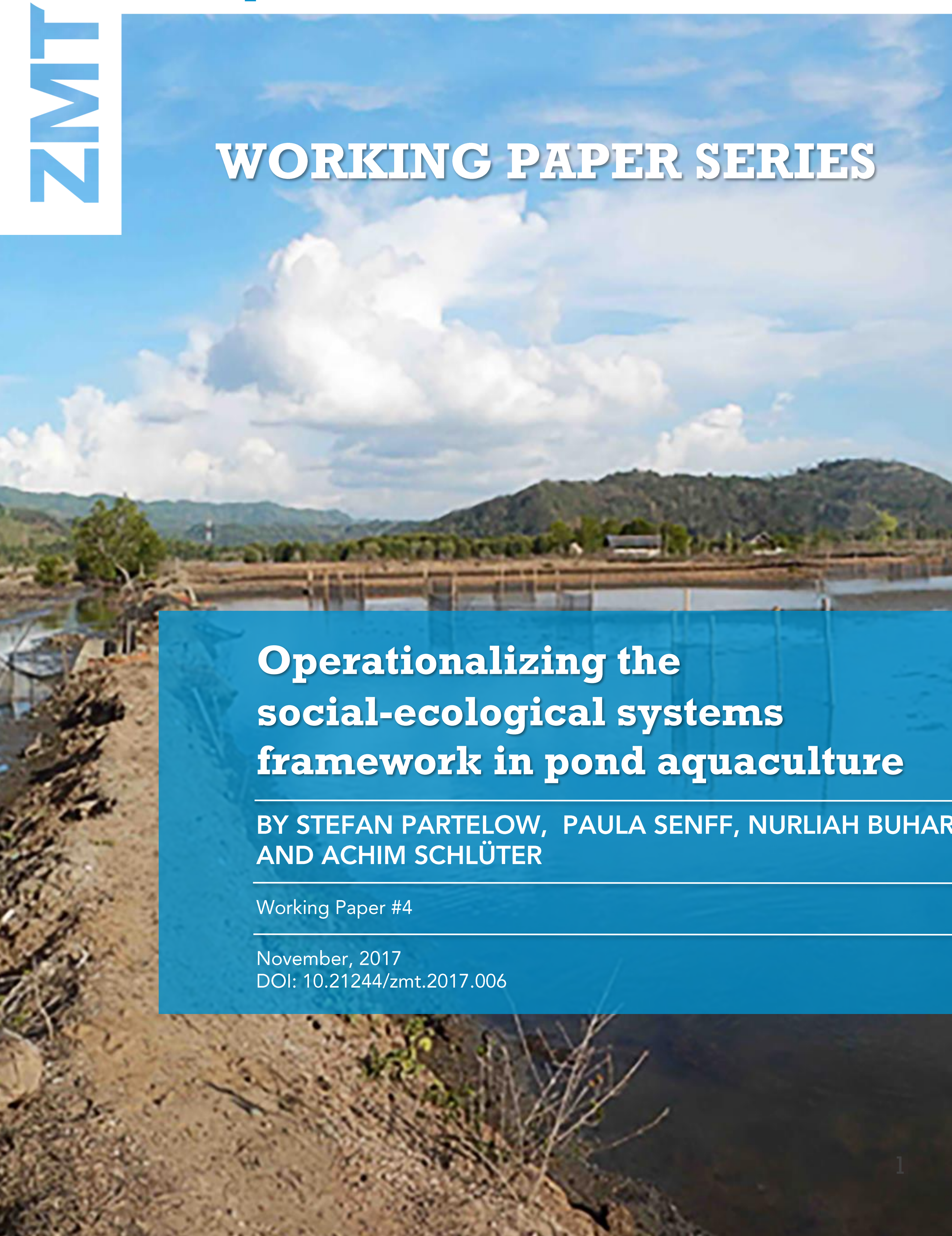
LEIBNIZ CENTRE
for Tropical Marine Research

ZMT



WORKING PAPER SERIES

Operationalizing the social-ecological systems framework in pond aquaculture

BY STEFAN PARTELOW, PAULA SENFF, NURLIAH BUHAR
AND ACHIM SCHLÜTER

Working Paper #4

November, 2017
DOI: 10.21244/zmt.2017.006

Abstract

This study develops and applies an interdisciplinary and mixed method approach to operationalize the social-ecological systems (SES) framework in the context of aquaculture, the fastest growing food sector worldwide. We apply this methodology to conduct a case study of community-based pond aquaculture on the island of Lombok, West Nusa Tenggara, Indonesia.

This diagnostic approach demonstrates how sustainability challenges are interrelated at multiple levels through an analysis applying common-pool resource (CPR) and collective action theories. At the community level, qualitative data show how pond aquaculture systems can be interpreted as CPR dilemmas and requiring communities to work together to solve them. This primarily relates to the provision of canal infrastructure with up and downstream water users similar to irrigation systems. Second, at the level of individual ponds, we developed indicators for the Resource System, Resource Unit, Governance and Actor tiers of the SES framework. Indicator data for each pond was measured and transformed into normalized quantitative scores to examine the relationships between social and ecological outcomes within and between ponds.

We combine the results of our multi-level analysis to discuss the broader social-ecological relationships which link collective action challenges in managing canal infrastructure with pond level outcomes and current government policies for advancing community development. We emphasize the need for increased knowledge and training on effective aquaculture practice as an underlying driver of current system conditions. This study raises many methodological challenges associated with designing empirically based SES research and building SES theory. We discuss challenges with integrating diverse data types, indicator selection and making normative assumptions about sustainability.

Keywords

Sustainability, collective action, interdisciplinary, mixed-methods, Indonesia, livelihoods

Leibniz Association

ZMT LEIBNIZ CENTER for Tropical Marine Research

Content

I. Introduction

The social-ecological systems (SES) framework has been proposed and is widely cited as a tool for advancing empirical SES research, developing SES theory and progressing sustainability science (Cox et al., 2016; McGinnis and Ostrom, 2014; Ostrom, 2009). However, there are few studies which demonstrate its potential for facilitating mixed-method empirical examinations to advance SES theory (Partelow, 2016; Thiel et al., 2015). This is in large part due to ambiguities in understanding the relationships between the many nested concepts and variables in the framework, which have different disciplinary origins. In addition, there are few attempts demonstrating how mixed-method data collection and analytical methods can be facilitated in practice. This includes defining SES concepts, developing indicators, testing field methods and integrating diverse data between multiple disciplines.

In this article, we attempt to advance interdisciplinary methods within SES research by operationalizing the SES framework in the context of pond aquaculture systems (Hinkel et al., 2015; Leslie et al., 2015; Partelow, 2015). We apply our approach to a community-based pond aquaculture system located in a deforested mangrove estuary on the island of Lombok, West Nusa Tenggara, Indonesia. We focus on the communities of Bertong, Madak and Empol in the district of Sekotong on the island's southwest peninsula (Figure 1). Our research design builds on the approach demonstrated by Leslie et al., (2015) and draws on existing literature applying the framework e.g. (Cox, 2014; Macneil and Cinner, 2013; Partelow and Boda, 2015; Schlüter and Madrigal, 2012). We examine our case study at two levels, the whole community and the individual ponds as distinct units of analysis.

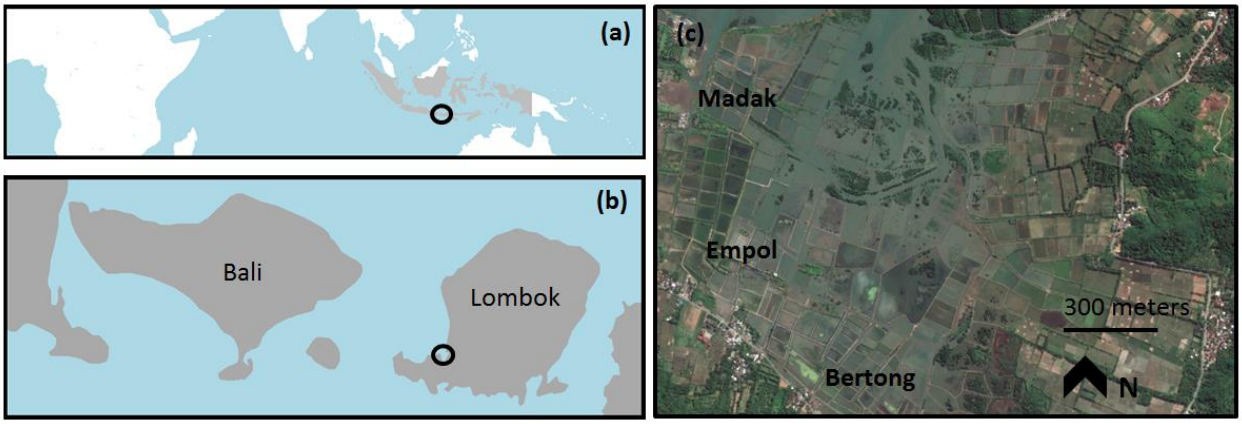


Figure 1. (a) Indonesia and location of Lombok. (b) Lombok and location of study site near the Sekotong Peninsula. (c) Satellite image over our three study sites Madak, Empol and Bertong. Top of the image is the mouth of the estuary into open water. Aquaculture ponds can be seen as square farming plots (Map data: Google, DigitalGlobe).

(1) At the community level we collect and analyze qualitative data to argue that certain social and ecological conditions are manifested from ineffective knowledge on how to maintain desirable pond conditions for aquaculture through improving water distribution canals. We draw on common-pool resource theory to hypothesize that the current social-ecological conditions present a supply-side provision dilemma of the canal infrastructure, which is related to creating, maintaining and improving the canals which the whole community depends on to regulate water exchange in their ponds (Ostrom, 1990; Ostrom et al., 1994).

