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REVIEW

REVIEWS IN Aquaculture

Governing aquaculture commons

Stefan Partelow[1] | **Achim Schlüter**[1,2] | **Aisa O. Manlosa**[1] | **Ben Nagel**[1,2] | **Adiska Octa Paramita**[1,2]

[1]Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2]Jacobs University, Bremen, Germany

Correspondence
Stefan Partelow, Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany.
Email: Stefan.partelow@leibniz-zmt.de

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Abstract

Knowledge of the shared resources—or commons—that aquaculture systems rely on, and the appropriate rule and norm systems to govern them—or institutions—is far behind other natural resource use sectors. In this article, we provide a conceptual framework for identifying the social and environmental commons creating collective action problems for aquaculture governance. Collective action problems, or social dilemmas, create problems for governing shared resources because the typical strategies for individual use (maximisation; free riding) are often divergent from broader group interests (e.g. fair contributions; sustainable use). This framework helps identify two types of collective action problems in aquaculture: first-order (direct use and provision of commons) and second-order (provision, maintenance and adaptation of institutions to govern commons). First-order aquaculture commons with governance challenges include water quality, water quantity, physical space, inputs, genetic diversity, mitigating infectious disease, earth and climate stability, infrastructure, knowledge and money. Second-order institutions govern the use of first-order commons. These include rule and norm systems that structure property rights and markets, aiming to better align individual behaviour and collective interests (e.g. sustainability goals) through governance. However, which combination of institutions will fit best is likely to be unique to context, where aquaculture has important differences from capture fisheries and agriculture. We provide four case examples applying our conceptual framework to identify existing aquaculture commons, institutions and governance challenges in Peru (mariculture), the Philippines (earthen ponds), Nepal (raceways) and Denmark (recirculation).

KEYWORDS
common pool resources, institutions, markets, property rights, public goods, sustainability

1 | INTRODUCTION

This article applies a shared resource, or commons, perspective to the aquaculture sector by developing a framework that can help conceptualise the origin of governance problems and analyse institutional interactions and solutions. On one hand, commons scholarship has a robust theoretical and empirical governance literature,[1-6] but lacks application to aquaculture contexts to further develop its theories and frameworks (shown in two recent reviews of the field).[6,7] On the other hand, aquaculture scholarship has only recently focussed

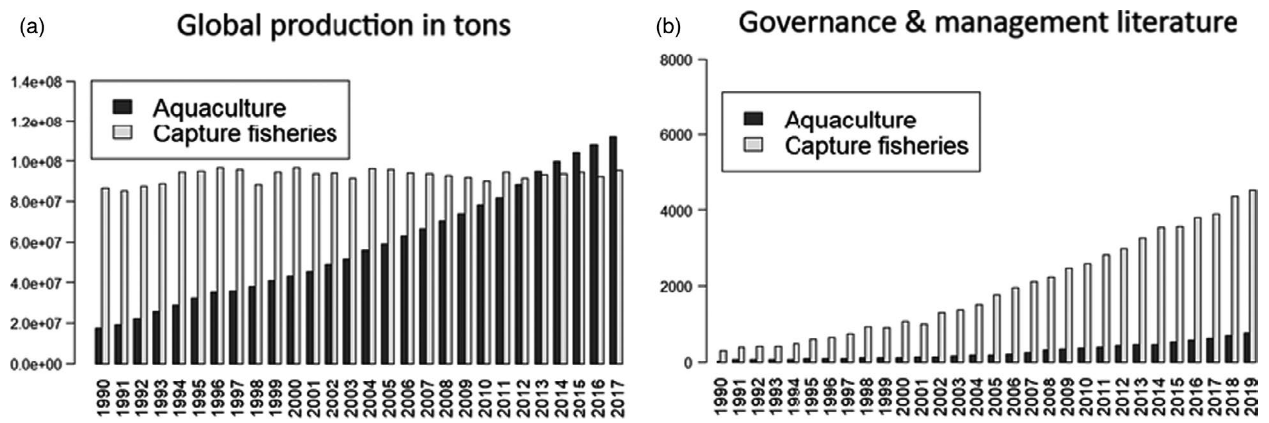

FIGURE 1 (a) Aquaculture versus capture fisheries production since 1990 from FAO data. (b) Amount of aquaculture versus capture fisheries governance and management peer-reviewed literature from the SCOPUS database as of November 2020. Aquaculture search string in SCOPUS (TITLE-ABS-KEY (aquaculture OR mariculture) AND TITLE-ABS-KEY (governance OR management)). Capture fisheries search string (TITLE-ABS-KEY (fish* AND NOT aquaculture OR mariculture) AND TITLE-ABS-KEY (governance OR management))

on governance issues. Compared to capture fisheries, the amount of governance and management literature on aquaculture is substantially lower (Figure 1). In turn, we argue that the two knowledge areas can inform each other. The few papers that have directly linked commons scholarship to aquaculture have provided important empirical examples for guiding future research,[8-16] helping catalyse the development of this article and framework. However, an agenda linking the two is lacking. We argue a framework is needed that provides theoretical explanations for the origins of governance problems unique to aquaculture, which can act as an analytical tool for future cases by providing definitions and conceptual relationships through an overview of related literature and examples of how it can be applied.

In doing so, the framework outlined in this article draws on common-pool resource (CPR) and public goods (PGs) theory as well as institutional theories and analysis, and their applications in aquaculture systems. This includes framing the over-appropriation of aquaculture CPRs and the provision of PGs as first-order collective action problems, and the provision of institutions (e.g. rule systems, informal norms, property rights, markets) as second-order collective action problems. There are likely similarities with other commons sectors (e.g. forestry, capture fisheries, agriculture) where learning can be transferred and governance principles can be applied. For example freshwater pond aquaculture may have similar canal provision and water distribution problems as irrigated agriculture, or mariculture similar appropriation problems as fisheries for wild capture of juveniles and associated property rights. However, there are also substantial contextual differences, and these need to be understood and appropriately framed.

1.1 | Why aquaculture needs governance

A primary reason for this overview and conceptual framework is the substantive lack of governance research on aquaculture despite governance issues being perhaps the most important piece of the puzzle for the sector's sustainable development.[17-20] Aquaculture, as a whole, arguably has the most varied governance across contexts and production systems compared to other large food production systems. It produces hundreds of species in many different environments and production systems.[21] There are countries with under- and over-regulation, diverse value chains and civil society organisations playing substantial roles in guiding actor behaviour and development activities.[20,22,23]

The sector also raises explicit land–sea connectivity issues and cross-sectoral interconnectivities due to shared risk.[24,25] Compared to capture fisheries and agriculture, aquaculture is less likely to have property rights, established state policies, legislation, farmer cooperatives, supply chains or co-management arrangements, although the sector competes for the use of many of the same resources.[26,27] This is in part because aquaculture will need to interface with, adapt to or even conform to the governance systems of other sectors due to shared risk in competing and using the same resources. Another unique challenge is that aquaculture does not just use water, it is produced in water which then flows out to be reused or absorbed into surrounding environments, creating a more materially open system.

A recent review of global aquaculture by Naylor et al.[22] importantly gives space for highlighting governance issues including the role of public–private partnerships, setting best practice standards and value chain dynamics and drivers. However, a major challenge is the limited literature to review and the lack of contextualization across the sector's diversity, where literature beyond the major producing countries is scarce. Although aquaculture production is by far the highest in Asia[1], it is expanding most rapidly in Africa, where the largest producers are Egypt and Nigeria.[21] In Latin America and the Caribbean, production is led by Chile, Ecuador and Brazil and in North America and Europe, by Norway and the United States. More

[1]China (57.5%), Indonesia (14.2%), India (5.5%), Vietnam (3.4%), Bangladesh (<3%), South Korea (<3%), Philippines (<3%) (Tacon, 2020).

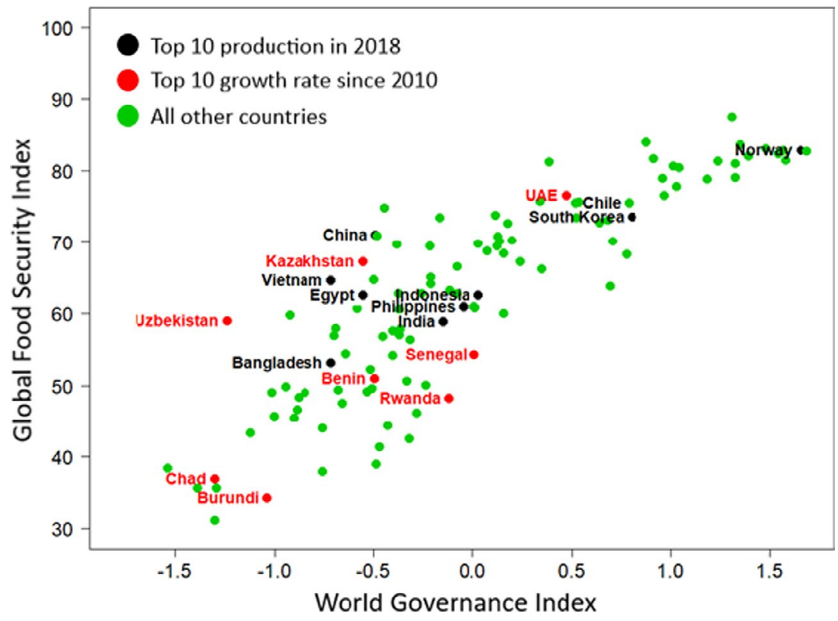

FIGURE 2 The Global Food Security Index (https://foodsecurityindex.eiu.com/) plotted against the World Governance Index (http://info.worldbank.org/governance/WGI) at the country level. Top 10 countries in total aquaculture production labelled in black, and the top 10 countries with the highest aquaculture production growth rate since 2010 labelled in red taken from FAO data. Barbados and the Bahamas are in the top 10 growth rate, but are not shown in red because they do not have GFSI scores

governance analyses are needed in these countries to identify specific hindering and enabling conditions for expansion and intensification. What we can currently assess is that aquaculture governance generally, in the context of country-level assessments across all sectors, is not optimal[28,29] (Figure 2).

