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Governance challenges for Indonesian pond aquaculture: a case study of milkfish production in Gresik

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Introduction: An important blind spot in current aquaculture governance research and practice is recognizing the high dependency of the sector on commons (i.e., shared resources), and their interconnectivity with other sectors such as agriculture. This is particularly evident in Indonesia where there is general lack of social and governance research on aquaculture. The purpose of this study is to: (1) identify the commons that need to be governed in pond aquaculture systems, and (2) identify the arising governance challenges from those commons and potential solutions.

Methods: We apply Elinor Ostrom's Socio-Ecological Systems Framework (SESF) to identify variables influencing collective action through semi-structuredinterviews with relevant key informant actors in a milkfish aquaculture village in Gresik, Indonesia. Our case study approach allows for a rich description through qualitative data to understand system interactions. We interviewed 22 stakeholders including regional and local government officials, fish farmers (owners and workers), patrons and local academics.

Results and discussion: Our findings indicate five governance challenges influencing collective action: (1) limited access to capital and dependence on patrons, (2) lack of govern institutions, (3) continued government program failure, (4) lack of community leadership, and (5) lack of motivation and incentives to collectively act. These imply that governance policies may be more successful if monitoring mechanisms are applied to ensure that government funding is more precisely targeted at improving the livelihoods of traditional fish farmers. Furthermore, attempts to support social capital, network structures, and improve trust-reciprocity among relevant stakeholders (i.e., farmers, extension officers, private business actors) in the form of capacity building is likely more effective than other monetary incentives or the enforcement of top-down rules that don't fit local needs.

KEYWORDS

aquaculture governance, milkfish pond, *Kampung Bandeng*, social-ecological system, Asia

1 Introduction

Indonesia's aquaculture sector dates back to at least the 15th century, and is often typified by the *Tambak* (pond) cultivation technique. Tambak aquaculture relies on traditional brackish-water pond and canal systems to produce shrimp, milkfish, and other finfish (Troell, 2009; Henriksson et al., 2017; Partelow et al., 2018). Over the last two decades, expansion and intensification of the sector has made Indonesia into the second largest producer of aquaculture products in the world after China (FAO, 2022). The sector, however, is highly dependent on shared environmental resources or environmental commons (Partelow et al., 2021). The current challenge is that investment in production growth is outpacing the ability of institutions at all levels of governance to respond with effective rules and norms to address sustainability concerns such as environmental integrity, or livelihood and food security (Hishamunda et al., 2014; Bush et al., 2019). Another challenge is that effective governance solutions very likely need to be adapted to fit local contexts (Epstein et al., 2015), so that the implementation of widespread policy programs can be more effective when they include pilot or initiation phases that account for understanding local needs and building capacities to ensure the program properly engages with communities (Belton and Little, 2011; Rimmer et al., 2013; Partelow et al., 2018).

Common pool resources are characterized by excludability challenges and a high degree of subtractability, meaning it is difficult for an undefined group of actors to share a resource (e.g., fish) without problems of overuse (e.g., overfishing). Commons can create complex multi-user conflicts that result in over-extraction or resource collapse if rules and norms (i.e., institutions) for governance are not properly established (Agrawal, 2003; Partelow et al., 2021). Elinor Ostrom's research on cooperative approaches (collective action) to commons governance has shown, however, that solving commons problems is possible under the right social and ecological conditions where rules and norms for governance fit local contexts (Ostrom, 1990). Collective action theory has emerged from this work to claim that high collective action is needed to maintain the commons and that with sufficient levels of collective action commons stakeholders can internalize externalities and prevent the over-use (Ostrom, 1990). Under the right conditions, collective action is made easier. Many variables have been shown to be influential on collective action (i.e., determining the conditions) including the size of the resource system, number of actors, resource unit mobility, leadership, norms, knowledge of the social-ecological system (SES), and dependence on the resource (Ostrom, 1990; Ostrom, 2007; Ostrom, 2009). The synthesized hypotheses of individual variables contributing to collective action are diverse and collated in the literature and in online databases such as SESMAD (https://sesmad.dartmouth.edu/theories/101). Based on an accumulated body of empirical commons research, Ostrom and colleagues developed a framework of potentially relevant variables for studying the commons that can be used to help scholars and practitioners diagnose governance problems in local contexts in order to improve understanding of the types of institutional solutions that might be most appropriate (Ostrom, 2007; Ostrom, 2009; McGinnis and Ostrom, 2014).

Ostrom's Social-Ecological Systems Framework (SESF) (Ostrom, 2009) has been widely adopted and applied to understand environmental governance problems, but seldom in aquaculture systems despite their high dependency on commons (Partelow et al., 2021). The SESF provides a common vocabulary for social-ecological commons research, but there is no specific approach for applying it. The SESF has been applied to small-n (<5) qualitative case studies (Carrillo et al., 2019), large-n (>30) quantitative comparative research (MacNeil and Cinner, 2013), meta-analyses (Villamayor-Tomas et al., 2019), and as a deliberation tool (Partelow et al., 2019). The SESF describes the eight essential dimensions, or first-tier variables, of a social-ecological system (Table 1). Actors within and outside government operate within a Governance System characterized by formal and informal rules at one or more identifiable geographic scales. Resource Units inhabit and interact with a broader Resource System that is characterized by particular ecosystem types and biophysical processes, also at one or more geographic scales.

TABLE 1 First and second-tier variables of the social-ecological systems framework.

First-tier	Second-tier
Social, Economic, and Political Settings (S)	S1 - Economic development
	S2 - Demographic trends
	S3 - Political stability
	S4 - Other governance systems
	S5 - Markets
	S6 - Media organizations
	S7 - Technology
Resource Systems (RS)	RS1 - Sector (e.g., water, forests, pasture)
	RS2 - Clarity of system boundaries
	RS3 - Size of resource system
	RS4 - Human-constructed facilities
	RS5 - Productivity of system
	RS6 - Equilibrium properties
	RS7 - Predictability of system dynamics
	RS8 - Storage characteristics
	RS9 - Location
Resource Units (RU)	RU1 - Resource unit mobility
	RU2 - Growth or replacement rate
	RU3 - Interaction among resource units

(Continued)

TABLE 1 Continued

First-tier	Second-tier
	RU4 - Economic value
	RU5 - Number of units
	RU6 - Distinctive characteristics
	RU7 - Spatial and temporal distribution
Governance Systems (GS)	GS1 - Government organizations
	GS2 - Nongovernmental organizations
	GS3 - Network structure
	GS4 - Property-rights systems
	GS5 - Operational rules
	GS6 - Collective choice rules
	GS7 - Constitutional rules
	GS8 - Monitoring and sanctioning
Actors (A)	A1 - Number of relevant actors
	A2 - Socioeconomic attributes
	A3 - History or past experiences
	A4 - Location
	A5 - Leadership/entrepreneurship
	A6 - Norms (trust-reciprocity/social capital)
	A7 - Knowledge of SES/mental models
	A8 - Importance of resource (dependence)
	A9 - Technologies available
Interactions (I)	I1 - Harvesting
	I2 - Information sharing
	I3 - Deliberation processes
	I4 - Conflicts
	I5 - Investment activities
	I6 - Lobbying activities
	I7 - Self-organizing activities
	I8 - Networking activities
	I9 - Monitoring activities
	I10 - Evaluative activities
Outcomes (O)	O1 - Social performance measures
	O2 - Ecological performance measures
	O3 - Externalities to other SESs
Related Ecosystems (ECO)	ECO1 - Climate patterns
	ECO2 - Pollution patterns
	ECO3 - Flows into and out of SES

Adapted from McGinnis and Ostrom (2014).