(2) At the pond level, social and ecological indicators were developed and measured for each pond unit we sampled. All pond level data was transformed and combined into quantitative normalized scores to analyze and compare social-ecological relationships. We hypothesize that the ecological conditions will vary between the ponds and will become less desirable the further into the network (away from the coast) due to continuously less effective water exchange, reducing productivity and income accordingly. Additionally, we build on the research from Leslie et al., (2015) to hypothesize that there will be positive relationships between scores of the first tier variables of the SES framework, social (Governance and Actors) and ecological (Resource system and Resource units). This results from our methodology where each pond will receive a score between 0-1 at the first tier level of the SES framework, allowing comparisons between first tier scores within ponds and between them. We can thus hypothesize what these relationships might be. We further hypothesize that there will be positive relationships between the Interactions tier with the Actors and Resource units tier scores. In our discussion, we qualitatively analyze the link between pond and community levels of our analysis through examining multi-level social-ecological relationships. In addition, we attempt to discuss distinctions between proximate and underlying causes of the current conditions, combining our analysis across levels. We highlight the role of problem recognition, government investments and knowledge of the SES as key drivers in shaping multi-level outcomes in ponds and the community at large.

1.1 Aquaculture

Aquaculture is the fastest growing food sector worldwide, bringing both potential solutions and new challenges for marine and coastal sustainability (FAO, 2016; Troell et al., 2014). Pond aquaculture is by far the most common type of fish production in the world, accounting for 65% of global fish production between 2005-2014, having the largest implications for food security in the sector (FAO, 2016). However, the sustainability of pond aquaculture remains largely unexamined compared to other food production systems and wild-catch fisheries (Partelow et al., 2017). In Southeast Asia, aquaculture provides an additional or alternative livelihood for communities traditionally dependent on harvesting marine resources which have become severely exploited throughout the region (Halim, 2001; Rimmer et al., 2013; Von Essen et al., 2013; White et al., 2005; Williams et al., 2014). Aquaculture has been considered a sector that can enhance the resilience of food systems compared to wild catch fisheries which are the last large-scale food source to make the transition from hunting and gathering to controlled production through farming (FAO, 2016; Klinger and Naylor, 2012; Neori et al., 2007).

In Indonesia, country level policies are driving research and development in search for new economic opportunities that can balance sustainable development trade-offs (Ferrol-Schulte et al., 2014). Securing nutrient rich food for a country of 250 million people scattered across more than 900 inhabited islands necessarily requires utilizing the vast abundance of coastal and marine resources in a sustainable way (Gurney et al., 2014; White et al., 2005). However, little is known about the challenges and impacts of transitioning livelihoods towards aquaculture, or the types of governance approaches or institutions which will be needed to secure a sustainable future for the sector (Eriksson et al., 2012; Von Essen et al., 2013).

There are different types of coastal aquaculture, such as terrestrial pond-based systems and ocean-based mariculture (Swann, 1992). In this study, we focus on a pond-based system which requires the maintenance of pond and canal infrastructure, typically constructed through networks of dikes and levees with earthen walls (Figure 2). Regular seawater exchange is essential to stabilize water levels, balance nutrients and expel waste generated by aquacultural practice. Water is typically exchanged through canal networks leading to point sources to the ocean. The mechanism of seawater transport is primarily dependent on daily tidal fluctuations. In contrast to mariculture systems, terrestrial ponds have physical boundaries between them, substantially isolating the ecosystem conditions, nutrient levels and pollution within each pond. This can create variability in production between ponds related to differing social and ecological conditions (Azim et al., 2002; Islam et al., 2005).

1.2 Analytical framework

The literature on common-pool resource (CPR) systems has become closely associated with that of social-ecological systems (SES) (Cox, 2014; Ostrom, 2007). In both streams of literature, resource use dilemmas have been shown to create difficulties in managing them sustainably due to combined social and ecological conditions (Hardin, 1968; Poteete et al., 2010). Individual use interests, often overharvesting or free riding, can conflict with the common interests of the group. Cooperation or collective action, either self-organized or externally motivated, has proven to be a key component for solving common-pool resource dilemmas (Poteete et al., 2010). Research building on collective action theories continues to examine why some groups can solve CPR dilemmas effectively through building institutions, while others do not (Agrawal, 2014; Dietz et al., 2003; Poteete et al., 2010). Common frameworks have played a considerable role in providing a structure to define and compare system components, interactions and outcomes across systems (Binder et al., 2013; Cox et al., 2016; Ostrom, 2009).

Using common frameworks "provides the basic vocabulary of concepts and terms that may be used to construct the kinds of causal explanations expected of a theory," (McGinnis and Ostrom, 2014). To advance SES theory, the framework provides a tool to explore causality between social and ecological system components through diagnostic empirical examinations of case studies (Partelow and Winkler, 2016). The SES framework is a synthesis of concepts from multiple disciplines, envisioned to be a common language or basic vocabulary of concepts for SES research. The framework is outlined in a nested and decomposable structure, acting as a diagnostic checklist to guide empirical research (McGinnis and Ostrom, 2014; Ostrom, 2009). The framework is constructed of tiers of nested concepts, the first tiers include the Resource System (RS), Resource Units (RU), Governance System (Gov), Actors (A), Social, Economic and Political Settings (S), Interactions (I), External Ecosystems (Eco) and Outcomes (O). Second tier concepts are nested within each first tier (Table 1).

Table 1. The social-ecological systems (SES) framework (McGinnis and Ostrom, 2014).

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	**Governance Systems (GS)** GS1- Government organizations GS2- Nongovernment organizations GS3- Network structure GS4- Property-rights systems GS5- Operational-choice rules GS6- Collective-choice rules GS7- Constitutional-choice rules GS8- Monitoring and sanctioning rules
Resource Units (RU) RU1- Resource unit mobility RU2- Growth or replacement rate RU3- Interaction among resource units RU4- Economic value RU5- Number of units RU6- Distinctive characteristics RU7- Spatial and temporal distribution	**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	

II. Methods

The research design of this study is a multi-step procedure combining a community level qualitative diagnosis with the quantitative research design from Leslie et al., (2015). We expand on this approach to demonstrate how it can be applied at the local level and to conduct an intra-case comparative analysis of aquaculture ponds conditions. Data collection was conducted between November - April 2016. Initial exploratory and observational phases focused on establishing contacts, meeting with local pond farmers, village leaders and community residents. Our exploratory observations and interviews were designed to gather data related to the concepts of the SES framework as well as to identify contextually relevant indicators to measure specific concepts at the pond level. Following our initial observations, we refined our focus to examine two units of analysis, recognizing two distinct levels in the SES: (1) the community level, and (2) the nested level of individual ponds, where each pond is considered its own social-ecological unit. Once we defined our two units of analysis, the next step was to identify appropriate indicators and the further methods needed to examine or measure them at each level.

2.1 Community level

A total of 74 interviews were conducted with the help of a translator into Indonesian (Bahasa) or the local language Sasak, depending on the interviewee. Interviews in the community were conducted in three rounds. After each round the interview questions were revised following a diagnostic approach by asking nested sets of increasingly refined questions (Cox, 2011). Snowball-sampling guided our selection of interviewees with multiple points of entry into the three communities. However, availability of individuals during field visits and working schedules mandated occasional convenience sampling after observing additional individuals to be included (n=16). The first round of interviews (n= 13) thus focused on the structure and activities of the farming group in Bertong, the Actor (A) and Governance (Gov) characteristics in the community as a whole. Upon completion of the first round, interview questions were further refined to generate structured interview data on the individual farmers of specific aquaculture ponds (n=35), who provided additional data on the community as well. Our aim was to link the social data of farmers with the ecological data from each pond. Interviews were conducted with pond farmers from all three communities. The indicators developed for the social data collection were linked to the SES framework concepts (Table 2).

Ten key informant interviews were conducted with members of the three communities and government actors in the regional district, who had been selected based on their leadership positions. Questions were designed to the broader role of local, regional and national government including subsidy programs and historical development in the area such as the evolution and distribution of property rights. Interview data was organized by coding it to the concepts of the SES framework using the software MaxQDA. Statistical analysis was conducted in Microsoft Excel, OpenOffice and R (R Core Team, 2016).

2.2 Pond level

At the pond level we hypothesized that individual ponds would have variable social-ecological outcomes due to their location in the pond-canal network and due to the individual characteristics of the pond farmers. This was done to offer a more in-depth examination of pond aquaculture and marine SES case studies which often generalize characteristics at the community or regional level (Leslie et al., 2015; Partelow et al., 2017). Our approach draws on similar studies in irrigation systems, where the literature attempts to investigate the role of single individuals with distinct farming plots in a network (Cox, 2014; Janssen et al., 2011). Thus we attempt to demonstrate that aquaculture ponds and social (individual) characteristics and outcomes may vary substantially within an otherwise perceived rather homogenous SES.

A sample of 62 ponds were analyzed as distinct social-ecological units, all ponds are biophysically separated by constructed mud walls (RS3) (Figure 1) and farmed by individual farmers (some farmers use more than one pond) (A1). We developed indicators to measure the social-ecological performance of our sample ponds. The concepts, indicators and type of data collected are shown in Table 2 below. All data for the individual pond indicators were transformed and analyzed as normalized quantitative scores (Table 2). A higher score is associated with a more desired environmental, social or economic condition. Categorical data were expressed as either 0 or 1. Continuous data were ranked according to the 0, 10, 25, 50 and 75, 90 and 100 percentiles, which were assigned the values 0, 0.1, 0.25, 0.5 and 0.75, 0.90 and 1 respectively. The indicator values were matched to the closest percentile from the resulting ranking. In case a high value represents a less desirable condition, the inverse of the value was taken. The resulting scores are presented in Table 2. For the individual pond scores, data was attributed to multiple ponds if they were owned by the same user, with the exception of "pond size" and "distance along canals" which are unique to each pond. Pond area was determined using the QGIS field calculator. The distance of each pond upstream within the canal upstream was measured manually using the QGIS ruler tool (details below).