Much of the production is in low- and middle-income countries with suboptimal scores on the World Governance[2] and Global Food Security Indices[3] (Figure 2). Seafood currently provides ~4.5 billion people with at least 15% of their average per capita animal protein consumption,[30] and ~3 billion with their main protein source. An increasing percentage of this will come from aquaculture given capture fishery stagnation,[20,31] as aquaculture production now exceeds capture fisheries in 39 countries and is roughly equal to capture fisheries production globally.[21] Economically, one in 10 people worldwide relies in some way on the fisheries and aquaculture economy for their livelihood,[32] many as part of the 'hidden middle' of diverse value chains,[20] making seafood products one of the most valuable traded food commodities[33-35] although a large majority of aquaculture products never cross an international border suggesting each country likely has its own domestic market, supply and value chain governance dynamics.[17] Fish can make substantial contributions to improved diets and nutrition security throughout the developing world. However, this is less likely to be realised without good governance that can provide healthy enabling environments for food quality, fair distribution and access.[30,36-39]

Another challenge is that countries generating most of the current production tend to be at high risk from climate change impacts[4,40], and score low on environmental performance indices[5,41]. A recent review of the current and future climate change impacts on aquaculture by Reid et al., [42] indicates a diverse spectrum of impacts from increased variability in environmental conditions to novel disease and pathogen emergence. Adequate governance knowledge will be needed to reduce the likelihood that continued expansion can cope with increased environmental variability and not further contribute to it.

Where aquaculture takes place is also important. Coastlines and waterways are hubs, but they are also the least governed spaces in terms of established institutions and property rights, often shared by multiple groups for multiple use purposes.[43-45] One concern is that the increasing enclosure of water spaces in low- and middle-income countries may lead to crowding out of food production by tourism, residential and port development under Blue Growth and Blue Economy strategies.[46,47] This raises another important issue that there are likely many cross-sectoral governance issues interlinking the development, shared resource dependencies and shared risk of aquaculture with capture fisheries or agriculture that governments and practitioners are dealing with. These can include physical space requirements, corresponding land and sea use changes and socio-economic implications of the expanding sector, which contribute to challenges for developing governance institutions. For governments, novel development of aquaculture may pose questions for public administration.

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

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

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

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

Which agency or department should oversee aquaculture? Do those agencies have capacity to administer the sector's diverse presence in both marine and terrestrial systems, and dimensions of farming and fishing? Every 2 years the FAO surveys its member states on the status of fishing and aquaculture governance in relation to the implementation of Code of Conduct for Responsible Fisheries.[48] In 2020, of the 118 members who responded to the survey in relation to aquaculture, 'slightly less than half of these Members had largely complete and enabling policy (45 percent), legislation (47 percent) and institutional (44 percent) frameworks' (p. 5), with the remainder having partially, none or insufficient ones. In industry, public–private partnerships, establishing best practice standards or certifications, and developing supply and value chain innovations may be difficult without enabling regulatory environments.[19,20,22,27,49]

Another challenge for aquaculture governance is contextualising its development amongst the sector's high diversity of production types, environments and species. Categorization has implications for how we make sense of aquaculture diversity and how we frame our research (e.g. collect data) and govern the sector (e.g. organise stakeholders, develop rules). At least 598 different species are grown across 194 countries in all types of waterways including freshwater rivers and lakes, brackish water lagoons and estuaries, pools and tanks, and in the sea.[21] Many typologies have been suggested to descriptively categorise this diversity,[50,51] however, none are specifically based on any governance theory. These include species groups (e.g. fin-fish, crustaceans, algae),[32] level of domestication,[52] production environment or technology type (e.g. pens and cages, earthen-ponds, tanks, lagoons, input or feed types (e.g. fed, un-fed, auto-trophic).[53] Social typologies tend to be more general, focussed on key principles, factors or human dimensions to consider.[54-56] Other typologies have used ecosystem services to differentiate values provided.[57-59]

In section 2.0, we detail the background and logic of our conceptual framework premised on commons governance theories. In section 3.0, we highlight four case studies demonstrating how the framework can be applied. Our case studies are as follows: (1) mariculture in Peru, (2) earthen ponds in the Philippines, (3) raceway through-flow systems in Nepal and (4) recirculating systems in Denmark. Each case reflects a different production system, which we first characterise generally. This is followed by a case-specific example of the collective action problems manifested by shared resource use. Importantly, we recognise that the four system types are broad generalisations, with large within-system diversity. Nonetheless, we believe the case examples provide useful contextual insights into why the governance of aquaculture commons is uniquely diverse, and demonstrate the applicability of the proposed framework across contexts.

2 | A FRAMEWORK FOR ANALYSING AQUACULTURE COMMONS

Common-pool resource and PGs theories explain how governance problems emerge from the use and maintenance of shared resources. Social dilemmas manifest here between individual interests (e.g. maximising gains or minimising effort) and group interests (e.g. sustained availability of resources). CPRs (e.g. fish, trees, pastures) are subtractable, only one person can use them at a time, and excluding others from using them is difficult. As a result, CPRs create temptations to overharvest in the short-term, taking more than is socially or ecologically sustainable. Institutions, rules and norms systems, are needed to help solve CPR appropriation, deciding who gets how much.

Public goods are not subtractable, many can use them simultaneously, but they do have an excludability problem because it is hard to restrict use (e.g. healthy ecosystems, public infrastructure and knowledge). PGs require someone to put effort into providing or maintaining them, but the problem is that for any one individual, not contributing and relying on the work of others (i.e. free-riding) can be the preferred individual strategy for reducing costs. Generally, two types of PGs problems exist that can blur the distinction between CPRs. One issue may be who provides the good, such as who creates the knowledge or builds the canal. Here, the input costs may be borne by few, with benefits for all. A second problem may be who is undermining the maintenance of the good and its quality for all, such as pollution problems. Pollution problems have a subtractability dilemma, only so many can pollute before the good is degraded, such as carbon emissions for climate change or fertilisers in a waterway. Here the costs are borne by all, benefitting the (few) polluters. This problem requires rules and norms for appropriating who can pollute and how much, similar to CPR appropriation.

For private goods, a third category, an owner is able to exclude use by others at a reasonable cost. They have rivalry for their acquisition and distribution, often requiring rules and norms to coordinate markets, hierarchies or other allocation mechanisms. Private goods, such as money and produced fish, fit here conceptually. A fourth good, club goods, are PGs with forms of privatisation to help solve the excludability problem; national parks with an entry fee are a good example. The different types of shared resources relevant for aquaculture are outlined in Table 1.

Two things are worth mentioning: First, the clear distinction between the goods is analytical and empirically fluid and changing over time, depending on technology and preferences. For example only pure PGs, like certain institutions, are entirely characterised by nonrivalry. Most PGs, like infrastructure or biodiversity, are affected at some threshold by overuse. Also, it is not sufficient for one agent to provide them, but many people have jointly agreed to contribute, creating another collective dilemma. Second, the type of good does not align with the kind of governance or property rights regime (open access, state, common, private property regime or any mixture thereof).[5] Any combination might be possible, each coming with its particular difficulties and opportunities in context.[60]

Institutions is a broad term for the sets of rules and norms that organise society and behaviour. In relation to shared resources or commons, institutions guide human behaviour and largely influence the sustainability of their appropriation and provision, helping to solve the first-order collective action problem of tangible resources. There are many types of institutions, and also different ways of

TABLE 1 Shared resources creating first-order collective action problems in aquaculture systems

Shared resource	Type of good	Governance challenge	Importance for aquaculture
Environmental commons			
Freshwater quantity and availability	Common-pool resource	Who has access, withdrawal, management, exclusion and alienation rights?	Inland aquaculture is dependent on freshwater, and competition can be high if water resources are limited or far away.
Water quality	Common-pool resource/ public good	How to reduce pollution incentives? How to increase maintenance incentives? Who has access, withdrawal, management, exclusion and alienation rights?	Growing aquatic plants and animals is dependent on available nutrients in the water, varied by species (e.g. oxygen, nitrogen, organic matter, temperature of water, salinity).
Physical space	Common-pool resource	Who has access, withdrawal, management, exclusion and alienation rights?	Aquaculture requires space, either on offshore surface water or on land, and competition and costs can be high.
Inputs—seed, juveniles, eggs or feed	Common-pool resource (harvested). Private good (produced)	Who has access, withdrawal, management, exclusion and alienation rights? How are private goods distributed?	Inputs are needed for farming, and where they come from, how they are produced and distributed can vary substantially.
Genetic diversity	Public good	How to increase incentives and reduce costs for maintaining species and ecosystem diversity?	Maintaining genetic diversity helps ensure future options for adaptation and innovation in food security, breeding and environmental resilience.
Mitigating infectious diseases	Public good	How to increase incentives and reduce costs of safe aquaculture practices?	Spread of disease threatens farming livelihoods and food security. Mitigating spread and enhancing species resilience is a social dilemma because increasing stocking density, monocultures and antibiotic use may increase individual farm economic efficiency but increase disease and resistance risk for all.
Earth system and climate stability	Public goods	Who contributes, and how, to maintaining physical earth system stability? (i.e. carbon, nitrogen, climate stability, sea-level rise, rainfall patterns, storm frequency)	Predictable and sufficient water availability and environmental conditions is essential. Coastal storms, sea-level rise, ocean acidification and increasingly varied temperatures makes this more difficult.
Social commons			
Knowledge	Public good/ private good	Who creates or maintains knowledge? Who distributes it, how and in what form? Who has access? How do knowledge systems interact?	Knowledge is needed on technology access and use; species growth rates, feed and conditions; environmental risks and mitigation strategies; market opportunities, prices, financial planning; cooperation and governance.
Public infrastructure	Public good	Who creates and maintains the infrastructure?	Public utility access is necessary such as roads, electricity, internet, phones, harbours, docks, physical market structures, irrigation canals.
Money/ financing	Private good	How is money allocated and distributed for aquaculture? Who determines these processes?	Farming requires investment because financial returns are delayed over time and require startup costs for equipment, feed, seed and juveniles. Financing may be sourced through personal capital, or loans from banks, cooperatives and informal financial services.

