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Review

# Resilience of Communities and Sustainable Aquaculture: Governance and Regulatory Effects

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**Abstract:** One of the key underlying principles of sustainable food and agriculture systems is to enhance the resilience of people, communities, and ecosystems. This paper discusses broadly the intersection of community resiliency and sustainability of our food system through the lens of positive and negative contributions of aquaculture within the context of the underlying environmental, economic, social, and governance dimensions. Aquaculture has been part of the food supply system for humans for millennia, and its contributions to the resiliency of communities and to sustainability is critical to meet the nutritional, economic, and ecological challenges of the world. Aquaculture, as any human endeavor, can result in negative impacts on the environment, economy, social structure, and resilience of communities. Recent work has reported continued progress in the sustainability of aquaculture and dispelled myths that have proliferated in public media. As a result, aquaculture is increasingly viewed as a potential solution to global challenges of supplying a sustainably raised protein source, complementing fishing and other activities in communities, improving water quality, and responding to climate change, among others. Communities face ever more complex pressures that affect their resiliency when confronted with an array of environmental, social, and economic challenges. Whether aquaculture enhances or decreases the resilience of communities depends largely on the regulatory framework and associated public governance policies at local, state/provincial and national levels. In locales where aquaculture is under-regulated, communities can be affected negatively from resulting environmental, economic, and social problems. Over-regulation of aquaculture can stifle aquaculture activities that enhance ecosystem services and provide social and economic benefits. Greater attention is needed to aquaculture governance and regulatory processes to ensure that rulemaking, implementation, and enforcement provide adequate oversight, but avoid unintended negative consequences to the environment, social networks, and local economies. Participatory approaches that entail effective engagement among regulatory agency staff, aquaculture producers, local citizens, and other stakeholders are more effective than command-and-control regulatory approaches. Aquaculture, when practiced responsibly and sustainably by farmers and when appropriate science-based regulations are implemented rationally and efficiently, can enhance the resiliency of communities.

**Keywords:** sustainability; resilience; aquaculture development; aquaculture governance; small-scale farms; communities



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## 1. Introduction

There is growing recognition that sustainable aquaculture can contribute in substantive ways to address global nutritional, economic, and environmental challenges [1,2]. Aquaculture, as any human endeavor, has the potential to have either positive or negative impacts on the environment and on local communities. Over the past decades, various allegations have been made with regard to aquaculture [3], with coastal and marine aquaculture bearing the brunt of the criticisms [4]. Over time, however, an increasing body of research data has shown that many forms of aquaculture have been practiced in a sustainable manner, and additional progress continues to be made [2].

Sustainability, however, encompasses much more than just environmental sustainability. At the heart of the sustainability of food and agriculture systems is the intersection of communities, ecosystems, economies, and their resilience to a wide array of external shocks [5]. While aquaculture is of some relevance to all 17 Sustainable Development Goals of the Food and Agriculture Organization of the United Nations, aquaculture is of especial relevance to those related to food security, economic growth, and employment [6]. Specific Sustainable Development Goals referenced include: #2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture; #8 Decent work & economic growth; #11 Sustainable cities & communities; #12 Responsible consumption & production; and #14 Conserve and sustainably use the oceans, seas and marine resources for sustainable development. Thus, development of indicators of sustainability and resource-use efficiency address not just environmental interactions, but include those related to economic and social sustainability [7,8]. Much of the literature on sustainability of aquaculture has drawn from the concept of "carrying capacity" developed [9] to describe the upper limit of a given population that can be supported by any given ecosystem. Use of the environmental carrying capacity concept was further suggested as a way to operationalize sustainable development [10] and, in subsequent years, greater research attention has been given to the use of carrying capacity as the basis for site selection for aquaculture development [11]. Carrying capacity concepts have been further expanded to include social perspectives. "Social carrying capacity" was defined as the level of development that is supported in an area without resulting in adverse social effects [12]. Other work [13] further reviewed various approaches to measuring the impacts of aquaculture from physical, production, ecological, and social perspectives. The emphasis in this strand of research literature is on ways to prevent harm to ecosystems from aquaculture development. Other perspectives in the literature question whether environmental constraints are absolute or whether they vary with the level of technology and governance structure [6]. Examination of the modern seafood sector supported the philosophic contention of John Stuart Mill that scarcity induces innovation (the innovations referenced included technological, market, and policy innovations) rather than the Malthusian perspective that scarcity necessarily imposes limits to human well-being [14].

The resilience of communities, however, is distinct from the concept of sustainability in that it focuses on the ability of a community to recover from various external shocks. Clearly, communities that cannot recover from external shocks are not sustainable. The resilience literature, however, has developed independently from that of the sustainability literature. The roots of the resilience literature lie in an engineering focus on system stability developed in the 1950s with an emphasis on return to an equilibrium following a disruption [15], whereas the sustainability literature has grown largely from the carrying capacity concept that is foundational to the discipline of ecology. Resilience initiatives have focused more on recovery from natural disasters [16–23], but have also recognized that external shocks such as global pandemics, civil unrest, political instability, and economic shocks (i.e., recessions, depressions, trade conflicts, financial collapse) can pose equally serious challenges to community resilience [24,25]. Research on resilience has evolved conceptually as researchers and practitioners have recognized the complexity of underlying dimensions of resilience [21,26–29] as have the lines of research on sustainability. Current thought in both strands of research literature recognizes that community resilience and sustainability are affected through the intersection of its environmental, social, economic, and governance dimensions (Figure 1).