19 ponds in the community of Bertong were selected to represent a cross-section of distance from shore, spanning from the edge of the water to the most inland point near a main road. Data on physical parameters of these ponds were collected in two-week intervals from December - March 2016. Measured parameters included salinity, temperature, pH and oxygen content, which were measured using a WTW Multi 3430 multimeter (Xylem Analytics, Weilheim). Water depth was measured on two locations per pond, one in the opening of the main gate as a reference point and another at a random location, where the pond bottom was perceived to level off. This data was used to assess temporal changes due to seasonality and to test the hypothesis that pond location (distance into the network) negatively influences the variation in pond conditions and can be used as an indicator for equilibrium properties (RS6) and location (RS9) in our analysis (Table 2). Spatial analysis and representation of pond parameters and indicators for each pond was done using the mapping software QGIS (projection EPSG:102029, Asia_South_Equidistant_Conic). Pond polygons were manually digitized using satellite imagery sourced through GoogleEarth and projected into QGIS.

III. Results

3.1 Community level

To examine the hypothesis that both social and ecological conditions, in combination, are acting as drivers of a provision dilemma to develop more effective pond-canal infrastructure, we describe the social-ecological conditions at the community level using the variables of the SES framework.

Resource system (RS)

Pond-based aquaculture (RS1) in Bertong, Madak and Empol is situated in a coastal mangrove estuary near the Sekotong bay (RS9). Due to the natural landscape, the ecological boundaries are clearly defined (RS2).The low lying estuary is separated from the sea by a thin strip of beach with canal and river outlets, and otherwise surrounded by hills. The estuary is dominated by human constructed canals and aquaculture ponds built from mud (RS4; Figure 2). Local mangrove habitat has been deforested due to farming and the use of mangrove wood for distilling salt from seawater as an alternative income. Most ponds contain no mangrove trees or a low density of naturally occurring trees. Seasonality plays a significant role in the production of food and perceptions of environmental change as the island experiences two main seasons, the wet season dominated by consistent rainfall from November to April and a dry season from May to September (RS6). During the wet season, freshwater creates brackish conditions with higher water levels, providing the most suitable conditions for aquaculture. During the dry season, ponds either contain water with high salinity content or no water. Tidal fluctuations bring sea water into the pond-canal network, and due to uneven water distribution in the canals, the pond conditions fluctuate based on the location. We further discuss details of the Resource units (RU) and Resource system at the pond level below.

Resource units (RU)

Pond-based aquaculture is focused on the production of milkfish (*Chanos chanos*) and seaweed (genus: *Gracilaria*) (RU4), following region wide trends. The species are typically grown together as a co-culture (RU3). Resource unit mobility (RU1) does not play a role as the ponds have clear physical boundaries between them, controlled by manual floodgates. However, it is more difficult to harvest mobile resources such as fish compared to seaweed, as many of the ponds are large (Table 2). Salt is produced during the dry season in smaller ponds through evaporation. Naturally occurring species, including tiger prawns, wild shrimp, crabs and various other fish species, are harvested periodically in small quantities as they enter the canals and ponds with the seawater (Figure 2). We further present characteristics of the Resource units (RU) below, as they differ at the individual pond level, including the economic value (RU4), number of units (RU5) and growth and replacement rate (RU2).

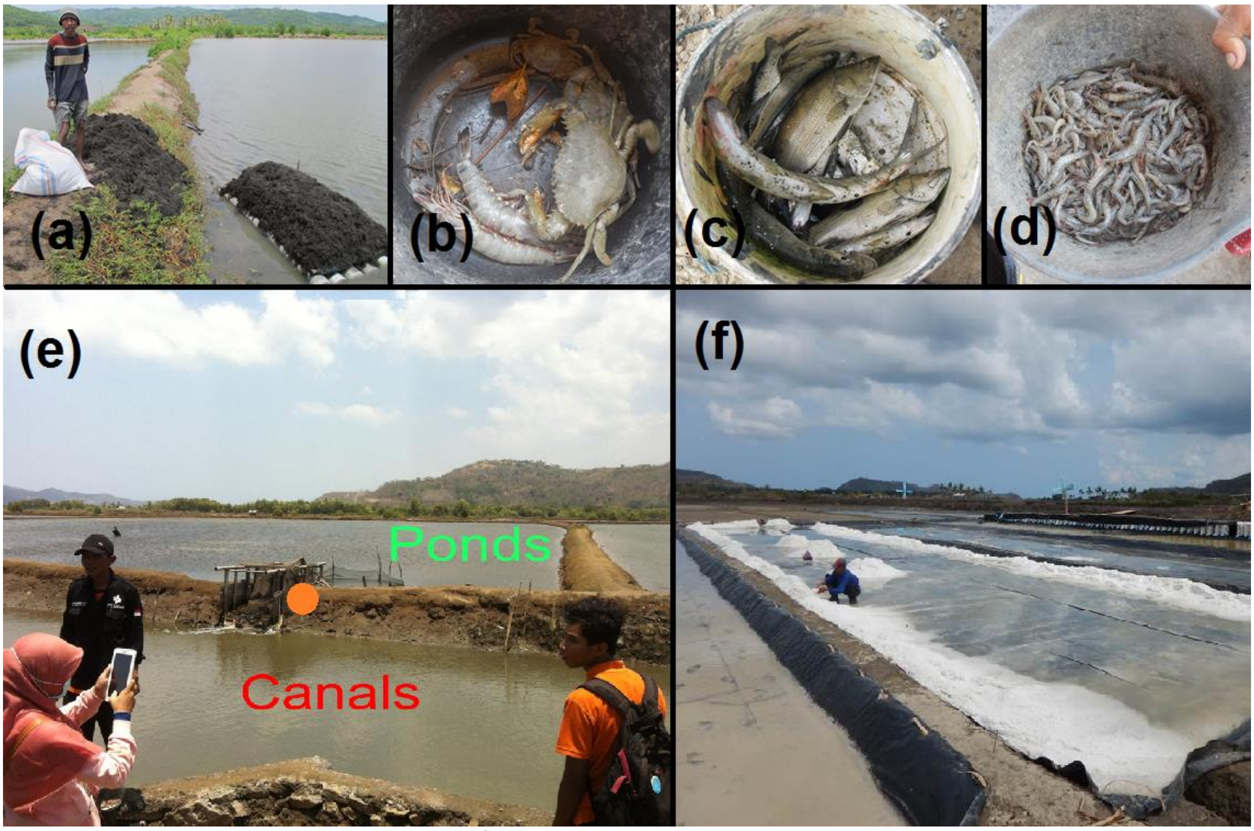


Figure 2. (a) Seaweed harvested with a float. (b) Prawns and crabs naturally occurring in pond-canal network. (c) Milkfish. (d) Shrimp, naturally occurring. (e) Pond (green), canal (red) with manual water exchange gate (orange). (f) Salt production in dry ponds. (All photos taken by authors)

Governance system (GS)

Three organizations provide funding and help to manage the area in different ways (GS1; GS2). The regional government through the Department of Fisheries and Aquaculture has instituted a program to support aquaculture activities in rural communities through subsidies and training. The Indonesian Institute of Sciences (*Lembaga Ilmu Pengetahuan Indonesia* - LIPI) conducts a pilot project to cultivate juvenile sea cucumbers (*Holothuria scabra*) in the area with ambitions to advance the prospects for more valuable species. The Coastal Community Development program of the International Fund for Agriculture Development (IFAD) consults on the advancement of aquaculture activities. In order to receive government aid, community members need to form farming groups (I7) and apply for specific projects. Support is never given as direct financing, but in the form of seaweed seed, fish fry, and equipment or as payment for labor to develop infrastructure (I5). The regional government officially monitors and enforces aquaculture activities in the region (GS8). They monitor the success of aquaculture groups who receive funding to assess future development aid. Farmers and community members provided mixed statements regarding the existence of formal rules for aquaculture or mangrove use. Few mentioned rules regarding the cutting of mangroves should come with a fine of 1,000,000 IDR (~75 USD) and the need to plant 100 mangroves, but cutting mangroves was interpreted more as an informal rule that is socially stigmatized. Our observations and interviews suggest this has never been observed by locals or enforced by the regional government (GS8). It was clear through observation in the communities that the use of mangrove wood for distillation fires and construction is regular. However, small patches of mangrove restoration areas are organized by the government and the International

Fund for Agricultural Development (IFAD) (I5). The use of poison to harvest fish from ponds is understood to be prohibited (GS5), but we received mixed statements that this may only be an informal rule. Access to documents containing formal rules were not attained, and likely do not exist. In addition, there is a high presence of illegal gold mining in the local hills, which is common among the communities, suggesting a general lack of enforcement of any formal rules.

The self-organization (I7) of aquaculture groups is required by the government to apply for and receive subsidies, equipment and training (I5). Groups are required to have a leader, secretary and treasurer (GS3; GS7; see Actors below), which may or may not work together in shared ponds. Groups are typically family members or friends (A6). The relevance of collective choice arrangements within groups are unclear but likely negligible as most members farm individually, with the group playing a minimal role except to receive aid (GS6). Pond ownership is regulated in a number of different ways (GS4) due to the historical continuity of land ownership and shifts in use over time (GS10). In 1989, the establishment of a shrimp farm changed the property rights system of parts of the area. An investor bought ponds, but has not used them since 1994, and abandoned a plan for a shopping mall in 2015 (I5). While this investor is the proprietor of many of the ponds, they are used by farmers of the local community who now have a mixed system of self-owned, rented, borrowed or profit sharing arrangements.