External variables are also considered in Social, Economic, and Political Settings insofar as they influence Outcomes (McGinnis and Ostrom, 2014).

The SESF has been applied to analyze many small-scale fisheries and irrigation case studies, both related to aquaculture. Furthermore, Johnson et al. (2019) provide a modified SESF for marine aquaculture, detailing the unique variables of mariculture systems for use in future studies. However, to our knowledge only two previous studies have applied the SESF to pond aquaculture systems – both examining cases on Lombok, Indonesia. The studies by Senff et al. (2018) and Partelow et al. (2018) showed that low system knowledge and low capacity building within policy programs to support fish farmers hindered production. Their findings indicated this was driven by the lack of problem awareness that maintenance of common canals was a driver of low water quality and insufficient quantity.

In this article, we aim to address this gap in SESF literature by examining the governance challenges of Indonesian milkfish farming using the SESF as a diagnostic tool in the Gresik district, the biggest milkfish producing region in Java, Indonesia, where ongoing government programs seek to develop a sustainable aquaculture business system within the sector. Within this context, this study is guided by four research questions:

1. What are the important aquaculture commons in Pangkah Wetan, Gresik?
2. What are the SES characteristics of traditional pond aquaculture in Pangkah Wetan, Gresik?
3. What are important SES variables hindering and/or enabling collective action to govern aquaculture commons?
4. What are the main governance challenges for traditional pond aquaculture in Pangkah Wetan, Gresik?

2 Material and methods

2.1 Study site

This case study is located in Pangkah Wetan village in Gresik, a district within the East Java Province of Indonesia. Gresik district is one of the leading producers of milkfish from coastal pond aquaculture in Indonesia (currently the second highest in national production after South Sulawesi). Gresik produces approximately 98,000 tons of milkfish per year, nearly triple the amount compared to other districts in the East Java Province (based on an interview with Dinas Perikanan Gresik). In Gresik, milkfish has become not only an economically, but also culturally important food source for communities, creating interdependent drivers of production. Every year before Eid al-Fitr, the regional government organizes a huge traditional market for milkfish for three consecutive days. The markets do not only provide fresh fish, but there is also a competition for the biggest milkfish cultured during the year. Pangkah Wetan village was selected due to the importance of milkfish production to the local economy, livelihoods, national

food and nutrition security, and as a local protein source for preventing stunting in childhood development. Milkfish are produced in traditional aquaculture ponds, and the total production area has expanded substantially over the last decade to cover a total area of 2,465.49 Hectares (ha) of ponds throughout the whole village, covering 77.3% of the total village area (Figure 1). The village is located in the delta of the biggest river in Java, Bengawan Solo. Milkfish (*Chanos chanos*) production is commonly practiced as monoculture or polyculture with Vanemei shrimp (*Litopenaeus vannamei*). In April 2022, MMAF (Ministry of Marine Affairs and Fisheries) also started the initial *Kampung Bandeng* project in the study area. This government program focuses on intensification and expansion strategies to secure national fish production by launching a national priority program for 2021-2024 called Corporate Farming (*Kampung Perikanan Budidaya*) stated in Indonesia Marine Affairs and Fisheries Ministrial Regulation number 47/2021. This program aims to encourage a sustainable aquaculture business system to secure national food security by continuous and scheduled production, and engages different processes along the value chain including the hatchery, fish feed factory, quality assurance, supporting infrastructure and facilities, cold storage, ice and packaging industries. However, the lack of socio-ecological and governance information on milkfish production hinders effective management decisions. This research provides basic information about the governance challenges of milkfish farming in Gresik and policy recommendation for the related stakeholders.

2.2 Data collection and analysis

Data collection was conducted from October-December 2021 using face-to-face semi-structured interviews. Purposive sampling was applied to identify key informant actors based on their contribution to solving collective action problems including government officials, community leaders, local university lecturers, and fish farmers (Table 2). Verbal prior informed consent was received from all interviewees, and this consent was recorded, which included background information on ourselves and purpose of the study. All participants asked were willing. Then, a snowball sampling approach was utilized to find additional relevant informants, especially among fish farmers. Snowball sampling (see Parker et al., 2019) was started with a casual talk with the fish farmers in the warung (food stall) located near the ponds. These were not considered formal interviews but provided substantive information about who to talk to. Semi-structured interviews with key informants inquired about variables of the SESF (Ostrom, 2009; McGinnis and Ostrom, 2014; Partelow, 2018) – which provided qualitative data to both characterize the social-ecological system functionality and diagnose commons governance challenges. This research followed existing general guidelines for applying the framework (Nagel and Partelow, 2022). As such, data were collected using a diagnostic approach guided by the updated version of the SESF (McGinnis and Ostrom, 2014). It is important to acknowledge, however, that although we pursued a diagnostic and saturation-based approach, our informants and interviewees may not reflect the full spectrum of actors involved in the pond systems, including the often hidden role of women in the value chain, other marginalized members or other value chain actors that shape incentives, prices or policies but whom may not be located in Gresik.

Interview data were transcribed into text and analyzed using content analysis (Stemler, 2001) to identify the key SESF variables characterizing the types of commons that exist in the system, as well as the factors influencing whether or not stakeholders are engaged in collective action to govern their aquaculture commons in Gresik. Interview data were organized and coded using the open-source coding software Taguette (https://www.taguette.org/). Data were coded to variables of the SESF, and could be coded to multiple variables. Data were collated into nested thematic areas, where more specific codes could be created and assigned to data enabling a full picture to emerge in a way that linked to the theory in the framework (i.e., variable nestedness and connectivity) while

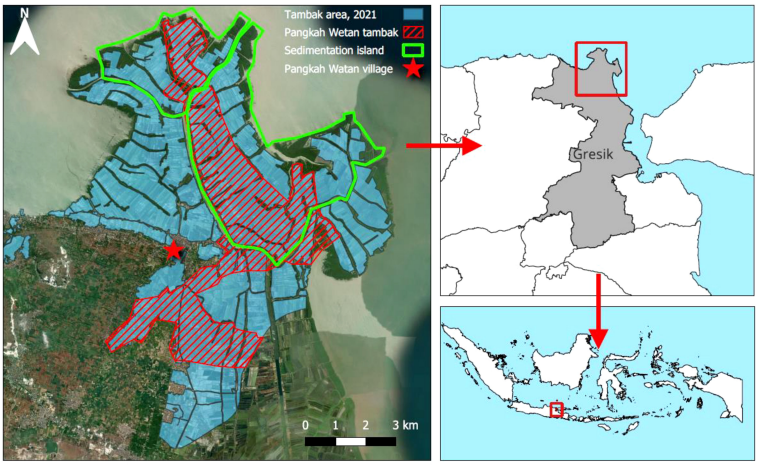

FIGURE 1
Location of *Kampung Bandeng* (Milkfish Aquaculture Village) in Pangkah Wetan (red star), Gresik. The spatial areas referenced in the paper are colored respectively. The Gresik district is located in east Java, Indonesia.

