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Coastal aquaculture in Zanzibar, Tanzania

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ABSTRACT

This study provides an overview of the multi-sectoral coastal aquaculture development in Zanzibar (Tanzania) over the last thirty years based on empirical evidence from interviews, field observations, policy reports and literature reviews. Despite the immense potential of aquaculture for food and livelihoods, only seaweed farming has so far established into commercial-scale production. This activity is dominated by women and became widespread in the early 1990s as a small but regular source of income. However, seaweed farming constraints such as frequent seaweed die-offs, as well as economic and institutional constraints inhibit its development. Other types of aquaculture activities such as fish farming, mud crab fattening, half-pearl farming, sea cucumber farming and sponge and coral cultures are under development with limited production or in experimental stages. Common constraints among these activities are economic limitations, lack of technical infrastructure and skills, small and irregular production, and limited trade and market availabilities. At the same time, there is a lack of sufficient management and monitoring systems, while there are no formal regulations or clear strategies to boost aquaculture at the national level. In addition, new aquaculture initiatives are often dominated by donor-driven projects instead of local entrepreneurships. This situation does not encourage engagement in aquaculture and thus such activities are outcompeted by other already established sectors (e.g. agriculture and fisheries). We conclude that aquaculture has great potential to evolve due to high environmental capacity. Nevertheless, achieving profitable production and a stronger commitment within local communities, as well as developing effective mariculture governance through support mechanisms and clear strategies to boost the sector at the national level, are essential for sustainable mariculture development in Zanzibar.

1. Introduction

Today, African contribution to world marine and coastal aquaculture production is minimal. In 2016, according to FAO (2018), African mariculture production of food fish and aquatic plants was hardly measurable, contributing less than 0.1% and 0.5% to the global production, respectively. The African mariculture production is today mainly distributed in a few countries, and except for Tunisia, these are concentrated in East Africa, i.e. in Madagascar (crustaceans and seaweed), South Africa (molluscs and seaweed) and Tanzania (seaweed, 0.4% of global production), where the seaweed production in Zanzibar is clearly the most important mariculture entity (FAO, 2018). Considering the continent's long coastline and its inhabitants' traditional high dependency on marine resources, the underdeveloped mariculture sector is challenging, especially in comparison with its immense development in, for example, South East Asia. The expansion potential of mariculture should be vast due to the natural conditions with low rates of polluted waters and comparably low pressure from coastal exploitation. The sector's potential to promote future food security, as well as the urge for alternative livelihoods in rural areas along the African coasts, would also be driving its expansion (Ateweberhan et al., 2018; Subasinghe et al., 2009).

Except for the seaweed farming industry, mariculture in East Africa is generally in its infancy (Ateweberhan et al., 2018; Troell et al., 2011),

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mainly due to the absence of traditional knowledge in aquaculture (Rönnbäck et al., 2002), along with various economic, technical and institutional constraints, which have so far inhibited major progress in the region (Ateweberhan et al., 2018; FAO, 2006; Subasinghe et al., 2009). Seaweed farming is though intense in certain areas, particularly in Zanzibar, which has been the main African seaweed producer since the 1990s through the farming of two carrageenan species, *Eucheuma denticulatum* and *Kappaphycus alvarezii* (Msuya, 2013). Attempts to introduce and establish other mariculture practices into the region, such as farming of fish, crabs, bivalves and sponges, often on a small-scale basis, have been initiated (Troell et al., 2011), but so far their significance has been limited. On Zanzibar, the Revolutionary Government of Zanzibar (RGoZ) encourages the development of aquaculture according to their Fisheries Policy documents (RGoZ, 2014, 2013). In particular, RGoZ had the ambition to raise the revenues produced by aquaculture by at least 100% by 2020 through adopting an Aquaculture Development Strategy and Action Plan (RGoZ, 2015a) intended to be a framework for action. This goal was, however, not achieved by 2020, but a big step was made with the establishment of a marine hatchery in 2018. The hatchery is aiming at producing fingerlings of milkfish, sea cucumber and mud crabs and it was funded by the Korea International Cooperation Agency (KOICA) in collaboration with RGoZ and the Food and Agriculture Organization of the United Nations (FAO).

The development of applicable and sustainable management and action plans to guide aquaculture expansion depends on a sound foundation of knowledge. Yet, there is no comprehensive information on the coastal aquaculture activities in Zanzibar. On the other hand, aquaculture is often associated with negative environmental impacts, mainly due to the lack of effective regulatory frameworks (e.g. Eklöf et al., 2006; Ottinger et al., 2016; Paul and Vogl, 2011; Primavera, 2006). In the case of Zanzibar, the management of natural resources in the intertidal zone, where most of the mariculture activities are found, is not yet developed or does not have effective enforcement (primarily due to limited funds) (Nordlund et al., 2014). Thus, the accomplishment of the RGoZ's ambition to increase the revenues from aquaculture by 100% while safeguarding natural resources is challenging. Therefore, there is a need to identify the sector's strengths, weaknesses and capabilities towards such a development. Understanding the socio-cultural and economic dynamics of the local community (Morgan et al., 2016; Slater et al., 2013), along with the institutional capacity (Davies et al., 2019; FAO, 2006), is an essential step to be able to reach a pragmatic action plan that is capable of being realised. Insights and willingness of local people, as well as potential favourable mariculture investments, need to be identified and investigated in conjunction with local policies and regulatory frameworks to support a sustainable mariculture expansion.

In our study, we investigate the case of multi-sectoral coastal aquaculture development in Zanzibar (Tanzania). Using empirical evidence from local community, manager and governance levels, this study aims to provide an overview of the coastal aquaculture's sectoral development over the last thirty years. We showcase how socio-economic, technical and institutional challenges shaped its current practice, status and governance and what is the potential for future development. The collected information could be used for a deficiency analysis aimed to improve policies and management strategies for future mariculture development as well as for long-term capacity building within the sector. The specific aims of the study were to investigate (1) the present coastal aquaculture activities and past trials and where they are located, (2) by whom and why they are conducted and what their challenges and future prospects are, and (3) the governance frameworks of coastal aquaculture.

2. Methodology

2.1. Case-study approach

A historical case study approach was used to elicit information on the evolution, current status, spatial distribution and governance of coastal aquaculture activities in Zanzibar over the last thirty years. We used a combination of methods, including focus group and individual interviews with stakeholders, field observations and reviews of policy documents, as well as scientific and grey literature. Coastal aquaculture farmers, coastal managers from the departments of the Revolutionary Government of Zanzibar (RGoZ) and key informants were interviewed. The key informants were locals with special knowledge regarding coastal resource management and local by-laws, such as members of village committees and beach recorders. In conjunction with interviews, the current status of the aquaculture activities was observed in the field and policy documents provided by RGoZ were consulted.

The aquaculture farmers were predominately interviewed in focus groups (gathering the respondents into sector groups due to their main aquaculture activity), while the managers and key informants were interviewed individually. All interviews were semi-structured with close- and open-ended questions to enable flexibility in succession and follow-up questions (for the interview form, see Appendix). The choice of using focus groups for the interviews with aquaculture farmers instead of undertaking individual interviews was a way to generate discussion and elicit information on the evolution of activities and the farmers' insights. Focus groups explicitly used the interaction of group members during discussions to explore farmers' experiences and to answer not only “what” they think, but also “how” and “why” they do so (Kitzinger, 1995; Morgan, 1996). The participants in each focus group were familiar with each other, forming “naturally occurring” groups (neighbours, farmers in the same group or nearby farmers), enabling them to reflect on each other's experiences (Kitzinger, 1995).