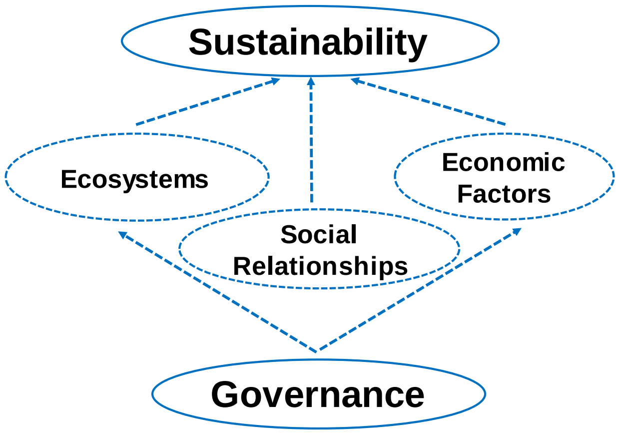


**Figure 1.** Dimensions of sustainability and community resilience.

Communities face increasing pressures from changing economic, environmental, and social conditions. Balancing these often-competing interests in communities is a challenge compounded by external shocks from natural and economic disasters, such as the COVID-19 pandemic. The COVID-19 pandemic was an unprecedented global disaster that created economic and social disruptions around the world. While the severity of the effects varied over time and across countries and regions, few if any communities were unaffected. As an example of the magnitude of the pandemic, detailed surveys in the U.S. found that 90% of aquaculture farm businesses experienced impacts from the pandemic and the ensuing economic shutdowns [30]. The initial effect was a sudden and dramatic loss of revenue when restaurants closed in response to shelter-at-home orders with corresponding sudden losses of revenue [31]. Given that the majority of seafood is consumed away from home in the U.S., the restaurant closures in 2020 created severe cash flow deficits for aquaculture farms as the pandemic was prolonged and the economic effects deepened. Aquaculture farms reported having to lay off employees and contend with labor disruptions as employees became either sick or were absent from work due to personal or family quarantine.

While a great deal of research has focused on measuring the limits to aquaculture production to reduce or prevent negative impacts, little research has examined broadly the intersection of aquaculture with the resilience of communities and their ability to recover from external shocks. This paper pulls from the community resilience literature to review what is known about the intersection of aquaculture with the environment, social factors, economics, and the degree of governance, all within the context of the need for sustainable communities, ecosystems, and economies. A comprehensive review of the breadth and depth of literature on aquaculture and the various dimensions of resilience and sustainability generally would be a lengthy treatise. Hence, this paper focuses on examples of both positive and negative contributions of aquaculture to resilience and sustainability, and the governance factors that play a major role in the end effect.

The paper proceeds first with a description of how aquaculture intersects with the environmental, social, economic, and governance dimensions of resilience and sustainability. Literature on the intersection with the environment focuses primarily on water quality, biodiversity, and use of antibiotics and chemicals. The social dimension addresses community relationships, networks, cultural heritages, and user conflicts over public resources, gender issues, and social license. The economics dimension is discussed in broad terms that include evidence of economic contributions to employment opportunities, value-added economic activity, diversification of economic opportunities, and interactions with fisheries supply chains and working waterfronts. Governance factors present examples of “under-regulation” that result in negative effects on resilience, and “over-regulation” that restricts the potential contributions of aquaculture to resilience. While beyond the scope of this paper to attempt to identify an “optimal” level of regulation, references are made to previous work that discuss what "good governance" of aquaculture entails [32–34]. Finally, suggestions for moving forward through regulatory reform and future research on aquaculture and effects on resilience and sustainability are discussed.

## 2. Environmental Dimension of Aquaculture, Sustainability, and Community Resilience

Environmental quality plays an important role in sustainability and the resilience of communities to external shocks. Ecosystem degradation can increase sensitivity to natural hazards, such as flooding [24], and conservation of species biodiversity provides greater stability of ecosystem services for the community [35]. Environmental air and water quality affect health outcomes of residents as well as the attractiveness of the community and its ability to recruit businesses and a productive workforce.

Aquaculture farms in some areas have caused negative environmental impacts. Some early shrimp farms were poorly sited, designed, and operated, which negatively affected the environment [36]. Effects included salination of adjoining farmland and drinking water sources, and destruction of common property mangrove wetland areas [37]. In the Philippines, nutrient pollution from cage culture [38], the loss of mangroves, destruction of bycatch from seed and broodstock collection, misuse of chemicals, and release of wastes have been reported [39]. Destruction of habitat for shrimp pond construction has, however, decreased notably since 2000 [40,41]. Un-regulated use of antibiotics and other chemicals in aquaculture [42–45] and livestock production in some countries has led to residual levels of compounds of concern in the environment and in aquatic products consumed by local populations [46,47]. In China, nutrient discharge from aquaculture represents 20% of the total nutrient input into freshwater systems [48], that are major sources of drinking water [49].

On the other hand, when managed responsibly and sustainably, aquaculture has the potential to assist with addressing environmental challenges [50]. The pressure for animal protein from wild fish stocks is reduced through farmed aquaculture rather than wild-caught supply [51]. Shellfish and seaweed aquaculture enhance ecosystem resilience [52,53] in important ways by restoring water quality [54–56], eutrophication control through nutrient uptake by shellfish [57] and farmed seaweed [58–60], creating habitat [12,61–63], and delivery of food to higher trophic levels [57,64].

Various approaches have been used to model the complexities of various marine sites to estimate the carrying capacity of shellfish aquaculture to identify new aquaculture sites for bivalve aquaculture [65]. A mass-balance model used to calculate the ecological carrying capacity of Narragansett Bay in Rhode Island, USA, showed that the biomass of cultured oysters in the bay could be increased by several orders of magnitude without exceeding the ecological carrying capacity of the Bay [66].

Aquaculture has further served as the central focus point for sustainable circular economies in which near-subsistence fish farms practiced fish polyculture in ponds integrated with animal and plant cropping systems that recycled farm resources through multiple crops [67]. While such integration of aquatic and terrestrial farming is primarily associated with farms in Asia, it has been applied in economies as distinct as Panama [68] and the United States [69]). Water productivity increases when aquatic and terrestrial crops re-use pond water and other resources and through production intensification [70]. Economic analyses have shown that intensification of production of aquaculture resulted in improved economic efficiencies of shrimp production in Vietnam and Thailand [71] and across a wide range of aquaculture species and production systems in the U.S. [72].