analysing them and their role in environmental governance generally. Below (Section 2.2.2) we identify the two overarching types of institutions, rule systems and norm systems, as the basis for understanding sets of more specific bundles of institutions such as property rights and markets, which are structured by numerous rules and norms (Table 2). All of us (and aquaculture stakeholders) benefit from the existence of institutions as a PG but we need to organise as a group when it comes to creating, maintaining or changing them for the benefit of all. Institutions are referred to as second-order collective action problems, because whilst they are needed to solve first-order collective action problems, creating them also requires collective action in order to do so.[3,61]

TABLE 2 Institutions are also shared social resources that require provisioning. They are second-order collective action problems, because providing them is a collective action problem on its own, needed to solve the first-order collective problems

Institutions	Key questions	Examples in aquaculture
Rule systems—i.e. laws, regulations, enforcement	Who should make the rules and rights, to whom do they apply, and who should enforce them? What are the goals? Who should be involved in setting the goals? How do formal and informal institutions interact?	Formal rules can mitigate undesirable externalities of production and trade such as pollution, food safety and land acquisition. They can structure markets and production standards and establish governing processes for rule development and enforcement.
Informal norms—i.e. cultural, religious, gender, power hierarchy norms	How do they develop, change and reproduce? Cultural norms, assumptions and traditions strongly influence human behaviour. Power and hierarchies structure social interactions and behaviour.	Such institutions often already exist, but may not be evolved from or for an aquaculture context. Some norms such as trust and reciprocity may advance positive community development, whilst others such as cultural or religious gender roles, may marginalise certain groups.
Markets	How does supply interface with demand? Who enables and controls access, and how? Who designs the market interactions?	Aquaculture products need to be exchanged, but also equipment, knowledge and land. Some seafood markets may exist from capture fisheries, but if not, how do they evolve and become more efficient, safe and fair?
Property rights	Who has access, withdrawal, management, exclusion and alienation rights? Who allocates property rights and how?	Space allocation, rights to use freshwater, knowledge protection, market access or rights to govern are all important institutions in aquaculture that in many contexts may not be well established due to the sector's relatively short history. Property rights in other sectors (fishing, farming) may strongly influence aquaculture

In this section, we identify the social and ecological shared resources (CPRs, PGs), and to a lesser extent private goods, in the aquaculture sector (Figure 3). We give an overview of the governance problems they tend to create by categorising them as first and second-order collective action problems. We define and explain each shared resource, and briefly outline the governance challenges they create and their importance to aquaculture. This is categorised below into environmental and social commons. This conceptual framework is then used as the basis to examine four detailed cases of different types of aquaculture systems and analyse the governance problems they create with more contextual detail in the following section (Figure 3).

2.1 | Environmental commons as first-order collective action problems

Environmental commons have been studied for over a century.[2,4,6,62-64] Fish, trees, freshwater and land have been extensively researched and share important natural CPR characteristics. Maintaining PGs such as climate stability and healthy environments (e.g. pollution mitigation) also share resource provision challenges. In the marine realm, a substantial amount of literature exists on how institutions shift the resource use behaviour of individuals once they are removed from an open-access context, and are placed along a diverse spectrum of rights from common to private property regimes.[45] This remains a lively focal area of scholarly discussion, which we only address in a basic form to convey its importance in aquaculture below.

Aquaculture is reliant on shared environmental resources, but governance problems will vary between contexts. Both environmental CPRs and PGs exist, and our conceptual framework can assist scholars in identifying those resources in aquaculture (Figure 3, Table 1). For example a watershed may not be owned by an individual, but is essential for providing the freshwater quantity and quality for filling ponds and tanks. Quality provision may refer to the amounts or ratios of nutrients or pollution, which may be difficult to assign rights to. All aquaculture requires seed stock which could be produced in the wild as a CPR or in a hatchery as a private good. Physical space might be CPR in an open-access setting, when establishing cage or pond production, but often has property rights making them private or communal spaces, whether on land or on the sea surface. Physical space could also be seen as a PG, having any form of property regime, in the sense that it produces the inputs of freshwater quality and nutrients that everyone requires for their private farms. This is more obvious in offshore aquaculture, which is not dependent on freshwater quantity, but instead relies on stable and predictable environmental conditions (PG) such as temperature, salinity, nutrients and storm cycles in the oceans. Our ocean water is a shared PG, moving fluidly between private pens, cages, harbours or estuaries. Thus the nutrients and pollution in the water are also shared, and difficult to control. All systems may be influenced by climate stability, either in relation to freshwater quantity, sea-level rise or increased temperature variability, but production systems often incur freeriding, not taking proactive actions to ensure that they remain stable for everyone whilst not overusing them. The following descriptions are the relevant environmental commons in aquaculture systems.

Freshwater quantity and availability is necessary for all non-marine aquaculture systems. Pressure and through flow are important characteristics for access and availability, as water needs

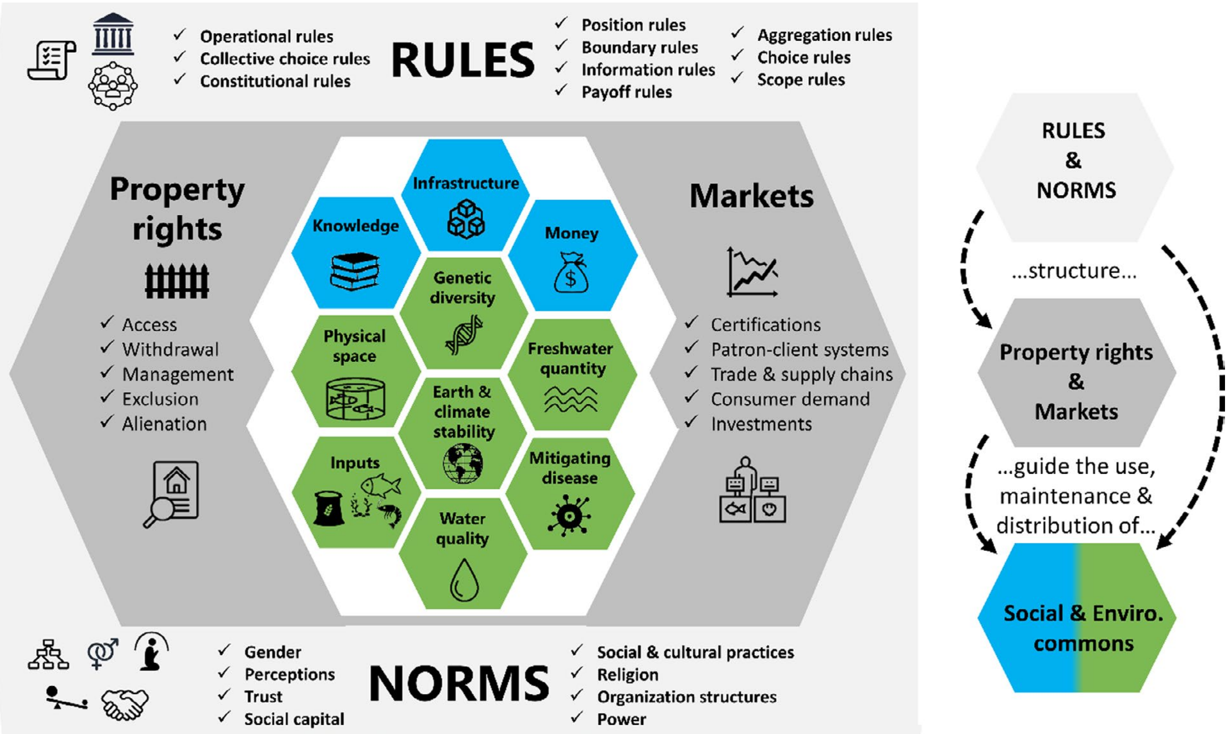

FIGURE 3 Visualisation of the conceptual framework outlined in this article. Rules and norms structure property rights and markets, which then guide the use, maintenance and distribution of shared resources. Rules and norms can also directly guide the use, maintenance and distribution of shared resources. Social and environmental commons are considered first-order collective action problems. The provision of institutions (rules, norms, property rights, markets) are considered second-order collective action problems, that need to be provided in order to solve first-order collective problems of specific shared resources. The right side of the framework indicates the relationship between items. Numerous icons sourced from the Noun Project under a Creative Commons License

to be moved around or circulated either by gravity or built infrastructure. There is rivalry in consumption but it is often difficult to exclude people from its use, for example, from digging a well, collecting rain or extracting from a river upstream. Therefore, it is a CPR. Availability can vary substantially by season, regional climate patterns, watershed connectivity, groundwater availability, the ecosystems in the surrounding area and of course the number of users extracting. Access may also vary, as water may not be naturally distributed or present in the areas where it is most needed. The classic CPR problem of 'who should get how much water' has a wide variety of documented institutional and property rights arrangements attempting to solve it in agriculture.[65-68] However, very few cases have examined this problem in aquaculture, especially in relation to how this problem is combined with other shared resource challenges, which may require specifically tailored institutional solutions for aquaculture governance.[69] For example passive water use (e.g. cages in a flowing river do not extract from source) versus consumptive uses of water (e.g. purposeful extraction or redirection of water to another area).