In the analyses of data from our interviews, we focused on the meaning condensation and the critical interpretation of the answers. A content analysis following three basic steps of defining the units of analysis, sampling the themes of importance and coding the sampling units into categories was used (Stewart et al., 2007). The coding of answers into categories, which was mostly data-driven and not predesigned (Sandelowski, 2000), provided a quantitative description of the data that facilitated the recognition of patterns and contents in the qualitative data.

2.2. Field study

The field observations and stakeholders' interviews were carried out in Zanzibar (Unguja Island), Tanzania, between July and September 2015. A pilot study was conducted to identify and locate sites harbouring ongoing coastal aquaculture activities by searching scientific- and grey literature, as well as interviewing local experts and managers in aquaculture. Fourteen sites were identified suitable for field visits (Fig. 2). The field sites were chosen in a systematic manner to include all types of coastal aquaculture and their different intensities, trying to incorporate sites with multiple activities where possible.

At the selected sites, coastal aquaculture activities were observed in the field and interviews were conducted with aquaculture farmers and key informants. At every study site, a local villager was hired as an assistant to introduce the study to the farmers prior to the interviews. In total, 164 aquaculture farmers were interviewed, predominantly in focus groups with four participants on average. Ten key informants and seven officers from relevant departments of RGoZ were interviewed individually (for the full list of interview responders per study site, see Table S1, Appendix). A general guideline of at least three focus groups per study site and three participants per group was used in the study. The interviewees were selected haphazardly among the farmers willing and available to participate, trying to include both sexes and varying age groups. Logistical problems such as a limited number of farmers and weak coordination did not enable the general guideline to be applied in a few cases. Individual interviews with farmers were conducted when no other person was available at that time. The interviews with farmers and key informants were conducted in Swahili with the help of a local

translator, whereas the interviews with managers were conducted in English. The focus group interviews lasted approximately 45 min to 1 h and the interviews with managers/ key informants lasted between 45 min and 2 h.

3. Sectoral development and governance of coastal aquaculture

3.1. Setting Zanzibar's aquaculture framework

At the time of our study, we identified seven different types of coastal aquaculture activities taking place in Zanzibar (Unguja Island). Seaweed farming was the only widespread mariculture acting on a commercial scale, while farming of finfish, crab, pearl, sea cucumber, sponge and coral were under development or in trial stages. Aquaculture is under the jurisdiction of the Department of Fisheries Development (DFD) (former Department of Marine Resources at the time of the field study) in the Revolutionary Government of Zanzibar (RGoZ). In the DFD, the Seaweed Section deals exclusively with seaweed farming issues and exports and the Aquaculture Section with the development of other aquaculture activities. However, aquaculture activities are not formally regulated by the DFD and they do not imply under any regular monitoring programme nor being the direct responsibility of beach recorders ("Bwana Diko"), who deal predominantly with landings from fishing activities.

In Zanzibar, there is no zoning or planning to define where in the coastal zone aquaculture can be conducted. Villagers have open access to the coastal zone to locally (i.e. close to their village) establish small-scale mariculture activities without any official license, permit or registration. However, despite the legally open access, natural resources and other activities that may influence mariculture development, such as mangrove cutting, are regulated at national level by the government (RGoZ, 2015b) and at local level by a system of community-based management (Fig. 1). Local communities develop their own written by-laws, defining the activities that can be conducted within their village, including mariculture. This is mostly relevant for aquaculture activities under development and not for seaweed farming which is considered established. The practice of every new activity has to be under the consent of the local leader "Sheha" and the Shehia committee. Different committees performing under Sheha might also play a role in decision-making such as the Village Conservation Committee (VCC) (dealing with forest and natural resources), the Village Development Committee (VDC) (dealing with e.g. financial management of projects) and the Village Fisheries Committee (VFC) (dealing with fisheries). Yet, new maricultures are still rarely developed and no disagreement or prohibition towards local small-scale initiatives was encountered by our interview study.

