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Aquaculture governance: five engagement arenas for sustainability transformation

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A greater focus on governance is needed to facilitate effective and substantive progress toward sustainability transformations in the aquaculture sector. Concerted governance efforts can help move the sector beyond fragmented technical questions associated with intensification and expansion, social and environmental impacts, and toward system-based approaches that address interconnected sustainability issues. Through a review and expert-elicitation process, we identify five engagement arenas to advance a governance agenda for aquaculture sustainability transformation: (1) setting sustainability transformation goals, (2) cross-sectoral linkages, (3) land–water–sea connectivity, (4) knowledge and innovation, and (5) value chains. We then outline the roles different actors and modes of governance can play in fostering sustainability transformations, and discuss action items for researchers, practitioners, and policymakers to operationalize activities within their engagement arenas.

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Introduction

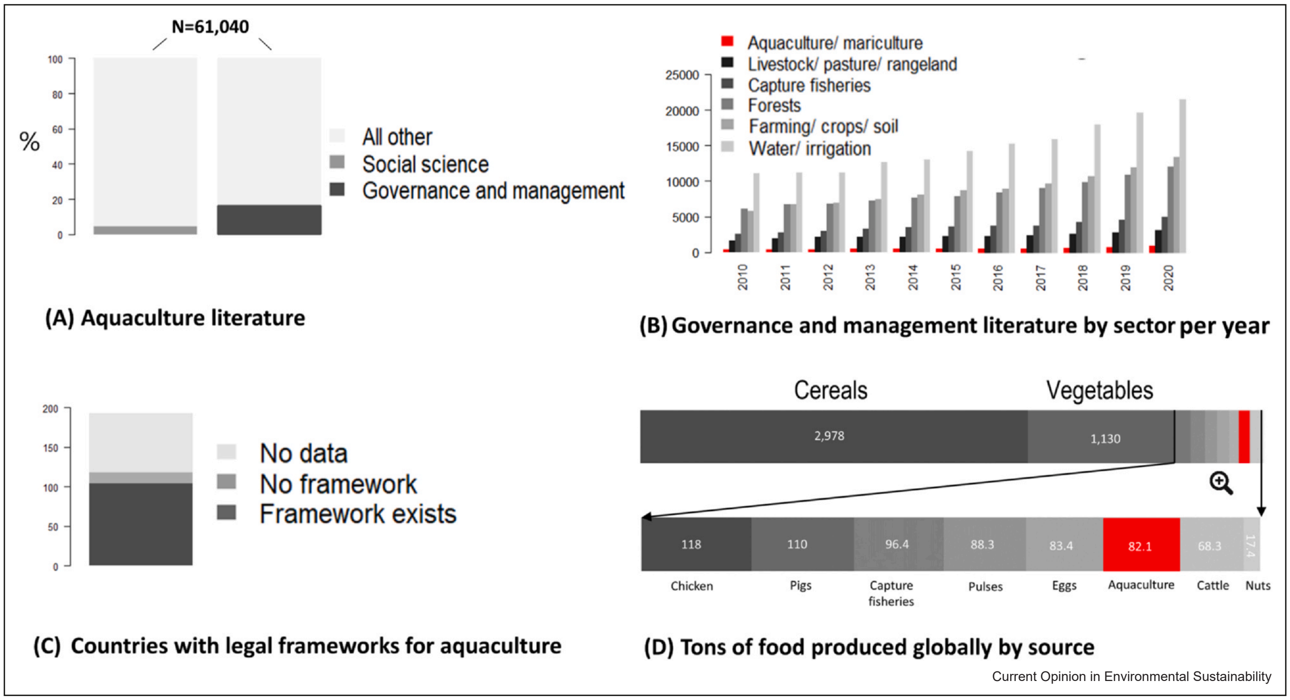
Aquaculture sustainability transformations involve intentional change in the composition, structure, and/or condition of aquaculture social–ecological systems to improve human well-being and limit environmental impacts [1,2]. Undergoing such transformation is recognized as essential [3–5] for securing the role of farmed aquatic food in the global food system [6,7]. Achieving the changes, however, requires successful design and implementation of governance arrangements that guide inclusive social interaction through an amalgamation of laws, norms, rule systems, institutions, discourses, power dynamics, and organizational hierarchies [8–10]. Intentional and concerted engagement with these social processes is where governance has the potential to be transformative (i.e. intentional) in achieving sustainability goals. As such, governing aquaculture sustainably has never been more urgent and important [3]. The sector now produces near-equal amounts of seafood as capture fisheries, and near-equal amounts of food in tons as eggs and pulses globally (Figure 1). However, the amount of governance and management literature on aquaculture compared with those other sectors is far behind (Figure 1).