Despite the many advances in sustainable production methods, aquaculture, particularly in marine environments, has been portrayed by some environmental organizations as detrimental to the environment. While specific allegations vary by locale and region, three-fourths of the papers published from 2000 to 2020 on aquaculture interactions with the environment were focused on mariculture [2], even though freshwater aquaculture produces 86% of total farmed finfish production globally [1]. In the U.S., many of the concerns expressed have focused on salmon net pen farming despite abundant evidence of the use of responsible management practices [73–77]. Interestingly, despite calls to convert farmed production to land-based recirculating aquaculture systems (RAS), many of those same organizations now oppose approval of permits for RAS farms in the U.S.

Nine myths related to marine aquaculture in the U.S. were identified as: "(1) federal regulations, permitting and environmental review processes are inadequate to manage offshore fish farms, (2) marine net pens are factory farms that in US waters would contribute marine pollution caused by excess feed, untreated fish waste, antibiotics, and antifoulants, (3) offshore farms entangle marine animals, (4) farms displace marine animals from important habitats and farmers harm marine mammals, (5) escaped farm-raised fish adversely impact wild fish stocks, (6) fish feed includes colorants, (7) fishmeal and fish oil in fish feeds is unsustainable, (8) farm-raised fish will displace US fisheries and are cheap and of low quality, (9) American commercial fishing and marine finfish aquaculture cannot coexist" [4]. These nine myths, along with, unfounded criticisms, and false assumptions of marine aquaculture in the U.S. have been the basis for allegations of environmental damage that have largely been dispelled [4]. One illustrative example is that of the lawsuit filed against the U.S. Environmental Protection Agency (EPA) that led to a reevaluation of the Clean Water Act standards for aquaculture. Following four years of detailed water quality data collection and technical review, EPA determined that the existing standards for aquaculture (with some revisions) assured adequate environmental protection, a finding that was not challenged in court. In addition to allegations of water pollution, a major allegation has been the extent of use of fishmeal and fish oil. However, the use of fishmeal and fish oil in aquaculture has been reduced in diets for many species [2]. In the U.S., the majority of aquaculture feeds are utilized by the catfish industry for which feed formulations are essentially plant-based diets with little to no fishmeal [78]. This is not the case everywhere, however. China, Thailand, and Vietnam continue to rely on wild-caught fish [79], with one-third of Chinese domestic fishery landings (89% of which are juvenile fish) used for aquaculture feed.

## 3. Social Dimension of Aquaculture, Sustainability, and Community Resilience

Sustainability and community resilience occur within the framework of the social relationships of the community [80]. Communities with strong social support networks are better positioned to respond more effectively and rapidly to external shocks [81]. On the other hand, socio-political conflict can lead to reduced resilience and devastating long-term effects from external shocks, as documented in Aceh, Indonesia, in the aftermath of the tsunami [82].

Aquaculture farms have been integral parts of local communities from the times of the earliest fish farms millennia ago [36,83]. Many coastal areas have long histories of aquaculture-related traditions and cultural heritages, such as the French mussel farms that date back to the 13th century [84]. Shells have been used as religious symbols, sacred wampum beads, as works of art [36,85], and as symbols of a connection to place and identity [86]. Strong aquaculture-based traditions provide incentives for people to remain in their communities rather than out-migrate to urban areas.

The earliest fish farms provided food for family households, but fish were also used for sharing or trading with neighbors [36], and, when integrated efficiently with staple crops [87], can provide cash for medical, educational, and other expenses [88]. Present-day family farms, while small-scale businesses, continue to be integral components of many communities. Farms that supply sportfish for angling contribute to the social quality of life of the community [36]. Volunteer sport fishery associations around the world construct and maintain hatcheries to increase angling opportunities for their members, enhance tourism, and support subsistence fisheries.

Aquaculture farms that provide new employment opportunities for women and youth contribute to the social structure as long as effective governance structures provide protection for workers. New tensions can arise, however, if women must balance work, social, and family responsibilities in an un-supportive social context. Wage discrimination for women has been reported, and ineffective worker safety laws and enforcement can lead to dangerous work environments.

Strong social bonds and networks support effective community organizations and services, such as medical and mental health services that are necessary for community resilience and sustainability [35]. Eating more seafood has long been recognized to enhance health outcomes, and aquaculture has been reported to "improve community health through increased consumption of fish" [89]. Healthy individuals are more productive and better able to take advantage of educational opportunities.

Despite the many social benefits of aquaculture, social conflicts with aquaculture have occurred. Coastal communities often encompass a wide range of user groups that include fishing fleets, sport fishermen, tourists, officials of harbors and ports, and town governance officials as well as aquaculture farmers. These various user groups can come into conflict over use of common areas [39,90]. In Norway, local communities initially were supportive of salmon farming. Later farm consolidation, however, resulted in fewer, larger farms, increased local conflicts, and calls for regulatory limits to the expansion of aquaculture farms [91]. Government efforts to attract large, export-oriented farms primarily to generate tax revenue and foreign exchange, have created conflicts with local residents [36]. In Thailand and Vietnam, access to water and public lands was disrupted by large-scale aquaculture farms, creating animosities [37]. As a result of these types of conflicts, aquaculture development has been reported to marginalize poor people in coastal communities in developing countries [92].

Aquaculture has further been characterized as being composed of "factory farms" [93]. The reality is that more than 80% of aquaculture farms globally are family farms that are classified as small-to-medium-scale enterprises [94,95]. In developing countries, the large aquaculture farms use more capital-intensive production systems to produce for sale into global markets, but traditional aquaculture farms in the same countries are more labor-intensive, family-run farms [91]. In the U.S., 85% of aquaculture farms had gross sales of less than $500,000/year [96]. Family farming traditions that underly aquaculture are closely tied to local social networks and institutions that contribute to the cohesiveness of their communities. The social bonds of family aquaculture farms increase resilience and reduce vulnerabilities that often depend on social relationships [97]. As one example, aquaculture was found to contribute to local communities by enhancing food security among low- and middle-income populations [98].