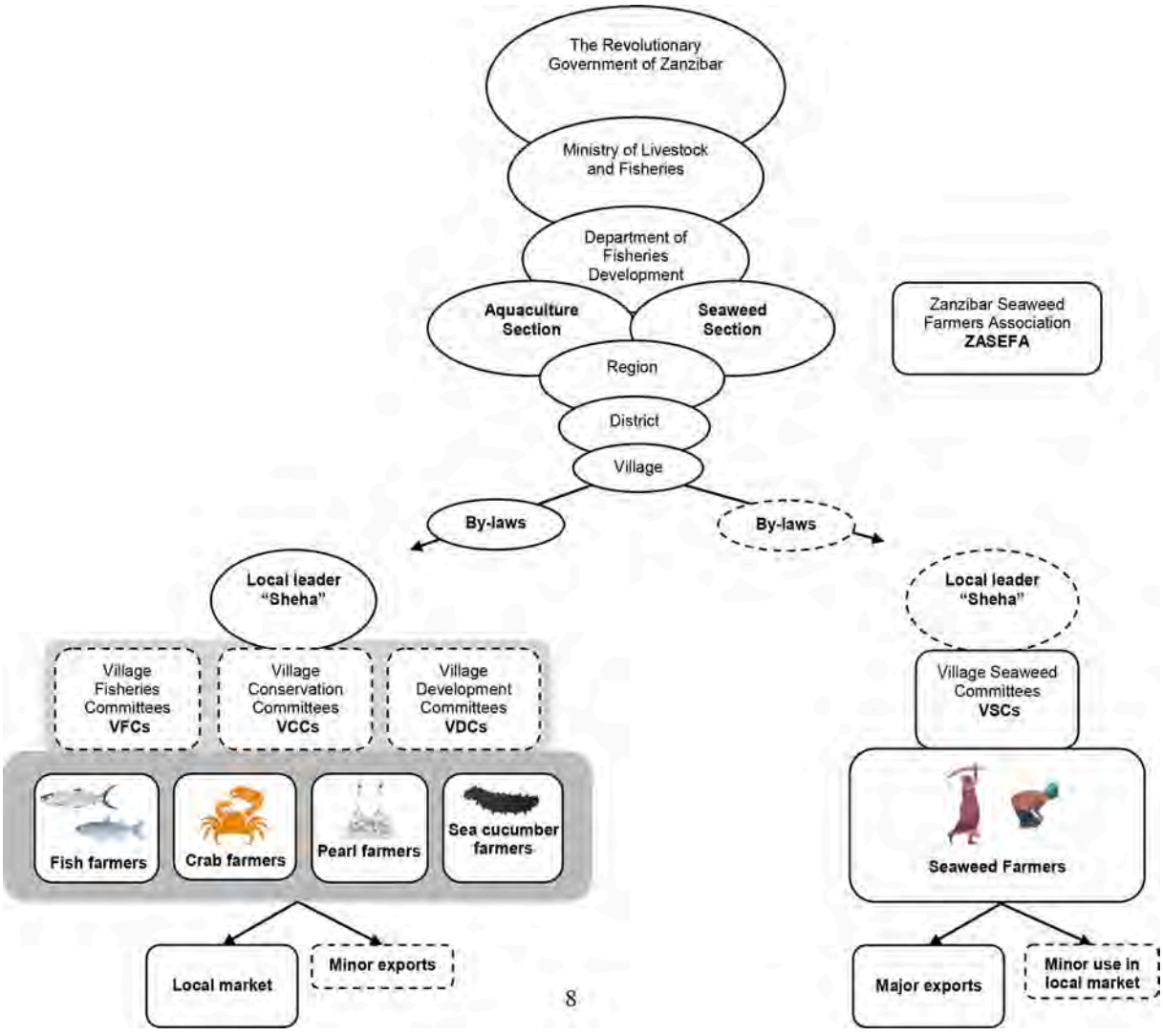

Fig. 1. The institutional framework of coastal aquaculture in Zanzibar, Tanzania. Dotted lines indicate indirect responsibility or minor trade. Aquaculture figures: © Thurber Christine; Tracey Dieter; Hawkey Jane; Saxby Tracey, IAN Image Library (http://ian.umces.edu/imagelibrary/).

The following sections assess each coastal aquaculture activity separately, elaborating on their historical development, current spatial distribution, status and governance-related issues. Moreover, potential larger-scale enterprises are further discussed.

3.2. Seaweed farming

Commercial seaweed cultivation of *Eucheuma denticulatum* and *Kappaphycus alvarezii* was established in Zanzibar in 1989 when the farming technique and the seaweed stocks were introduced from the Philippines, as the native East African wild stocks of these species became less common and productive, probably due to overharvesting (Halling et al., 2013). The farming activity became very popular due to its regular harvesting periods every 4 to 6 weeks, especially among the women, providing a small but regular and predictable income for poor community households (Msuya, 2013; Tobisson, 2013).

At the time of our study in 2015, seaweed farming was practised in almost all coastal villages (51) in Zanzibar (Fig. 2). According to a census of the Department of Marine Resources (DMR) (currently Department of Fisheries Development) in 2011, seaweed farms in Zanzibar (Unguja Island) covered a coastal area of 359,115 m^2. Yet, due to the absence of formal regulation, the distribution and size of farming sites can vary over time. In Zanzibar, seaweed is farmed (at commercial level) exclusively with the off-bottom method. The farmers work at farm plots of around 10 × 10 m in size (farmers use on average 30 lines of 10 m each) (Fig. 3A). Vegetatively propagated seaweeds are tied to farming ropes that are fixed to the bottom with wooden sticks, or in few areas with small rocks (e.g. Bweleo). Most farmers use branches of seaweed from their own farms as seeds, or in case of die-offs, seeds can be supplied for free or purchased from other, often neighbouring, farms. Seaweed farming is practised mainly in the intertidal zone, with one-third of the farms being placed in the upper subtidal (Hedberg et al., 2018) since most farmers do not know how to swim or possess boats while the algae should not be overexposed to the sun (Msuya, 2013). Seaweed farms occupy various habitats, especially intertidal or shallow subtidal sand and patches of seagrass meadows and to a smaller extent rocky substrate with and without algal beds (Hedberg et al., 2018). Many farmers actively select seagrass meadows to locate at least parts of their farms, as the habitat is associated with "cooler" temperatures and stable farm construction (Hedberg et al., 2018).

Seaweed farming is practised all year round, with a farming high season (more farmers and effort) during the cold and dry period (June–September). Farming low seasons occur especially in the long rainy period (March–May) and to a minor extent during the short rains (November–December) and the warm period (December–February). According to the farmers, rainy periods hamper the activity since they cannot dry the harvested seaweed (usually seaweed dries uncovered on the beach or out of houses) and the seaweed decays, as it is sensitive to the elevated temperatures during warmer seasons (Table 1, present study; Msuya, 2013).

The field study showed that the vast majority of Zanzibar's production comes from *E. denticulatum*, whereas *K. alvarezii* is successfully farmed only in very few sites. The species *K. alvarezii* is preferred due to its quality and price (Lange and Jiddawi, 2009), but during the last decade it has been suffering from "ice-ice" disease (the infected thallus becomes white and fragile) and epiphyte infections, likely because of climate- and/or environmental changes resulting in production failure (Msuya et al., 2014). From 2010, incidents of heavy epiphyte infections on *E. denticulatum* have also been reported within the Western Indian Ocean region (Msuya et al., 2014). In Zanzibar, seaweed die-offs due to epiphyte infections were stated as the major factor implicating productivity reduction, according to our interview study (Table 1). Die-offs due to epiphyte infections and elevated temperatures highlight the need for improved management of practices and vitalization of productive native cultivars of *E. denticualtum* and *K. alvarezii* (Halling et al., 2013 (Tano et al., 2015)) or a shift to deeper farming methods (which prerequisites access to boats and swimming ability) and the consideration of alternative native species of economic potential such as *Gracilaria* sp. (Eggertsen and Halling, 2020; Msuya, 2013). The need for advanced techniques and more resistant seaweeds was also recognized by the farmers and it was proposed as a recommendation to revitalise the sector (Table 1). Recently, some attempts have been made to culture seaweed in deep water using floating tubular nets with a positive outcome (Brugere et al., 2019).

In Zanzibar, considering the open access to the coastal zone, the number of seaweed farmers are not regulated and can vary over time. According to a DMR census, 8664 people were employed within seaweed farming in 2011 in Unguja Island, generally, women working individually or together with other family members at one or several farm plots. Cooperative groups that work collectively and share the profit or groups allowing micro-financial transactions among the members (e.g. micro-credits and loans) such as Saving and Credit Cooperative Societies (SACCOS) exist but are rare. At coastal areas (Fig. 2), the activity can be practised by less than 10 up to more than 400 farmers per village (village populations range usually between 1000 and 3000 people). The spatial distribution and popularity of seaweed farming in coastal areas depend on the access to suitable coastal sites (e.g. less seaweed farming occurs in mangrove areas and no farming in the greater Stone Town urban area), and the presence of alternative labours (e.g. agriculture, opportunities in town). According to our interviews, seaweed farming is generally a part-time activity, with 80% of the farmers engaged in other labours, due to its production cycle and farming activities that only take place during low tides. However, for almost half of the farmers (47%), seaweed farming contributes 50% or more to their total income per person.

After being harvested and dried, the seaweed is mainly exported from Zanzibar for carrageenan extraction and processing overseas (Msuya, 2013). The farmers sell the dried seaweed directly to exporting companies or in remote villages to middlemen with a price of 0.28–0.37 USD kg^{-1} (600–800 TZS, prices for September 2015) for *E. denticulatum* and 0.46–0.55 USD kg^{-1} (1000–1200 TZS, prices for September 2015) for *K. alvarezii*. In Zanzibar, the market for seaweed is a monopsony and the prices paid have been defined by the exporting companies, with very little influence by the farmers (Lange and Jiddawi, 2009). Prices in Zanzibar are therefore generally lower than the prices given for seaweed in the Philippines and Indonesia, where the market works differently, the logistics sector is developed and the transportation costs are lower due to proximity to processing centres (Valderrama et al., 2015). Efforts to add value in seaweed farming by producing cosmetics and food products (e.g. seaweed powder, soaps, massage oil, seaweed jam and cakes) started in 2006 by the Zanzibar Seaweed Cluster Initiative (ZaSCI) (Msuya, 2006) with a small but increasing trend over the years (Msuya and Hurtado, 2017). At the time of the study, still very little value addition in seaweed was taking place in Zanzibar with the support of ZaSCI.