TABLE 2 Respondents list.

Summary of interviewed key informants.		
Actor category	Description	No. of interviews
Local government	Heads of fisheries agency and aquaculture section	6
	Heads of production, processing and marketing	
	Head of natural resource supervision	
	Fisheries program officer	
Community	Village and fish farmer association leaders	15
	Heads of fish farmer groups	
	Fish farmer business coordinator	
	Boat service owner	
	Fish farmers from inland and island ponds (both owners and renters)	
Academic	Head of university aquaculture program	1

remaining flexible to context. Nested coding structures enable the aggregation and separation of themes based on similarities and differences across text segments. The SESF is a practical tool for coding qualitative data because it provides the core concepts and relationships central to the analysis of commons, but because it provides a nested structure for identifying social-ecological interactions that become easier to identify with coding software. Using the description of each second-tier variable in the case, we further examined the data through the lens of collective action theory, where each variable in the framework has its own literature in relation to its role in collective action, particularly in the coastal small-scale fisheries literature. Data were coded as being high/low or strong/weak in the final assessments in relation to the hypothesis for collective action for each variable. If not explicitly coded in relation to high/low, for example, the interpretation of the influence of the variable was guided by the literature on the hypothesized role of the variable. For example, leadership has shown to be a critically important factor in collective action because good leadership can organize groups, motivate information sharing and help build social capital for self-organizing working together on commons issues (Lobo et al., 2016; Crona et al., 2017). Given the lack of available literature on pond aquaculture collective action problems, for some variables we proposed new hypotheses regarding their relationship to collective action. This gives more explanation about the variable's role and its impact on the governance outcomes related to collective action in the local context. Secondary data were also collected. However, there is so little research and knowledge about the topic and the case area specifically, that hardly any documents were found from the regional government, university archives or published research in English or Bahasa in peer-reviewed journals. There is even a lack production data despite governments efforts to pursue production as the key indicator. In summary, this study is both a diagnostic qualitative assessment and an exploratory, in that there is little prior knowledge to base it on, making it one of first few studies on commons and aquaculture governance in the country.

3 Results

3.1 Characterizing pond aquaculture in Gresik as a social-ecological system

3.1.1 Resource systems

Pangkah Wetan is the center of milkfish farming in Indonesia aquaculture (RS1), which is largely split across the main inland area, and a nearby sedimentation island. Ponds located inland are adjacent to people's houses and are traversed by fishery irrigation canals. Meanwhile, the ponds on the sedimentation island are bordered by the Bengawan Solo river as the ecological boundary (RS2). Most inland ponds are not surrounded by mangroves or other plant species, while the dikes of the island-based ponds are dominated by *Avicennia* spp (Api-api in local language). In several locations on the island, new land clearing for more intensive fish farming has been observed, with the consequence of clearing large mangrove areas. The total pond area in Pangkah Wetan covers 50% of the total pond area in Gresik with a total of 2,003.09 Ha (RS3). Since 2000, fish farmers started to use fish feed as an additional source of food for the cultured species, and now approximately 90% of fish farmers use fish feed which no longer makes it a traditional farming practice, but rather semi-intensive. Local communities recognized it as a "traditional plus" farming system.

The total area of each pond is estimated between 3-7 Ha and each fish farmer owns a pond area between 3 to 50 Ha (RS4). In Pangkah Wetan, farmers normally conduct three farming cycles in two years with an average production of 8-10 tons per farming cycle dominated by a polyculture system between milkfish, tilapia, and Vanamei shrimp (RS5). Pangkah Wetan area has two main seasons. The wet season is from October-April, and dry season from May-September. Water is available all year around from the Bengawan Solo river (RS 6). In general, pond aquaculture in Pangkah Wetan Village is located in two separate areas: (1) inland and (2) on a sedimented island in the Solo Delta Estuary (RS9). During the wet season, fish farmers with island ponds experience annual floods,

potentially losing their harvest due to broken dikes followed by fish escapes (RS7). Ponds in the sedimentation islands require larger operational funds than inland ponds because they require boats to transport people, feed and harvest fish (RS9).

3.1.2 Resource units

Brackish water pond aquaculture is centered around milkfish (*Chanos chanos*) production. There are three types of farming systems: (1) milkfish monoculture, (2) milkfish and Vannamei shrimp polyculture, and (3) milkfish, Vannamei shrimp, and tilapia polyculture. However, milkfish input and production remains the largest. Due to the large pond size, milkfish fries have to reach 10-15cm long in the nursery pond before moving in to the rearing pond for feeding. Most of the fry are produced in Central Java or Bali because of the high demand in Gresik (RU1). As the main commodity in Gresik, milkfish production contributes over one trillion rupiahs (68.8 million USD)/year) (RU4). Both monoculture and polyculture usually needs 1 packaged shoal of fry (5,000 individuals) per hectare of pond (RU5). For Vannamei shrimp, up to 10 packs of fry per hectare can be grown depending on the willingness and capital availability. Every year there are three peak times where market value for pond aquaculture products are highest, which are the dry season on the north coast of Java, Ramadhan/Eid Festival, and New Year's Eve.

3.1.3 Actors

Pangkah wetan has a total of 601 fish farmers, 13 fish farmer groups (Pokdakan), one fish processing group (Poklasar) and one fish farmer association (A1). Fisheries field officers (Petugas Penyuluh Lapang/PPL) are assigned directly by the Ministry of Marine Affairs and Fisheries, with one officer covering 1 sub-district. However, the area covered by one officer can be quite large, for example, the Ujung Pangkah sub-district consists of 11 villages. There are also other entities along the value chain such as private fish feed suppliers (GS2, A1) and fish buyers (Patrons) (A5). Trust and reciprocity occurs between fish farmers and patrons. Every patron supports around 50 fish farmers every farming cycle (A6). Most of the milkfish farmers in Pangkah Wetan village have been cultivating for generations, but cultivation practices make limited use of technology (A3). Until now, the use of technology is only limited to diesel fuel pumps that function as water pumps in and out of the pond and as an aerator (A9). Traditional plus milkfish farmers also understand that feed is not the only determinant of harvest success, but also water and soil. Soil needs to be managed (i.e., removed from the bottom of the ponds) after harvest to get better outcomes for the next harvesting cycles by removing fish waste (A7). Unfortunately, since the pond area is rented land, they must effectively utilize the pond during rental time, because this is the main source of income for 'traditional plus' (i.e., fed system) fish farmers (A8). The larger the pond, although more difficult to manage, yields a greater profit (A5). Based on the government documents and the interviews, the goals of each major actor are shown in Table 3.