We define governance as the organizing of social processes through goal identification and mobilizing capacity for social cooperation between diverse actors operating in and across multiple contexts or 'engagement arenas' [1,3,13]. Governance processes will create rules, norms, processes, and structures (i.e. institutions) for organizing social and social–ecological interactions and behavior to meet goals across multiple levels and scale [14–16]. Governance that is transformative will have intentional goals and/or processes (i.e. toward sustainability) that guide institutional development and change [10,17,18]. Importantly, transformative governance in aquaculture is enacted through context-specific adaptations that affect a given system. Important for intentional transformative governance is the identification of 'engagement arenas,' because they enable coordinated dialog and action between research, policy, and practice within focused themes [18,19].

The engagement arenas, outlined below, complement current global sustainability agendas in the sector such as the Food and Agricultural Organization of the United Nations (FAO) Blue Transformations initiative and 2030 Roadmap [20,21]. The arenas further aim to advance existing agendas because they explicitly acknowledge interactions with other sectors, recognize cross-linkages, and detail dependencies within the sector in a way that showcases the variety of challenges and actions that can be taken in the framing and operationalization of a more comprehensive transformative governance agenda. Importantly, the first target of the FAO Blue Transformations Roadmap for aquaculture is the "Effective global and regional cooperation, planning and governance" [20]. Our arenas champion and strengthen this target by detailing essential mechanisms and context for governance in the current literature by specifying the factors relevant for engaging with, for example, value chains, intersectoral issues, innovation, and diverse knowledge systems. Further alignments exist with the FAO subcommittee on aquaculture, which has drafted the Guidelines for Sustainable Aquaculture with a grounded recognition of interconnected problems and potential solutions [22]. Our parallel but independent work offers promising opportunities for continued academic-practitioner coproduction in the sector through constructive comparison of agendas and deliberation of findings where context and normative goals matter. Ultimately, all of these combined efforts can strengthen the role of governance to address sector-specific problems and solutions in ways that can make progress toward realizing broader initiatives such as the United Nations Sustainable Development Goals (SDGs), the Global Sustainable Development Report [1], and the EAT (https://eatforum.org/) Lancet Commission report on healthy diets from sustainable food systems [4,7], which sparsely mention governance let alone specify details on how the Great Transformation should actually take place. While these broader agendas inspire coordinated effort, they still need to be translated through governance arrangements for sectors such as aquaculture to enable social engagement, adaptation, and ultimately system change [23,24].

Aquaculture governance involves the wider challenge of transforming food systems [4,25,26] through coordinated interaction between multiple actors from production to consumption [3,10,27–29]. Sustainability issues from a food system perspective, such as resource use, food security, and environmental degradation, cannot be seen as isolated problems, nor can they be resolved through technical solutions that are often applied with limited understanding of the social and political conditions that affect their uptake into practice

Figure 1



Lack of knowledge on aquaculture governance despite importance. **(a)** The percentage of literature classified as social science among reviewed aquaculture literature (left). The percentage of literature search results retrieved when searching for 'governance OR management' among all aquaculture literature (right). Data from the Scopus database (July 1, 2021). **(b)** The amount of governance literature in related food and environment sectors from the Scopus peer-reviewed literature database over time. Aquaculture has by far the least. Search strings in Appendix 1. **(c)** The number of countries with self-reported legal frameworks for aquaculture, taken from the 2021 report [11] on the compliance with the Code of Conduct for Responsible Fisheries [12] Article 9. **(d)** Tons (millions) of food produced in 2019 (live weight), subdivided by major protein sources (bottom). **(d)** Data from FAOSTAT (https://www.fao.org/faostat/en/#home).

[4,30,31]. Aquaculture governance arrangements, in contrast, seek to address these social and political conditions by co-ordinating and empowering diverse actors and forms of knowledge [32] to enable reflexive learning for solving sustainability challenges across the sector [33]. Governance as such sees 'aquaculture' as a socially connected food system encompassing sustainable livelihoods, nutrition security, political decision-making, and environmental integrity, rather than a set of technical production and trade processes [4,6,34].

In this article, we propose five engagement arenas to guide and coordinate governance across aquaculture actor groups. Reviewing recent literature, we first outline current knowledge of challenges faced by different actors in addressing sustainability issues and different modes of governing and their limitations. We then discuss the five engagement arenas and specify action items that researchers, practitioners, and policymakers can adopt in their governance activities. Both the engagement arenas and action items are derived from an elicitation process with aquaculture experts who are co-authors of this article. Each has a diverse set of social, economic, ecological, and technical knowledge and experience across the sector's geographies.