Social conflicts can lead to the use of regulations to exert control. To avoid consequences of negative local opinions, mining companies in Canada and Australia developed social license initiatives [99]. Social license concepts have since been applied to wind energy [100], forestry [101], farming [102], and marine industries [103]. Social license relies upon interpersonal trust that occurs at the local level and is often influenced by individuals who are most trusted and respected within their community. For aquaculture, social license was found to be site specific in New Zealand [104], and public opinion on salmon farming in Scotland was found to be shaped by just a few individuals [105]. To foster positive relationships with local communities, some aquaculture farms have invested in medical, educational, and other facilities in local communities. Others have contracted smaller-scale farms as suppliers, and provided credit, production inputs, and technical assistance.

Yet, social license issues for aquaculture continue. Other examples of social conflicts related to aquaculture involve "Not-in-My-Backyard" ("NIMBY"). In Canada, opposition to site licenses for shellfish farms has severely constrained its growth, with respondents to a 2009 survey reporting that public opposition to aquaculture was "very detrimental" to aquaculture [106]. While shellfish aquaculture is widely recognized to result in environmental benefits, some wealthy homeowners on the coast have opposed shellfish farming because they do not wish to have buoys, lines, or working boats visible when looking out over the water [107].

## 4. Economic Dimension of Aquaculture, Sustainability, and Community Resilience

The community resilience literature shows that a wide variety of economic factors play important roles in the resilience and sustainability of communities (Table 1). Components of the economic dimension of community resilience include: (1) value-added economic activity; (2) creating and sustaining employment opportunities; (3) support for increased household spending; and (4) stimulating development of secondary businesses. Business activity from aquaculture farms or other enterprises generates the capital and revenue necessary to support lifestyle amenities enjoyed and expected by community residents and provides employment opportunities. Limited employment alternatives in a community often encourage outmigration that reduces demand for goods and services that support local businesses. Business development in communities is associated with reduction of vulnerabilities associated with poverty [108] and expands the base of financial resources available for response and recovery from external shocks [15]. A diverse business sector further offers a broad array of employment opportunities and greater economic stability through alternative means to sustain the economy if one particular business sector struggles.

**Table 1.** Dimensions and characteristics of a resilient community.

| Dimension | Description |
|---|---|
| Environmental (natural assets, quality, diversity, ecosystems & services) | Air, land, water, mineral resources; water quality, air quality; diversity in ecological systems; biodiversity; services, stability |
| Social (includes human and cultural) | Relationship patterns/social support; community bonds; social institutions & participation; social memory; access to services; trust & reciprocity; political engagement; volunteerism |
| Economic (Economic diversity, economic stability, economic development, investment in physical infrastructure) | Size and diversity of businesses and forms of economic livelihood, economic growth or contraction; physical infrastructure (Commercial & industrial buildings, schools, residential housing, response support facilities, power, transportation (bridges & roads), communications, water, wastewater treatment) |
| Governance (political, institutions; leadership, management & regulations) | Services, preparedness, disaster & emergency management experience & capacity; governance/regulatory |

Sources: [22,24,35,80,81,109–121].

Coastal aquaculture historically has consisted primarily of shellfish farms, many of which date back to the late 1800s in the U.S. [122]. Aquaculture technologies have expanded, however, to offer a variety of diverse business opportunities to farm hundreds of plant and animal species in various production systems, scales, and intensities [96]. For example, pond production of marine species for food and as ornamentals, nearshore seaweed farms, net pen farms nearshore and offshore, and recirculating aquaculture systems (RAS) have emerged as viable business options. Interest in restorative aquaculture to improve environmental quality has also increased [56].

Aquaculture farming businesses provide income and employment for many communities around the world [123] and offer potential for increased positive social and economic impacts upstream and downstream [124]. An early formal estimate of the economic contribution of U.S. aquaculture was $5.6 billion to Gross Domestic Product and 181,000 jobs [125]. Farms that support recreational fisheries have high multipliers ($36 of angler expenditures for every dollar spent on the fish stocked) [126]. Aquaculture was found to support more than 500 economic sectors. The IMPLAN-based input-output models used to estimate economic contributions use the North American Industrial Classification System (NAICS) to define "economic sectors." [127] The economic sectors identified range from grain farms that supply fish feed ingredients, to automotive repair and maintenance, transportation, retail trade, and other sectors [128,129]. In addition to direct, on-farm employment opportunities, aquaculture farms stimulate development of new upstream and downstream businesses that multiply the number of jobs in rural economies that often suffer from high unemployment [130–132].

While some fishing communities fear that farm-raised fish will displace fisheries [90], the increased farmed supply was found to increase total sales and consumption of wild and farmed shrimp and salmon, with wild product becoming a premium, higher-priced product [133]. Aquaculture can also support infrastructure (i.e., working waterfronts) for fishing activities and stimulate new supply chain actors. In Norway, aquaculture farms were found to benefit primarily local communities [91,134]. In Washington (U.S.), the 2012 economic contribution in one county alone was $90 M that stimulated new shucking and processing businesses that further increased economic and employment impacts [135]. The shellfish processing capacity in Virginia (U.S.) was a major reason for its greater economic impact ($81.2 million) [136] as compared to Maryland ($8.1 to $9.7 million) [137]. In Maine, economic contributions of aquaculture increased from $50 to $137 million from 2007 to 2014, fueled primarily by growth of Atlantic salmon, oyster and blue mussel farms [138].