Water quality is essential for aquaculture. Numerous organic and inorganic compounds are likely to be present. These can be either beneficial, essential nutrients for plants and animals to grow, or they can be pollutants, hindering growth and food safety. Whether they are needed or undesired, might be an issue of concentration or species requirements. For example filter-feeding species may remove excess nutrients and clean water sources, however, these may not be beneficial in poor nutrient environments or in highly polluted environments where absorbed concentrations threaten food safety. Water quality, as with pollution generally, is a unique provision problem for mostly non-excludable benefits.[70] A water body has a limited pollution capacity, and only so many can pollute it before it erodes the common good. In this sense, pollution has characteristics of CPR problems in regards to who can pollute and how much, an appropriation type problem. On the other hand, active efforts to provision watershed health may require incentivizing stakeholders to contribute through restoration, land sparing or infrastructure provision, where more contributors are needed to overcome free-riders who benefit without contributing.

Physical space has also been studied extensively, with a large literature on property rights debating the benefits and challenges of public, private and state lands, for example.[45,71] In aquaculture, land and aquatic areas are necessary for production. Most aspects of land have private resource characteristics. On land and sea, location is important for the suitability of aquaculture establishments, they often need to be in close proximity to water resources. Some land will be more optimal than others, such as head-enders in terms of upstream river access on land, or in an aquatic location with more water exchange than in a stagnant area. In addition, pollution on that land or aquatic space will likely affect others in the surrounding area. However, private property regimes on land generally create less collective action problems (not considering equity issues) than in the sea. Due to the materiality of aquatic environments, the CPR characteristics are much more pronounced.[72] In nearshore environments, we often find state (exclusive economic zone) or common property regimes. In mariculture, access to sea surface and underwater space is important. Only one farmer can access the space of, for example, a cage, at a time, so some property rights are assigned in the form of leasing agreements, and that access allows the use of water (PG) and nutrients (CPR) in the area. In the sea, the location of the space may be less important than on land, or even than in a smaller lake or river, because nutrients in the sea may be more evenly distributed and pollution may be more dispersed, although circulation issues may exist. On land, additional infrastructure (PG) may be needed to access and distribute water and nutrients, where the location may incur additional costs for this access. However, sea space may face more multi-use conflicts, for example, with fishers, recreational users, oil drilling or ship traffic.[69]

Seed stock and feed such as plant seedlings, animal eggs or juveniles, are essential aquaculture inputs along with feed inputs such as fishmeal. These can be private goods or CPRs depending on their origin. If sourced from the wild, they are CPRs, clearly linking aquaculture sustainability to capture fisheries.[73] However, if produced by an individual, company or state agency, they exist directly as private goods. Aquaculture farmers need access to seed stock and feed, and who produces or sources them, and the mechanisms for distribution are often social dilemmas and important governance questions. Particularly, aquaculture that produces carnivorous fish, in high demand by many wealthy people, still relies heavily on fishmeal produced from wild fish caught from somewhere in world. This creates a global CPR dilemma.[74]

Genetic diversity is a PG and cornerstone of aquaculture,[75] but it is hard to assess its value and maintain it. In 2019, the FAO released the first global report on the state of the world's aquatic genetic resources for food and agriculture, which includes 'DNA, genes, chromosomes, tissues, gametes, embryos and other early life-history stages, individuals, strains, stocks and communities of organisms',[75 (p. xxix)]. The report also notes that compared to other food production sectors, species use in aquaculture is extremely diverse. It also highlights six governance and management topics impacting aquatic genetic resources including limited diversity in founder populations, small private hatcheries with limited broodstock, global dissemination from limited sources, limitations for refreshing genetics from wild stocks, private sector non-compliance with rules and poor controls on accidental release into the wild[75 (Table 30)]. The costs of sustaining genetic resources may be less evident than other shared resources, but can be viewed as the income or future opportunities foregone by not switching to, discovering or innovating with species varieties or ecosystem diversity to develop other economic pursuits or social benefits. As a PGs problem, it may be difficult to expect that farmers and aquaculture actors proactively contribute to maintaining genetic diversity given individual and short-term incentives to move towards intensification and specialisation in farming systems, despite long-term incentives to keep genetic diversity available for all indefinitely. Although over 300 species are currently farmed worldwide,[76] aquaculture is likely moving towards intensification and consolidation with a few species dominating production.[77] Agriculture research has linked increased crop diversity with increased ecosystems service provisions[78] as well as increased genetic diversity with increased nutritional availability and increased economic options for sector expansion.[79] The State of the World's Aquatic Genetic Resources report[75] concludes that 'a common thread across all of these issues is the important need to build relevant capacity in governance, policy, institutions and the private sector'[(p. 244)].

Mitigating infectious diseases is a PGs problem.[80] In aquaculture, all farmers prefer to avoid disease outbreaks on their plants and animals, however, individual actions to increase production such as stocking density, long-distance trade networks and intensive single species production all increase the risk of infectious disease outbreaks within and between farms. In addition, the use of antibiotics by individual farmers to mitigate and protect their fish, may lead to resistant disease strains over time for the whole sector, intensifying the problem, undermining individual and group interests.

Earth system and climate stability is a PGs maintenance problem with pollution appropriation challenges similar to CPRs. It is a pure PG because there is no rivalry, everyone uses it without possibility of exclusion. However, adding carbon dioxide and pollutants to the earth system is often free for polluters, distributing the costs across everyone. Only so many can do this until earth and climate stability is compromised for all. Appropriating who can pollute, and how much, with rules and norms, is needed to maintain stability. These PGs are not limited to aquaculture, but are very important for it. Sea-level rise, rainfall patterns, increased storm intensity and variable temperature changes amongst others will affect coastal areas and make other aspects of production more difficult.

2.2 | Social commons

Shared resources can be either material (e.g. physical infrastructure) or immaterial (e.g. rules, norms, knowledge). We can produce private goods (e.g. money) and PGs (e.g. knowledge, infrastructure), and we also produce institutions (PGs) for determining who should make or provide the resources (provisioning) and who should get some, how and how much (appropriation). We can see that shared resources often have interrelated governance and collective action problems, and exist together in bundles.[3] For example public infrastructure such as canals may be needed to distribute freshwater (CPR) to private ponds. Both have their own collective action problems, but interdependencies exist between them, and solving those problems often requires joint institutional solutions that fit their joint context (e.g. rules, norms, rights). Thus, there are both first- and second-order collective action problems in social commons, bundled together. For example sufficient markets, consisting of a bundle of rules and norms

(PG, second-order dilemma), are needed to develop institutions to appropriate wild-caught fish juveniles (ecological CPR, first-order collective dilemma) for aquaculture. The following descriptions are the relevant social commons in aquaculture systems.

2.2.1 | Shared resources—first-order collective action problems

Knowledge has been studied as a public and private good for decades.[81] We all need and use various forms of knowledge, but who should invest in providing it? Who should have access to it, who should be responsible for distributing it, or how should it spread? Aquaculture is a knowledge-intensive farming activity, because each species may require different growing conditions, inputs and technology, and corresponding governance arrangements. Understanding what those conditions are, and how to change or keep them stable (e.g. with technology, policies, capacities), requires specialised knowledge. Similarly, aquaculture requires social and economic knowledge, for example on how to make investments, or develop cooperative strategies for sharing resources, as well as knowledge of rules, markets and product values. Government organisations play important roles in knowledge distribution through various capacity building and knowledge transfer programmes. Informal social networks in communities also function as channels of knowledge exchange. However, a lot of this knowledge is produced and held privately, and rules such as patents exist to incentivize knowledge production by protecting it for private use. Actors with knowledge on markets, money, and technology may have substantial power over other actors without it, with no incentives to share that knowledge and lose their advantage. The question arises, what are the optimal bundles of institutions for knowledge provision and distribution? How do they influence the system's functionality and outcomes? For example actors with private knowledge might drive market establishment and technology innovation, later diffusing to other actors, benefitting all. On the other hand, some actors may exploit others and the environment with their knowledge, undermining the long-term sector interests for short-term gains. Another issue is public access to scientific knowledge, which is often published with restricted access, substantially limiting access beyond academic spheres although open access publishing is increasing.

Public infrastructure traditionally refers to roads, railroads, water, electricity cables, gas lines, sewage and telephone services. For example without roads and railroads, goods cannot get to markets, and local economies cannot enter the global market which is important for aquaculture. Without water distribution and perhaps electricity, filling aquaculture ponds and tanks is not possible. Without docks and harbours, access to offshore farms may be difficult. The state has been a key player in providing PGs, but their provision is being increasingly privatised,[82] not only the infrastructure itself, but the institutions to make the rules as well. Cooperatives are also emerging in the energy and financial sectors[83] and specifically to provide aquaculture services.[26,84] State governments, private companies and cooperatives are all emerging to provide needed public infrastructure. The implications, challenges and relationships between the three, as they create interrelated goods and institutions, are important questions for aquaculture governance analysis.[27]

Money is a complex good that is not easily classified. It is typically viewed as a private good needed throughout society, requiring many institutions (second-order collective action problems) to allow its availability.[85] However, money is also a PG in the sense that it is an agreed upon system of value standardisation that requires everyone's trust who uses it. The trust is the PG, in part backed by central governments or banks in many cases, but also requires repeated user provision of that trust. It is produced as a private good because an individual or entity always own amounts of it immediately (e.g. there is no open-access money) and it is easy to exclude others from use. However, it also faces challenges with appropriation in the form of publicly accessible common property in the form of loans, investment and credit distribution which have rivalry similar to CPRs. Aquaculture is a rapidly growing sector and many new businesses require capital investments, loans and credit access. Competition within and between the sector for available financing requires some governance institutions to enable continued development. It is particularly important for aquaculture. Compared to fisheries it normally requires much more investment for equipment, space and regular costs for inputs (e.g. seedlings/fry, feed, labour) with delayed returns, perhaps months until the end of growing periods without income. Organising the availability of money is particularly a collective action challenge for small-scale producers.