Methodology

Data were collected through a survey developed by SP, AOM, and AS, which solicited input from all co-authors to identify key governance challenges in the aquaculture sector (i.e. disciplinary, topical, and geographical). Co-authors were selected based on one or more of the following criteria: specific expertise on aquaculture, governance, and/or sustainability transformations. Selection started within the lead authors' networks, and expanded to a global search based on recently published literature, expertise in different areas of aquaculture knowledge, and balanced intersectional representation. We acknowledge that our co-author group is not fully representative of, for example, all top-10 producing countries or broader stakeholder groups such as the FAO. However, many co-authors have been or are currently working directly with the FAO, WorldFish, and/or in top-10 producing countries for years if not decades. We further acknowledge that pursuing intersectional representation is challenging, because there are many ways to consider it. For example, having co-authors balanced across all continents, across top-10 producing countries, across different stakeholder groups, gender balance, and early career versus senior scholars. We have made a conscious and deliberate effort to consider these intersectional aspects in our author group, and still recognize that it may not be possible to be optimally diverse. What is also not observable is the many participation invitations sent to potential contributors representing the above intersectional groups that were either declined or never responded to. All survey participants are co-authors.

The following engagement arenas and action items are a synthesis of the co-author survey responses. The core team of co-authors (SP, FA, CB, SB, AOM, BN, and AS) were assigned (in pairs) to complete a formal content analysis and synthesis of the survey results focused directly on identifying governance and sustainability-related issues and topics. Written text and tables were provided as an output. The core team then distilled the content into the major thematic areas, which we then deliberated as the core team, and named them the 'engagement arenas,' which emerged as cross-cutting themes across the survey sections. The name of each specific engagement arena and its subthemes were discussed and commented on in numerous rounds by all co-authors. This ensured that each was carefully placed and considered. The five themes representing the engagement arenas are, in our view, purposeful and directed, attempting to distill the diverse set of knowledge on both governance and sustainability transformation issues. The engagement arenas are thus not fully comprehensive about all important aquaculture issues from other perspectives but indicate a forward-looking agenda for continued aquaculture governance and sustainability research. This forward-looking dimension is captured in the identification and presentation of specific action items for each stakeholder group. A specific section of the survey asked for direct inputs on action items for specific stakeholder groups, in relation to governance and sustainability, for the types of agenda-setting activities would be most needed. In doing so, the themes in the engagement arenas and action item topics were streamlined in the data collection and analysis process. Additional data were collected from publicly available sources (i.e. FAO) to inform our secondary data graphics. Literature was sourced from Scopus using search strings (Table S2). Data on countries with self-reported legal frameworks for aquaculture were taken from the latest FAO State of Fisheries and Aquaculture report [35] and other reports (see Supplementary Materials Table S3).

Current knowledge, key actors, and modes of governing

The academic literature on aquaculture sustainability has grown rapidly over the years [3,29,36–38] (Figure 1a, b). However, the volume of literature focused on the governance of the aquaculture sector has lagged behind other food and resource sectors (Figure 1b, d). Overall, the literature on aquaculture governance remains (1) fragmented, (2) focused on a single or limited number of actor groups, (3) is underpinned by assumptions that knowledge from capture fisheries or agriculture is transferrable, and/or (4) that aquaculture-related knowledge is absorbed or easily dealt with by established fisheries or agricultural institutions (i.e. ministries, cooperatives, and value chains).

The current literature emphasizes the need to better understand how social–ecological and multi-actor interactions coshape the aquaculture sector's diversity, as well as how these interactions influence the structure and conduct of aquaculture and/or broader seafood value chains [39,40]. Research has emphasized the diversity of governance arrangements [10,41], species cultured (700+ farmed globally) [35,42], production systems [43], business models [37], and dependencies on common resources [9,44,45] that characterizes the sector. Additionally, the interdependencies between production and key input resources, including water, land, marine, and terrestrial-based feed ingredients, are highlighted [28,38,46]. There is also considerable attention given to the global scale of the sector, existing in at least 119 countries, of which 39 produce more farmed aquatic animals than capture fisheries tonnage [35].

Considerable attention has also been given to the diversity and role of different actors in the sector (Table 1). The role of governments has in particular received critical attention, with evidence of struggling with both over- or under-regulation of social and environmental protections [36]. These struggles are understood in the context of the growth of the sector outpacing "the development of legislation and legal frameworks" (see [35], p. 100). It could also be, however, that the lack of legal governance frameworks hinders sectoral growth. As illustrated in Figure 1c, in 2018, just over 50% of the 118 reporting member countries had established aquaculture policy frameworks in line with the Code of Conduct for Responsible Fisheries [11,12]. In response to weak public governance, industry and civil society actors have sought a range of nongovernmental governance arrangements, including certification. However, certification has had limited adoption at the global scale due to weak compliance, high costs, and declining market incentives [47–49], especially in the context of smallholders who continue to represent the majority of producers globally [3,50].

Recent literature emphasizes the role of public–private partnerships, including comanagement [41,51,52] (Table 1), aimed at reallocating responsibilities and risks for sustainability [36,37]. Comanagement is often praised in the literature as a promising means of fostering sustainability transformation locally through

Table 1

General governance actor groups, and their constituent organizations, institutional arrangements, and societal partnerships.