Declining fishing stocks in some areas have affected livelihoods of fishing communities as has competition from sportfishing groups for catch allocations. Declining fisheries activities in many communities have created economic challenges that reduce overall resiliency. Development of aquaculture businesses in such areas can support and sustain existing fisheries supply chains and working waterfronts. Shellfish and seaweed farms, for example, support demand for boats, buoys, ropes, docks, cleaning/processing, and cold storage facilities. In Maryland (U.S.), the state enacted programs to encourage watermen to farm oysters rather than fish for crabs for conservation purposes [139]. In Vietnam and Thailand, traders, brokers, feed manufacturers, and equipment suppliers reported that growth of aquaculture supported demand for their products [37]. Thus, the growth of coastal aquaculture provides economic support for boat-building companies, and manufacturers of fishing gear, processing facilities, cold storage warehouses, and transportation services for shellfish, finfish, and seaweed products. Aquaculture farms have attracted investment capital for RAS production of finfish [140] and for shrimp farming in Vietnam and Thailand [37].

Economic development and job opportunities are strongly correlated with higher educational levels, greater social amenities, and overall greater engagement among social groups within communities [35]. Greater educational levels and experience, in turn, provide a greater pool of higher quality management and leadership. Strong economic bases for communities provide resources that expand available options for planning, preparation, and effective recovery from natural disasters and other external shocks.

Greater tax revenue provides greater financial resources for investments in physical infrastructure necessary for recovery from various disasters. The availability of emergency response facilities, power, bridges and roads, telephone and internet infrastructure, water systems, and wastewater treatment units facilitate community response to emergencies [35]. Successful sustainable aquaculture farms not only contribute tax revenue to the community, but also increase household income that offers opportunities for private investments by residents in infrastructure for their homes and property. Overall, the various economic contributions of aquaculture to coastal communities contribute to their vibrancy and attractiveness to businesses and prospective employees, thus strengthening the economic base, and the diversity of knowledge and skillsets available to the community.

A strong advantage of aquaculture farming businesses is the control that farmers have over the supply of the farm products they produce. Despite the negative effects of the COVID-19 pandemic, aquaculture farms may have been able to begin to recover more rapidly than other businesses because of the available on-farm inventory. U.S. surveys showed that many aquaculture farms began to show recovery in the latter part of 2020 [31]. The year-round availability of product on aquaculture farms provided greater flexibility and offered opportunities to respond more rapidly to new market opportunities.

## 5. Governance Dimension of Aquaculture, Sustainability, and Community Resilience

The governance dimension of resilience and sustainability is critical to the question of whether aquaculture enhances or decreases resiliency and sustainability [32] and has been referred to as "being perhaps the most important piece of the puzzle for the sector's sustainable development" [141]. The governance dimension of sustainability provides the contextual structure for community resilience through leadership, institutions and services for emergency management, and a regulatory framework [24]. Adequate and effective governance can protect ecosystem services, promote development of strong social networks, and provide support for local economic activity through creating an enabling environment that requires good policy and planning [6]. Appropriate and well-designed policy and planning are critical preconditions for reliable food supplies. Governance, and its associated regulations, are necessary for effective environmental management, and to achieve and maintain the desired degree of environmental, social, and economic quality [85,142].

The governance dimension of sustainability and resilience includes laws and regulations at local, state/provincial, and national levels. Coastal areas in particular, often have especially complex and overlapping jurisdictional and regulatory authorities [143], in which local authority by diverse entities is often more prominent [144,145]. Detailed case studies on legal and regulatory impediments to shellfish aquaculture in the U.S. can be found from NOAA [146].

It is important to note that the term "regulation" is a broad, generic term that encompasses processes other than simply the laws and statutes. The regulatory process begins with laws and statutes, but then is followed by rulemaking, permitting, implementation, and enforcement processes. Different actors, working at different levels of national, state/provincial, and local government agencies, carry out the various processes. In the U.S., for example, laws are passed by elected representatives, but the subsequent rule-making process at either (or both) the federal and state level is conducted by personnel of the relevant agencies, not lawmakers. Once a rule is finalized, its implementation involves managers of various divisions of one or more state/federal agencies, and permit writers in a different division, with enforcement personnel in yet another division. This suite of actors that influence the requirements for an individual farm to be in compliance is further complicated by overlapping jurisdictions, such that parallel rule-making efforts occur across multiple agencies, increasing the number of individuals involved and reports to be filed, often of the same monitoring data.

Widely differing sets of laws, statutes, and rules across the world, combined with their uneven implementation have led to regional disparities. Social pressure for regulation of all production activities has been considerable in developed countries, whereas in developing countries, the emphasis on maximizing production has led to greater political flexibility, less regulation, and less enforcement of regulations of aquaculture and other productive activities [124]. However, governance of aquaculture in many countries continues to be an issue [32]. For example, in Asia, Norway, and Chile, governments have facilitated the expansion of aquaculture, whereas in the EU and U.S., governance has constrained its growth [147]. Thus, the effect of aquaculture can be positive in some communities and negative in others, depending on the nature of the regulatory framework and the degree to which aquaculture is "over-" or "under-" regulated [2,141].

The stringency of the regulatory environment has been compared explicitly with respect to the growth of aquaculture across 97 countries [148]. Developing countries had the least stringent environmental regulations, while the U.S., Japan, and Norway were the most stringent. Those countries with the least stringent environmental regulations (Vietnam, Indonesia, Thailand, China, and India) also had the greatest aquaculture growth rates and are major exporters of aquaculture products to the U.S. and EU. With respect to the global environment, it has been stated that, "By opposing the development of a domestic aquaculture sector, anti-aquaculture special interest groups bear some responsibility for these negative environmental and social impacts in countries with lower regulatory oversight" [149].