Seaweed farming became popular due to its practice, which requires low investment and provides regular harvests (Msuya, 2013; Tobisson, 2013). However, our study showed that even if still small, the level of investment is higher today than in the past, since exporting companies have generally stopped supplying the farmers with materials such as "tie-tie" plastic ropes, though it may still happen. This situation occurred after farmers stopped being obliged to sell the dried seaweed to the same companies that they were supplied materials from in 2006 (Lange and Jiddawi, 2009). Today, seaweed farmers are required to provide most of the farming materials on their own, buying ropes and "tie-tie" and preparing themselves or buying the wooden sticks. The very low price for dried products that the farmers are being paid, together with the (mostly) financial difficulties to acquire equipment, are ranked as the top constraining factors in seaweed farming according to our interview study (Table 1.)

A recent action to improve farming management and working conditions for seaweed farmers and strengthen their role in the value chain

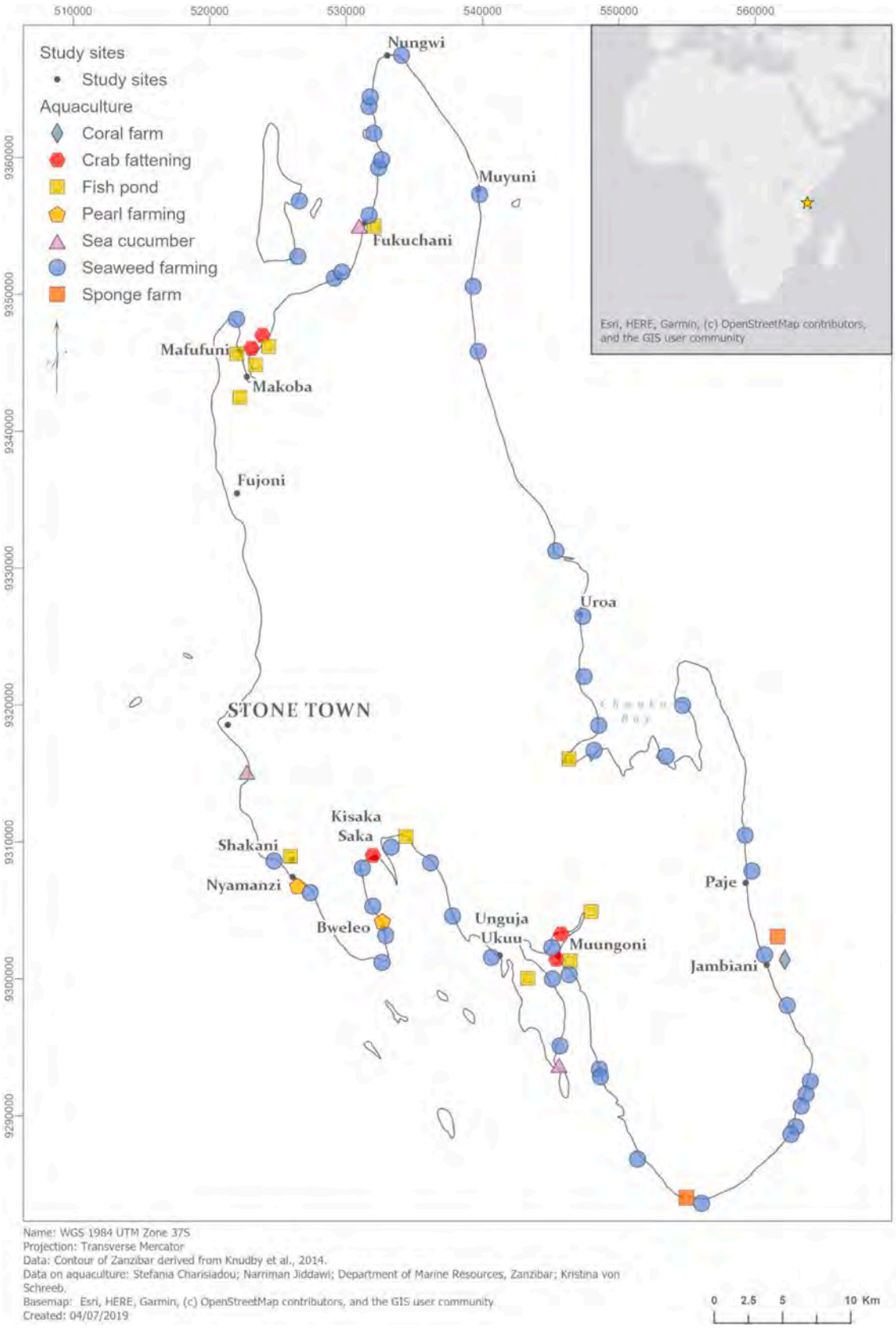

Fig. 2. Map of mariculture activities around the coast of Zanzibar. The coloured symbols on the map illustrate coastal villages and/or nearby areas where mariculture activities take place; they do not relate to size or number of farms. This map was created using ArcGIS® software by Esri and the contour of Zanzibar by Knudby et al. (2014). ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com.

