Sustainability Potentials of Integrated Multi-Trophic Aquaculture

Subjects: Fisheries

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Integrated multi-trophic aquaculture (IMTA) systems integrate the cultivation of species from different trophic levels. Uneaten feed, solid wastes, and dissolved nutrients are turned into harvestable and healthy food, making IMTA a driver for ecologically sustainable aquaculture. Its wider sustainability potentials arise from social, environmental, and economic sustainability enhancement options.

Keywords: IMTA ; coastal aquaculture ; sustainable aquaculture

1. Introduction

Aquaculture is the food-producing sector with the highest annual growth rate [1]. Production has increased steadily over the past three decades and will likely continue to do so in the future to ensure the needs of a more populous and affluent world [1]. Aquaculture is widely recognized as an important strategy for food security and poverty eradication [2], addressing at least seven of the 17 United Nations Sustainable Development Goals (UN SDGs) [3], and it plays an important role in ensuring human food security and nutrition in the future, as wild fisheries fail to meet the demand for aquatic products [4]. Fish contributes to around 20% of total animal protein intake [5] and is one of the cheapest sources of animal protein. Over recent decades, the contribution of aquaculture to global fish output has increased, reaching 82.1 million tons (46%) of the estimated 179 million tons of global production in 2020, and this is expected to rise to 53% by 2030 [4]. This is mostly due to the commercialization of farm-raised aquatic animals such as shrimp, salmon, bivalves, tilapia, and catfish [6]. With the growing scarcity of freshwater, aquaculture growth may increasingly occur in marine and coastal environments. Ongoing environmental change processes, global population growth, and fisheries and food availability trends also imply a steadily increasing role for coastal aquaculture across the globe. This has raised concerns about environmental consequences and conflicts of aquaculture with other coastal uses in Europe, North America, Australia, and Asia [6]. At the same time, the available space for coastal aquaculture is altering: by 2080, sea level rise is expected to have turned approximately twenty percent of coastal wetlands into marine spaces [7].

The use and wastage of aquaculture feeds can negatively affect surrounding ecosystems. Feed waste and faecal production contribute to significant organic matter and nutrient loadings in marine and coastal ecosystems. Feed wastage can reach up to 38%, and this is one of the most significant sources of pollution [8][9]. Several countries have also imposed restrictions on the practice of chemotherapeutic agents and reduced the use of feed additives, such as antibiotics and oil, in aquaculture feeds [10][11], rendering classical single cultivar aquaculture less viable. Nonetheless, current aquaculture practices cause the eutrophication of coastal and other aquatic systems [12]. It is important to increase the understanding of how intensive and single species (monocultural) aquaculture generates deleterious environmental and social impacts. This has raised interest in ecosystem-based aquaculture such as integrated multi-trophic aquaculture (IMTA) [13][14].

IMTA integrates aquatic organisms from various trophic levels in order to mimic ecosystem functions [15][16][17][18][19]. Waste material from production in higher trophic layers (i.e., of finfish and crustaceans) serves as food for organisms cultivated at lower trophic levels that transform the otherwise wasted and polluting resources into valuable products. Waste is thus minimized or eliminated and the overall productivity of the food system boosted [20][21][22]. It has been argued that IMTA is capable of supporting ecologically, environmentally, and socially viable aquaculture with economic viability [23]. By using the by-products of some cultivars to produce further useable or marketable plants and animals, it may support ecological sustainability through biomitigation, economic security through product diversification and risk mitigation, societal acceptance through better management, and social sustainability through a wider spread of aquaculture benefits than what is possible through conventional aquaculture. The main potentials of IMTA are thus environmental neutrality, economic viability, and social sustainability [24], although MTA can improve the long-term viability of aquaculture by generating environmental, economic, and social benefits. All this notwithstanding, implementation over the past decades has been low [16][25].