2.2.2 | Institutions—second-order collective action problems

Institutions are a central feature of governance analysis, both in commons literature and beyond. Institutional analysis, in its diverse forms, is increasingly being applied to better understand aquaculture governance.[86-95] Below we specify the role of institutions within our framework, and review the contributing literature.

Rule systems and governance structures are critically important social PGs. Formal rules typically refer to written rules that could often be formally enforced. Ostrom[96] defines rules as 'the set of instructions for creating an action situation in a particular environment,'[(p. 17)]. Different nested levels of rules exist at the group or societal level.[97-99] Operational rules are the practical day-to-day rules, providing a set of options for aquaculture stakeholders to make actionable choices (e.g. gear restrictions, zoning requirements, food safety rules, pollution restrictions). There are also collective-choice rules, the rules for making the operational rules, such as decision making and enforcement strategies, as well as deciding who the rules apply to and who can participate in making the rules and how. Third, constitutional rules, dictate who is or should be empowered to participate in making collective and operational rules.[4] There is also scholarship outlining more specific detailed sets of rules, notably the Institutions Analysis and Development (IAD) framework in commons scholarship detailing action situations where actors interact with each other, and the sets of rules that apply to them.[96,100-102] These rules apply more to the individual or small group level, including position rules, boundary rules, information rules, payoff rules, aggregation rules, choice rules and scope rules.[100,103] To analyse rules, the institutional grammar approach is well established,[104-106] which has been applied in aquaculture.[91,92] In certain places, a major challenge within aquaculture, as an emerging sector, is that formal rules and actors enforcing them, in many cases government agencies or private certifiers, do not yet exist to provide formal rules, or their administrative and regulatory capacity is minimal.

Norm systems in the form of social and cultural practices, or conventions making up a good proportion of social capital of a community, can be classified as PGs. They are typically unwritten but socially mainstreamed expectations for human behaviour, often shaped by local culture or religion.[107-110] Whilst one could imagine a society with minimal formal rules, it is almost impossible to imagine a society without locally embedded norms.[111] They can often be more influential in shaping system outcomes than formal rules and enforcement.[112-115] As aquaculture is a relatively new sector, norms may be more established or have evolved in relation to other sectors and contexts before formal governance rules (e.g. state regulations). For example gender norms and the role of women in production processes,[116-118] knowledge sharing practices, age or social power structures, development or species preferences in relation to local production knowledge practices,[119] consumer preferences[120] or the historical seafood culture (or lack thereof) of a community can influence governance decisions and outcomes. Whilst norms may tend to evolve on their own, who should invest in changing them towards group goals? Changing norms and perceptions of how to behave can be very challenging, but often very much needed to achieve sustainable development pathways.[113,114] Two important institutional configurations, made up of combinations of both rules and norm systems, are markets and property rights. Therefore, they get special attention here, although more research on the influence of norms is needed.[121]

Markets are bundles of rules and norms or institutional combinations. They are important PGs in society generally, and also for seafood consumers and producers to exchange produce, materials and money. How should markets be designed, and who should invest in designing them to provide access opportunities, incentivize contributions and enable efficient transactions? Some fish are sold internationally and some are sold locally, but why? How do buyers find sellers, determine prices, transport costs and enable market access? These can be problematic social dilemmas.[122,123] If insufficient, this can stall other important necessities such as financial investment, farmer income and consumer access to food. For example patron-client systems may rely on trust and built-up norms as much as (formal) contracts. Market access may be based on tenure norms as much as formal applications. Knowledge of prices and demand may be linked to cultural social capital as well as formal education. Power to steer markets may be reflective of formal organisational structures or religious-oriented norms. There is an established and growing literature on aquaculture markets including value chains,[23,124] certifications,[18,125,126] global trade[34,35] and local markets.[127,128]

Property rights refer to who has access, withdrawal, management, exclusion and alienation rights to shared resources.[1] Ostrom[96] notes that 'the property rights that participants hold in diverse settings are a result of the underlying set of rules-in-use' [(p. 17)]. Thus, property rights (as well as markets) are structured by rules and norms, and exist in many forms to solve first-order collective action problems (Table 1). They can be both formal and informal, are often bundled together in different combinations and in some cases can be traded in markets, for example, to buy and sell land access or amounts of fish (i.e. transferable quotas). Property rights can be applicable institutional solutions for dealing with collective action challenges[129] of nearly all first-order commons in aquaculture including to physical entities such as land or sea space and freshwater access.[130-133] They can also be applied to knowledge and access to genetic resources in the form of intellectual property rights.[134-137] As a second-order collective problem, who should invest in creating or changing property rights? If no institutions exist, it may be difficult to solve first-order collective action problems such as water distribution or space allocation. If governments are slow to establish clear rules, or to enforce them, who should step in? If government rules exist, but they do not work well, who should invest in trying to change them?

3 | APPLYING THE FRAMEWORK: CASE EXAMPLES AND CHALLENGES

This section provides four practical case examples (Figures 4-7) of how to apply our above conceptual framework (Figure 3) to describe and analyse aquaculture governance challenges. Our goal is not to provide representative cases of the most common typologies of aquaculture production, but to provide examples that highlight some of the contextual (e.g. shared resource dependencies) and institutional diversity challenges (i.e. rules, norms, markets, property rights) within each system. We focus on four types of aquaculture systems, based on their shared resources and technologies used: (1) mariculture, (2) earthen ponds, (3) raceway flow-through systems and (4) recirculating aquaculture systems (RAS). Below, each is briefly characterised by their use of specific shared resources, institutional configurations and challenges. A case study is then provided for each production system to demonstrate the practical context, used commons and institutional challenges. The case studies demonstrate that each case has unique combinations of commons being used and institutional configurations.

3.1 | Mariculture

Mariculture includes offshore or near-shore cages, pens, bottom culture, suspended or line culture. Cages are free-floating nets with high investment costs, and pens are the 'fences of the sea'. All mariculture uses a shared waterbody, which leads to non-excludability challenges during production that can have positive but most often negative externalities. With limited carrying capacity, there is rivalry

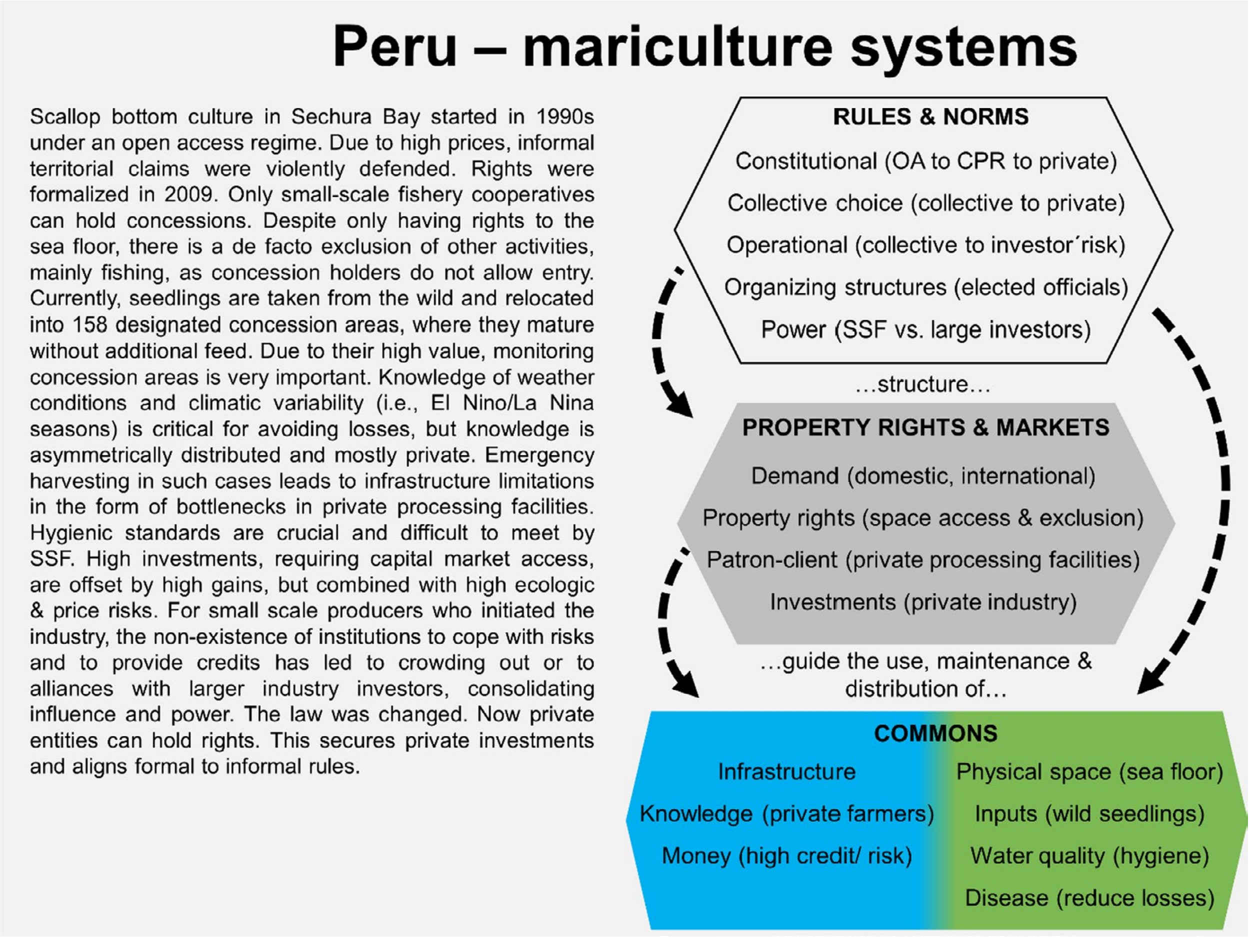

FIGURE 4 The framework applied to the case of scallop mariculture in Sechura Bay, Peru

in consumption to produce private aquaculture goods. Pollution is an important collective action problem for cages and pens if they are close to shore and use extensive feeding or medicine to mitigate infectious diseases due to high stocking densities and intensification. Offshore, nutrients are quickly diluted and the collective action problem may only arise overtime. Except for bivalve or algae mariculture, fish production requires feed, which may be sourced from capture fisheries, marginalising small-scale fishers who rely on wild populations for food, but instead are caught to feed exported high value species to wealthy consumers abroad.[138,139] Some operations use seeds from the wild, a capture fisheries CPR problem, whilst some are grown in hatcheries.