Actors (A)

Aquaculture groups are supposed to have a maximum membership of 10 people (A1), who select a leader, secretary and a treasurer (GS3). The leader has an organizational role, distributing tasks among the group members (A5). In this study we interviewed members of 9 government supported groups. The average annual income per person from aquaculture, typically the main source of income, is 10,375,000 IDR (~740 USD), which averages less than two USD per day (A2). However, the vast majority of respondents stated that they feel financially secure. Culturally, the community is highly homogeneous, identifying as Muslim and/ or Sasak, the local ethnic group. We observed apparent socioeconomic divides among older community members living slightly removed from the villages in the pond area in comparatively less desirable conditions. These individuals also complained about inequalities of access to government resources through the group program. Overall, the community is remotely located in a rural setting with minimal access to public services and infrastructure (A4). This is relative to the rural development context within Indonesia as there is a basic school and hospital with a decent road to the area.

Aquaculture has been practiced for more than three generations and many respondents consider it a part of their family history (A3). Much of the farming used to be for subsistence, however, prices for fish, seaweed and shrimp have increased and can now be sold on the market or to middlemen (A8). Illegal gold mining, roadside shops and agriculture supplement the income from aquaculture for many families. Farmers often assist each other, sharing seed and pond maintenance efforts (A6). However, theft from ponds is a problem, mostly from outside the community, as it is difficult to continuously monitor the ponds, individuals want to avoid conflict and police enforcement is lacking (I9).

Aquaculture is practiced in an artisanal way, using basic traditional tools and gill nets for harvesting fish or floats to collect seaweed (A9) (Figure 2). One aquaculture group was given a motorized pump to regulate water levels for salt production through evaporation. However, most individuals regulate pond water levels with tidal flows and manual floodgates (A9) (Figure 2). The need for pumps to clean the ponds or to keep the water levels high in the dry season was frequently stated and observed as necessary (A9). Tidal knowledge plays an important role in regulating the water levels and pond conditions, but knowledge on how this relates to effective aquaculture practice and environmental stewardship is generally low (A7). Environmental perceptions are largely shaped by seasonal changes, with the majority stating that the natural environment has not changed in their lifetime, but some said that they used to be able to collect more shrimp, fish and crab from the wild in the past (A7). Statements of seasonal predictability were varied along with the importance of mangrove in the estuary (A7). Individual variability is further examined at the pond level below.

3.2 Pond level

To test the hypothesis that pond conditions vary in relation to location in the network, we analyzed the standard deviations of salinity, pH and temperature in relation to distance into the canal network (from the coast) (Figure 3). The distribution of pond conditions averaged over time are shown in Figure 4. We observe positive relationships between pond conditions, salinity in particular, and distance into the network, which confirms our hypothesis. Salinity is the most relevant indicator of seawater infiltration. This indicates that pond conditions become less stable and thus less desirable for aquaculture the further into the network due to continuously less effective and stable seawater distribution and exchange. As a result, the distance from the coast was used as an indicator for location (RS9) in the calculation of the social-ecological pond scores.

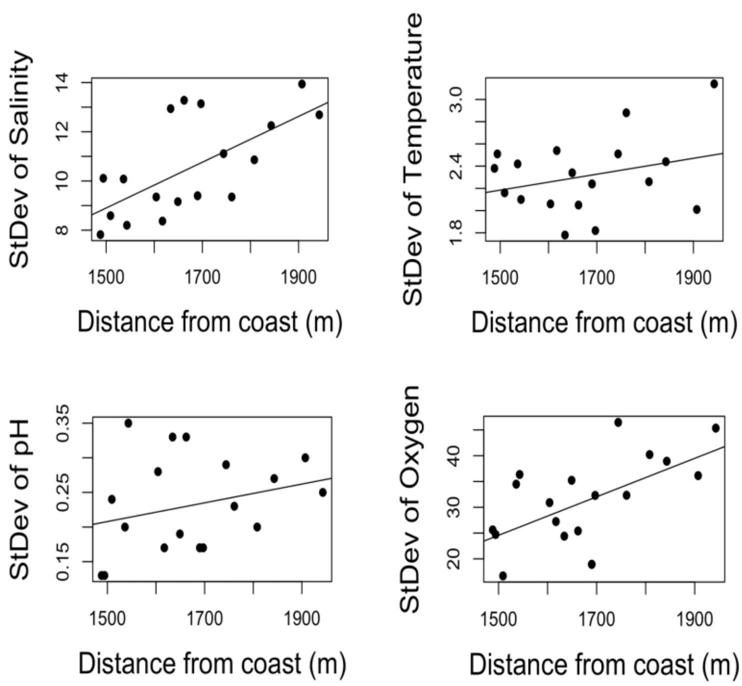


Figure 3. The standard deviation of the water parameters measured in the sampling ponds dependent on the distance along the canals from the center of the pond to the coast.

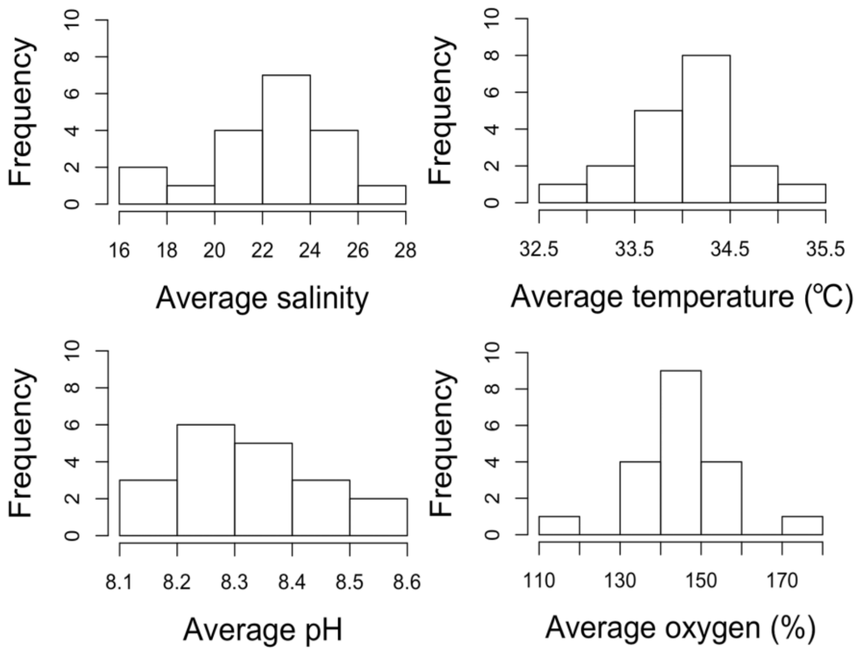


Figure 4: Histograms of the frequency distribution of the average water parameter measurements for the ponds.

Indicator values were calculated into five scores for each pond, one aggregate score for each of the measured first tier variable (RS, RU, G, A, I) of the SES framework. The indicators, data ranges and weighting system for the calculation are shown in Table 2. First tier pond scores were plotted in a correlation matrix to analyze their relationships (Figure 5). As hypothesized, we observe a strong positive relationship between RS and RU, suggesting ecological pond conditions influence aquaculture production and the income derived from it. In addition we observe a strong relationship between RU and GS as well as RS and GS, suggesting that pond ownership and group membership relate to increased production. There was no significant relationship between A and GS or between I and RU. A total social-ecological score was calculated for each pond from the first tier scores, which are mapped and plotted in Figure 6. Despite spatially dependent ecological conditions, we observe that combined scores are spatially variable, due to heterogeneity in the social conditions. Despite ponds which exhibited high individual 1st tier scores or high single indicator scores, few ponds have high combined scores, or high scores in multiple tiers of the SES framework (Figure 6). Scores do not exhibit a spatial relationship due to heterogeneity in governance and actor scores (Figure 6). This occurs despite indications that ecological conditions are in large part dictated by location in the pond-canal network. This suggests that outcomes are dependent on coupled social-ecological conditions.

Table 2. Indicators, normalized data ranges and weights used to calculate pond level scores. Each indicator is categorized by its relationship to the 1st and 2nd tier concepts of the SES framework. Theoretical importance of each indicator in the case context is shown.

First Tier	Second Tier	Indicator	Theoretical importance	Normalized data (transformed) * Original data	Weight Second tier
RS	Size (RS3)	Pond size	Pond size reflects production capacity.	1.00 – 54876 m2 0.90 – 10696.8 m2 0.75 – 6970.5 m2 0.50 – 4073.5 m2 0.25 – 3072 m2 0.10 – 1822.5 m2 0.99 - 667 m2	1/4
RS	Productivity (RS5)	Kg of milkfish	Higher productivity indicates suitable pond conditions and leads to higher income.	1.00 – 1125 kg year-1 0.90 – 785 kg year-1 0.75 – 450 kg year-1 0.50 – 258 kg year-1 0.25 – 136.5 kg year-1 0.10 – 100 kg year-1 0.00 - 0 kg year-1	1/4
RS	Predictability of system dynamics (RS7)	Flooding	Floods damage ponds and growing conditions. Economic and labor losses incurred.	1.00 – Never floods. 0.00 – Floods at least once a year.	1/8
		Drying out	Drying out prevents aquaculture.	1.00 –Never dry. 0.00 – Dry at least once a year.	1/8
RS	Location (RS9)	Distance from coast	Shorter distance along the canals leads to better water supply and more stable water parameters	1.00 - 25 m 0.90 - 259 m 0.75 - 1000 m 0.50 - 1489 m 0.25 - 1835 m 0.10 - 2027 m 0.00 - 2164 m	1/4
GS	Network structure (GS3)	Group member	Membership provides access to subsidies and training.	1.00 – Member of a group. 0.00 – Not a group member	1/2
GS	Property rights (GS4)	Ownership	Investment and conservation is more likely with owners (Acheson, 2006). Greater autonomy and are more likely pass it to future generations.	1.00 – Owner of pond property 0.00 – Does not own.	1/4
		Cost	Rent or profit sharing is an economic cost and implies a lack of autonomy.	1.00 – Does not have to pay for pond use. 0.00 – Has to pay to use the pond.	1/4
RU	Resource units (RU)	Species grown	Multiple commodities increases earnings and resilience to prices and pond conditions.	1.00 – milkfish, seaweed, salt and shrimp/crab. 0.50 – milkfish + 0.17 for each additional.	1/3
RU	Growth/ replacement rate (RU2)	Number of harvests	Indicates productivity and the potential earnings.	1.00 – 4.5 harvests year-1 0.90 – 3 harvests year-1 0.75 – 2.5 harvests year-1 0.50 – 2 harvests year-1 0.25 – 2 harvests year-1 0.10 – 1.6 harvests year-1 0.00 - 0 harvests year-1	1/3