2. Sustainability Potentials of IMTA

2.1. Environmental Sustainability

Population growth increases demand for food, but global resources cannot indefinitely satisfy this demand [26]. Environmental sustainability is concerned with pollution control, the wise and effective use of natural resources, ecosystem integrity and the carrying capacity of the natural environment [27]. One of the most harmful environmental effects of coastal aquaculture is the release of polluted effluents containing uneaten feed and faeces. By increasing nutrients in the water, particularly nitrogen and phosphorus, a phenomenon also denominated as “organic enrichment”, it degrades receiving water bodies and sediments [28]. IMTA may turn aquaculture more sustainable by removing nitrogen and phosphorus from the water column, thus mitigating eutrophication and lowering biological degradation risks [29]. Improved coastal aquaculture waste management also reduces the risk of disease transmission and allows for higher quality production by improving water quality. The treatment of wastes from aquaculture requires the development of sustainable coastal aquaculture. The utilization of IMTA systems and the microbial nitrification and denitrification that occurs in sediments play an important role here [28][29].

Assimilative biofiltration by algae increases the environmental capacity for nutrient assimilation. Macroalgae are an efficient instrument for bioremediation because they can absorb anthropogenic nutrients [28]. Seaweeds are best suited for biofiltration since they have the highest productivity of all plants, as well as high economic potential [21]. An Atlantic Coast IMTA study that focuses on algae (Rhodophyta) with fish (turbot *Scophthalmus maximus*, and sea bass *Dicentrarchus labrax*), also identified algae as great candidates for biofiltering and wastewater reduction [24]. Research has also been conducted on *Gracilaria bursa-pastoris*, *Gracilaria gracilis*, *Chondrus crispus*, *Palmaria palmata*, *Porphyra dioica*, *Asparagopsis armata*, *Gracilariopsis longissima*, *Ulva rotundata* (Rhodophyta), and *Ulva intestinalis* (Chlorophyta) as biofiltration in IMTA approaches. Experimental studies have continued on the integration of algae with sea bass and turbot [30][31]. *Gracilaria bursa pastoris* had the best yields and nitrogen absorption efficiency of the three species examined (*Gracilaria bursa pastoris*, *Chondrus crispus*, and *Palmaria palmata*), and was thus recommended as the best choice for integration with sea bass or turbot [31]. *Ulva rotundata*, *Ulva intestinalis*, *and Gracilaria gracilis* were co-cultivated with sea bass and found to be effective biofilters of phosphate (PO_4^{3-}) and ammonium (NH_4^+) from waste waters [32].

2.2. Economic Sustainability

Economic sustainability requires the use, recycling, and protection of human and material resources in ways which create sustainable values over the longer term [33]. Economic sustainability also calls for a production system that meets consumption needs without jeopardizing future requirements [34]. Human life on Earth is nourished and perpetuated by utilizing the limited natural resources available [35]. The profit component of sustainability is concerned with achieving economic growth, resource efficiency, and the financial viability of businesses [36].

Blue mussel (*Mytilus edulis*) near commercial salmon farms in the Bay of Fundy, Canada, developed 20 percent faster than those at reference locations further away, indicating that harvested mussel production is higher in an integrated aquaculture system than in a monocultural one [37]. Evidence from the BIOFAQs project on the west coast of Scotland supports this. Here, mussel growth was considerably higher at a site within 10 m of a salmon farm than at a control site 500 m away [38]. The mussel lines acted as in situ biofilters, and increased growth of the mussels was linked to the use of organic waste from the salmon farm. Economic research has focused on the diversity of benefits for growers, consumers, and society that result from the implementation of IMTA systems [39]. A study of South African abalone farming shows that IMTA can stabilize seafood supply by increasing product diversity and reducing market risks from price volatility, as well as increase job diversity by providing high-pay jobs for trained personnel while offering lower-pay jobs for untrained people in peripheral locations [40]. Invertebrates, seaweeds, and detritivorous fish may be economically beneficial in terms of supplying local consumption needs, while high-value fish and shrimp are exported for foreign currency. Implementing IMTA improves waste assimilation capabilities at farm level and in the wider environment. This may be a main reason why IMTA today is practised most widely in China [41][42].