Governance actor groups	Associated organizations, institutions, and/or partnership arrangements	Role in sustainability transformations
Practitioners, private, and/or civil society initiatives	Public–private partnerships	Develop joint decision-making processes, investments, and service delivery, while improving the allocation of skills and risks between private and public sector.
	Businesses along the value chain	Increase efficiency, inclusivity, investments, and innovations in supply and value chain sustainability through buyer-driven (e.g. contract farming, franchising, and joint ventures), producer-driven (e.g. farmer-owned, sharecropping), and intermediary-driven (e.g. certification) models.
	Cooperatives and/or community-based	Represent and organize smallholders to advance local sustainability goals through mobilizing resources, market access, governance activities, representation, knowledge exchange, and institutional development for access rights, subsidies, and labor issues.
	Comanagement	Provide institutional space for actor coordination, communication, and deliberative decision-making processes toward inclusive sustainability goals. Typically, government-led and cross-level, but can also be community-based.
	Nongovernmental organizations (NGOs)	Promote best practices, standards, innovatio,n and/or capacity-building to support governance actors and the livelihoods of smallholders. Support cross-learning and knowledge-sharing between localities, regions, and countries.
Policymakers	National, provincial, and local governments	Develop policies, legislation, legal frameworks, and financing that provide enabling conditions for development while ensuring social and environmental protections during implementation.
	Intergovernmental organizations	Develop international policy agendas, legal frameworks, and monitoring through inclusive and transparent multilateral cooperation that builds capacity for communication and coordination across actor groups, often directly with governments or communities of practice.
Researchers	Universities, professional associations, and publishers, funders	Pursue responsible, ethical, and efficient approaches while providing foundational knowledge and evidence-based options for action, offering perspectives on the opportunities and pitfalls of governance alternatives and trade-offs toward sustainability goals. Assess impacts of actions and interventions.

The role of each in fostering sustainability transformations is briefly outlined.

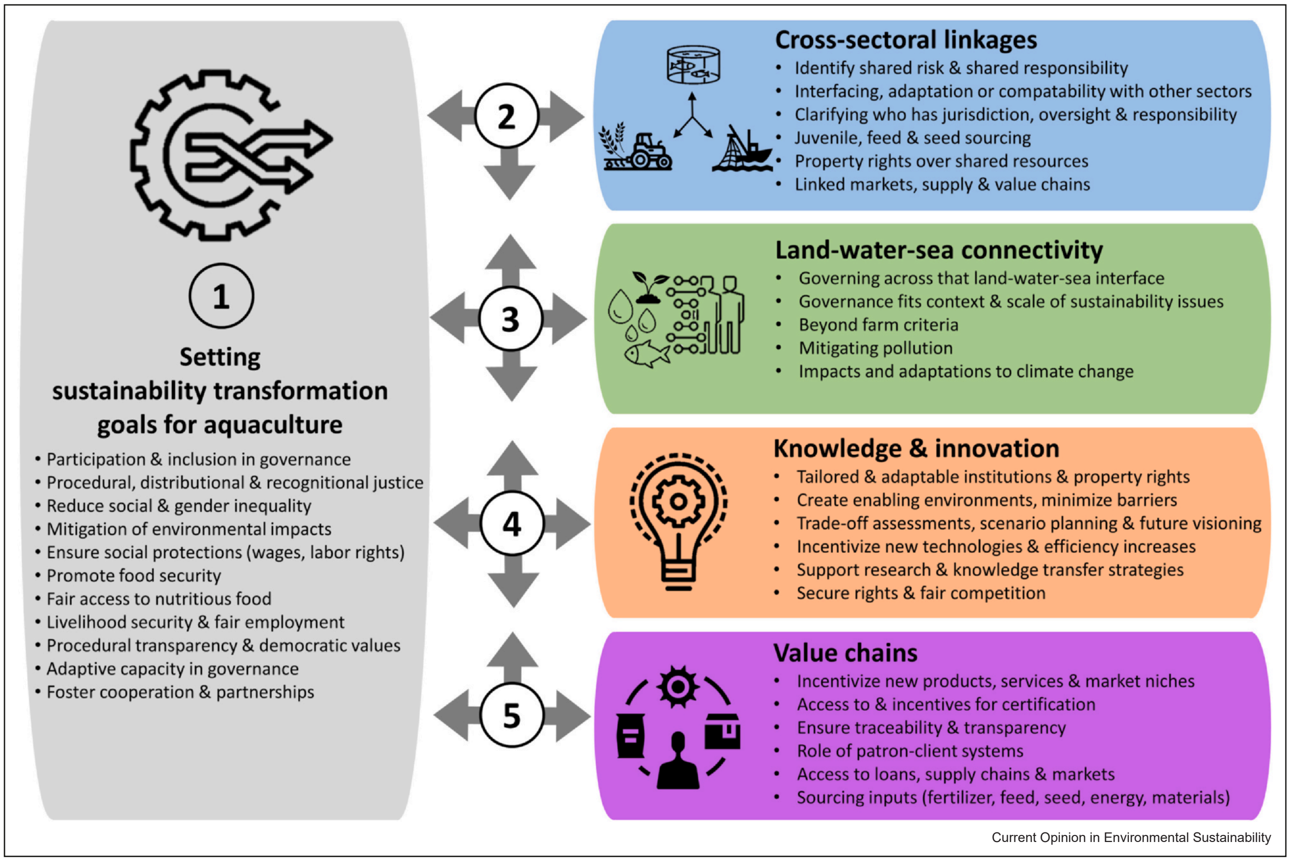
increased inclusion and participation in decisions within the sector [37]. However, comanagement for sustainability transformation requires governments to support the capacities of stakeholders to self-organize and represent themselves (particularly smallholders and women). As shown in the literature reviewed, this entails ensuring inclusive deliberation processes that account for power imbalances, trust and social capital-building, and knowledge-sharing processes [53–55] (Table 1).