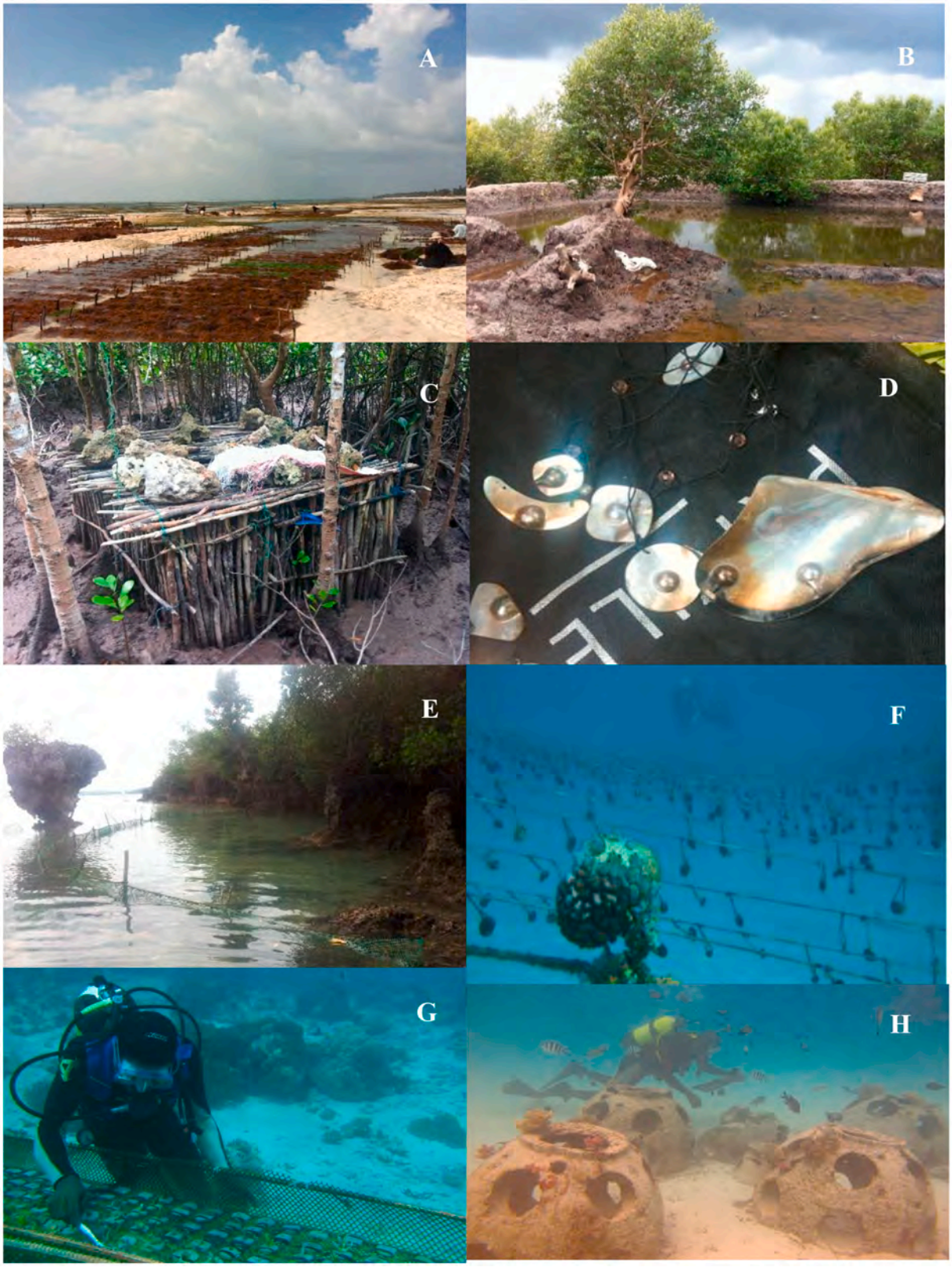

Fig. 3. Photos of mariculture activities in Zanzibar: A) seaweed farming in Uroa, B) fish pond on mangrove forest in Makoba, C) wooden cages for crab stocking in Kisakasaka, D) oyster nacre with half-pearls and jewellery in Nyamanzi, E) sea cucumber pen in Fukuchani, F) deep sponge farm in Jambiani, G) coral cultures on underwater tables in Jambiani, H) cement reef balls. Photos A–E were taken by Stefania Charisiadou and photos F–H were provided by the NGO maricultures.org.

Table 1
Constraints and recommendations towards seaweed farming mentioned by the focus groups of seaweed farmers and their frequencies (frequency equals 1 means that a reply appeared in all the 28 focus groups).

Frequency	Constraints
1	Low price of dried seaweed
0.9	Difficulties to acquire equipment ("tie-tie", rope and sticks)
0.8	Seaweed die-offs due to epiphytes
0.6	Lack of external support in case of crop loss (compensations from companies, other donors or government)
0.4	Loss of crop due to strong wind/currents
	Problematic drying process (during rainy seasons or when beaches are occupied by tourism)
0.3	Farmers' health problems (e.g. irritations, stings by marine animals)
	Loss of crop due to grazing by marine animals (sea urchins, fish)
	Seaweed die-offs due to strong sun during warm periods
0.1	No connection to authorities/other farmers
	Difficulty to sell the seaweed (in cases of remote villages)

Frequency	Recommendations
0.68	Supply of equipment – Introduction of advanced techniques and training
0.57	Expert advice for die-offs in seaweed
0.21	Financial support from the government
0.18	Introduction of new species
0.14	More collaboration with authorities and other seaweed farmers
0.07	More monitoring by the authorities
	Farming only periods with favourable weather conditions for seaweed (cold period)
	Compensations by authorities or seaweed companies when crop is lost
0.04	Involvement of more men
	Stop seaweed farming/Involve in other aquaculture activities

was the establishment of the Zanzibar Seaweed Farmers Association (ZASEFA) (Swahili: Jumuiya ya Wakulima wa Mwani Zanzibar, JUWAMWAZA) in 2010. Accordingly, as executive bodies, 50 Village Seaweed Committees (VSCs) were formed in Zanzibar (Unguja) at every village ("Shehia") with seaweed activities. At the district level, members of the VSCs should coordinate and construct the Executive Seaweed Committees (ESCs) (Fig. 1). The association aims to lobby the farmers, link all the stakeholders within the seaweed industry (farmers-government-exporting companies), strengthen their bargaining power and improve seaweed marketing. Moreover, it aims to help implement seaweed projects and spread new information and farming practices.

The interviews revealed that the status of ZASEFA and the participatory framework integrating all actors in the industry is poor. The major reasons behind the dysfunctionality of ZASEFA are financial limitations, the lack of policies and action plans to implement such a framework (by the time of our study[1]) and the nested perception among the farmers that seaweed farming is solely an individual business. The majority of the focus groups' participants were not aware of the association's existence (72% in total, $n = 121$). Most of the farmers were indeed aware of the VSC in their villages, but generally, they could not describe its role or associate it with ZASEFA. When the role of ZASEFA and VSCs was explained to the farmers, the vast majority of them responded positively to the idea of being more actively involved in it (93%, n = 121). The responders who answered negatively supported that seaweed farming is merely an individual activity, or they expressed fears that the committees would benefit only some "elite" members. The association has a very limited budget with no office and its fundraising requires a donation of 0.23 USD (500 TZS, price for September 2015) of every member to the association after selling the seaweed, which most of the farmers cannot afford to pay.

Collective action and participatory governance frameworks have fostered socioeconomic development and reduction of environmental impact in small-scale aquacultures, such as in Sri Lankan and Indian shrimp aquaculture (Galappaththi and Berkes, 2015; Umesh et al., 2010). Therefore, we argue that in conjunction with technical interventions, empowering the participatory framework and the role of ZASEFA is instrumental to revitalise seaweed farming in Zanzibar. ZASEFA could play a significant role in disseminating new technologies and training to the farmers by collaborating with local research institutions and the government. Moreover, the investigation and establishment of favourable seaweed farming sites to achieve higher yields, while reducing environmental impact (Eggertsen and Halling, 2020; Hedberg et al., 2018) and competition with other coastal uses could also aid the seaweed farming development on Zanzibar. Alternative farming systems, such as those adopted in Southeast Asia, require higher investment (Valderrama et al., 2015) and the association could aid farmers to receive microloans from crediting institutions to support those enterprises or to expand the seaweed value addition efforts. Moreover, ZASEFA could help identify and reach new markets and bilateral agreements. Thus, government-led interventions, such as the adoption and prioritization of policies and action plans fostering a stronger participatory governance framework are integral.