The negative environmental and social problems associated with aquaculture have largely occurred in countries that are "under-regulated", in the sense of the deficiency of adequate laws, rulemaking, local-level implementation, and lack of adequate enforcement. Good policy and planning was reported to be "surprisingly weak in most countries" [6]. The lack of governance of pangasius farming in Vietnam, for example, was reported to have reduced environmental sustainability of that sector [150]. In Southeast Asia, early growth of milkfish and shrimp aquaculture was accompanied by environmental degradation because policies prioritized foreign exchange without attention to negative environmental impacts of the destruction of mangroves [151]. In countries without effective regulation of worker protection and workplace safety (i.e., no minimum wage laws, no laws that prohibit discrimination in hiring, etc.), worker abuses have occurred in aquaculture and other businesses. Women, youth, and immigrant workers are more vulnerable to abuse in countries with insufficient or ineffective governance. The lack of social benefits such as maternity/paternity leave or family medical leave can pose significant barriers to women from accessing benefits from growth of aquaculture. In other countries, women are prohibited by law from engaging in the workforce, whether aquaculture or in other occupations.

In countries with stringent governance structures, regulations can be overly cumbersome and lead an otherwise successful business to failure [133]. There is growing evidence of "over-" regulation that has constrained the growth and development of offshore aquaculture in Scotland [152], limited innovation in seafood production [14], and potentially created comparative disadvantages for aquaculture producers if competitors in another country have a less-stringent regulatory framework [153]. Compliance costs in the U.S. were found to account for 29% of total costs on Pacific Coast shellfish farms, 25% on baitfish/sportfish farms, 12% on salmonid farms, and 8% on catfish farms [145,154–156]. In addition to direct regulatory compliance costs, sales were lost when regulatory requirements either forced farms to reduce production capacity, prevented farms from access to markets, or prevented farms from expanding to meet new market demand. Lost sales were estimated to be $6.9 million for U.S. baitfish/sportfish farms [154], $23 million on Florida tropical farms [157], $35 million on catfish farms [156], $52.5 million for salmonid farms [155], and $280 million for Pacific Coast shellfish farms [145].

Inefficient regulatory frameworks have also created extensive permitting delays for shellfish farms [145]. The lengthy permitting process has forced small-scale shellfish farms to continue to use outmoded, less environmentally friendly production gear because the lack of revenue during the permitting application period would render their farm financially unviable. Additional inefficiencies result from the amount of time that farm owners and managers must spend on regulatory record-keeping. Such time diverts farm personnel attention from production and marketing innovations to regulatory reporting, thereby reducing technical efficiency [158]. The high degree of inefficiency created by poor coordination among agencies, and an often ad hoc approach to implementation of laws, is a primary driver of the high on-farm regulatory compliance costs. Manifestations of these inefficiencies include duplication and redundancy of reporting requirements, and intensive monitoring even when farm records show long histories of no non-conformities.

Overly stringent and inefficient regulatory systems can create negative global environmental effects if constraints on aquaculture trigger increased imports from countries that allow pollution from aquaculture [149]. Over-regulation has also been reported to contribute to increased poverty rates in the U.S. [159]. Constraints to aquaculture growth from over-regulation reduce its potential contributions to community resilience through reduced employment and tax revenue necessary for communities to invest in infrastructure critical for preparedness for natural and economic disasters.

Additional negative social effects from over-regulation of aquaculture include disproportionately negative effects on smaller-scale farms and suggest that increasing regulatory costs have contributed to the loss of small-scale aquaculture farms in the U.S. (Figure 2). Similar trends were found on Florida ornamental fish farms [157]. The greater negative effect on small farms occurs because regulatory costs are primarily fixed costs, and smaller farms have lower volumes of production across which to spread fixed costs.