3.1.4 Governance system

Aquaculture in Gresik is under the authority of Department of Fisheries of Kabupaten Gresik at the regional level, Department of Marine and Fisheries at the provincial level, and the Ministry of Marine Affairs and Fisheries nationally (GS1). At the time of this analysis, the Department of Fisheries has not published their new strategic plan (2021-2026), so insights here examine existing programs. There are four main focal areas within the department according to its organizational structure as of 2016: the aquaculture sector, capture fisheries sector, management and supervision of fisheries resources, and processing and marketing of fisheries product (GS3). For supporting technical issues, the Department of Fisheries has two Technical Unit Divisions (UPT- Unit Pelaksana Teknis) in the Gresik region, which are Fresh/Brackish water aquaculture unit and the Campurejo Fish Market.

For aquaculture, the Department of Fisheries was focused on land rights certification for fish farmers (GS4), development of fish cultivator diversification (A2), introduction of catfish and biofloc aquaculture (A9), independent fish feed movement, Vannamei demonstration plot, and fish farmer's insurance facilities (A9). In Pangkah Wetan, all programs were carried out except the catfish introduction and biofloc for product diversification.

The Ministry of Marine Affairs and Fisheries assigns field extension officers for fisheries in every sub-district (Kecamatan) in Indonesia with the functions of coaching, controlling, licensing, and sharing information related to all marine activities and fisheries (GS3). The field extension officer (Petugas Penyuluh Lapang- PPL) is responsible to the ministry but not to the regional Department of Fisheries. The regional government encourages the registration of aquaculture businesses to all cultivators but not many have registered their businesses (GS4). Therefore, monitoring and control functions can only be done for registered fish farmers (GS8). Traditional plus farming systems (i.e., fed systems) are well established in Pangkah Wetan, which means adding fish feed at the beginning of the cycle by almost all fish farmers. The use of unregistered drugs is understood to be prohibited, but according to the fish farmers, other registered drugs don't work well (GS5). Every fish farmer has their own best practice for aquaculture based on previous experience, even though an aquaculture best practice guide (CBIB) has been provided by the government. Furthermore, for the general population, the government has aimed to increase public awareness about the importance of fish consumption (S5). For example, in campaigns such as the GEMARIKAN (Gemar Makan Ikan) providing annual and monthly programs in collaboration with community-based healthcare providers (sub district level) to reduce stunting in children.

In the farming community, there are four key social structures. The social structure is stratified based on control on property rights, capital, and labor that relate to power and influence. At the top of the social hierarchy are farm owners, followed by tenants and manager farmers in the middle, and farm workers at the bottom.

3.1.4.1 Farm owners

Are those who control the pond's profits and management, either by using their own power or the labor of others, typically owning the land and using hired labor. Farm owners and pond workers have transactional relationships, some permanent. On average, owners invest between IDR rupiahs 6-10 million (400-650 USD) per hectare for milkfish farming.

TABLE 3 Actors goal in each jurisdiction based on document analysis and interview analysis.

Actors	Goal
Data from government documents	
National government Ministry of Marine Affairs and Fisheries (KKP, 2020)	●Sustainable aquaculture practice ●Higher production, higher GDP ●Improve the welfare of marine and fishery communities ●Increase the export value of fishery products ●Increase the number of fish consumption ●Increase the area of water conservation ●Improve compliance with the law ●Fish quarantine operations ●Independence of Integrated Marine Fisheries Center ●Research and development innovation ●Increasing fishery community class groups
National government Directorate General of Aquaculture (DJPB, 2020)	●Increasing aquaculture community welfare ●The economy of the aquaculture sector increase ●Sustainable aquaculture management ●Increasing aquaculture production ●Implementation of control and supervision of aquaculture resources participatory ●Good Governance within Directorate General of Aquaculture
Data from interview analysis	
Regional government Fisheries Agency	●Higher production and productivity of fisheries sector ●Increasing rehabilitated coastal areas ●Increasing number of fish consumption ●Function: Controlling, Coaching, Infrastructure, Permit, Funding
Fisheries field officer	●Independent fish farmer ●Knowledge transfer ●Fish farmer group development
Fish farmer	●Higher productivity ●Higher income
Fish farmer group (Pokdakan)	●Access to government investment ●Mitigation toward natural phenomenon
Fish farmer association	●Access to private investment
Village leader	●Access to government investment ●Higher income
Local Academic	●Collaboration for development of aquaculture sector ●Knowledge implementation to aquaculture farmer
Patrons	●Buy fish directly from farmers to bring to market ●Sell feed and necessary materials to farmers from the market

3.1.4.2 Tenant farmers

Are those who have sufficient capital but do not own the land. To be able to control the profit, they rent ponds under contract agreements. Tenant farmers rely on sufficient capital in their pond business. For example, the capital required for a 12 hectare area for milkfish cultivation is IDR 400 million (26,500 USD) for one production cycle within seven months (Laksono et al., 2020).

3.1.4.3 Managers

Are farmers who have a lot of energy and skills, but do not have rights to farm profits, and do not have enough capital to rent. They work in other people's ponds under profit-sharing agreements, also sharing production costs.

3.1.4.4 Pond workers (Pandega)

Are hired laborers in ponds. They do not have the capital to buy - let alone rent - so they depend entirely on being employed by owners and tenant farmers to work. On average, pond workers are paid IDR rupiah 2 million per month for feeding and securing the pond. During harvesting, some are paid extra for use of specific tools and techniques.

Pond owners/tenants with large pond sizes, normally employ workers (Pandega) for daily work including feeding, operating pumps, checking water quality, and securing ponds. The workers usually take a day off on Friday due to Friday Prayer in Muslim communities (GS5). Profit sharing between workers and pond owners/tenants can be between 10-25% of the total profit, or can also be in the form of a monthly salary system.

To carry out cultivation activities, a large amount of capital is needed. Fish feed is the largest expenditure in traditional plus systems. On the island-based systems, acquiring feed depends heavily on patrons (*Juragan*) to provide daily fish feed and as an eventual buyer for their harvest (GS2.1). There are five Patrons (Juragan) in Pangkah wetan area, and each Patron can handle more or less 50 fish farmers with harvest quantities up to 10 tons of fish per fish farmer. Feeding starts from the beginning of the growing phase, and when the fish weight between 200-300 grams, water pumps are activated every night for aeration (A7, A9). When it comes to harvest time, milkfish are caught with a net (*krikit*).

Government subsidies for fish fry or machinery for fish feed processing can be accessed by farming groups. The main farmer group recognized by the government is Pokdakan (*Kelompok Pembudidaya Ikan*- Fish Farmer Group) whose formation needs to be approved by the village chief (GS7). In Pangkah Wetan, group formation is based on the location of the pond. Especially for ponds located on islands, the groups are divided depending on the location of tributaries to make it easier to organize (GS6). For example, Pokdakan Kali Paloh, Pokdakan Kali Kunti, Pokdakan Kali Sumbalan, etc. The function of monitoring and sanctions by the government is carried out for large-scale or intensive cultivators such as Vannamei shrimp cultivation. In addition, the monitoring function is only carried out if there is a report from the community about irresponsible aquaculture activities (GS8).