3.3. Fish farming

Despite few earlier attempts, small-scale polyculture fish farms operated by farmers were first established in Makoba village on the east coast of Zanzibar in 2008 after local initiatives. Before the establishment, research on integrated mariculture systems of finfish, shellfish and seaweed had been ongoing since 1998 in the area, which strengthened the incentives for fish production (Kyewalyanga and Mwandya, 2004; Mmochi and Mwandya, 2003; Mmochi et al., 2001). Since the first establishment, fish farms have been spread, mainly within the area of Makoba and Mafufuni, but also to seven other sites around the island (Fig. 2), mostly in mangrove areas where man-made ponds can be constructed or in natural coastal enclosed lagunes. There is a single case in Shakani village (south of Stone Town) where fish are farmed in earthen ponds, located behind the mangrove zone with naturally occurring seawater, developed after gravel mining. Finfish mariculture experimental trials started in the 1980s with a study of rabbitfish cage culture (Siganus sp) (Bwathondi, 1982), but aquaculture in fish cages are absent from Zanzibar so far.

Fish farming in mangrove areas, which is the predominant type, is practised in small ponds (Fig. 3B) made of mud dikes with pipes or cement dams to facilitate water exchange since no water pumping takes place. Mangrove forests are limited in Zanzibar (5274 ha) and they are protected as Forest Conservation Areas (FCAs) (RGoZ, 2015b). Prohibition of deforestation falls also under local by-laws. Therefore, the fish ponds are located in inferred mangrove areas (e.g. due to previous mangrove cutting), where tree cutting is not required for their construction.

Fish farming is practised as polycultures, including mostly milkfish and mullets. Wild-caught fingerlings are reared for 6 months while fed with fish feed prepared by the farmers such as fish offal or small trash fish "dagaa", mixed with grains of maize. Occasionally farms can also rear snappers, tilapias and barracudas if caught and released to the ponds by the farmers. Fish farming takes place all year round enabling for up to two full pond harvests per year. An increased effort of milkfish juvenile collection occurs during the long rainy season (March–May), which according to the farmers provides a high abundance of juvenile milkfish. The size of the ponds can vary from 15 × 15 m to 30 × 30 m, with an estimated yearly fish production of about 0.3 kg per m^2. As an indication of production (according to one focus group), a big pond can stock up to 200 individuals with little fishing effort of fingerlings.

Fish farming employs around 200–300 locals in Zanzibar, with the majority of people working in the Makoba area (around 30 farms). The fish farmers are both men and women that usually form cooperative

[1] Supporting ZASEFA is mentioned in the Aquaculture Development Strategy and Action Plan (RGoZ, 2015a), but the action plan was unfinished and not operational by the time of our study.

groups (around 10–20 people) and manage collectively one or a few (2–5) ponds. After being harvested, fishes are sold by the farmers to local markets at the same price as wild catches. However, fish farming is a part-time activity due to small production and rare harvests (maximum twice per year) and merely supplements the farmers' income (less than 50% of annual income per person) that mainly comes from other labours (mostly agriculture).

Fish farming requires a substantial initial investment for basic constructing materials (e.g. cement, pipes, excavation equipment), as well as an annual investment for fishing gear such as nets, boat and fish feed, raising the total investment much higher than e.g. seaweed farming. The farmers' lack of technical knowledge and the poor construction of the ponds lacking equipment (e.g. water pumps), as well as difficulties in fingerling collection (e.g. lack of appropriate mesh size nets) were identified as major factors hindering progress in fish farming according to the interview study. Even if rare, fish mortalities and poaching were also mentioned as constraints. According to the interviews, achieving higher fish stocking densities through hatcheries and technical expertise and the acquisition of appropriate equipment (e.g. water pumps and pH loggers) could improve the production and profitability of fish farming.

The improvement of farming practices together with the simultaneous development of other segments of the value chain to provide input (i.e. feed mills, hatcheries and nurseries) and the support of domestic trade towards large urban centres, have been key factors to lead fish aquaculture evolution in several African and South Asian countries (e.g., Kaminski et al., 2018; Kassam and Dorward, 2017; Belton et al., 2018; Belton et al., 2017; Hernandez et al., 2018). However, production in Zanzibar is minor, there is no trade network or farmers' association to coordinate actions and the value chain of farmed fish is practically non-existent. Fish farming in Zanzibar does not yet generate other employment and market multipliers since there is no seed production, fish processing or significant trade to large urban centre. At the same time, farmed fish do not create any leverage to the alternative target groups. Due to equal prices with wild catches and rare harvests, it is neither considered a cheaper source for poor community households nor can it attract buyers from tourist restaurants or hotels. Fish farming is gaining grounds also in mainland Tanzania mostly in earthen ponds (Mmanda et al., 2020; Mmochi, 2015) and together with the newly established hatchery for milkfish in Zanzibar, there are prospect for further development of upstream and downstream value chain segments. We argue that the simultaneous development of other non-farm segments, as well as which consumer groups the fish farming should target, need to be appropriately addressed in the development plans.

3.4. Crab fattening

Crab fattening, i.e. the stocking and grow-out of sub-adult mud crabs (*Scylla serrata*), is practised as an alternative livelihood towards mangrove conservation since 2006. The activity was first introduced in Kisakasaka by local researchers at the Institute of Marine Sciences (IMS; Dar es Salaam University) and it has been tried out in five areas around Zanzibar (Fig. 2).

Sub-adult crabs (around 250 g), caught from the wild by the farmers or purchased by fishers, are stocked in low densities (maximum 50 individuals per farm) in wooden cages in mangroves (Fig. 3C) up to 3 months until marketable size of around 1 kg. Crabs are fed with fish offal, trash fish “dagaa” and bivalve meat, collected or purchased by the farmers. A small hatchery is operating at the State University of Zanzibar (SUZA) sponsored by the Commission for Science and Tourism (COSTECH) for research and/or educational purposes but does not generally supply juveniles to the crab farmers. Crab fattening takes place all year round, with a high farming season right before and during the cold and high tourist season (June–September) and a low farming season in the long rains (March–May) due to decreased salinity in low tides that affect the crabs under fattening according to the farmers. During the rainy seasons, fishing of grown crabs is practised by some crab farmers instead of fattening.

Crab fattening involves both men and women working locally as cooperative groups (around 10–20 people per group). Crab fattening is a part-time task, which provides only a small and supplementary income to the farmers (less than 50% of the annual income). For most crab farmers, their main income comes from other labours (e.g. seaweed farming, agriculture and fishing) and many of the farmers are also engaged in mangrove conservation actions such as replanting. Crab farmers supply mainly local hotels after oral agreements. Crabs can also be sold to middlemen for the local markets or rarely for further export to the mainland. As an indication of the production and the agreements with the hotels, the group in Kisakasaka sells 50 kg of crabs when this quantity is reached and the group in Muungoni sells 10 kg per week during the tourist season. Consequently, the production is irregular and very low, without exceeding 150–160 kg of crabs per year (assuming 50 kg $\times$ 3 full harvests for Kisakasaka and 10 kg $\times$ 16 weeks for Muungoni, respectively). The prices vary between the hoteliers that buy in bulk for 2–2.5 USD kg^{-1} (4500–5500 TZS, price for September 2015) and the local market, where the price is around 2.7 USD kg^{-1} (6000 TZS, price for September 2015). In general, the annual gross revenue is around 338 USD (750,000 TZS) for one group of farmers.