Physical space is another CPR problem. Arguments for expansion and tough rivalry have been put forward.[53,140,141] However, much of the production is near shore and a rivalry for physical space is usually given due to multiple uses.[142,143] Often, mariculture excludes other activities such as fishing, making multi-use space difficult through commons enclosure. However, mariculture enclosure is not usually permanent. Rights to access and use leases of 10 to 30 years (the investment cycle) are typically provided by states.[133,144,145] However, it is a young sector in most countries, where informal and formal rules still need to emerge, creating second-order collective dilemmas for labour and product markets, and property rights (space, water column), but also in other areas like environmental protection or gender roles.

Industrial mariculture tends to focus on a few marketable species,[21] often non-native to the production area leading to invasive species.[146] Production environments such as temperature, salinity and storm frequency also depend on climate variability.[147] The provision of a stable climate (mitigating emissions) is beyond the control of producers. Mariculture is knowledge intensive, where a lot of knowledge is not publicly available but held by privately experienced producers, reducing overall wealth potential.[148] Good public infrastructure is essential for mariculture expansion. Mariculture is capital intensive, requiring good credit access and financial resources. A case study of scallop bottom culture in Sechura Bay, Peru is provided in Figure 4.

3.2 | Earthen ponds

Earthen ponds are the oldest and most common type of aquaculture.[149] They are comparatively inexpensive to construct and maintain with simple water in-flow/out-flow gates (i.e. monks) or pumps,

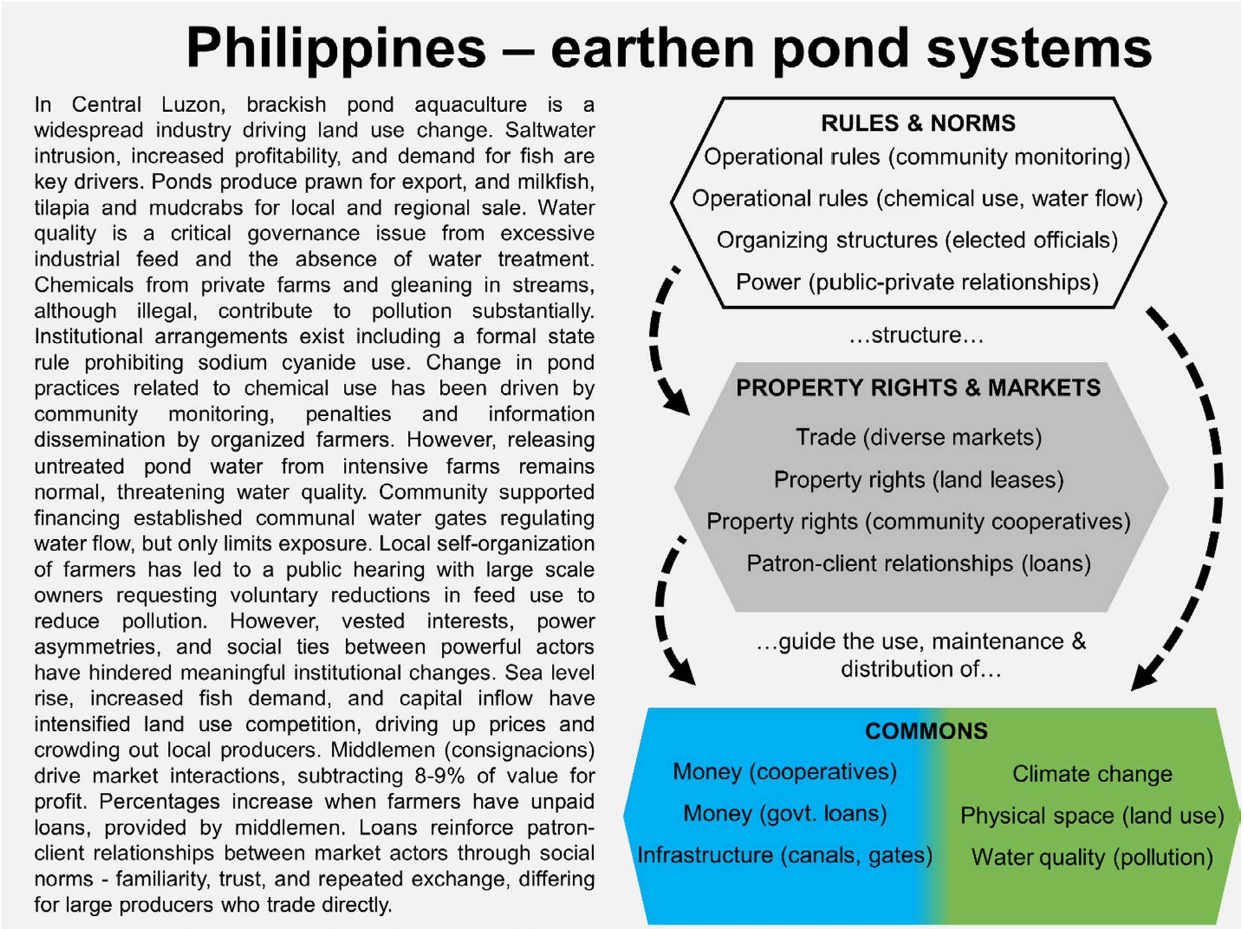

FIGURE 5 The framework applied to the case of brackish water fish pond aquaculture in Bulacan, Central Luzon, Philippines

and simple production strategies. Although many variations exist, they all consist of a large earthen pit (sometimes lined with plastic or concrete) surrounded by earthen levees or dikes, often in groups of interconnected ponds. They can rely on fresh or brackish water inputs depending on the species and water sources (e.g. rivers, tidal), enabling a large diversity of plants (e.g. algae), finfish (e.g. catfish, tilapia, milkfish) and invertebrates (e.g. shrimp, crabs, sea cucumber) in both mono and polycultures to be produced. Some require no inputs, relying on external water-based nutrients and feed from plants, whilst others are input intensive.

Environmentally, all ponds require the appropriation of terrestrial space, water quantity and quality. Farming inputs can range from CPRs such as wild-sourced seedlings, larvae or fingerlings passively brought in by tides or freshwater bodies, to actively fished or privately produced juveniles (e.g. finfish, crustaceans). Production is also reliant on the provision of water quality, however, it can also cause pollution from excess fertiliser, antibiotics and excrement,[149] requiring institutions for who can pollute and how much.[150] Ponds are often in low-lying coastal areas vulnerable to unstable climate patterns such as sea-level rise and increased storms, or to increased flooding and drought cycles in inland systems.[9,151,152] Shared social resources include water distribution infrastructure (e.g. canals, pipes). Ponds with water pumps will require electricity access or windmills. Depending on production goals, earthen pond aquaculture can be done with relatively minimal knowledge of species biology, growing conditions and technology, although economic risk, production, efficiency and pollution mitigation may be improved with increased knowledge. Financing for pond construction, inputs and maintenance will be required, but is likely to be lower than other systems. A case study of brackish water fish pond aquaculture in Bulacan, Central Luzon, Philippines is provided in Figure 5.

3.3 | Raceway flow-through systems

Raceway aquaculture is a semi-closed system consisting of long, narrow channels relying on high water flow (flow-through) to maintain cultured fish species.[153] Raceways can range from earthen gravity-fed flumes to concrete channels with powered water pumps and oxygenators. High water flow distinguishes raceways from earthen ponds, allowing for much higher stocking densities. Thus, a distinguishing feature of raceways is that quantity of water flow, rather than culture area, limits the production yield.[154] Wastewater outputs are typically discharged to the natural water source (e.g.