RU	Economic value (RU4)	Income	Higher earnings indicate higher economic security. Higher earnings from aquaculture also make the continued use of this livelihood more likely.	1.00 – 72,000,000 IDR year-1 0.90 – 19,600,000 IDR year-1 0.75 – 10,000,000 IDR year-1 0.50 – 6,250,000 IDR year-1 0.25 – 3,000,000 IDR year-1 0.10 – 1,000,000 IDR year-1 0.00 - 0 IDR year-1	1/3
A	Leadership/Entrepreneurship (A5)	Leader	Group leadership indicates a certain level of social standing competence, influence or motivation.	1.00 – Individual is a group leader. 0.00 – Individual is not a leader.	1/10
		Entrepreneurship	The openness to sea cucumber cultivation indicates an interest in new aquaculture activities	1.00 - Interest in sea cucumber cultivation 0.00 - No interest in sea cucumber cultivation	1/10
A	Social capital (A6)	Theft	Theft reduces harvest potential, predictability and trust (Agrawal, 2003).	1.00 – Theft does not occur. 0.00 – Theft does occur.	1/5
A	Knowledge of SES (A7)	Perception of mangrove	The perception indicates knowledge of condition and importance for flood and erosion mitigation.	1.00 – Mangroves are important. 0.50 – Important elsewhere. 0.00 – Not important.	1/5
A	Dependence (A8)	Number of livelihoods	High dependence on a livelihood higher likelihood to invest and cooperate with others.	1.00 – High dependence, only livelihood. 0.50 – Medium, multiple livelihoods. 0.00 – Low, less important for livelihood.	1/5
A	Technologie available (A9)	Access to a pump	A pump can be used to regulate water levels in the pond in order to avoid drought or flood and the associated harvests losses and infrastructure damages	1.00 - Access to a pump 0.00 - No access to a pump	1/5
I	Information sharing (I2)	Teaching aquaculture to next generation in the family	Teaching aquaculture to the next generation increases the livelihood that it will be practiced in the future	1.00 - Teaches aquaculture as livelihood to children 0.00 - Does not teach aquaculture to children	1/2
	Investment activities (I5) Investment activities (I5)	Hours spent working at pond per day	The more hours can be spent working at the pond, the better it can be maintained. More time investment also shows a willingness to invest in the livelihood	1.00 - 7 hour day-1 0.90 - 6 hours day -1 0.75 - 5 hours day -1 0.5 - 3 hours day -1 0.25 - 1.5 hours day-1 0.10 - 0.75 hours day-1 0.00 - 0 hours day-1	1/12
I		Purchasing of fertilizer	Purchasing of fish feed, fish fry and seaweed seed show ability and willingness to invest in aquaculture practices aimed at increasing production	1.00 - does purchase fertilizer 0.00 - does not purchase fertilizer	1/12
I		Purchasing of fish feed		1.00 - does purchase fish feed 0.00 - does not purchase fish feed	1/12
I		Purchasing of fish fry		1.00 - does purchase fish fry 0.00 - does not purchase fish fry	1/12
I		Purchasing of seaweed seed		1.00 - does purchase seaweed seed 0.00 - does not purchase seaweed seed	1/12
I		Receives government subsidies	Reception of government subsidies (mostly in the form of fish fry or seaweed seed) means that less personal investment needs to be made	1.00 - does receive subsidies 0.00 - does not receive subsidies	1/12

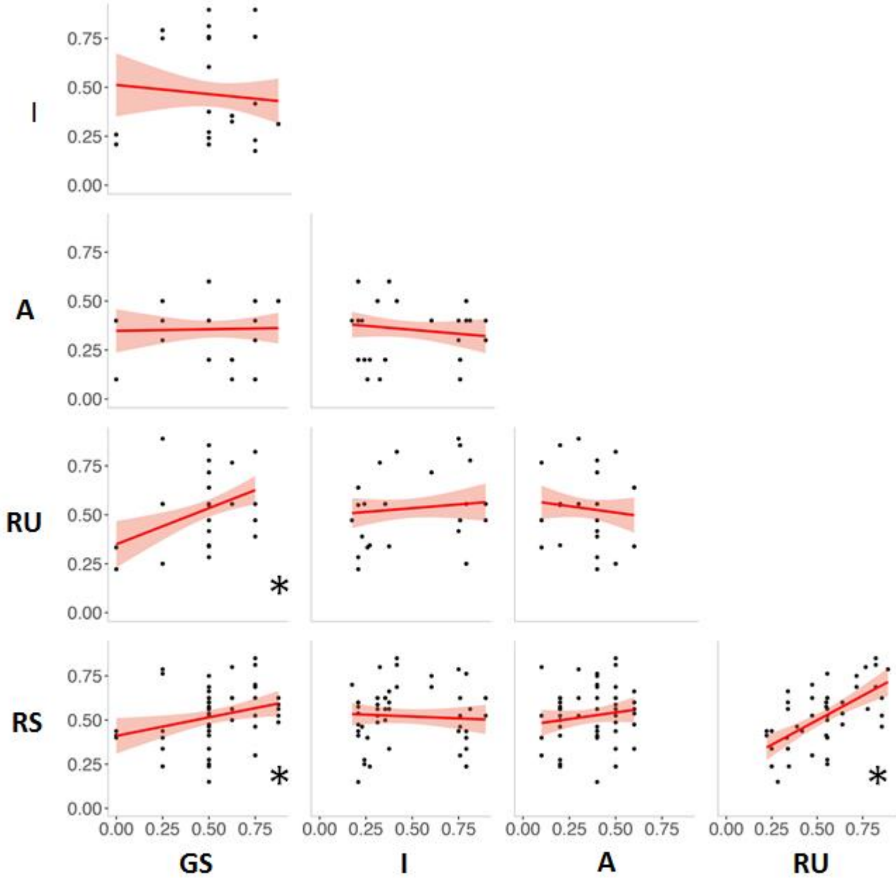


Figure 5. Correlation matrices between cumulative pond scores at the first tier level of the SES framework (every first-tier variable given the same weight). Axis labels refer to the 1st tier concepts GS (Governance System), A (Actors), RU (Resource Units), RS (Resource System) and I (Interactions). Trend lines are fitted with linear regression and the shaded area refers to the 95% confidence intervals. Models marked with an asterisk are statistically significant at p ≤ 0.05.

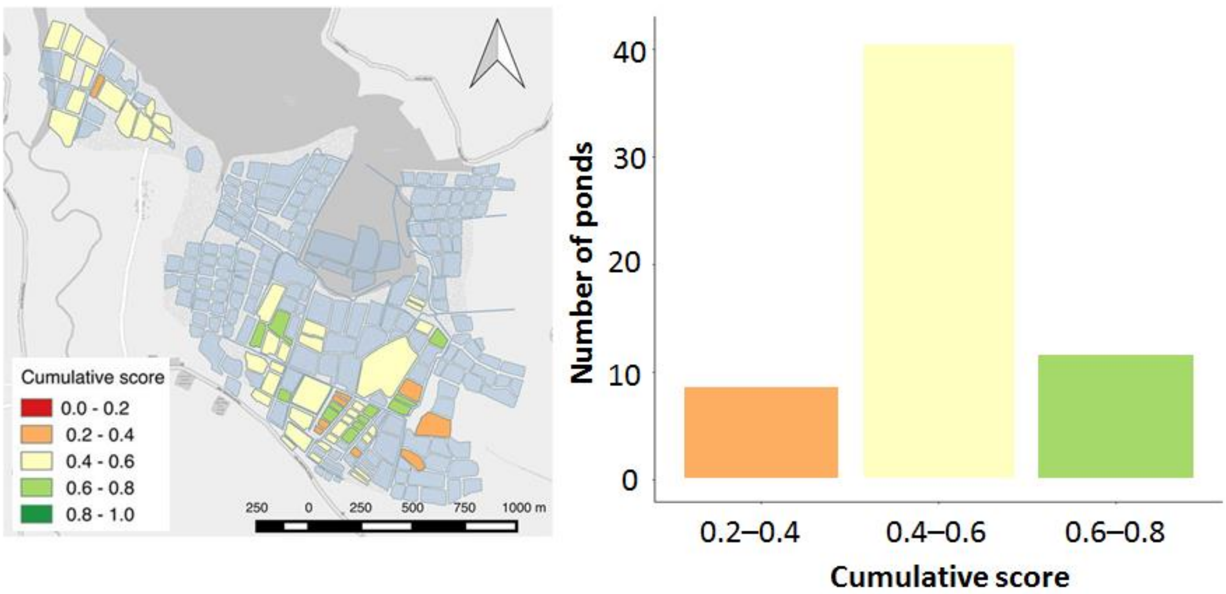


Figure 6. (a) Spatial distribution of cumulative pond scores. (b) Number of ponds in each score category.

IV. Discussion

Pond aquaculture presents a new and largely unexplored context for defining the conditions in which CPR dilemmas can manifest and for examining how community-based institutions and governance have evolved in response. In this section we sort through our case analysis to discuss how linked social-ecological conditions present challenges for improving the desired conditions to further develop pond aquaculture in the area. Improving aquaculture production is the goal to be achieved for LIPI and in these communities as revealed by our community level and key informant interviews.