Crab fattening requires small investment from the farmers, associated mainly with fishing gears, feed supply and wood collection for cage construction. According to the interviewed farmers, limitations in crab fattening are primarily related to the difficulties in sub-adult crab collection and economic difficulties to improve the construction of wooden cages that needs reconstruction every year. In addition, cases of poaching and vandalism (e.g. killing of crabs) by villagers also hamper the activity. Trials to rear crabs have been carried out in several other locations than those areas indicated in Fig. 2 for crab fattening (e.g. Bumbwini, Fukuchani and Fujoni), but failed to be established due to poaching, inabilities to sell the stock and economic difficulties to proceed. Provision of new equipment, the construction of a hatchery for commercial purposes and further technical advice, as well as mitigation of poaching and vandalism, could improve the production according to the interviewed focus groups. Moreover, the boost of market by achieving more connections with hotels or by exporting the product were also mentioned.

Overall, the study showed that crab farming in Zanzibar is limited to fattening of sub-adult crabs, without the adoption of other farming systems that could yield higher production. At the same time, the market outlets are very limited, providing no incentive for the farmers to farm. In neighbouring coastal Kenya, crab farming is established more successfully (yet with problems and far from reaching the level of Southeast Asian production) (Mirera, 2011; Mirera et al., 2014). In Kenya, diverse systems have been tried and used such as net dive-in and floating cages, mangrove pens and lately earthen ponds with higher potential, also targeting smaller juvenile grabs (Mirera, 2011; Mirera et al., 2014). Moreover, with the organization of Kenyan farmers into community groups, important market links have been created to supply tourist hotels, restaurants and exporters, with higher price per kilo than in the local market (Mirera et al., 2014). Kenyan examples point out that strengthening the functionality of farmers' groups in the value chain to develop stable market outlets, while promoting trials and research of other farming systems, could boost profitability and the general role of crab farming in Zanzibar and generally in Tanzania. Future crab seed supply from the newly established government-supported hatchery could aid the transition towards more profitable farming systems. Pond cultures of mud crabs could potentially become a sustainable and profitable activity provided that issues related to seed availability, high mortality rates and marketing (such as outlets and reduction of the marketable size) are tackled (Moksnes et al., 2015).

3.5. Bivalve cultures

3.5.1. Half-pearl farming and jewellery making

Pearl farming of the native black-lip (*Pinctada margaritifera*) and winged (*Pteria penguin*) oysters, producing half-pearls- and shell-jewelleries, was introduced by Hilo University of Hawaii and the local Institute of Marine Sciences (IMS) in the Fumba peninsula in 2006. At the time of our study, there were three farms active in the Fumba peninsula, with two in Bweleo and one located in Nyamanzi village (Fig. 2).

The farming is based on a long-line floating system in the subtidal zone, stocked with wild-collected adult oysters (4–5) in nets (no juvenile "spat" collection). After placing a nucleus in the oysters, half pearls are formed within 9 to 12 months of rearing. The production of pearls is not regular throughout the year. As an indication, the farmers on a farm in Bweleo estimated that 400 oysters per years can be collected from the wild, while only around 200 of them are appropriate to be placed on the farm for pearl production. Pearl farming is practised all year round, with a farming low season (only farm maintenance) during June–August (southeast monsoon "kusi") because of limited visibility due to currents.

Pearl farming is conducted by cooperative groups (at the time of our study there were three groups in total with around 15 members each), including both men – the actual farmers – and women that process the pearl-oysters and make jewellery (Fig. 3D). It is a part-time job, and for most of the people engaged, this is supplementary labour (less than 50% of total annual income) to other main livelihoods such as fishing, seaweed farming and sewing. Jewellery made of pearls and shells is sold in the Fumba Resource Centre and trade fairs such as exhibitions and festivals in Zanzibar and mainland Tanzania. Jewellery and unprocessed half-pearls can be sold in the local markets and rarely exhibited in trade fairs in neighbouring African countries. An indicative price of a pair of earrings made of pearls was about 18–23 USD (40,000–50,000 TZS) and of an unprocessed pearl around 9 USD (20,000 TZS) (prices for September 2015). Therefore, a production of 200 pearls per year, which enables 100 pairs of earrings to be made, would contribute if sold a maximum gross annual revenue of around 2025 USD (4.5 million TZS) per farm. Pearl farming and jewellery making, however, require substantial initial investment compared to other aquaculture activities that include processing equipment for jewellery making, bivalve collecting materials (fishing gears or spat collectors) and farm construction materials (e.g. nets, sticks).

According to the interview study, the main constraints in pearl farming constitute the irregular and unreliable market (products are sold with difficulty after a long time), the lack of technical expertise to achieve high quality of pearls (surface and shape imperfections and low lustre), the insufficient farming and jewellery equipment (due to economic reasons) and difficulties to locate adult oysters. Pearl farming was also practised for few years after its introduction in the villages Fumba and Unguja Ukuu, but has completely ceased due to reduced interest for the aforementioned reasons. Fumba village is generally exposed to high currents, which also had negative effects on production. Towards improvements in pearl farming, the focus groups emphasized the need for more technical training to achieve high quality and the full-pearl technique and a stable oyster stock by establishing a hatchery, as well as skills to conserve the environment.

Successful examples of half-pearl production that could work in Zanzibar come from the South Pacific. In South Pacific countries, the activity is becoming valuable for the rural population and has a higher potential than full-pearl production since it is less costly and requires less capital and training (Johnston et al., 2019; Johnston et al., 2020). In Tonga, a rapid expansion of half-pearl production is arising recently, triggered by stable spat production from a government-led hatchery and the deployment of more efficient farming methods such as by using protective cylinders (Johnston et al., 2020). Moreover, in Fiji, diverse small-scale enterprises related to pearl farming have recently been developed, such as spat collectors, half-pearl producers and handicraft makers (Southgate et al., 2019). These groups, with policy and training support from the government, have managed to prosper and create market links with each other and other marketers (Southgate et al., 2019).

Our study case showed that in Zanzibar, irregular production due to the absence of spat collection, low quality of half-pearls produced due to insufficient training and limited trade links have kept the activity underdeveloped. According to Ishengoma et al. (2011), a sufficient spat collection from the Tanzanian coast for the black-lip oyster should be possible to support the activity. Thus, the use of spat collectors to provide juveniles should be encouraged and if proved insufficient, a hatchery for spat production could subsequently be considered. At the same time, further training workshops to improve both production and jewellery making to achieve a higher grade of half-pearls and attractive jewellery are important. These efforts could diversify the activities performed by different groups to generate segments of the value chain and trade links. Moreover, trade links for export should be identified if local trade proves unsuccessful.