Less attention, however, has been given by governance scholars on the role value chain actors in the aquaculture sector play in affecting resource allocation and/or enabling smallholders and other stakeholders to improve their sustainability performance, for example, [56,57] (Table 1). Research on aquaculture cooperatives, for instance, shows how they may advance local sustainability goals if they assist with mobilizing resources, market access, governance activities (e.g. rule formation, monitoring, and leadership selection), representation, knowledge exchange, and institutional development for access rights, subsidies, and labor issues [30,58]. However, cooperatives often lack the capacities for self-organization, representation, and administration [59,60]. Thus, cooperative membership may be required for smallholders to access government loans or subsidies. Overall, the range of actors and governance arrangements in the aquaculture sector remains fragmented. Despite this, there is growing recognition for new forms of coordination and integration that can support sustainability transformation toward improved environmental performance, social equity, and enhanced nutrition.

Five governance engagement arenas for sustainability transformation

Based on the current literature and expert knowledge, we identify five governance engagement arenas that are

Figure 2



Five key engagement arenas for aquaculture governance that can foster sustainability transformation. Each arena has a list of examples of potentially important topics and issues to prioritize. The relevance of each engagement arena and the listed subarenas will depend on context. Distinguishing between the five arenas is conceptually useful, however, there are many overlaps, linkages, and interdependencies indicated by the bridging arrows.

scalable and cross-cutting, and thus applicable to a diversity of aquaculture systems and actors (Figure 2). We recognize that these engagement arenas are not mutually exclusive, but still offer conceptual simplification and, as such, clarity for debate. Together, they enable aquaculture to be understood in the wider context of food systems, as well as representing sites of action for enabling systemic change. Each engagement arena is presented with contextualized examples and a discussion of future opportunities for contributing to the governance of aquaculture sustainability.

Setting sustainability transformation goals

Systemic challenges in the aquaculture industry require system-level goals, that is, goals that address broad challenges such as climate change [61], environmental performance [62], and food and livelihood security [6,63], and are aligned with capabilities and practices of actors throughout the aquaculture food system. This is important because the social, economic, and environmental conditions under which the majority of aquaculture[1] is currently produced fall far below optimal (Table 2). For example, 66% of all aquaculture is produced under suboptimal national-level governance conditions, 76% of all aquaculture is produced in countries facing the highest climate risks, and 90% of global production is in countries scoring in the bottom half of the global rankings in environmental performance [64] (Table 2). These data highlight the need for governance to mitigate risks guided by sustainability transformation goals. The capacity of national governments to both set and implement system-level goals for aquaculture remains crucial. Similarly, limited state oversight and self-governance by industry can lead to uncontrolled domestic aquaculture growth [65], as well as increased demand from sometimes poorly managed fisheries delivering fish meal and fish oil for feed from other countries [66,67]. Weak or misaligned cross-sector collaboration

[1] China (57.5%), Indonesia (14.2%), India (5.5%), Vietnam (3.4%), Bangladesh (< 3%), South Korea (< 3%), and Philippines (< 3%) [70].

Table 2

The percent of global aquaculture produced within each quartile range of each index.

Country level index	Percent of global aquaculture production aggregated from countries with scores in the quartile ranges of each index			
	1st quartile (worst)	2nd quartile	3rd quartile	4th quartile (best)
World Governance Index[2]	5.8 %	66.1 %	20.7 %	7.2 %
Climate Risk Index[3]	76.3 %	17.9 %	2.8 %	3.1 %
Environmental Performance Index[4]	13.9 %	75.5 %	4.4 %	6.3 %
Global Food Security Index[5]	2.9 %	24.5 %	67.8 %	4.8 %
Doing Business score[6]	3.9 %	5.4 %	83.4 %	7.3 %

Each country has a score for each individual index, and therefore, each country can be assigned to a quartile range based on the score it received for each index. The total amount of aquaculture production for all the countries assigned to each quartile for each index is shown as a percentage of global production. The darkest-shaded quartile has the most production within each index, the lighter shading has the second most.

