems. Scaling out, understood as sustainable systems change at scale, offers a ToC that is a more durable, legitimate, and socially embedded pathway for aquaculture development transformation. A post-2030 sustainability framework for aquaculture therefore requires a reframing of aquaculture development beyond industrial gigantism. The challenge is not simply to produce more fish, but to cultivate systems that are ecologically bound, socially legitimate, and institutionally robust. Without such a shift, scaling up risks amplifies precisely the vulnerabilities that sustainability agendas seek to resolve.

ToC transformation requires not only top-down transformations but also bottom-up ones. Governance systems must subsidize only where public money uses incentives aligned with explicit applications. A post-20203 sustainability science framework for aquaculture's transformation requires increased capacity building for aquaculture to be planned, implemented, and monitored not only for its production values and environmental interactions but also as sustainable community development. Aquaculture investment proposals must be evaluated not only as to their planning and impacts of scaling, but also for their development of value chains and impacts on consumers. Investments in rural extension services that understand the values of early participation, inclusion, benefit-sharing, and cultural fit are prerequisites for additional legitimacy and durability. Without institutional reforms, elimination of perverse subsidies and financial fraud, aquaculture risks neglect and incrementalist failures in its new geographies, not transformation.

## DATA AVAILABILITY

No new experimental data was generated from the study.

## CONFLICTS OF INTEREST

The author declares there is no conflicts of interest.

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## REFERENCES

1. Food and Agriculture Organization of the United Nations (FAO). The State of world fisheries and Aquaculture 2024. Rome (Italy): FAO; 2024. doi: 10.4060/cd0683en
2. Mair GC, Halwart M, Derun Y, Costa-Pierce BA. A decadal outlook for global aquaculture. J World Aquac Soc. 2023;54(2):196-205. doi: 10.1111/jwas.12977
3. Hilborn R, Banobi J, Hall S, Pucylowski, T, Walsworth T. The environmental cost of animal source foods. Front. Ecol. Environ. 2018;16(6):329-35. doi: 10.1002/fee.1822
4. Olsen MS, Amundsen VS, Alexander KA, Thorarinsdottir R, Wilke M, Osmundsen TC. Social license to operate for aquaculture–A cross-country comparison. Aquaculture. 2024;584:740662. doi: 10.1016/j.aquaculture.2024.740662
5. Wang CD, Olsen Y. Quantifying regional feed utilization, production and nutrient waste emission of Norwegian salmon cage aquaculture. Aqua Environ Int. 2023;15:231-49. doi: 10.3354/aei00463
6. Hamouda L, Hipel KW, Kilgour DM, Noakes DJ, Fang L, McDaniels T. The salmon aquaculture conflict in British Columbia: A graph model analysis. Ocean Coast Manag. 2005;48(7-8):571-87. doi: 10.1016/j.ocecoaman.2005.02.001
7. Lu J, Li X. Review of rice–fish-farming systems in China—one of the globally important ingenious agricultural heritage systems (GIAHS). Aquaculture 2006;260(1-4):106-13. doi: 10.1016/J.AQUACULTURE.2006.05.059
8. Edwards P. Co-evolution of fish and rice farming by Austroasiatic communities in the Neolithic Era and early documentation of aquaculture in China. Front Aquac. 2025;3:1437833. doi: 10.3389/faquc.2024.1437833
9. Wyban C. Tide and Current: Fishponds of Hawai‘i. Honolulu (HI, US): University of Hawaii Press; 1992.
10. Gon S III, Winter K. A Hawaiian renaissance that could save the world. Am Sci. 2019;107(4):232-9.