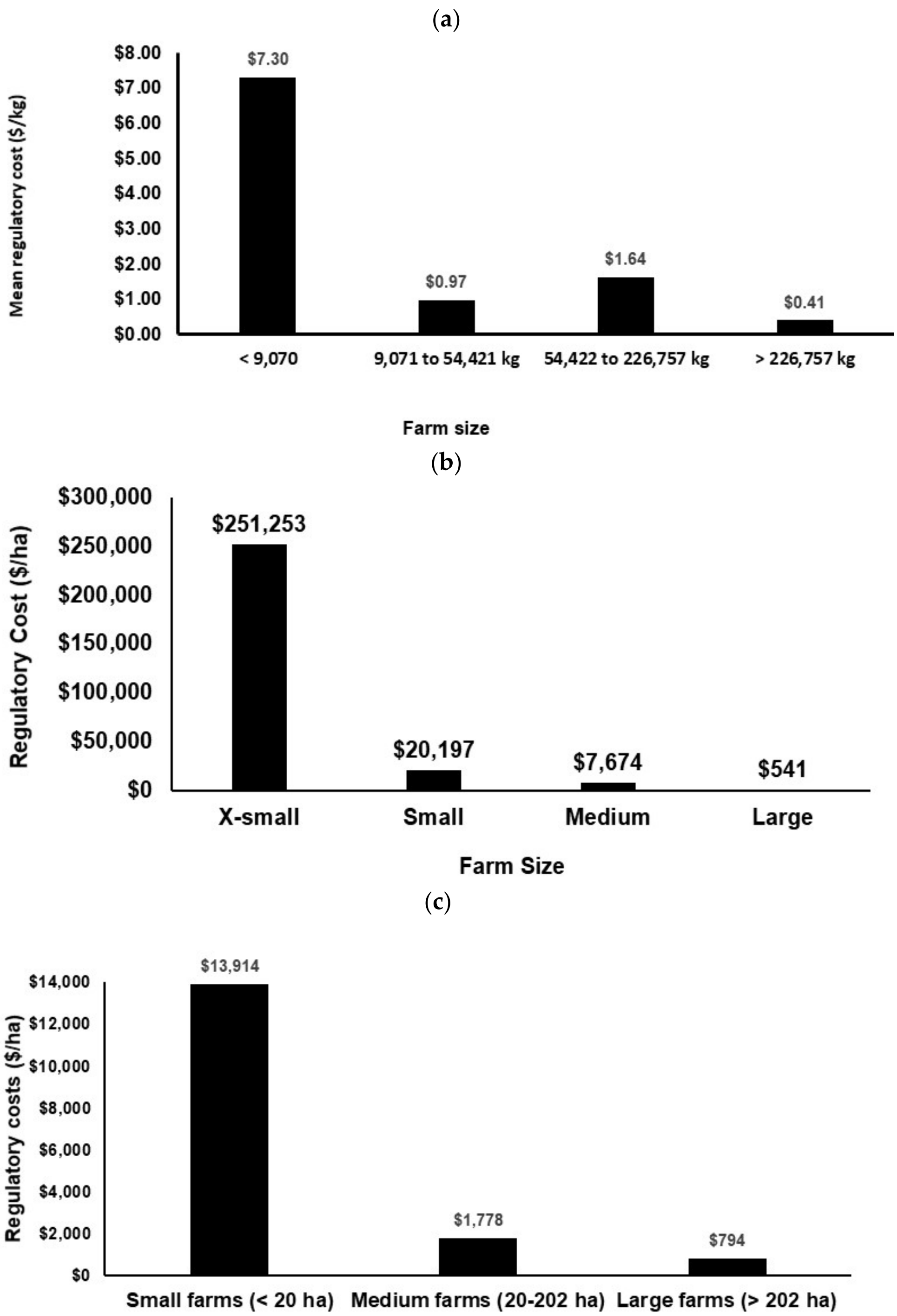


**Figure 2.** Regulatory costs by farm size on: (**a**) U.S. salmonid farms; (**b**) Pacific Coast shellfish farms; and (**c**) U.S. baitfish/sportfish farms. Data source: Data used to calculate regulatory costs were obtained from national surveys that censused primarily via in-person interviews) the U.S. baitfish/sportfish, salmonid, and Pacific Coast shellfish farms [15,154,155].

The loss of smaller aquaculture farms is a concern with respect to community resilience and sustainability because smaller farms typically are well integrated into communities and engage actively with institutions such as churches, local government, and civic associations.

Smaller, local farms, moreover, tend to purchase inputs locally, support local businesses and stimulate creation of new businesses that lead to economic growth and development [130].

As aquaculture continues to grow and develop worldwide, the potential for conflict over the use of space increases. In the U.S., NOAA [160] is leading an effort to map marine areas to identify those appropriate for aquaculture development. The marine mapping effort takes into consideration Marine Protected Areas, commercial and recreational fishing areas, and shipping and boating lanes, among others [161] and represents a positive regulatory initiative.

## 6. Moving Forward

Aquaculture has potential to contribute positively to sustainability and to the resilience of communities around the world, when practiced responsibly by farmers and when appropriate, science-based regulations are developed and implemented rationally. The growing human population on the planet, however, requires that aquaculture production systems continue to increase efficiency of use of increasingly scarce resources to improve environmental and economic sustainability [162].

Common approaches to regulation have been based on "command-and-control" approaches that have been shown to be less effective than incentive-based approaches. Command-and-control is a rigid policy approach in which government agency staff dictate specific processes and quantities to all firms in a sector without provisions for flexible adaptation based on specific circumstances. A key component of regulatory reform is to avoid overly prescriptive standards [2] and increase flexibility to enable regulatory agencies to adjust to the rapid changes and advances in aquaculture [34]. The key to tapping the potential of aquaculture to support core Sustainable Development Goals of FAO was reported to "be responsive and adaptive to new and constantly changing conditions" [6]. An example of the failure of non-responsive, command-and-control regulations were those in Thailand where outdated laws led to non-compliance by producers and, ultimately, the failure to adopt sustainable shrimp farming practices [163]. Effective governance requires sunset clauses and periodic reviews of regulations to re-assess the relevance and effectiveness of regulations and provide a mechanism to adapt to new, improved technologies [34]. Periodic reviews also provide an opportunity to remove redundant regulations that duplicate those of other agencies and jurisdictions [32]. Similarly, in the EU and the U.S., periodic reviews of regulations could lead to reduced complexity, redundancy, inefficiency, and the on-farm regulatory compliance burden [14]. Streamlining on-farm reporting and testing has been shown to have potential to reduce farm costs for several U.S. aquaculture sectors [164,165].

In countries where negative environmental and social impacts occur, community resilience and sustainability require improved governance frameworks with effective enforcement infrastructure. For example, improved governance frameworks were recommended for urban areas in Thailand and Indonesia that would guide coastal infrastructure design and limit ground water extraction [166]. The areas described showed subsidence of coastlines as a result of ground water withdrawal from urban population growth and expansion, alteration of river flows, and from growth of aquaculture.

Engaging aquaculture farmers collaboratively in the regulatory process will result in more effective and efficient regulatory frameworks [167]. True engagement with all relevant stakeholders was found to develop effective regulatory frameworks that consider unintended environmental, economic, and social negative consequences [13]. Such engagement should include aquaculture producers and environmental groups as well as local residents [168]. Participatory approaches to governance were reported to result in greater effectiveness [32] with examples that included: (1) the adoption of improved production practices of fallowing and treatment of salmon in Scotland [169]; (2) co-management of animal welfare of aquaculture in Norway [170]; and (3) codes of conduct implemented in Canada, Chile, and by the Federation of European Aquaculture Producers. Not all attempts to develop participatory approaches have been successful, however. A notable example is that of the ISA outbreak in Chile. Weak enforcement, combined with licenses that had been granted in perpetuity led to heavy losses of salmon [32] (Hishamunda et al., 2012) as well as social issues related to a number of labor violations [171].