[2]https://info.worldbank.org/governance/wgi/.

[3]https://germanwatch.org/en/cri.

[4]https://epi.yale.edu/.

[5]https://foodsecurityindex.eiu.com/.

[6]https://www.doingbusiness.org/en/doingbusiness.

can also undermine the capacity of aquaculture producers to adapt to climate change [68,69], in particular leaving smallholders most reliant on public land and water resources without protections.

The fragmented nature of aquaculture governance, spanning multiple levels across the public and private sectors, calls for proactive alignment of sustainability goals. These goals should, however, not only be outcome-oriented, but measured in terms of performance thresholds [71]. The identification and implementation of these goals, and their eventual rules and regulation, should also be deemed legitimate by those subject to them. To this end, rule formation should be viewed as just in terms of the fairness of their procedures and processes of governing, just in their distribution of costs, benefits, risks, and opportunities, and just in their recognition of different views, identities, interests, and knowledge, for example, [69,72]. Such legitimacy is needed to address key social issues in the industry related to gender equality [73], improved wages and decent working conditions [74], the elimination of human rights abuses [75,76], and wider issues related to the property rights [35,77] and the displacement of other sectors including farmers and fishers [78,79]. Goals are also key for addressing environmental pressures related to access and tenure of land and water [80,81]. Finally, goal-setting will only be fruitful if it is coupled with proactive capacity-building within partnership arrangements. Pillars of capacity-building will need to be supported by transparent communication and democratic values if they are to enable the assurances and mitigation of shared risk, which is in the interest of all actors (Figure 2).

Cross-sectoral linkages

Aquaculture both affects and is affected by many other food production and natural resource use sectors, including both capture fisheries and agriculture, as well as beyond them such as tourism or offshore energy, broadly spanning societal imperatives of public health (e.g. nutrition, consumption). However, the institutions governing aquaculture vis-a-vis these other sectors and societal goals are often not aligned, opening up the risks for a range of unseen and/or unintended outcomes. At worst, aquaculture governance is disconnected from these other sectors, as a function of administrative and technical management histories, and government ministry configurations. However, given their shared risks and interdependencies, greater cross-sector alignment of public policy and regulation with private standards offers considerable opportunities for more effective food system-level governance.

There are many examples of opportunities for 'cross-sector' aquaculture governance. The dependence of feed on agriculture and capture fisheries, as well as seed on capture fisheries, illustrates the need for sector-spanning approaches to governance [82–84]. Inland aquaculture, making up 75% of overall global edible production, is also dependent on or, in some cases, contributing to agriculture systems [85,86], as well as competing and/or impacting on water quality and quantity [87]. Aquaculture is increasingly recognized for its important role in human nutrition [88,89] and the need for greater connections with public health policies [90] to ensure that farmed aquatic foods can reduce micronutrient deficiencies and provide inclusive healthy diets [88].

Collaborative forms of cross-sectoral governance are needed that can reconcile misalignments, mitigate conflicts, and proactively enable strategies to deal with shared risks [27,49,50,91,92]. Importantly, fostering greater collaboration does not mean reinventing the wheel. Knowledge and experience on collaborative governance have already been built for fisheries, water, and agriculture. All these sectors have experience with different models of establishing regulation, property rights, and developing operational capacities for compliance and innovation that include state, civil society, and the private sector — both domestically and internationally [93]. Cross-sector collaboration may be best served by linking to and expanding these established governance arrangements [94] — even when these existing arrangements have been historically suboptimal or not directly transferable to aquaculture [57,95,96]. Governance systems, especially those leading to tenure rights, for example, in capture fisheries, must consider carrying capacity limits and not just space opportunities, in the allocation of mariculture rights [95]. Nevertheless, such arrangements provide a starting point for enhancing bidirectional cross-sector knowledge transfer between practitioners, producers, and value chain to enable more fit-for-purpose tenure arrangements over the long term [97].

Land–water–sea connectivity

Since water is the medium of production, fluidity across system borders is a critical management and governance issue because it can carry waste, pathogens, and nutrients [98,99], with high competition for use primarily in freshwater systems. Production systems face biosecurity risks [100,101] and breakage/release incidents, problems that influence profitability, food safety, and linked aquatic environments at the land–sea interface [26,92]. Furthermore, cross-border freshwater governance issues remain a continuing challenge in many world regions because demand and water quality are often threatened by upstream pollution or water grabbing [102]. Aquatic environments also contribute to the development and spread of antibiotic-resistant bacteria and genes, complicating governance across agricultural and land–sea sectors [103].