11. Lepofsky D, Smith NF, Cardinal N, Harper J, Morris M, White G, et al. Ancient Shellfish Mariculture on the Northwest Coast of North America. Am Antiq. 2015;80(2):236-59. doi: 10.7183/0002-7316.80.2.236
12. FAO. GIAHS: Globally Important Agricultural Heritage Systems. Rome (Italy): FAO; 2019.
13. Costa-Pierce BA. The anthropology of aquaculture. Front Sustain Food Syst. 2022;6:843743. doi: 10.3389/fsufs.2022.843743
14. FAO, Fisheries and Aquaculture Management Division. Aquaculture development. 4. Ecosystem approach to aquaculture. Rome (Italy): FAO; 2010.
15. Costa-Pierce, BA. Aquaculture, ecological. In: Sustainable Food Production. New York (NY, US): Springer; 2013. doi: 10.1007/978-1-4614-5797-8_172
16. FAO. Sustainable aquaculture guidelines. Rome (Italy): FAO; 2025.
17. Allen C, Malekpour S, Weitz N, Bennich T, Pedercini M, Sagar A, et al. A theory of change approach to enhance the post-2030 sustainable development agenda. Science. 2026;391(6782):241-4. doi: 10.1126/science.adz5704
18. Biermann F, Hickmann T, Sénit CA, Beisheim M, Bernstein S, Chasek P, et al. Scientific evidence on the political impact of the Sustainable Development Goals. Nat Sustain. 2022;5:795-800. doi: 10.1038/s41893-022-00909-5
19. Costa-Pierce BA, Page GG. Aquaculture, Sustainability Science in. In: Sustainable Food Production. New York (NY, US): Springer; 2013. doi: 10.1007/978-1-4614-5797-8_175
20. Sahle M, Lahoti SA, Lee SY, Brundiers K, van Riper CJ, Pohl C, et al. Revisiting the sustainability science research agenda. Sustain Sci. 2025;20:1-19. doi: 10.1007/s11625-024-01586-3
21. Linnér BO, Wibeck V. Sustainability transformations: Agents and drivers across societies. Cambridge (UK): Cambridge University Press; 2019.
22. Toonen H, Bush S, Ibarra R, O'Sullivan C, Hudson E, Asif F, et al. Aquaculture governance indicators: A diagnostic framework for steering towards sustainability. PLOS Sustain Transform. 2025;4(4):e0000165. doi: 10.1371/journal.pstr.0000165
23. Woltering L, Fehlenberg K, Gerard B, Ubels J, Cooley L. Scaling–from "reaching many" to sustainable systems change at scale: A critical shift in mindset. Agric Syst. 2019;176:102652. doi: 10.1016/j.agsy.2019.102652
24. Kaplinsky R, Morris M. Handbook for value chain research. Ottawa (ON, Canada): IDRC; 2001.
25. Steffen W, Richardson K, Rockström J, Cornell S, Fetzer I, Bennett E, et al. Planetary boundaries: Guiding human development on a changing planet. Science. 2015;347(6223):1259855. doi: 10.1126/science.1259855
26. Earth Charter Commission. The Earth Charter. 2000. Available from: https://earthcharter.org. Accessed on 2026 May 15.
27. FAO. Fisheries and aquaculture in the context of the 2030 Agenda: Scaling up sustainable and equitable solutions. Rome (Italy): FAO; 2021.
28. Weirich CR, Swann L, Garber N, Rath MA. NOAA National Sea Grant College Program's Support of Aquaculture and Its Current Aquaculture Investment Portfolio. Oceanography. 2024;37(1):92-8. doi: 10.5670/oceanog.2024.234

29. Guillen J, Asche F, Carvalho N, Fernández Polanco JM, Llorente I, Nielsen R, et al. Aquaculture subsidies in the European Union: Evolution, impact and future potential for growth. Mar Policy. 2019;104:19-28. doi: 10.1016/j.marpol.2019.02.045
30. Troell M, Costa-Pierce BA, Stead S, Cottrell RS, Brugere C, Farmery AK, et al. Perspectives on aquaculture's contribution to the Sustainable Development Goals for improved human and planetary health. J World Aquac Soc. 2023;54(2):251-342. doi: 10.1111/jwas.12946
31. International Integrated Reporting Council (IIRC). Integrated reporting framework. 2021. Available from: https://www.ifrs.org/issued-standards/integrated-reporting/. Accessed on 2026 May 15.
32. Musinguzi L, Lugya J, Rwezawula P, Kamya A, Nuwahereza C, Halafo J, et al. The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters. J Great Lakes Res. 2019;45(6):1340-1347. doi: 10.1016/j.jglr.2019.09.011
33. Garlock TM, Asche F, Anderson JL, Eggert H, Anderson TM, Che B, et al. Environmental, economic, and social sustainability in aquaculture: the aquaculture performance indicators. Nat Commun. 2024;15:5274. doi: 10.1038/s41467-024-49556-8
34. UN-Habitat. World Cities Report 2022: Envisaging the Future of Cities. Nairobi (Kenya): UN-Habitat; 2022.
35. United Nations Department of Economic and Social Affairs (UN DESA), Population Division. World Urbanization Prospects 2025. New York (NY, US): UN DESA; 2025.
36. UNSD. Statistical Yearbook 2024. New York (NY, US): United Nations; 2024.
37. Engle CR, Kumar G, van Senten J. Cost drivers and profitability of US pond, raceway, and RAS aquaculture. J World Aquac Soc. 2020;51(4):847-73. doi: 10.1111/jwas.12706
38. Tezzo X, Bush SR, Oosterveer P, Belton B. Food system perspective on fisheries and aquaculture development in Asia. Agric Hum Values. 2020;38:73-90. doi: 10.1007/s10460-020-10037-5
39. Haylor G, Bland S. Integrating aquaculture into rural development in Coastal and Inland Areas. In: Aquaculture in the Third Millennium. Bangkok (Thailand)/Rome (Italy): NACA/FAO; 2001; p. 73-80.
40. Filipski M, Belton B. Give a Man a Fishpond: Modeling the Impacts of Aquaculture in the Rural Economy. World Dev. 2018;110:205-223. doi: 10.1016/j.worlddev.2018.05.023
41. Knapp G, Rubino M. The Political Economics of Marine Aquaculture in the United States. Rev Fish Sci Aquac. 2016;24(3). doi: 10.1080/23308249.2015.1121202
42. Martin SJ, Mather C, Knott C, Bavington D. 'Landing' salmon aquaculture: Ecologies, infrastructures and the promise of sustainability. Geoforum, 2021;123:47-55. doi: 10.1016/j.geoforum.2021.04.025