2.3. Social Sustainability

Social sustainability has been conceptualized to include equity, empowerment, access, involvement, cultural identity, and institutional stability [43]. It has also been related to poverty reduction and deemed essential to help achieve a meaningful life by focusing on sound health care, nutrition, education, peace, and stability around the globe [44][45]. Social sustainability has also been related to human rights, gender equity, public engagement and participation, and the rule of law in promoting peace and social stability for sustainable development [46][47]. A conceptual framework for elaborating context-specific working definitions of the social dimension in ecosystem management comprises seven criteria: (1) population and resource use; (2) poverty, basic needs and well-being; (3) equity and justice; (4) social and human capital; (5) participation, management and governance; (6) resilience, vulnerability, and adaptive capacity; and (7) collaborative learning and reflexivity [48][49]. The Sustainable Europe Research Institute [50] proposes that social sustainability is "a distinct feature of sustainable development that is equally as vital as the economic or environmental dimensions", but that it is still underappreciated by scientists and policymakers alike. In economic and environmental systems, flows and cycles tend to be readily observable. In contrast, social interactions can be more intangible and more difficult to model [51][52]. Sustainable development in agriculture, forestry, fisheries and also in aquaculture conserves land, water, plant, and animal resources while remaining environmentally non-degrading, technically feasible, economically successful, and socially equitable and benign and socially acceptable [53]. Aquaculture is a diversified industry and its effects, particularly on the environment, vary with species, farming methods, local environmental conditions, and socioeconomic context [54].

Fish farms employ 18.7 million people worldwide, and this number rises three- to four-fold when secondary and post-harvest jobs are factored in [55]. Each employed person supports up to four dependents [56]. Aquaculture is thus a major contributor to global welfare, providing jobs and the potential for positive social change. It can result in enormous societal advantages in terms of food production, infrastructural development, and employment possibilities (e.g., India, Bangladesh) [57]. However, there is still a lot of contextual heterogeneity among communities when it comes to aquaculture [57], and many key concerns remain unsolved. Finfish aquaculture appears to have a greater positive impact than rope mussel farming; however, the latter can hold important cultural values and contributes to place-based understanding, connecting people with place and identity, and thus, it plays a critical role in the preservation of the working waterfront identity [58].

Most knowledge of aquaculture's social effects is produced in the Global South. In industrialized Global North countries, aquaculture generates employment and infrastructure, particularly in rural areas. Here, aquaculture suffers from a lack of high-paying employment opportunities and workers willing to accept low-paying menial positions. There have been only a few sociological studies conducted on aquaculture in the Global North [59], while research continues to focus on economic and societal conflicts surrounding resource utilization and environmental concerns in the Global South. This has promoted regulatory responses that are becoming more rigorous and expensive [60][61]. The concept of "social license", defined as "the needs and expectations on a business by neighborhoods, environmental groups, community members", is gaining importance in democratic countries of the Global North [62]. Studies on the social and economic impacts of aquaculture that are conducted with a broad range of stakeholders contribute to better understanding of and, consequently, a higher level of trust in aquaculture activities across the globe [63].

Aquaculture has negative social impacts if it contracts or collapses, for instance, because of disease outbreaks, food safety issues, or natural disasters [64]. As coastal aquaculture expands, new expertise is needed to comprehend environmental and social implications and develop new cultivation techniques on the basis of integrated system understanding [65]. A contextualized systems perspective [66] is needed to identify the diverse sustainability implications of an intervention such as IMTA [67]. A recent study on Canadian customers' views of IMTA products identifies "double needs" among consumers: firstly, to consume the purchased product; secondly, for the production and consumption of the purchased product to safeguard the natural environment. The same study finds that consumers were more interested in the "usefulness" of IMTA products than in their price or quality [68][69]. Environmentalism (understood as environmental concern and 'perceived consumer effectiveness' (PCE) [68], refers to how confident a consumer is that they can obtain the results they want and value [70]). This "perceived social welfare" was found to affect purchasing behaviour.

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