3.1.5 Key interactions

There are two key types of investment in Gresik, (1) government investments (I5.1) and (2) farming practice investments (I5.2). The government - through the Ministry of Marine Affairs and Fisheries - supports collective action among fish farmers through the creation of Pokdakan (Kelompok Pembudidaya Ikan/Fish Farmer Groups) to access government support (I5). For example, they can receive information on Indonesian good farming practices (CBIB), which refers to the FAO Technical Guidelines for Aquaculture Certification and Asean Good Aquaculture Practice (GAqp) (I2), receive fish seed and tools, or get social benefits for the fish ponds affected by the flood. The Ministry of Marine Affairs and Fisheries has its own certification scheme for aquaculture practices called CBIB (Cara Budidaya Ikan Yang Baik) or Good Aquaculture Practice certification. CBIB is based on the FAO Good Farming Standard. Although in practice, subsidies given are often not utilized by the farmers for aquaculture improvements, but instead used for other purposes. For example, fish seed allocation for one group can only be used for one person due to the pond size and fish need in each pond. One group, in our findings, stated that the support only lasted for one farming cycle and the money from harvests was to reconstructed the road to access the ponds (I7). In many cases, groups sell the fish feed right away and distribute the money evenly to all farmers, rather than directly utilizing it to improve shared aquaculture resources. Another form of support is the natural feed makers and a package of starter materials because of the high prices of raw materials compared to factory made feed. There are no monitoring activities after the aid is delivered because most of it was in the grant scheme (I9). Fish farmers also form an association group at the village level to attract investments from companies operating around the area (I8). Based on the pond location the aquaculture commons dependencies in Gresik are shown in Table 2. For example, an important difference between island and inland ponds is that island areas have restricted access to formal monetary institutions although the government has provided several options for low interest loans. A common financial institution requires a land certificate as capital loan collateral. Due to its vulnerable location in the Bengawan Solo Delta, the milkfish ponds are exposed to the risk of annual floods. This drives the fish farmers to refuse formal financial support from banks because they would then have to give their land certificates as a requirement for the loan, which they perceive as too risky.

3.2 Aquaculture commons and drivers of collective action

3.2.1 Aquaculture commons in Gresik

Commons are the shared resources that aquaculture stakeholders use and rely on together, and need to govern together, in order to produce aquaculture products. Aquaculture systems in Gresik have numerous commons that create a need for collective action to provide and maintain the condition or availability of the shared commons (Table 4).

3.2.2 Hindering and enabling conditions for collective action

From the perspective of the fish farmers, there are three main drivers to collectively govern milkfish aquaculture in Milkfish Village. They are to (1) increase productivity for their livelihood, (2) become independent fish farmers, and (3) receive assistance from the government. These motivations arise to get the desired outcomes to be able to farm sustainably, have better access to the market, reduce dependence on the patrons (intermediary traders), and access suitable government aid.

Fish farmers that operate in inland areas have more access to financial support and the aquaculture value chain, including financial support from formal institution (Bank and others), best market prices, infrastructure (i.e., roads and electricity) and better fish feed and seed. Island-based fish farmers have limited access to above mentioned goods. Additionally, island farms are prone to flood. Thus, island-based fish farmers are more willingly to form a group to work together with the purpose of maintaining public goods, for example, the road and dikes to mitigate their deterioration due to raining and floods.

Compared to the island-based fish farmers, inland fish farmers have more public goods including appropriate road access for fish feed delivery and harvest, although less capital and collective action needed to maintain roads and electricity infrastructure. For inland farmers, good environmental conditions supporting milkfish aquaculture and low risk from natural hazards reduce incentives for farmers for collaborating compared to island-based fish farmers.

TABLE 4 Aquaculture commons in island and inland pond systems.

Aquaculture commons	Commons description	Island Pond	Inland Pond
Electricity	Electricity is needed to operate lights, pumps and storage.	No	Yes
Road	Roads need to be maintained to access ponds and markets.	No	Yes
Financing	Due to the high risk of the annual flood, the formal financial institution cannot cover the financial capital of the fish farmers on the island.	No	Yes
Water canals	Water canals are shared by all ponds, and need to be maintained so water is delivered to each pond.	Yes	Yes
Water quality	The main water source comes from the Bengawan Solo river and Pangkah Wetan is in the estuary. Located downstream, the water quality has been mixed with domestic waste, industry and other ecological processes.	Yes	Yes
Fish seed	Fish fry are needed by all farmers, either wild caught or farmed and sold.	Yes	Yes
Fish feed	Fish feed is a needed in traditional plus systems grow fish larger and faster.	Yes	Yes
Market	Markets need to be established to allow reasonable and stable prices for aquaculture products.	Yes	Yes
Government program	Local and National Governments had several program in the area, but not all fish farmers are compatible as a program recipient. Larger government incentives are applied for fish farmers in the mainland.	Yes	Yes
Flood risk reduction	Because of the location in the estuary, island based ponds are more prone to flood compare to the inland based pond	Yes	No

Linking the above results to collective action theory, we discuss the interactions between key variables in relation to their influence to collective action (Table 5). Despite the collective efforts taken between the government and fish farmers to increase productivity, challenges for governance still remain including who is eligible for funding, how to better implement the program, how to monitor the program, and who is responsible for specific tasks. It has also been observed that there is a strong interaction between the pond location, fish farmers' location, and heterogeneity of the actors increasing transaction cost (deliberation and collective choice rules). Low monitoring of group performance by the government, lack of government staff, and weak leadership by the group leader are supporting reasons for reduced willingness for collective action. A full list of 2nd and 3rd tier SES framework variables and their relation to collective action is provided in Table 6.

Over the years, ponds were no longer owned by local fish farmers. Due to urbanization, next generation inheritance and higher education in the third generation of the farming society shows low interest in farming activity. More and more ponds were sold to external inhabitants, left to be rented by hired fish farmers. A typical situation is that a hired fish farmer (with minimum capital) practices traditional aquaculture (non-fed), while pond owners or tenants (more capital) prefer a traditional plus (feeding) techniques. The traditional technique requires less capital and less effort or time investment. Pond tenants only interested in fish production and not taking care of the pond, like strengthening the dike or maintenance of public infrastructure even if it can affect their production. Since they live far away from the pond, and can only be there once in a while, it makes it difficult to collectively work in a group. This can cause a problem when the ponds are located in the riverbank as the first embankment for other ponds. If not strengthened through maintenance, risk from floods is higher that the surrounding ponds will be destroyed causing harvest losses.

Therefore, from the perspective of resource user, location clearly influences motivation for collective action. Island-based farmers are more willing to form a group due to the risk of the annual flood. Especially those which are located on the riverside. Every year, high tide is predicted to happen at night and noon. This natural phenomenon can cause the brake of the embankment leading to harvest losses. Therefore, collective action is needed to protect their pond from the loss and to have good access to the ponds by collectively maintaining the road. Contrarily, fish farmers in the inland area feel no urgency to form a group. Just recently, fish farmers in the inland area formed a group because of the need to

TABLE 5 Drivers of collective action in milkfish aquaculture and the desired outcomes.

Drivers of collective action	Desired outcomes
Increase productivity and increase livelihood	●Protect their neighborhood ponds to secure the individual harvest and sustain their livelihood ●Maintain the infrastructure to ponds for easier access and less effort ●Conduct best aquaculture practice including post-harvest management ●To have better water quality ●To be able to mitigate the annual flood phenomenon ●More access to market
Independent fish farmers	●Reduce dependence on the patron
Requirements to receive government programs	●Access to subsidies ●Access to funding or other supports

TABLE 6 SES second and third-tier variables related to collective action problem in Gresik Milkfish Village.