Better management practices (BMPs) are a form of participatory governance that has been used to engage local communities to alleviate conflicts [172]. Small-scale farmers may benefit from a BMP governance-based regulatory framework that facilitates compliance with customer expectations on quality, safety, and environmental performance of aquaculture products [173]. Specifically, establishing a single-agency clearinghouse that enhances collaboration among agencies and the use of Best Management Practices offer opportunities to embed flexibility into the regulatory process and reduce regulatory costs [33,157].

The designation of a lead agency for aquaculture is a strategy that has improved the quality of governance [32]. Aquaculture frequently has been regulated by laws developed for other sectors because aquaculture in many countries is a new economic sector [174]. The lack of familiarity or understanding of a new enterprise can lead to regulations that result in unintended, negative consequences, especially in situations where officials have discretionary authority [175]. The type of agency designated as the lead for aquaculture varies around the world from a department of fisheries with jurisdiction and regulations for capture fisheries [176] to the Ministry of Agriculture, as in China, India, and Thailand, the Ministry of Economics in Chile, and the Ministry of the Environment and Tourism in Zimbabwe, as examples. The lack of a lead agency has been reported to stymy aquaculture development in other countries, such as in the case of marine aquaculture in the United States [177]. A lead agency can coordinate regulatory requirements and streamline licensing processes that are often cited as the cause of costly lengthy delays in permitting and increased overall administrative costs.

Norway has been considered a model for effective aquaculture governance [32]. A dedicated aquaculture law was promulgated in Norway that was based with a primary focus on economic viability but included constraints that addressed environmental sustainability. Norwegian local communities participate in governance through their jurisdiction over siting and licenses. In time, however, restrictions on new site leases have become more common. The ensuing scarcity of sites has driven prices of licenses from NOK 0 in 2002 to NOK (10 NOK = $1.00 (U.S.)) 10 million in 2013–2014, with additional license trading at prices of NOK 55 to 66 million [178,179].

Other approaches to more effective governance are based on economic incentives through price or tax effects [32], or payments for environmental services to offset carbon emissions, such as in Mexico [180]. The emphasis on environmental impact assessments prior to awarding a license may not be warranted because of the high administrative costs entailed. A more outcome-based approach may be more efficient, if accompanied by appropriate incentives [6].

Integrated coastal zone management (ICZM) can balance aquaculture siting and spatial issues among various user groups and interests and facilitate mapping, siting, and licensing decisions [32,181]. Marine zoning can take into account environmentally sensitive areas and carrying capacity estimations while identifying areas to be licensed for aquaculture production [177]. Zoning has been proposed in Australia [182], Chile, Belize, the Philippines [32], Namibia [183], Europe [184], and the U.S. [185,186].

One of the challenges with assessing the intersection of community resilience with sustainable aquaculture is the lack of baseline data on the various dimensions of resilience before aquaculture farms are developed. There is a strong need for research efforts to fill this important gap. Study site opportunities exist in communities where RAS investments have been announced. It takes several years from the time of announcement of intent to develop a RAS until actual startup. That time period offers an important opportunity for an interdisciplinary team of researchers to develop baseline data on resilience of that community, by documenting the relevant environmental, social, economic, and governance factors in that specific location. Follow-up monitoring would provide a basis from which to parse out specific effects of aquaculture development, whether positive or negative, on community resilience. Similar opportunities exist in the U.S. with the newly identified

Aquaculture Opportunity Areas. Obtaining baseline data on resilience of the communities in those areas offers a point of comparison with subsequent effects following development of aquaculture farms.

## 7. Conclusions

Sustainable aquaculture has a long history of positive contributions to the resilience of communities. The historical contributions of long-established finfish and shellfish farming sectors have expanded to include those from RAS, seaweed, and other types of aquaculture farms. As economic activity from fishing has declined in many areas, aquaculture has provided alternative employment opportunities and helped sustain working waterfronts and associated seafood supply chain infrastructure.

Current thought on community resilience recognizes its multi-dimensionality. Serious efforts to increase community resilience need to integrate its various dimensions to be effective. Aquaculture has contributed to environmental, social, and economic dimensions of resilience in areas in which the governance framework has been participatory, rational, science-based, and has provided flexibility to accommodate the rapid technological changes of aquaculture. Shellfish and seaweed aquaculture enhance environmental water quality, biodiversity, and increase ecosystem stability and services. Less studied, but equally important, are the contributions of family-owned aquaculture farms to social networks and institutions that are critical to community resilience. In communities with long histories of aquaculture, aquaculture is of important cultural significance. Economic contributions have included sources of income and revenue to communities through tax revenue and to households through increased incomes from employment opportunities. Providing alternative sources of revenue and jobs diversifies the economic base and provides greater economic stability. Aquaculture businesses have further contributed to a reversal of declining economic conditions by offering an alternative source of employment to fishermen.

Yet, the regulatory framework has constrained growth of aquaculture in the U.S. and EU. Detailed analyses of farm production and financial records have shown that it is not the laws themselves, but the complex, poorly coordinated, and in many cases, ad hoc approach to implementation of these laws on the part of multiple agencies with overlapping jurisdictions, that have created problems. Evidence points to the regulatory framework contributing to the demise of increasing numbers of smaller-scale farms, likely reducing the resilience and sustainability of their local communities. Elsewhere, the regulatory framework has not provided sufficient protection for common property resources, the environment, and local communities. Attention is needed to identify ways that provide adequate regulatory oversight without driving smaller-scale farms out of business.

As global populations continue to increase, the pressure on communities and the environment will increase. With increased population pressure, the ability of communities to rebound and recover from external shocks and the need for sustainable food production systems will become ever more important. Communities with greater economic resources and more cohesive social networks are likely to be those that will be more resilient to continued changes as well as to external shocks. Aquaculture, when managed in environmentally and socially responsible ways, can be an important contributor to increased resilience of communities. Greater attention is needed on aquaculture regulatory processes to ensure that regulatory rulemaking, implementation, and enforcement measures address environmental and social issues adequately but avoid unintended negative consequences to the environment, local economies, and social networks.

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