43. Vielma J, Kankainen M, Setälä J. Current status of recirculation aquaculture systems (RAS) and their profitability and competitiveness in the Baltic Sea area. Natural Resources and Bioeconomy Studies 75/2022. Helsinki (Finland): Natural Resources Institute Finland; 2022.
44. Young N, Brattland C, Digiovanni C, Hersoug B, Johnsen JP, Karlsen KM, et al. Limitations to growth: Social-ecological challenges to aquaculture development in five wealthy nations. Mar. Pol. 2019;104:216-24. doi: 10.1016/j.marpol.2019.02.022
45. Atlantic Sapphire. Aquaculture Innovation. Available from: https://atlanticsapphire.com/innovation/. Accessed on 2026 May 15.
46. The Fish Site. 100,000 tonne underground salmon farm seals genetics deal. Available from: https://thefishsite.com/articles/100-000-tonne-underground-salmon-farm-seals-genetics-deal. Accessed on 2026 May 15.
47. Müller C. Releasing agriculture from the food security mandate. Science 2026;391(6790):1085. doi: 10.1126/science.aeg4691
48. Costa-Pierce BA. Radical aquaculture: Transformational social-ecological systems that advance Sustainable Development Goals (SDGs). World Aquac. 2021;52(4):18-32.
49. Pérez Agúndez JA, Filgueira R, Ahmed N, Asif F, Billing SL, Fanning L, et al. Strengthening policy action to tackle social acceptability issues in European aquaculture. ICES J Mar Sci. 2025;82(7):fsaf100. doi: 10.1093/icesjms/fsaf100
50. OECD. The Ocean Economy to 2050. Paris (France): OECD.
51. Everett S, Aitchison C. The role of food tourism in sustaining regional identity: A case study of Cornwall, South West England. J Sustain Tour. 2008;16(2):150-67. doi: 10.2167/jost696.0
52. Lowitt, K. The Reinvention and Performance of Traditional Newfoundland Foodways in Culinary Tourism in the Bonne Bay Region. Newfoundland Labrador Stud. 2021;27(1):63-78.
53. Doiron S, Weissenberger S. Sustainable dive tourism: Social and environmental impacts—The case of Roatan, Honduras. Tour Manag Perspect. 2014;10:19-26. doi: 10.1016/j.tmp.2013.12.003
54. Gössling S, Hall C. Tourism and global environmental change: Ecological, Economic, Social and Political Interrelationships. London (UK); Routledge; 2006. doi: 10.4324/9780203011911
55. Belias C, Vassilis G, Dassenakis M, Scoullos M. Environmental impacts of coastal aquaculture in eastern Mediterranean bays: the case of Astakos Gulf, Greece. Environ Sci Pollut Res Int. 2003;10(5):287-95. doi: 10.1065/espr2003.06.159
56. Waycott B. Aquaculture tourism: an unexpected synergy for the blue economy. Available from: https://www.globalseafood.org/advocate/aquaculture-tourism-an-unexpected-synergy-for-the-blue-economy/. Accessed on 2026 May 15.
57. Helgadóttir G, Renssen H, Olk TR, Oredalen TJ, Haraldsdóttir L, Skúlason S, et al. Wild and farmed Arctic charr as a Tourism Product in an Era of Climate Change. Front Sustain Food Syst. 2021;5:654117. doi: 10.3389/fsufs.2021.654117