Governing the land–water–sea interface requires non-static (e.g. spatially, socially) and temporally dynamic forms of collaboration between actors and institutions that are not historically aligned [104]. Here, again aquaculture can be a means of innovating existing governance arrangements by providing a focal point for adapting institutions designed for land, water, and/or the sea to set new incentives for collaboration, knowledge transfer, and deliberative problem-solving across levels, scales, and actor groups [105]. If present arrangements do not exist, there is opportunity to establish public and private ‘land–water–sea partnerships’ that span actor groups and institutions.

Climate change presents perhaps one of the best test cases for aquaculture to foster new land–water–sea governance arrangements. As coastal production faces increased storm frequency, intensity, erosion, and salt water intrusion [95], and inland aquaculture greater water scarcity, state- and private sector-led governance will need to adapt to (1) conflicting resource rights [102,106], (2) increased scarcity and variability of production inputs [68,107], (3) changing species tolerances [68], and (4) market adaptations to water scarcity and reduced yields [108]. All these challenges at the land–water–sea interface will require multilateral state coordination, as well as clearer incentives and roles for private and civil society to share knowledge and innovate solutions that foster adaptive capacity across natural and political boundaries [94,109]. Aquaculture governance, as such, will need to move far beyond technical fixes to embrace sustainability transformation as a regenerative economic and social challenge that requires risk transfer mechanisms, disaster reduction strategies, and assurances from governments for maintaining social welfare. Integrated governance approaches are needed, as exemplified in the FAO report on the ‘Impact of climate change on fisheries and aquaculture,’ which states “that interactions between aquaculture, fisheries and agriculture can either exacerbate the impacts or help create solutions for adaptation.” [110].

Knowledge and innovation

More diverse types of knowledge are needed to enable sustainability transformations in the aquaculture sector that move beyond technical solutions alone [111]. Faced with greater environmental uncertainty, recognition of knowledge systems that are relevant to the ecosystems in which aquaculture is located, but that have been historically marginalized or excluded [112], is needed. Local and/or indigenous knowledge can both broaden system understanding [113] as well as the range of solutions, aspirations, and desired futures needed to achieve positive social and environmental outcomes. New approaches to knowledge coproduction are needed in the aquaculture sector that can enable responsible innovation that is context-based, pluralistic, and goal-oriented [32].

Enabling diverse knowledge systems to coproduce the aquaculture sector presents both challenges and opportunities. Increasing species diversity based on local knowledge, as has been seen in the past with shrimp and various integrated freshwater water farming systems [30,114], can offer potential for more resilient production systems by offering a greater selection of breeding innovations and production systems [115]. In addition to local knowledge, genetics research can play an important role. For example, the diversity of aquaculture products and genetics is well-cataloged by the FAO Aquatic Genetic Resources report [42], which can be more effectively leveraged with knowledge innovations. Greater diversity of farmed species, also with input from knowledge on local cuisines, can also increase nutritional diversity and offer more options for value chain innovation [89]. Social diversity is key to knowledge coproduction by leveraging a wide range of practices and knowledge for adapting assumed or prescribed practices [63]. Transferring and scaling these diverse types of knowledge, however, will require public and private collaboration that enables pre- or noncompetitive learning and cocreation [94,116].

Investments and political will are needed that can enable iterative colearning processes and work toward transformation goals. Furthermore, investments from actors into knowledge- sharing and capacity transfer strategies to and among smallholders, women and/or young entrepreneurs, and from the Global North to the Global South, will be essential. Within science, inter- and transdisciplinary knowledge coproduction processes can modify research agendas to adopt the governance frames articulated by the five engagement arenas. Current initiatives offering tangible examples include the Aquaculture Performance Indicators,[2] Aquaculture Governance Indicators,[3] and One Health [26], along with other nonaquaculture food system initiatives [117].

Value chains

Sustainable aquatic food value chains require collaboration between the full range of actors and their successive activities to produce, transform, and ultimately consume nutritional products that provide equitable benefits and minimal environmental impact [118]. Processing, transporting, trading, and post-consumption disposal [119] are all challenged with improving their sustainability [51,120]. Governing the sustainable conduct of these activities requires coordination of the chain [29,120,121], both domestically and internationally [3,51]. Improving the sustainability of aquaculture value chains is also dependent on the exchange of transparent information across multiple social and environmental performance goals [118] between actors interacting through a diverse range of social relations (e.g. formal contract and informal patron–client relations) [9].

Governing sustainability through value chains has been limited to metric-based standards and certification. While they have continued to expand the volume of compliant production over time, with the three major certifiers each growing nearly 400% in the last 10 years [122], their overall reach has remained limited by poor uptake from producers driven in part by weak global consumer demand for certified products, particularly in domestic markets throughout Asia, Latin America, and Africa [3,50]. As a result, alternative governance arrangements for enhancing the sustainability conduct and performance through value chains, while being cost-sensitive, are needed that target actors selling to these domestic markets. Specific attention is also needed to engaging smallholders through new forms of value chain governance that improve livelihood outcomes [123], such as contracts that leverage sustainability improvement against access to secure contracts, finance, and insurance [3].