SESF	Case explanation	Theoretical claim/hypothesis for collective action (CA)	Case Importance	Case Trend
GS2 Nongovernment organizations	Non-government organizations exist in terms of Patrons, membership to Patron group is common in sedimented island pond	Existence of NGO incentives increases CA	High	Increasing
RS4 Human constructed facilities	Ponds on sedimented island have limited access and road maintenance	A basic need of infrastructure to support aquaculture increasing CA	High	Stable
RS7 Predictability of system dynamics	Ponds located on sedimented island are vulnerable to flooding. Especially ponds near the main river.	More predictable a resource is, the easier it is for its users to engage in collective action (Agrawal 2001; Di Gregorio et al., 2008)	High	Stable
RS9 Location	Island-based pond has limited access and facilities, some ponds need boat as the main transportation for fish feed and harvest delivery	More accessible the system is enabling CA	High	Stable
GS2.1 Private organizations	Private actors (Patrons) served as a non-governmental organization in Gresik milkfish village	Patron existence increase CA to increase fish production and monitoring activities (McGinnis and Ostrom, 2014)	High	Stable
GS5 Operational-choice rules	Differences in operational rules between traditional and traditional plus feeding pond farmers	Heterogeneity of the fish farmers in their operational choice rules decrease CA	High	Stable
A6 Norms (trust-reciprocity)/ social capital	Fish farmer with higher capital earn more and tend to have more stable income. Highest social capital between Patron and fish farmers, followed by worker and pond owner.	High to moderate levels of confidence and close relationship among local actors is likely to increase CA	High	Stable
A6 Norms (trust-reciprocity)/ social capital	A group with traditional aquaculture techniques (homogeneous) is more likely to cooperate than heterogeneous aquaculture practices.	The heterogeneous preferences among users (Cinti et al., 2010) and the divergent characteristics of the SES gave rise to different responses to the problem of resource management	High	Stable
A5 Leadership/ entrepreneurship	Organization in Pokdakan level is highly depended on the quality of the leader. While in higher level (Village), influenced by conflict of interest.	Accountable leadership increases likelihood of CA	High	Stable
I5 Investment activities	Too busy working at the pond, less likely willing to cooperate	External support/investment increase likelihood of CA	High	Stable
I5.2 Farmer investment	High time investment to farming hinders CA by limiting available time for communication and deliberation in the community. Higher capital investment motivates CA for the purpose of securing investment returns	Farming practice investment in time and capital	High	Stable
I7 Self-organizing activities	More effort goes to securing the aquaculture supplies and markets due to existence of the Patron. Less effort to govern the water.	Economic factor motivate more than collective action effort to governing common	High	Stable
GS4 Property-rights system	Some ponds are rented, making it difficult to act collectively. Predictably the more land to be rented less likely to do CA	Investment and conservation are more likely with owners (Acheson, 2006).	High	Decreasing
A3 History or past experiences	Shifting behavior from traditional to traditional + requires more time spent at the pond. More capital needed, and more dependence on Patron. Previous government investment program was not fit to the local need.	High frequency of negative experiences with management affects actor's behavior, decreasing the likelihood of CA.	High	Decreasing
I5.1 Government investment	Government incentives only require group registration as the main requirement, with no consideration to how the groups are actually operationalized	Government assistance programs are expected to be able to stimulate collective action	High	Unclear
GS1 Government organizations, RS7	Group formation is needed as a requirement to receive government program. It also helps to coordinate flooding mitigation	Government policy increase likelihood of CA, a regulation to form fish farmers group for example	Medium	Stable

(Continued)

TABLE 6 Continued

SESF	Case explanation	Theoretical claim/hypothesis for collective action (CA)	Case Importance	Case Trend
Predictability of system dynamics				
I8 Networking activities	Fish farmer association communicate with surrounding industries to get funding to maintain the bridge.	Networking activity arises due to group needs and not eligible to receive government assistance	Medium	Stable
GS3 Network structure	Fish farmers can communicate directly with government but that scheme is not working. Fisheries field officer cannot cover all aquaculture area	Increased connectivity increases participation (e.g., Gould 1993; Putnam 2000)	Medium	Decreasing
A7 Knowledge of SES/mental models	Fish farmers are aware of pond conditions and have similar predictions of the system. But less motivation to follow best aquaculture practices.	Common understanding of the systems among resource users of CPRs has also been stated in the literature as a factor that could affect collective action, given that users find it difficult to agree on a joint strategy that allows them to conserve the resources (Poteete et al., 2010)	Low	Stable
A8 Importance of resource (dependence)	Fish farmers with traditional technique have less incentive to cooperate because of the minimum effort and capital to the pond	High dependence on the resources to obtain incomes and sustain livelihoods increases the likelihood of CA	Low	Stable
GS6 Collective-choice rules	Collective fund in Pokdakan to maintain road access to the pond, amount dependent on group consideration. Better communication and high leadership skill in fish farmer group increases participation in the decision making process and increases likelihood of CA	Collective choice rules of decision making process increases likelihood of CA	Low	Unclear
GS8 Monitoring and sanctioning rules	No monitoring and sanctioning for aquaculture activities, only between Patron members.	Graduated sanction increase compliance and trust in institution for CA	Low	Unclear
A4 Location, RS9 Location	Compared to inland ponds, ponds on the sedimented island have limited access and no electricity. Due to its vulnerability to the flood, joining Patrons is the most reasonable option. Village distance to the capital is 35 km and take 1-2 hours by car.	Actors located far apart increases transaction costs (e.g. monitoring, getting together), decreasing the likelihood of CA	Low	Unclear

receive government aid which requires road and electricity access as the main requirements for the recipient of the aid. External factors from the government's intervention (providing a financial incentive to cooperate) have proven to enable collective action. This confirms that these two variables - location and government investment - are very influential in motivating primarily pond farmers to work together. However, it is unclear if collective action would continue if or when government aid programs stop.

In Gresik, it is still perceived by many fish farmers that they are facing a decline in productivity due to the behavior of pond farmers who are not environmentally friendly (e.g., using feed without water and post-harvest soil treatment) even though the government has provided knowledge facilities on how to do this as a 'best aquaculture practice'. Such government efforts include a district fisheries government extension officer who works in the area daily with farmers to discuss challenges. The officer is tasked with introducing central government programs, organizing fish farmers group, informing farmers how to receive aid, but rarely provides inputs on farming technique interventions. The reasons for these perceived declines among farmers despite extension officer efforts are diverse. For example, fish farmers are heterogeneous actors, with major differences in property rights, operational rules, and also different levels of knowledge. Milkfish farming activities in Gresik have been carried out on the island and on the mainland for a long time. However, group formation for island-based fish farmers started around 5-7 years ago. During that time, there has only been minimum monitoring and control from the government. Low monitoring or control causes a low level of trust and reciprocity, which have been shown to increase the likelihood that people will contribute to maintaining the quality and quantity of resources (Marshall, 2004). Building trust and establishing norms of reciprocity can therefore help overcome other norms (e.g., lack of trust, individualism) to help break barriers to collective action (Graham et al., 2019). Patrons (GS2), in contrast, have leveraged their position of shaping and creating norms well. They have established a group consisting of 50 fish farmers and are typically able to encourage participatory monitoring carried out among fellow members in the patron group due to high connectivity and trust reciprocity (A6).