58. Budhathoki M, Pounds A, Younes JA, Baltadakis A. Little DC. Mariculture in Natural Environments: Tourists' Attitudes Towards Aquaculture During Marine Tours in Oban, Scotland. Sustainability. 2025;17(2):710. doi: 10.3390/su17020710
59. Martineau C. Beauty and Brine: Prince Edward Island Is an Oyster-Lover's Paradise. Available from: https://www.bonappetit.com/story/pei-oysters. Accessed on 2026 May 15.
60. F3 Aquaculture Tourism. Available from: www.youtube.com/@F3AquacultureTourism. Accessed on 2026 May 15.
61. FAO. Noto's Satoyama and Satoumi, Japan. Available from: https://www.fao.org/giahs/giahs-around-the-world/japan-noto-satoyama-and-satoumi/en Accessed on 2026 May 15.
62. Salmon Eye-World's largest floating art installation. Available from: https://hardangerfjord.com/en/attractions/salmon-eye-a-aquaculture-learning-experience-6788353. Accessed on 2026 May 15.
63. Armbrecht J, Skallerud K. Attitudes and intentional reactions towards mariculture development–local residents' perspective. Ocean Coast Manag. 2019;174:56-62. doi: 10.1016/j.ocecoaman.2019.03.017
64. Sutherland J, Armbrecht J. Media representation of aquaculture in Sweden. Aquaculture. 2024;583:740578. doi: 10.1016/j.aquaculture.2024.740578
65. Troell M, Robertson-Andersson D, Anderson RJ, Bolton JJ, Maneveldt G, Halling CT, et al. Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. Aquaculture. 2006;257:266-81. doi: 10.1016/j.aquaculture.2006.02.066
66. Msuya FE. Environmental changes and their impact on seaweed farming in Tanzania. World Aquac. 2011;71(4):34-7.
67. The Catfish Institute. Available from: https://uscatfish.com/catfish-trail. Accessed on 2026 May 15.
68. Segerson K, Polasky S, Scheffer M, Sumaila UR, Cárdenas JC, Nyborg K, et al. A cautious approach to subsidies for environmental sustainability. Science. 2024;386(6717):28-30. doi: 10.1126/science.ado2615
69. European Court of Auditors. The Effectiveness of European Fisheries Fund Support for Aquaculture. Special Report Nº. Luxembourg (Luxembourg): European Court of Auditors; 2014.
70. European Court of Auditors. EU aquaculture policy–Stagnating production and unclear results despite increased EU funding. Special Report No. 25/2023. Luxembourg (Luxembourg): European Court of Auditors; 2023.
71. Stead SM. Using systems thinking and open innovation to strengthen aquaculture policy for the United Nations Sustainable Development Goals. J Fish Biol. 2019;94(6):837-44. doi: 10.1111/jfb.13970
72. World Bank. Harnessing the Waters: global strategy for aquaculture. Washington (DC, US): World Bank; 2025.

73. misPeces. EPPO Charges Nine Individuals and Five Italian Companies in €4.5 Million Aquaculture Fraud Case. Available from: https://www.mispeces.com/en/news/EPPO-Charges-Nine-Individuals-and-Five-Italian-Companies-in-4.5-Million-Aquaculture-Fraud-Case. Accessed on 2026 May 31.
74. stratsea. Hard Lessons from eFishery's Fishy Business. Available from: https://stratsea.com/2025/04/30/hard-lessons-from-efisherys-fishy-business/. Accessed on 2026 May 30.
75. Cunha IGF, Policarpo RVS, Oliveira PCS, Abdala EC, do Nascimento Rebelatto DA. A systematic review of ESG indicators and corporate performance: proposal for a conceptual framework. Future Bus J. 2025;11:106. doi: 10.1186/s43093-025-00539-1
76. Arena M, Conte A, Melacini M. Linking environmental accounting to reward systems: the case of the Environmental Profit and Loss Account. J Clean Prod. 2015;108(Part A):625-36. doi: 10.1016/j.jclepro.2015.07.068
77. Varyash I, Mikhaylov A, Moiseev N, Aleshin K. Triple bottom line and corporate social responsibility performance indicators for Russian companies. J Entrep Sustain Issues. 2020;8(1):313-29. doi: 10.9770/jesi.2020.8.1(22)
78. FAO. The 2030 Agenda and the Sustainable Development Goals: The challenge for aquaculture development and management. Rome (Italy): FAO; 2017.

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