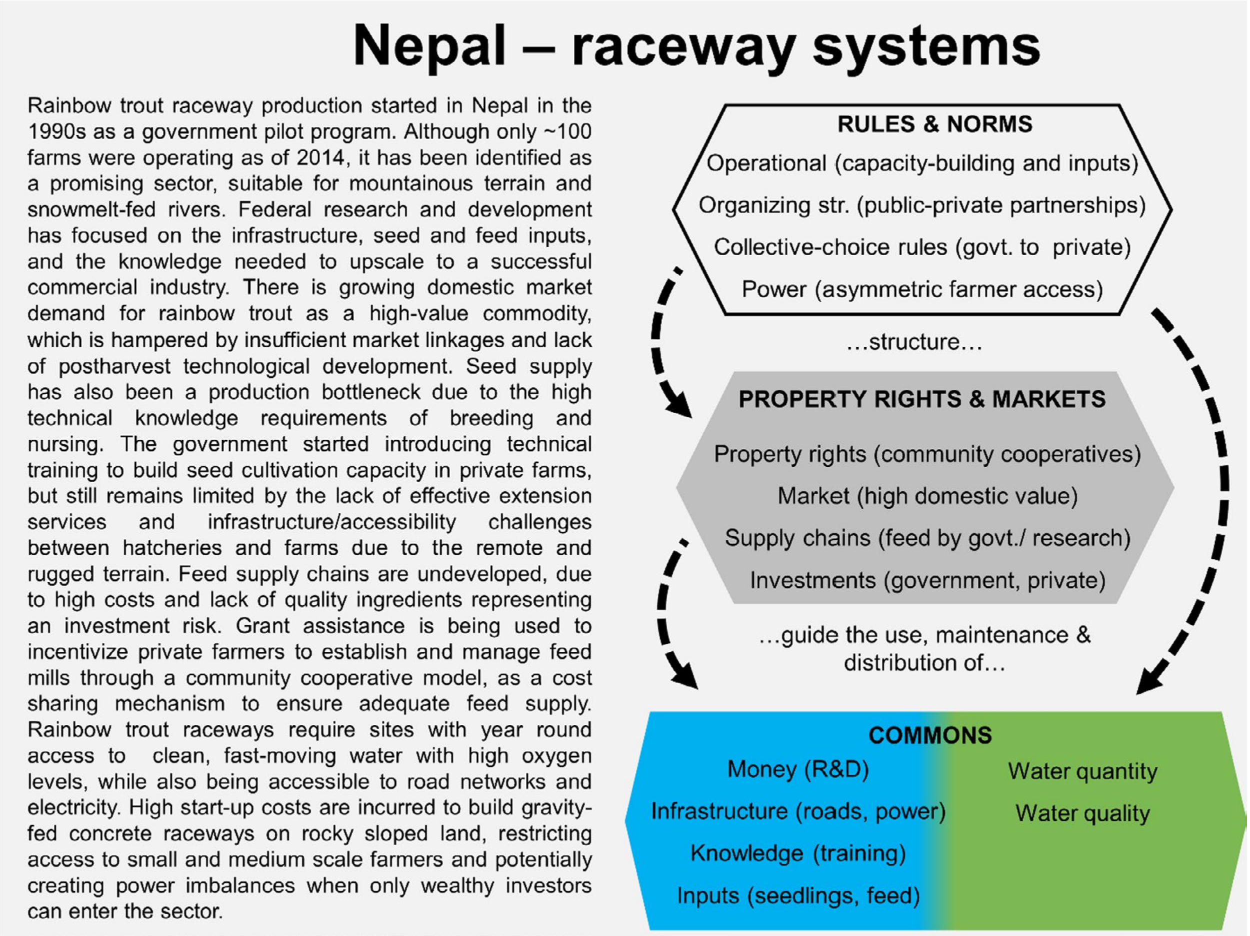

FIGURE 6 The framework applied to the case of rainbow trout raceway aquaculture in Nepal

river). The most commonly cultured species are trout and other salmonids, tilapia and catfish,[155,156] others include seabream and seabass.[157,158]

Raceways are highly dependent on environmental commons. They are limited by a requirement of extremely high volumes of fresh, oxygenated water flow, typically from groundwater or surface water from snowmelt.[153,154] Although total land requirements are much lower than pond aquaculture, raceway systems are preferably constructed on areas with sufficient slope for gravity-assisted water flow, making appropriate physical space important.[159] Water quality is essential, but these systems are also a major producer of wastewater effluent due to intensive stocking and feeding practices. This can pollute downstream users, and result in a head-and-tail provision problem with asymmetric incentives.[160-162]

Raceways typically achieve high production per unit volume through a careful balance of stocking densities, feed inputs, oxygen and ammonia monitoring, making knowledge requirements quite high. Raceways are often reliant on access to electricity to maintain water pumps and oxygenators, however, this may be less necessary in low-tech earthen systems that primarily rely on gravity. Public infrastructure allowing for physical access to markets is also notably important in cases where appropriate raceway sites are in remote mountainous regions. Additionally, construction costs of channels as well as intensive feed and seed requirements make financial requirements for rural entrepreneurs, and the need for shared maintenance costs a collective action problem in some cases.[163] A case study of rainbow trout raceway aquaculture in the mountains of Nepal is provided in Figure 6.

3.4 | Recirculating aquaculture systems (RAS)

Recirculating squaculture systems (RAS) are enclosed and controlled production environments.[164,165] Basic designs include a chamber where fish are kept and a chamber where waste can settle to the bottom and be removed, recycling the remaining water.[166] Temperature, salinity and nutrient levels are controlled by removing produced solids and carbon dioxide, then filtering and aerating water for reuse. Stable conditions lead to more predictable production.[164,165] RAS can be built outdoors or indoors, and many different designs exist depending on the species and economic constraints.[167] Several species are successfully being cultivated in intensive RAS systems including tilapia, striped bass, cobia, pompano, barramundi and marine shrimp.[168]

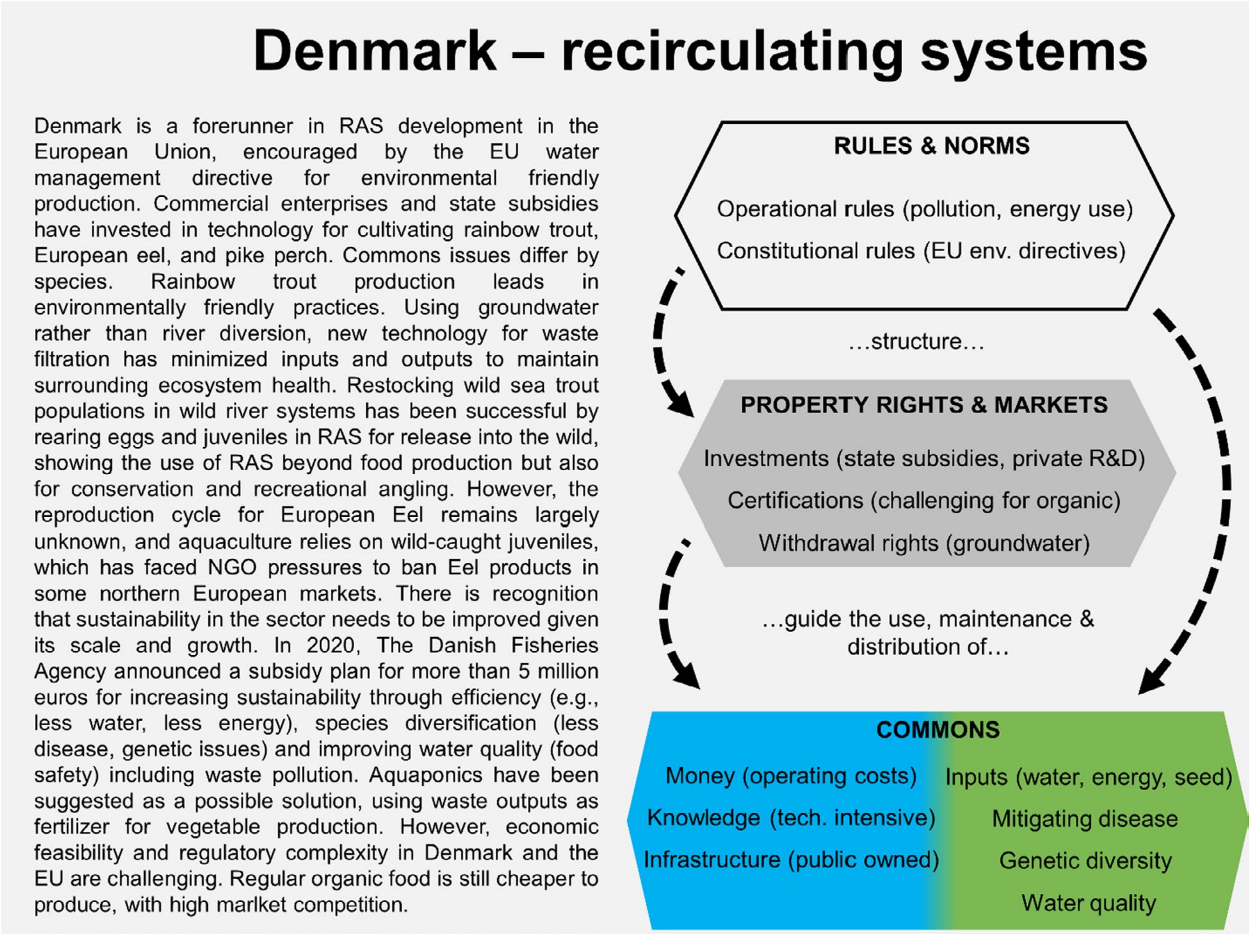

FIGURE 7 The framework applied to the case of recirculating aquaculture systems in Denmark

RAS interact with commons in unique ways compared to other systems. Socially, highly skilled labour is needed to design, build and operate RAS, and much of this knowledge is produced and kept privately. Many businesses have failed due to a lack of knowledge on system design, maintenance or management efficiency.[169,170] Although keeping knowledge private can help individuals capitalise on innovation with market advantages, it also hinders the speed and extent of knowledge dissemination as a PG. Financing is also essential, but can hinder RAS adoption due to high startup costs and potentially long time frames before returns on investments materialise. State subsidies may play a large role in catalysing investment. RAS also requires access to stable infrastructure such as electricity and freshwater, where production would not be possible without a constant supply.