In this case study, we found that the location of the pond (RS9) affects the availability of human-constructed facilities (RS4) to incentivize self-organization between island-based fish farmers to take care of the road access to their pond. Not only the road access, but challenges in doing milkfish farming in island areas also involves the risk of harvest loss during high tide in the wet season because of the broken dikes located on the Bengawan Solo river.

However, some fish farmers face difficulties in bringing people together to solve the challenges. This is due to several factors, including changes in the behavior (A3) of the cultivation community from traditional to traditional plus feed (GS5). This also has an impact on investment activities (I5) in terms of energy, time, and cost. Conversely, a group consisting of the farmers using the same aquaculture techniques and having similar socio-economic status, for example among traditional fish farmers, tend to cooperate better. Homogenous characteristics among farmers seems to increase the likelihood of collective action, whereas in contract, diverse groups face more barriers due to higher transaction costs in understanding or identifying with each other.

In addition, changes in land ownership (GS3) that were previously owned by pond farmers, are now often leased out. This plays an important role because tenants usually do not intervene in pond repairs such as strengthening embankments or repairing roads to ponds. Usually, the tenants live far from the pond (A4) so it is difficult to meet, where the only communication options are calling or texting *via* cellular phones for pond management. With traditional pond farming, due to lower input requirements, farmers can still carry out other professions as shrimp collectors or fishing because they have more available time compared to pond farmers with feed. Therefore, the desire to work together to improve shared public goods is lacking due to less dependence on the system. Leadership at the community level (A5) has proven to be able to encourage groups to work together. Unfortunately, not many leaders have the ability to persuade others. Some leaders use their power to access government programs for themselves. Others choose to ignore the problems only to avoid conflict. Better leadership skills at the community level can be seen within the fish farmer association, where they have built a network (I8) with the private company operating in the area to access funding for maintaining the bridge to access their ponds.

Fish farmers in general understand various social-ecological system interactions, but the knowledge they have has not proven to be enough to enable collective action to reduce their risks and increase income or sustainability outcomes. Farmers typically understand variables of the biophysical environment required for milkfish cultivation such as coping with sudden changes in weather, predictability of the upcoming high tide (RS7), use of appropriate feed, how to do best aquaculture practices, pond waste management needs, local politics, market choices, as well as the patrons have available capital to support farming activities and market access.

In order to increase knowledge, fish farmer group formation aims to facilitate guidance and information/knowledge sharing by the government. This aims to encourage fish farmers to solve problems as a group and to generate added value in their products so they are able to improve their livelihood and welfare (interview with Gresik Fisheries Agency, 2021). However, this target is unlikely to be achieved in the near future in Gresik milkfish village because the perceived goal of the aquaculture community is to produce as much fish as possible rather than cooperate to solve joint problems. Despite the training and lots of assistance with seeds of various species to cultivate, milkfish pond farmers have rather fixed perspectives that milkfish farming is the only reasonable option due to the biophysical condition of the ponds, market, characteristics of the milkfish itself, knowledge of milkfish culturing, and capital availability (A8). As a result, fish farmer groups (Pokdakan) typically work together with the intention of fulfilling government requirements to get assistance (Zulkarnain, 2020), and are not formed as an institution that can accommodate all the interests of group members. In addition, high dependence on the system doesn't influence fish farmers to act beyond economic motives. Low monitoring provides minimal feedback to inform policy changes.

4 Discussion

4.1 Five governance challenges facing Gresik milkfish aquaculture

Gresik milkfish aquaculture relies on a range of social and environmental commons, however the extent to which local actors are collectively acting to manage their shared resources is mixed. The five main factors influencing collective action have been identified with the application of the SES Framework. The five governance challenges are: (1) limited access to capital and dependence on patrons, (2) lack of govern institutions governing the common, (3) continued government program failure, (4) lack of community leadership skill and knowledge exchange, and (5) lack of motivation and incentives to collectively act. In the following sections, we explore the details of each.

4.1.1 Limited access to capital and dependence on patrons

Financing aquaculture production is a major issue for fish farmers in Gresik. The challenge is exacerbated by the general trends of decreasing farm productivity, and the limited scope of government subsidy programs, which are often only enough to support one farmer in a given group. Farmers therefore remain highly dependent on wealthy patrons. Patron-client relationships remain central to aquaculture value chains, therefore including them in formal governance strategies has the potential to harness their influence of farmer behavior within policy design and implementation (Drury O'Neill et al., 2019). Literature has shown that fishers may be particularly vulnerable to exploitation because they are often in debt to buyers (patrons) and have no access to collective-choice arenas (decision-making processes) shaping their working conditions (Basurto et al., 2020). Patron-client relations in fisheries and aquaculture might have different institutional arrangements, however. Patrons in Gresik have been establishing positive relationships with fish farmers for years with minimal conflict. Although the interaction between fish farmers and patron needs to be studied in the future, there is a potential of collaboration between actors through informal governance.

4.1.2 Lack of institutions amongst heterogeneous farmers to govern shared aquaculture commons

The consistent lack of appropriate operational rules amongst fish farmer groups in Gresik is exacerbated by inadequate law enforcement at the government level. Additionally, the demand for economic returns and high actor diversity were identified to create a system exhibiting high transaction costs, making deliberation, cooperation, and shared rule-making difficult (Ostrom, 2009). A large degree of heterogeneity was identified between fish farmers, such as dependence on aquaculture as either a full-time or part time livelihood and socio-economic attributes. This leads to low levels of interaction and little sense of community (Acheson, 2006). Similar findings in other cases have shown that homogenous and smaller group are likely to cooperate more effectively (Agrawal, 2001). The tambak resource systems in Gresik are heterogeneous as well, for example island ponds face higher sedimentation and transportation challenges which may require different institutional solutions than inland ponds. Identifying farms and farmers with similar characteristics, and then forming groups around them, may be a potential option.

4.1.3 Continued government program failure

Government programs to develop pond aquaculture as a sustainable business in Gresik can be characterized by a consistent lack of success, notably the lack of aquaculture business registration which is a requirement to access additional government support, and limited uptake of Indonesian good aquaculture practice (CBIB) protocols. Relatedly, the lack of registered aquaculture business degrades the capacity of government monitoring and control of the farmer group development, namely the extent to which government assistance provides solutions for fish farmers. Low monitoring can lead to lower levels of trust and reciprocity between government and resource user actors due to perceived lack to control over the behavior of others. In contrast, trusting relationships have been found to increase the likelihood that people will contribute to maintaining the quality and quantity of resources (Marshall, 2004). These issues are exacerbated by the lack of field officers for aquaculture in Gresik. Actors serving in these extension roles can fill an important bridging role between government and local fish farmers to improve uptake of government development programs (Thompson et al., 2006).