Our diagnostic approach has asked nested sets of questions, starting with more general deductive inquiries related to concepts of the SES framework, to more nuanced, specific and inductive sets of reevaluated research questions (Cox, 2011). In doing so, we have demonstrated how to use a mixed method approach for applying the SES framework. However, this has not come without difficulties in understanding how to appropriately characterize and diagnose pond aquaculture SES, as there is sparse literature to guide indicator selection and context appropriate methods. This has allowed room for developing a new methodological application of the SES framework and testing the fit of CPR theories in a new context.

4.1 Proximate causes and collective action

It is evident that variable pond conditions are in part due to poor canal infrastructure and its management, hindering effective water distribution and exchange. Canals are a shared resource between all pond farmers, and finding ways to collectively manage them is a central factor of achieving successful social-ecological outcomes. We can interpret this canal maintenance as the proximate cause of the variable and uneven distribution of pond conditions. We observe a social-ecological linkage reinforced by this dilemma, where poor pond conditions hinder production capacity and stability, transferring this instability to the social conditions such as income generated. This is reflected above in the significant positive correlation between the ecological tiers (RU; RS) and the governance system (GS), as well as between the resource unit (RU) and the resource system (RS) scores. This supports similar observations by Leslie et al., (2015). It is of considerable interest to understand which specific social and ecological conditions are driving these relationships, and how these may affect the ability of the community to cooperate and build institutions which can effectively respond (Ostrom, 1990; Poteete et al., 2010), which we explore in detail below with CPR and collective action theories.

Minimal cooperative efforts exist in Bertong, Madak and Empol to address the community's and government's desire to improve aquaculture development. We can briefly relate the conditions we observe in the community to the existing body of CPR literature for potential explanations. Farming groups have been externally motivated to self-organize in order to be eligible for government subsidies, which leaves an ambiguous answer to the idea that they are able to self-organize effectively through intrinsic motivations (without external incentives) with their given capacity or knowledge of how the system functions (Poteete and Ostrom, 2004).

Leaders are mandatory to establish each group (Gutiérrez et al., 2011), but otherwise play a minimal role in further organizing group activities which may be similarly explained by the fact that they are not self-actualized in their role. Although, there is likely some reason why these individuals were selected as leaders which may be related to social status, age or experience.

Organized farming groups are largely composed of extended family members with close relations and frequent communication, which suggests a certain degree of trust or social capital as a barrier for entry to the group (Poteete et al., 2010). However, the communities are relatively homogeneous in regards to culture, dependence on the resource and socioeconomic attributes, which may suggest a higher potential to cooperate collectively, and group sizes are relatively small (Poteete and Ostrom, 2004; Vedeld, 2000). The ponds, community boundaries and canal network are clearly defined, and ponds are easily assigned a system of property rights (Ostrom, 1990; Schlager and Ostrom, 1992). However, while ponds are easily distinguished with property rights, the canals exist as the jointly owned common infrastructure, and there is a lack of formal or informal institutional mechanisms to deal with its provision. Similarly, there is a lack of formal and informal rules-in-use for aquaculture and the mangrove forests in general, as well as for monitoring pond or social conditions which have been shown to be important determinants of whether institutions are likely to achieve desired outcomes (Cox et al., 2010; Ostrom et al., 2004). Some informal rules were mentioned but no enforcement or sanctioning has been observed or reported.

In summary, with the characteristics we observe, it is not surprising to see that the current conditions the likelihood of further collective action are fairly unfavorable when interpreted through the lens of collective action theories. The prospects for improving aquaculture development will require institution building such as rules and procedures for canal maintenance as well as addressing the underlying challenges which are stagnating current conditions, which we explore below. In addition, it is important to recognize that this study cannot be considered fully exhaustive. As mentioned above, it is evident that social capital, mental models, trust and reciprocity very likely play a role, but we cannot support strong conclusions about their influence.

4.2 Underlying causes and the need for knowledge

It is apparent a more underlying cause in the lack of cooperation to improve pond conditions is the lack of knowledge and problem recognition in government programs and among farmers. There is little awareness of pond conditions, how they fluctuate over time and how this affects ecological performance via water exchange from canals, and is ultimately coupled to social outcomes. Stabilizing temperature, salinity and pH levels in the appropriate combination is necessary and will differ between target species. Suitable equipment and training would be needed to monitor these parameters, but this requires targeted investments from the government or NGOs (GS8; I2; I9). Existing training programs have been well received and further requested, but these have focused on supporting current aquaculture procedures with subsidies rather than investigating what challenges exist and how to best address them. It is evident that government programs could better prioritize improving the canal network through monitoring themselves or partnering with external researchers, and then training and incentivizing maintenance that better conveys how and why stable pond conditions can improve aquaculture production. Investing in training to improve canal infrastructure could stabilize pond water levels in the dry season and water quality throughout the year, potentially allowing year-round aquaculture or at least a prolonged growing season.

Salt production is a current solution for ponds during the dry season through a government sponsored pilot program. Salt can be stored year round and be sold when needed or when prices on the market are higher (RU6; RS8). However, income generated from salt production is considerably lower than for fish or sea cucumbers. Improved farming techniques will need to be informed through government or NGO programs. Milkfish are currently farmed due to their adaptability to high salinity ranges. If co-culture with more valuable commodities such as sea cucumbers is to be established, fluctuating pond conditions need to be considered. Sea cucumbers (*H. scabra*) are considered a robust species for pond aquaculture, but our results indicate that current pond conditions do not have suitable temperature and salinity ranges for them (Battaglene et al., 1999), despite active government research programs to pilot the development of sea cucumber aquaculture in the area.

Seawater is not yet a subtractable resource in this context, leaving the main challenge to improving the canal network. However this requires further problem recognition to motivate a collective effort among farmers to solve it. Government aid and NGO support has not been able to successfully achieve so far (Fujiie et al., 2005). If problem recognition increases, we can draw on common-pool resource theory to still foresee a provision dilemma between farmers, depending on their location within the network (A4; RS9). In the ponds located closer to the coast, we measured more stable water parameters than in ponds further into the network (away from the coast), some of which even receive a high influx of freshwater during flooding and rainfall in the wet season. Thus there are different degrees of dependence on collective action to improve the network among farmers, and there are inherent heterogeneous preferences about the kind of joint investment needed, with incentives to free ride (Poteete and Ostrom, 2004). There is greater variability of pond conditions further into the network. Even though seasonal temperature and salinity fluctuations will always occur to some degree, high variability could likely be mitigated for more predictable and stable production and income. In addition, selecting the appropriate species that can cope with fluctuating pond conditions and using seasonal species rotations may aid in maintaining productivity across seasonal changes (Wang and Lu, 2015).

Here we reflect more broadly on the nature of pond aquaculture dilemmas, and how we can situate the type of dilemma we observe into the existing understanding of CPR dilemmas. The conditions for a provision dilemma exist, but the subtractability of seawater does not create a problem with appropriation. We are not aware of any literature which assesses whether cases faced with the dual dilemma of infrastructure provision and subtractable water appropriation such as irrigation systems, which is presumed to be a more difficult situation to solve institutionally, actually facilitates a more dire scenario where the joint problem is more easily recognized than cases with a single dilemma. Facing a dual dilemma increases the necessity of collective action due to more drastic consequences of inaction. However evidence that the severity of a dilemma leads to higher or lower cooperation is mixed (Blanco et al., 2015; Cox et al., 2012; Osés-Eraso and Viladrich-Grau, 2007). In our case it is apparent that the single provision problem is not recognized or too subtle and indirect to generate sufficient collective efforts. It is worth considering the role of problem severity and persistence over temporal and spatial scales, such as the role of seasonality across aquaculture farming plots, when framing the conditions under which CPR dilemmas (particularly in diverse cases like aquaculture) effectively motivate collective action or effective institutional responses.

4.2 Assessing sustainability

Assessing the drivers of outcomes between multiple levels of a social-ecological system is a complex task. We have attempted an empirical analysis which may suggest that we are assessing the sustainability of Bertong, Madak and Empol, which we caution as being abstracted. We suggest a more nuanced discussion on the methodological process of attempting to understand how complex and context dependent systems function. This analysis evaluates the current pond level conditions with normalized indicator values, calculated to provide a pond score for each first tier variable of the SES framework (i.e. RS, RU, Gov, A, I). Justification for what constitutes a higher or lower value for any indicator was contextually grounded at the community level. However it is difficult to directly associate higher or lower pond scores to conditions which are sustainable for any given pond. The preferential condition for any individual may vary, or not align practically, with what we interpret as the more desirable conditions at the community level, or theoretically with normative values of sustainability in the literature or with the global agenda for sustainable development. Heterogeneous preferences for sustainable development likely exist within communities and across multi-level governance systems, and this has methodological implications for how we can measure and draw conclusions about sustainable outcomes in our research design.

For example, we assume in the community level analysis that a farmer who rents a pond would rather own his pond, and thus receives a lower score for the indicator of property rights because renting is less desirable due to the risks associated with decreased autonomy, regular costs and less economic certainty due to dependence on another owner (Acheson, 2006; Feder and Onchan, 1987). However, there may be other reasons that explain why a farmer is renting a pond, which are more desirable for his particular situation, and this may change over time. Simultaneously, government subsidy programs may incentivize lending programs which favor the transfer of private property to state control to better enforce regulations. Many scales on which indicators are measured can be associated with normative value preferences which may differ from what is generalized as more desirable when creating the measurement scale at the group or community level. The variability in what contributes to a sustainable outcome for specific ponds is not reflected when preferential values are assumed to be homogenous and weighted equally in the calculation between all ponds. This is a methodological problem associated with comparing quantitative values on a fixed and generalized scale, and implicates the need for further research to understand dynamic value preferences and decision-making processes relative to normative goals at multiple levels, and how this may differ between individuals, groups and communities.