Environmentally, RAS operate on land, but may require less than other systems due to stocking density and intensification. Thus, they can operate in urban areas, potentially enabling better market access and reduced transport costs that might also reduce spoilage and food safety.[166,170] All RAS require seed, nutrient, electricity, construction material and water inputs, and produce waste that needs to be disposed of. However, controlled waste outputs can also be reused, such as fertiliser to integrate with agriculture or aquaponic plant-based food production in greenhouses. High stocking densities may require disease mitigation measures such as antibiotic use. RAS can be highly water efficient, but the wastes need to be disposed of properly.[171] Perhaps, the largest environmental impact is indirect via energy use, depending on the source.[169] A case study of RAS in Denmark is provided in Figure 7.

4 | DISCUSSION AND CONCLUSIONS

4.1 | Governing aquaculture diversity

The framework developed in this article provides a starting point for better understanding the diversity of aquaculture governance challenges and potential solutions. Although we know little outside of the major producing countries, aquaculture is likely to differ across localities and production systems in relation to the commons it relies on and the government institutions that relate to them. The framework can help better understand these nuances, and the case studies above have attempted to demonstrate the basic differences through a simple analysis of each. In Peru, shifts from open access regimes to privatisation has characterised Sechura Bay, where recognition for shared risk has led to attempts to internalise and secure risk for investors, putting cooperatives and small-scale fishers against large private industry actors in their ability to use and access shared resources such as water space, docks, influential institutions and officials in power as well as processing facilities.[147,172,173] In the Philippines, creating incentives and mechanisms to reduce pollution and reduce shared risk is a major collective action problem for the interconnected pond network of Central Luzon. Decision-making processes for pollution mitigation are influenced by public–private partnerships and the power held by local elected officials despite community self-organisational efforts to create space for institutional development and change. The diverse markets are controlled by established patron-client systems, where patrons also provide the financial capital needed to establish and maintain small-scale production under systems of trust.[95] In contrast, Nepal highlights the role states can or might need to play in supporting research and development in countries with emerging aquaculture sectors. State efforts to develop research on breeding, seed and feed production, and efforts to transfer that knowledge and build capacity for decentralised production with local cooperatives groups provide evidence for the argument that interventionist development by states remains a possibility (see[174]). This contrasts Central Luzon, where immanent development processes of demand and profitability played larger roles in driving growth than the state. In Denmark, multi-level governance frameworks from the EU provide an overarching set of constitutional and operational rules incentivizing sustainability through improvements in efficiency. However, consumer adoption and market competition remain challenges due to certification limitations and seed sourcing challenges, although conservation efforts through repopulating wild rivers have demonstrated the use of aquaculture beyond food for human consumption.

4.2 | Broadening aquaculture governance perspectives

Given the lack of governance research on aquaculture, a diversity of different theories, frameworks and perspectives are needed to advance the field. Many general environmental governance theories exist.[175-180] There is also a growing literature applying these different governance approaches to aquaculture and on other topics beyond commons.[17,28,116,181-184] The framework presented in this article provides only one of many potential perspectives. In the field of commons research, the community level is arguably the most important unit of analysis focussed on individual, within and between group interrelations in how they interact with local to provincial surrounding environments (e.g. commons) and higher levels of government. However, this perspective is limited in its ability to analyse other areas of governance, which other fields, theories and frameworks address.

Other important perspectives include state and non-state interactions such as public–private partnerships (e.g. political science, public policy and administration),[22,27] the broader political economy linkages between markets and states (e.g. political economy, macro economics),[185,186] international and multilateral politics (e.g. law, foreign policy)[135,136,187,188] and discursive analyses on the evolution, development and change of topics and framings around aquaculture (e.g. political ecology, sociology, human geography).[186,189-191] Power relations are a missing link on many governance analyses including in the field of commons.[192-195] There is also a growing literature on specific topics of governance, and although our framework may broadly encompass many of them, it does not provide a detailed means of analysis for each of which there is a growing literature specific to aquaculture. These include privatisation processes and certification schemes,[18,125,126,196] value, supply chains and trade,[23,34,35,124] gender roles and perspectives[116-118,197,198] and livelihoods and employment.[199] Lastly, shared risk and beyond farm governance links closely to commons, with an emerging literature.[24,25,27]

4.3 | Applying the framework

When developing a framework, it is necessary to guide interested scholars in how it can be applied. Whilst our framework is malleable and conceptually broad, the following considerations are useful for empirical application and analysis. Applying the framework can be done in a diagnostic or checklist way.[200,201] Start with the commons, and go through each in the new case study to assess the degree to which it may be playing a role. It is likely that only a subset of commons will be relevant for any case. Once the relevant commons have been identified, analysing the role of institutions comes next. What property rights and markets are shaping the use or provision of these commons? What rules and norms are involved? This could be done through literature review or empirical research. Further questions include: how do the commons and institutions interrelate to each other, and how have they evolved over time? Do the institutions match issues and challenges in relation to the commons or are there significant institutional gaps? For aquaculture governance scholars, identifying the different commons and institutional configurations across cases will enable comparisons that can lead to further understanding the degree to which aquaculture governance differs from other sectors, and how institutional development and change processes can best evolve in a way that leads to desired outcomes that fit local contexts. As shown in the case studies above, the level of analysis can differ from a local case up to a country-level focus, or even a multi-country analysis if the commons being shared involve cross-border interactions and governance. In Demark, the European Union sets many of the constitutional conditions for operating and financial incentives, and the commons used exist at multiple levels such as finance and institutions (EU, state-level), seed and feed sourcing (provincial, state), infrastructure (state, local) and groundwater (local). Identifying the commons and institutions at different levels may benefit by combining them with other theories beyond commons and collective action theories such as multi-level governance theory, network governance or polycentricity to further unpack governance interactions.[175] Furthermore, applying the framework will likely require multi- and inter-disciplinary knowledge, and a willingness to view aquaculture development as a system of interconnected systems both within and beyond the sector.

4.4 | Directions forward

Aquaculture is full of collective action problems because the sector is dependent on many shared resources. Similar to capture fisheries, forestry, irrigation and water commons, we can infer some generalisation across contexts, but need to remain rooted in the nuances of how collective action problems and institutional solutions materialise in each. Our conceptual framework provides an initial tool for scholars to identify and analyse existing shared resources in aquaculture. This can serve as a starting point for further institutional analysis, diagnostic and applied research in this largely expanding sector. We encourage aquaculture, governance and commons scholars to engage with the framework, apply it to novel cases, and to constructively critique and further develop it.

Although focussed on a commons governance perspective, we believe the framework can help catalyse the development of a more robust agenda for aquaculture governance research. This includes four key points to consider when applying the framework and analysing aquaculture governance generally. These are (1) cross-sector linkages between capture fisheries, agriculture and public health and nutrition, amongst others, (2) land–water–sea connectivity issues, (3) recognition that governance is broader than government and pluralistic, and understanding that governance is an embedded feature of social systems and (4) that external and generalised governing strategies (e.g. policies, legislation, property rights configurations, market mechanisms), are not likely to be successful unless they are evolved within or in tangent to local context, or at least tailored to context.

Shared risk captures many of the reasons why cross-sectoral linkages with capture fisheries and agriculture are important governance problems.[24,25] They often rely on the same commons, and thus the governance strategies of each sector individually will have implications for the other.[202] In Sechura Bay, Peru, all fishers and aquaculture framers, large and small, rely on shared infrastructure, financing, market access and space in the water.[147,172,173] Mitigating risk (e.g. financial) from disease and processing inefficiencies is a shared burden that those with power can better protect themselves from the shared costs and damage imposed by all, where the internalisation of those risks has been attempted through privatisation processes. The intensive use of capture fisheries to provide fish meal for aquaculture feed, where Peru is the largest producer, is a nexus that requires joint governance and sustainability reflections.[73,139,203,204] Other feeds are produced in agriculture, where aquaculture expansion begins to compete with other sectors in securing land and yields.[205]

Land–water–sea connectivity is an important governance issue for many coastal earthen pond systems due to the material fluidity of aquaculture.[45,182] In the Philippines, effluent leading to polluted waterways effects both local capture fisheries and continued aquaculture production.[95] In mariculture systems, invasive species in near-shore pens such as salmon can break out and mix with wild populations in local rivers, disrupting their ecosystems and public perceptions.[206-208] Importantly, another issue is recognition that governance and governing mechanisms are inherent features of the embedded social systems where aquaculture occurs. Social norms, cultural practices, hierarchical structures and power dynamics are emergent properties of all social systems, shaping use and provision or resources, and aquaculture is no exception. Framing governance as beyond government is critically important in recognising that states are not the only actor or even the most important actor in shaping the sector's development. Public–private partnerships to develop best practice standards and certifications are becoming increasingly important.[22,27] In many countries such as Nigeria, the second largest producer in Africa, there is no legal framework for aquaculture and government currently plays an enabling role, at most, in developing the sector that is primarily driven by small holders in the value chain and private interests.[209] Markets and commoditization through the actions of many small value chain actors are playing an often under recognised role in governing and development.[20,210]

In conclusion, we argue that there is substantial potential to apply the concepts and theories from commons literature to aquaculture, in cohesion with other streams of literature discussed above. Current production data suggest that the sector will continue to expand and intensify, and governance will be one of the most important pieces for sustainable development. However, our knowledge of aquaculture commons, and the appropriate institutions to govern them, is far behind other sectors. We encourage further engagement with the commons' framework in this paper, and continued efforts to apply and modify it to advance the field.

ORCID

Stefan Partelow https://orcid.org/0000-0002-7751-4005
Aisa O. Manlosa https://orcid.org/0000-0001-8058-412X

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