Governing sustainable value chains also needs to consider access to nutritious aquatic food. Inclusion and communication across groups through industry partnerships and cooperatives are key considerations for private companies coordinating these chains, as well for governments and NGOs [37]. Attention is also needed to understand how sustainability is included in the everyday routines of consumers who are not conscious of social or environmental impacts associated with the aquatic food they eat [3]. Multiple strategies are needed, including, but not limited to (1) certifications that can balance trade-offs between standard strictness and increasing the share of market compliance, (2) traceability innovations, (3) social protections (e.g. laws, insurances), and (4) financial access and security (e.g. microcredit, subsidies, and patent protections).

Directions forward: operationalizing the engagement arenas

Transformation toward sustainability is essential if aquaculture is to be a main provider of safe, stable, and nutritious aquatic food into the future. Building capacity for governance can help move the sector beyond technical solutions related to intensification, pollution, livelihoods, and other environmental impacts, and toward system-based approaches to sustainability. Governance is not a panacea that will solve all complex issues [124]. Rather, it is a set of social processes and arrangements that, when negotiated among governance actors, can lead to inclusive, innovative, and adaptive approaches for resolving the many challenges of sustainably increasing farmed aquatic food production.

The five engagement arenas presented above provide guidance for building the necessary capacity for governance in research and practice alike. The engagement arenas are overlapping in many ways, and in order to make meaningful steps forward, reflection is needed on

[2] https://www.fpilab.org/api-home/
[3] https://www.aquaculturegovernance.org/

their application to any specific case. Detailed case descriptions of governance arrangements that align closely with many of the arenas and action items are outlined by Jolly and colleagues [10], showing the dynamics and context dependencies of aquaculture governance. We build on and strengthen this recent literature, including the FAO Blue Transformations roadmap [21] and aquaculture subcommittee developments [22], to suggest the types of actions and activities that can be taken in research, practice, and policy to make progress toward meaningfully engaging with the arenas. Below, in the main text, we provide an abbreviated list of what we argue should be priority action items. However, we provide a full table of extended action items for each group in Table S4. The action items are strategic advice, and to specify the tactics for operationalizing them universally would be misguided. Rather, we advocate for teams of researchers, practitioners, and policymakers to find practical tactics for operationalizing them in a flexible way within their own problem and practical contexts.

(1) Cross-cutting action items widely applicable across engaged actors:

- Prioritize goal-setting through inclusion, deliberation, and participation
- Knowledge coproduction through multi-actor and cross-sector partnerships
- Innovative partnership models and cooperation strategies
- Support transparency, inclusion, and best practices across the whole value chain
- Invest in knowledge, capacity, and technology development and transfer.

(2) Practitioners in the aquaculture sector can make progress on the engagement arenas by coordinating activities that guide operational and investment strategies. To do this, collective action is needed to support transparency and best practices across the whole value chain, and to develop adaptive operational strategies that consider impacts and governance beyond local operations. Furthermore, garnering widespread social license and acceptance of aquaculture remains an essential challenge. Priority action items include:

- Self-organize associations for goal-setting, coordination, and knowledge-sharing
- Increase business disclosure and transparency
- Pursue inclusive business models
- Pursue efficiency increases in resource use.

(3) Policymakers can leverage the engagement arenas by guiding cooperative efforts across groups and levels, aggregating information and expertise to set place-based priorities and enable stakeholder capabilities for change. This can include fiscal incentives for cross-sectoral cooperation, regulation of markets, and coordination between finance, insurance, and sustainability assurance for programs that stimulate support for investment and innovation.

- Enable transparent and participatory governance processes at multiple levels
- Create enabling conditions for innovations and sustainability initiatives
- Invest in research, knowledge, and technology transfer programs
- Coordinate vertical and horizontal integration of government
- Support transparent monitoring, data collection, and evaluation strategies

(4) Researchers can strengthen the engagement areas by providing evidence-based knowledge on how each contributes to aquaculture's role in advancing sustainable systemic transformation.

- Pursue inter- and trans-disciplinarity knowledge coproduction
- Examine opportunities, trade-offs, and challenges of governance approaches
- Link problem-driven and solution-oriented research with fundamental research
- Expand geographical diversity of empirical research
- Identify how, when, where, and why different actors are involved

Moving forward, we urge a pluralism of governance activities and transformative agendas to advance aquaculture governance within the engagement arenas and across the sector's diverse contexts and geographies. We encourage the adoption, modification, and constructive critique of the engagement arenas in pursuit of advancing multi-actor efforts and partnerships to foster sustainability transformations in the sector. The action items, as a direction forward, provide more specific steps that, if adopted, can help ensure that aquaculture can play a positive role in societal transformations toward sustainability.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

We declare no conflicts of interest.

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Supporting information

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