4.3 Methodology and diagnosing aquaculture systems

The SES framework has been frequently applied in coastal and marine settings (Basurto et al., 2013; Guevara et al., 2016; Partelow, 2015; Schlüter and Madrigal, 2012). However, we are not aware of existing literature applying the framework to pond based aquaculture systems. We have found the framework well suited for examining aquaculture systems, in contrast to literature suggesting the need for adaptations to improve the detailed analysis of other sectors e.g. (Basurto et al., 2013; Epstein et al., 2013; Guevara et al., 2016; Marshall, 2015; Partelow and Boda, 2015; Vogt et al., 2015). In addition we are unaware of existing studies which apply this methodology (Leslie et al., 2015) in a community-based setting, or to compare units of analysis within a single case. This has revealed numerous methodological challenges, some of which confirm existing literature, and some being more nuanced in relation to our methodology and specifically to aquaculture systems. We elaborate on a few relevant methodological examples more specifically below.

A brief discussion is warranted on the implications of indicator selection and the use of mixed methods for comparative research. Indicators are often selected to measure the 2nd tier concepts of the SES framework, and this selection as well as the methods to measure them are typically driven by a combination of the research questions and context. Our framework indicators may be suitable for application to other cases within this sector, but unlikely for cases with different settings (Guevara et al., 2016; McGinnis and Ostrom, 2014; Partelow, 2016) or different research questions. Comparing results with other applications of the framework outside the sector must proceed with caution. Identifying system conditions linked to outcomes becomes abstracted from the place-based context without considering the indicators used or context relevant definition of the concept it measures. Further meta-analysis work using the SES framework and within the CPR field will need to find ways to address concept-indicator gaps to enhance the accuracy and transparency of synthesis work which contributes to theory building.

More specifically, this analysis provides numerous examples of the role that indicator selection and measurement play in determining results. For example, individual pond scores are influenced by the weight that each indicator is attributed. Multiple indicators may represent a single 2nd tier concept, and many second tier concepts contribute to the aggregate score of each first tier. The relative influence that any indicator has on system conditions is difficult to assess empirically which makes it difficult to justify specific weighting calculations. In this case-study, we gave all second-tier variables equal weights within the first-tier. The influence each indicator has on the final score or the first-tier variable thus depends on the number of indicators used. This raises the possibility of over- or under-representation. A possible way to address this issue would be to statistically investigate the influence of variables on fixed and measurable outcomes such as known ecological pond conditions which are viable for selected aquaculture species or income levels relative to meeting basic needs. However, as we discussed above in relation to sustainability, fixed scales for measuring outcomes or the more desirable conditions for any indicator will likely vary between pond units and individuals. Modelling may be a viable method to explore how changes in weighting affect outcomes across pond units.

It is difficult to theoretically position or empirically analyze the influence of any single independent variable without considering interactive effects with others, which remains a challenge for interdisciplinary research on complex systems, and this analysis. This can be addressed by using mixed method approaches. At the community level we attempt to do so by qualitatively discussing distinctions between proximate and underlying causes. At the pond level quantitative relationships can be examined between single indicators or aggregate second and first tier scores. However, there are many shortcomings in making claims about causal links in complex systems, particularly when relying on theory which is not fully developed to assess complex system dynamics or within the context of study, such as pond aquaculture.

For example the relationship between resource unit production and resource system conditions may be oversimplified without considering how knowledge sharing among group members takes place or the role of theft on trust and reciprocity. Both aspects are very difficult to empirically measure. In addition, property rights allocations and group leader selection is likely influenced by historically evolved social networks or community relationships which have developed power asymmetries between individuals in group decision making processes (Dasgupta and Beard, 2007). Similarly, interest and cultural homogeneity may not play a significant role in influencing community level cooperation when we observe high dependence on government subsidy programs which prioritize group membership and group competition in the same communities for subsidy aid. This occurs despite apparent collective interests in developing the whole area and common canal network. This may change at the individual or family unit level, where working together to maximize income can only be done by distributing labor and time efficiently between the few family members involved.

V. Conclusion

This study has built on previous research attempting to operationalize the SES framework through a mixed method research approach that integrates quantitative and qualitative data at multiple levels of analysis. We have adapted the methodology from Leslie et al., (2015) for application to community based pond aquaculture systems. We have shown that pond aquaculture systems have potential to be effectively analyzed with common-pool resource theories, to be characterized as SES and diagnosed with the SES framework. This has allowed us to better understand the system dynamics which facilitate the current conditions, showing that there are strong relationships between social and ecological variables on outcomes. We have shown that ecological pond conditions fluctuate based on location within the canal network, and argued that this is likely due to a lack of problem recognition to motivate collective efforts to improve infrastructure maintenance. Drawing on common-pool resource theory, we observe the conditions of a provision dilemma which may hinder efforts for farmers to cooperate and address existing challenges. In addition we have shown that relationships between first tier SES framework scores (conditions) of individual ponds can be tested with our methodology when indicators and measurement techniques are justified within the context. We observe relationships between the following pond scores: RS - RU, RU - GS and RS - GS, building the empirical understanding that finding sustainable pathways for aquaculture requires examining them as social-ecological systems. However, the approach we present can be critiqued and improved as a methodological foundation for further research. We highlight the role of context in indicator selection and measurement for data comparability. We have discussed the challenges with drawing conclusions on system sustainability when value preferences are likely to vary between individuals, groups, communities and the researchers involved.

VI. References

Acheson, J.M., 2006. Institutional Failure in Resource Management. Annu. Rev. Anthropol. 35, 117–134. doi:10.1146/annurev.anthro.35.081705.123238
Agrawal, A., 2014. Studying the commons, governing common-pool resource outcomes: Some concluding thoughts. Environ. Sci. Policy 36, 86–91. doi:10.1016/j.envsci.2013.08.012
Azim, M.E., Verdegem, M.C.J., Khatoon, H., Wahab, M.A., Van Dam, A.A., Beveridge, M.C.M., 2002. A comparison of fertilization, feeding and three periphyton substrates for increasing fish production in freshwater pond aquaculture in Bangladesh. Aquaculture 212, 227–243. doi:10.1016/S0044-8486(02)00093-5
Basurto, X., Gelcich, S., Ostrom, E., 2013. The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. Glob. Environ. Chang. 23, 1366–1380. doi:10.1016/j.gloenvcha.2013.08.001
Battaglene, S.C., Evizel Seymour, J., Ramofafia, C., 1999. Survival and growth of cultured juvenile sea cucumbers, Holothuria scabra. Aquaculture 178, 293–322.
Binder, C., Hinkel, J., Bots, P.W.G., Pahl-Wostl, C., 2013. Comparison of frameworks for analyzing social-ecological systems. Ecol. Soc. 18, 26. doi:10.5751/ES-05551-180426
Blanco, E., Lopez, M.C., Villamayor-Tomas, S., 2015. Exogenous degradation in the commons: Field experimental evidence. Ecol. Econ. 120, 430–439.
Cox, J.C., Ostrom, E., Sadiraj, V., Walker, J.M., 2012. Provision versus Appropiation in Symmetric and Asymmetric Social Dilemmas. South. Econ. J. 30.
Cox, M., 2014. Applying a Social-Ecological System Framework to the Study of the Taos Valley Irrigation System. Hum. Ecol. 42, 311–324. doi:10.1007/s10745-014-9651-y
Cox, M., 2011. Advancing the diagnostic analysis of environmental problems. Int. J. Commons 5, 346–363. doi:10.18352/ijc.273
Cox, M., Arnold, G., Tomas, S.V., 2010. A Review of Design Principles for Community-based Natural Resource Management. Ecol. Soc. 15.
Cox, M., Villamayor-tomas, S., Epstein, G., Evans, L., Ban, N.C., Fleischman, F., Nenadovic, M., Garcia-lopez, G., 2016. Synthesizing theories of natural resource management and governance. Glob. Environ. Chang. 39, 45–56. doi:10.1016/j.gloenvcha.2016.04.011
Dasgupta, A., Beard, V., 2007. Community Driven Development, Collective Action and Elite Capture in Indonesia. Dev. Change 38, 229–249.
Dietz, T., Ostrom, E., Stern, P.C., 2003. The struggle to govern the commons. Science 302, 1907–12. doi:10.1126/science.1091015
Epstein, G., Vogt, J.M., Mincey, S.K., Cox, M., Fischer, B., 2013. Missing ecology: Integrating ecological perspectives with the social-ecological system framework. Int. J. Commons 7, 432–453.
Eriksson, H., Robinson, G., Slater, M.J., Troell, M., 2012. Sea cucumber aquaculture in the Western Indian Ocean: Challenges for sustainable livelihood and stock improvement. Ambio 41, 109–121. doi:10.1007/s13280-011-0195-8
FAO, 2016. The State of World Fisheries and Aquaculture. Rome.
Feder, G., Onchan, T., 1987. Land Ownership Security and Farm Investment in Thailand. Am. J. Agric. Econ. 69, 311–320. doi:10.2307/1242281
Ferrol-Schulte, D.., Ferse, S.C.A.., Glaser, M.. b, 2014. Patron-client relationships, livelihoods and natural resource management in tropical coastal communities. Ocean Coast. Manag. 100, 63–73. doi:10.1016/j.ocecoaman.2014.07.016
Fujiie, M., Hayami, Y., Kikuchi, M., 2005. The conditions of collective action for local commons management: The case of irrigation in the Philippines. Agric. Econ. 33. doi:10.1111/j.1574-0862.2005.00351.x
Guevara, L.E.T., Schlüter, A., Lopez, M.C., 2016. Collective action in a tropical estuarine lagoon : adapting Ostrom's SES framework to Ciénaga Grande de Santa Marta. Int. J. Commons 10, 1–29. doi:10.18352/ijc.623
Gurney, G.G., Cinner, J., Ban, N.C., Pressey, R.L., Pollnac, R., Campbell, S.J., Tasidjawa, S., Setiawan, F., 2014. Poverty and protected areas: An evaluation of a marine integrated conservation and development project in Indonesia. Glob. Environ. Chang. 26, 98–107. doi:10.1016/j.gloenvcha.2014.04.003

Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470, 386–9. doi:10.1038/nature09689
Halim, A., 2001. Grouper Culture: An Option for Grouper Management in Indonesia. Coast. Manag. 29, 319–326. doi:10.1080/089207501750475136
Hardin, G., 1968. The Tragedy of the Commons. Science (80-.). 162, 1243–1248.
Hinkel, J., Cox, M.E., Schluter, M., Binder, C.R., Falk, T., 2015. A diagnostic procedure for applying the social-ecological systems framework in diverse cases. Ecol. Soc. 20, 32. doi:10.5751/ES-07023-200132
Islam, M.S., Milstein, A., Wahab, M.A., Kamal, A.H.M., Dewan, S., 2005. Production and economic return of shrimp aquaculture in coastal ponds of different sizes and with different management regimes. Aquac. Int. 13, 489–500. doi:10.1007/s10499-005-9000-7
Janssen, M.A., Anderies, J.M., Cardenas, J.C., 2011. Head-enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field. Ecol. Econ. 70, 1590–1598. doi:10.1016/j.ecolecon.2011.01.006
Klinger, D., Naylor, R., 2012. Searching for Solutions in Aquaculture: Charting a Sustainable Course. Annu. Rev. Environ. Resour. 37, 247–276. doi:10.1146/annurev-environ-021111-161531
Leslie, H.M., Basurto, X., Nenadovic, M., Sievanen, L., Cavanaugh, K.C., Cota-Nieto, J.J., Erismang, B.E., Finkbeiner, E., Hinojosa-Arango, G., Moreno-Báez, M., Nagavarapu, S., Reddy, S.M.W., Sánchez-Rodríguez, A., Siegel, K., Ulibarria-Valenzuela, J.J., Weaver, A.H., Aburto-Oropeza, O., 2015. Operationalizing the social-ecological systems framework to assess sustainability. Proc. Natl. Acad. Sci. 112, 5979–5984. doi:10.1073/pnas.1414640112
Macneil, M.A., Cinner, J.E., 2013. Hierarchical livelihood outcomes among co-managed fisheries. Glob. Environ. Chang. doi:10.1016/j.gloenvcha.2013.04.003
Marshall, G.R., 2015. A social-ecological systems framework for food systems research: accommodating transformation systems and their products. Int. J. Commons 9, 1–28. doi:1875-0281
McGinnis, M.D., Ostrom, E., 2014. Social-ecological system framework: initial changes and continuing challenges. Ecol. Soc. 19, 30. doi:10.5751/ES-06387-190230
Neori, A., Troell, M., Chopin, T., Yarish, C., Critchley, A., Buschmann, A.H., 2007. The Need for a Balanced Ecosystem Approach to Blue Revolution Aquaculture. Environ. Sci. Policy Sustain. Dev. 49, 36–43. doi:10.3200/ENVT.49.3.36-43
Osés-Eraso, N., Viladrich-Grau, M., 2007. Appropriation and concern for resource scarcity in the commons: An experimental study. Ecol. Econ. 63, 435–445. doi:10.1016/j.ecolecon.2006.11.016
Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–22. doi:10.1126/science.1172133
Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proc. Natl. Acad. Sci. U. S. A. 104, 15181–7. doi:10.1073/pnas.0702288104
Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge, UK.
Ostrom, E., Gardner, R., Walker, J., 2004. Rules, games, and common-pool resources.
Ostrom, E., Gardner, R., Walker, J., 1994. Rules, Games, and Common-Pool Resources.
Partelow, S., 2016. Coevolving Ostrom's social–ecological systems (SES) framework and sustainability science: four key co-benefits. Sustain. Sci. 11, 399–410. doi:10.1007/s11625-015-0351-3
Partelow, S., 2015. Key steps for operationalizing social–ecological system framework research in small-scale fisheries: A heuristic conceptual approach. Mar. Policy 51, 507–511. doi:10.1016/j.marpol.2014.09.005
Partelow, S., Boda, C., 2015. A modified diagnostic social-ecological system framework for lobster fisheries: Case implementation and sustainability assessment in Southern California. Ocean Coast. Manag. 114, 204–217. doi:10.1016/j.ocecoaman.2015.06.022
Partelow, S., Schlüter, A., von Wehrden, H., Jänig, M., Senff, P., 2017. A Sustainability Agenda for Tropical Marine Science. Conserv. Lett. 00, 1–14. doi:10.1111/conl.12351
Partelow, S., Winkler, K.J., 2016. Interlinking ecosystem services and Ostrom's framework

through orientation in sustainability research. Ecol. Soc. 21. doi:10.5751/ES-08524-210327
Poteete, A., Janssen, M. a., Ostrom, E., 2010. Working Together: Collective action, the commons and multiple methods in practice. Ch. 4, 5, 6, in: Working Together: Collective Action, the Commons and Multiple Methods in Practice. pp. 64–103.
Poteete, A.R., Ostrom, E., 2004. Heterogeneity, Group Size and Collective Action: The Role of Institutions in Forest Management. Dev. Change 35, 435–461.
R Core Team, 2016. R: A language and environment for statistical computing. doi:3-900051-07-0
Rimmer, M.A., Sugama, K., Rakhmawati, D., Rofiq, R., Habgood, R.H., 2013. A review and SWOT analysis of aquaculture development in Indonesia. Rev. Aquac. 5, 255–279.
Schlager, E., Ostrom, E., 1992. Property-Rights Regimes and Natural Resources : A Conceptual Analysis. Land Econ. 68, 249–262.
Schlüter, A., Madrigal, R., 2012. The SES Framework in a Marine Setting : Methodological Lessons *. RMM 3, 148–167.
Swann, L., 1992. A Basic Overview of Aquaculture. Tech. Bull. Ser. # 102 Funding 1–10.
Thiel, A., Adamseged, M.E., Baake, C., 2015. Evaluating an instrument for institutional crafting: How Ostrom's social–ecological systems framework is applied. Environ. Sci. Policy 53, 152–164. doi:10.1016/j.envsci.2015.04.020
Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., Arrow, K.J., Barrett, S., Crépin, A.-S., Ehrlich, P.R., Gren, Å., Kautsky, N., Levin, S. a., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Walker, B.H., Xepapadeas, T., de Zeeuw, A., 2014. Does aquaculture add resilience to the global food system? Proc. Natl. Acad. Sci. 111, 13257–13263. doi:10.1073/pnas.1404067111
Vedeld, T., 2000. Village politics: Heterogeneity, leadership and collective action. J. Dev. Stud. 36, 105–134. doi:10.1080/00220380008422648
Vogt, J.M., Epstein, G.B., Mincey, S.K., Fischer, B.C., Mccord, P., 2015. Putting the " E " in SES : unpacking the ecology in the Ostrom social-ecological system framework. Ecol. Soc. 20. doi:10.5751/ES-07239-200155
Von Essen, L.M., Ferse, S.C. a, Glaser, M., Kunzmann, A., 2013. Attitudes and perceptions of villagers toward community-based mariculture in Minahasa, North Sulawesi, Indonesia. Ocean Coast. Manag. 73, 101–112. doi:10.1016/j.ocecoaman.2012.12.012
Wang, M., Lu, M., 2015. Tilapia polyculture: a global review. Aquac. Res. 47, 1–12. doi:10.1111/are.12708
White, A.T., Christie, P., D'Agnes, H., Lowry, K., Milne, N., 2005. Designing ICM projects for sustainability: Lessons from the Philippines and Indonesia. Ocean Coast. Manag. 48, 271–296. doi:10.1016/j.ocecoaman.2005.04.007
Williams, S.L., Janetski, N., Abbott, J., Blankenhorn, S., Cheng, B., Crafton, R.E., Hameed, S.O., Rapi, S., Trockel, D., 2014. Ornamental Marine Species Culture in the Coral Triangle: Seahorse Demonstration Project in the Spermonde Islands, Sulawesi, Indonesia. Environ. Manage. 54, 1342–1355. doi:10.1007/s00267-014-0343-6

ZMT LEIBNIZ CENTER for Tropical Marine Research

Working Paper Series

Previously published:

1. Katherine M. Nelson, Achim Schlüter & Colin Vance (2017) Distributional preferences and donation behaviour among marine resource users in Wakatobi, Indonesia. DOI:10.21244/zmt.2017.001

2. Carina Goldbach, Achim Schlüter & Marie Fujitani (2017) Analyzing potential effects of migration on coastal resources in Southeastern Ghana. DOI:10.21244/zmt.2017.003

3. Sam Perrin, Rapti Siriwardane-de-Zoysa (2017) Women in marine science: efficacy of ecofeminist theory in the wake of historical critique. DOI: 10.21244/zmt.2017.004

ZMT LEIBNIZ CENTER for Tropical Marine Research

Working Paper Series

December, 2017

Editors:

Sonia Bejarano, Werner Ekau, Sebastian Ferse, Astrid Gärdes, Marion Glaser, Anna-Katharina Hornidge, Tim Jennerjahn, Andreas Kunzmann, Douglas MacMillan, Agostino Merico, Nils Moosdorf, Hauke Reuter, Tim Rixen, Alessio Rovere, Achim Schlüter, Mirta Teichberg, Hildegard Westphal, Matthias Wolff, Martin Zimmer

Editorial Notes:

Author: Stefan Partelow

Contact: stefan.partelow@leibniz-zmt.de

Published by

Leibniz-Zentrum für Marine Tropenforschung (ZMT) GmbH

Leibniz Centre for Tropical Marine Research (ZMT)

Fahrenheitstr. 6
28359 Bremen
Germany
Tel: +49 421 23800 21
Fax: +49 421 23800 30
Email: contact@leibniz-zmt.de
www.leibniz-zmt.de