4.1.4 Lack of leadership skill at the community level

At the community level, fish farmers' leadership skills have been observed to motivate the group members to participate in self-organizing activities for governing public goods (road access to pond) and private goods (broken dikes). These findings align with other literature suggesting that strong leadership has been relevant in motivating self-organization (Poteete et al., 2010; Basurto et al., 2013). In Gresik, leaders are chosen based on their experience and social status, which leads to differences in leadership qualities. When the period ends, the new leader does not necessarily have the same skills because there are no mechanisms for knowledge transfer or leadership training in the community.

4.1.5 Lack of motivation and incentives to collectively act

Knowledge of SES did not motivate fish farmers' collective action in order to increase the added value or diversify products with the aim of increasing income. Although the fish farmers are aware that the productivity of the system is declining, their limited resources (money/pond size) (I5) reduce incentives for collective action. Existing research (Basurto and Ostrom, 2009) strongly indicate that the lack of knowledge about the resource prevents fishers from making a prediction about the dynamic of the system and thus affects their self-organized ability. Our findings that while fish farmers recognize SES problems, there may be a lack of knowledge regarding how these problems are shared resource problems requiring self-organization and cooperation. For example, while farmers may be aware of the impact of degrading water quality on production, they may not be recognizing how the upkeep of common waterways (i.e., irrigation canals) can contribute to water quality upkeep. Without appropriate understanding regarding how investing this money can improve shared aquaculture resources and long-term production outcomes, farmers will favor short-term financial incentives rather than long term investments in aquaculture. A lack of problem recognition reducing incentives for collective action is a challenge which has previously been documented in other cases of pond aquaculture in Indonesia (Partelow et al., 2018).

4.2 Policy recommendations

To summarize our findings, we here provide a brief summary of potential policy solutions to the most influential governance challenges hindering collective action in Gresik and suggested policy solution (Table 7). The following list can be used to reflect on policy program designs that can better address sustainability issues. Each problem is matched with potential policy solutions that may help improve success.

Policy makers are encouraged to understand the aquaculture systems they aim to change through a social-ecological approach by getting feedback from extension officers and coordinating knowledge sharing activities among local to regional extension officers, universities and aquaculture stakeholders to synthesize challenges and potential improvements that can be used as inputs into revising policy. This means that better efforts can be made to consider a wider range of factors related to the sector to be regulated in order to ensure the most appropriate and sustainable management. Policy is a key lever of governance, and if governance aims to shape the behavior of actors in the system, then understanding the conditions that those actors operate in can inform the development of rules and norms that better address the hindering conditions for collective action (e.g., group diversity, low monitoring, location differences) while leveraging the enabling conditions (e.g., positive patron-client relations). Developing context appropriate rules and norms can directly guide the use, maintenance, and distribution of shared resources in aquaculture although such approaches to the sector to governance are rarely discussed (Partelow et al., 2021).

TABLE 7 Main governance problems identified for milkfish aquaculture in Gresik. Suggested policy solutions to address each problem are provided.

Main problems	Policy solutions	Target group
Lack of institutions amongst heterogeneous farmers to govern shared aquaculture commons	Bring different farmer groups together in workshops to help understand each other. Form groups around farmers with similar backgrounds. Motivate farm group formation and rule development that leverage existing norms of best practice and collaboration.	Local village leadership; milkfish community organizations; government extension officers
Limited access to capital and dependence on patrons	Increase access options to financing and basic infrastructure like roads. Explore pathways to more directly integrate wealthy fish farmer patrons into formal governance strategies.	Regional and national governments; patron communities
Continued government program failure	Increase monitoring of program implementation and iterative learning to improve program designs in ways that meets local needs. Align policy program ambitions with sufficient implementation resources, particularly increased field extension officer capacity to serve in a bridging role to improve uptake of government best aquaculture practice strategies. Extension programs incentivizing monitoring by farmers themselves which can in turn strengthen norms of trust and reciprocity.	All levels of government
Lack of leadership skill at the community level	Include leadership and administrative training in policy programs. Develop knowledge exchange and transfer initiatives to improve transitions between community aquaculture leaders.	Local village leadership; government extension officers: local universities
Lack of motivation and incentives to collectively act	Develop training programs to improve knowledge capacity regarding shared goods and shared risks of common water bodies such as irrigation canals. Find context appropriate incentives that reward cooperative behavior. Invest in capacity building trainings coupled with research.	All levels of government; Local village leadership; milkfish community organizations; government extension officers; local universities

Science-based information can be used to support government programs. To do this, establishing collaboration between actors in Gresik aquaculture is a good starting point. Collaborative development and sharing of knowledge by multiple actors have been shown as an effective pre-condition for contextualizing policy design and improving science (Armitage et al., 2012). For example, partnerships with local universities who have been doing research in the area for years can help build relationships with local fish farmers. Training programs which increase knowledge capacity of farmers in regards to shared resource problem recognition can increase the incentives for farmers to collaborate to reduce shared risks. Collaboration and learning are a potential way for managers (regional agency) and scientists to engage (and not necessarily formally) with different types of knowledge and perspectives (Armitage et al., 2012). Even though no single blueprint exists for how to succeed by using collaborative approaches, emerging insights suggest that effective collaborative arrangement leverages several factors underlying collective action problems such as increasing the quantity and quality of communication to lower transaction costs and build trust (Bodin, 2017).

5 Conclusions

This study provides an initial assessment into aquaculture governance challenges in pond aquaculture systems through examining the case of Gresik, the largest pond production area for milkfish (*Chanos chanos*) in Indonesia. We have identified the commons the system depends on, and its emergent governance challenges in governing them effectively. We highlight five factors influencing governance and collective action, which ultimately drive production and farmer livelihood outcomes such as income: (1) limited access to capital and dependence on patrons, (2) lack of govern institutions, (3) continued government program failure, (4) lack of community leadership, and (5) lack of motivation and incentives to collectively act. Following these, this study draws three important conclusions. First, establishing partnerships among local stakeholders to improve communication and share knowledge, including with the local university, can help inform aquaculture governance fit to address local challenges and adjust policy program implementation in a way that works locally. Second, government investments may be more effective when they incentivize collective action when they avoid monetary incentives, but instead focus on improving leadership skills in the community. Third, the government programs - initiated through extension officers and regional inter-governmental partnerships - should consider co-producing knowledge with different actors to provide a baseline for monitoring mechanisms and to avoid program failures based on a lack of trust or knowledge of programs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors upon request, without undue reservation.

Ethics statement

The project within which this research was funded (COMPASS, BMBF) followed required ethical clearance procedures in its research packages and projects outlined by the funder and institutional mandates of the Leibniz Centre for Tropical Marine Research (ZMT). The authors state that good scientific practices were followed, and that the low risk of the study in obtaining interview data from prior informed consenting adults meets ethical clearnance standards outlined by the institute, funders and in Indonesia. The studies were conducted in accordance with the local legislation and institutional requirements. Verbal prior informed consent was obtained from all participants and recorded with audio. These meets local standards in this context for obtaining interviews in Indonesia and the host institute.

Author contributions

CR: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. SP: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing. BN: Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author SP declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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