3.5.2. Other bivalves

In Zanzibar, attempts to use other native intertidal mussel and clam farming species (such as *Anadara* sp.) for food and jewellery making have also been practised at the Fumba peninsula between 2004 and 2008. The activity ceased due to poor growth rate, mortalities, poaching and low profit. In addition, a pilot farming trial using the Pacific oyster, *C. gigas*, has once been assessed in Bububu village in the north of Zanzibar, but the investor did never proceed. Bivalve culture due to their no need for pelleted feed and their relatively low environmental impact (if native species are used) could be a suitable form of mariculture in Zanzibar. In South Africa, for example, mussel and oyster farming production contributes significantly to the local market's demand, but also international demand (Olivier et al., 2013). However, in Zanzibar, appropriate species and methods for cultivation, both profitable and suitable for the farmer's profiles need to be investigated before a future initiation.

3.6. Sea cucumber culture

Stocking of sea cucumbers in subtidal sea pens (Fig. 3E) is practised since 2012 at Fukuchani village in Zanzibar by a cooperative group of 12 men and women. At the time of the study, it was the only active sea cucumber farm in Unguja Island. The species sandfish (*H. scabra*) is particularly targeted and continuously wild-caught fingerlings are reared up to 6 months (to a weight of approximately 300 g), occasionally supplied with chicken leftovers to achieve higher growth. Other species with lower value can also be farmed if caught. The production of sea cucumbers is irregular throughout the year and depends on the availability of stocking fingerlings; a low farming season occurs during the warm period (January–February) when the availability of fingerlings is very limited. According to the interviewed group, around 5–6 fingerlings can be collected per day in low tide (around 10 days per month), which would yield a maximum production of 500 individuals per year.

Sea cucumber farming is merely a supplementary occupation for the farmers because of the small production. Harvested sea cucumbers are sold unprocessed to middlemen for export to China, where they are used in the local cuisine. The farmers get 0.70–1.90 USD (1500–4000 TZS, prices for September 2015) per sea cucumber depending on the size, which brings an estimated annual revenue of 540 USD (1.2 million TZS), assuming that 500 individuals are sold with an average price. Sea cucumber farming requires a small investment for basic construction materials (wooden sticks and net) and fishing gears. The constraining factors in sea cucumber farming according to the farmers were the reduced availability of fingerlings, especially during the warm periods and economic limitations towards farming materials for pen construction. In the past, sea cucumber culture was tried out as a pilot study in Bweleo in 2013–2014. However, the activity failed to be established

after the project was completed, due to poaching, lack of construction materials and mobilization to restart from the locals. For improving their production, the farmers pointed out the construction of hatchery and technical advice concerning farming and potential hatching techniques.

Sea cucumber farming was particularly popular among other aquaculturists when the potential future engagement in other mariculture activities was discussed. Yet, sea cucumber stocks in Zanzibar face high fishing pressure (Eriksson et al., 2010) and hatcheries' development may be costly but should be encouraged (Eriksson et al., 2012) both for stock preservation and regular and profitable aquaculture production. Currently, there are emerging sea cucumber farms at Unguja Ukuu and Uzi Island that have been supported by the first distribution of fingerlings from the newly established marine hatchery in Zanzibar. Seed production in closed areas is also tried out at Bungi. Moreover, experimental co-cultures of sea cucumbers with seaweeds in pens showed positive results and in particular when cultured with *K. alvarezii* (Hamad et al., 2019), suggesting that integrated mariculture systems should be further explored. For successful development, however, alongside farming advancements, links with exporting companies should also be developed. Moreover, local community-based management and by-laws should be in place to deal with potential poaching events due to the high value of the species. In the Western Indian Ocean, a successful example of establishment comes from Madagascar, where a community-based sea cucumber culture and hatchery have been developed by a collaboration of different actors (local communities, research institutions, NGOs and a private export company) (Mmochi, 2015; Troell et al., 2011).

3.7. Sponge- and coral cultures

Sponge culture trials have been ongoing since 2009 by the Swiss Non-Governmental Organization (NGO) maricultures.org that has a branch in Jambiani village, where they test its potential as a new mariculture livelihood in Zanzibar. The organization has conducted a trial project to test farming methods and depths for potential commercial farming, which is suitable for Zanzibar locals to operate. Moreover, for enabling further farming engagement and to secure sustainability, the NGO aims to establish an adequate broodstock supply of native sponge species. Yet, the NGO has employed and trained a few local women in Jambiani to develop their own farms and test the activity's feasibility.

Culturing of the native black (*Agelas mauritiana* var. *oxeata*) and grey sponges (family *Callyspongiidae*) is practised in the upper subtidal zone (0.5–5 m depth) using floating long-lines for about 8 months until harvest. A deeper farm (6–10 m depth) has already been established in the area (Fig. 3F) and is being used for broodstock development as well as broodstock supply for the farms run by the women. Snorkelling gears are required for handling the shallow farms and SCUBA diving for the broodstock farm. Sponge culture is practised all year around with a particularly sensitive period during the rainy seasons when die-offs might occur in the shallow farms. The organization, besides growing broodstock, continues to develop the farming potential by trying other species and locations, as well as intermediate depths for higher production.

The harvested sponges are processed by the farmers to clear sponge skeletons and sold as bath sponges to local shops, hotels or trade fairs with prices depending on their size and shape (15–40 USD per bath sponge, price for September 2015). The general lack of swimming and snorkelling ability among Zanzibar women and the need for SCUBA diving equipment in broodstock farms, as well as the sensitivity of commercial, shallow farms during rainy seasons are the main constraining factors in sponge culture development in Zanzibar.

Coral culture trials for potential aquarium trade, as well as for coral reef restoration were initiated by maricultures.org in 2014 in Jambiani as a new livelihood (Fig. 3G). Native hard and soft corals are cultured fixed on underwater tables in the subtidal zone aiming at establishing broodstock supply for potential sustainable commercial coral culture and restoration actions in the future. Moreover, cement reef balls with the potential to be planted with cultured corals when broodstock is achieved have been placed underwater in Jambiani as a restoration measure to replace the destroyed habitats by creating artificial coral reefs (Fig. 3H). Coral nurseries in damaged areas have been tried previously in Chumbe and Mafia Islands in Tanzania, with positive results (Mbije et al., 2010).

3.8. Potential larger-scale aquaculture activities

For the potential establishment of medium or large-scale mariculture activities that involve non-local investors or industrial enterprises, there is no concise procedure for issuing permits in Zanzibar. The newly established Zanzibar Environmental Management Authority (ZEMA), according to the Zanzibar Environmental Management Act (RGoZ, 2015c), is authorized to coordinate Environmental Impact Assessments (EIAs) and issue permits for activities in the coastal zone. However, no direct connection of ZEMA to aquaculture is referred to in the Act. Besides, there are several ministries and departments that have stake in the coastal zone and are involved in the decision making such as the Departments Fisheries Development, the Department of Forest and Non-Renewable Natural Resources (in mangrove areas), the Department of Environment and the Ministry of Land, Housing, Water and Energy. Beyond the governmental permits, the procedure of agreement is bottom-up since the first level is the consensus of the local communities in the selected areas for establishment. Yet, there has been limited interest by investors to establish larger mariculture activities in Zanzibar, and by the time of the study, no successful establishment had taken place. However, three such cases were encountered by the present study, which all failed due to the investors' economic issues and an unsatisfactory agreement with the locals.

4. Discussion and conclusions

Small-scale coastal aquaculture activities take place around the coast of Zanzibar (Unguja Island) in many rural areas (Fig. 2). Seaweed farming is the predominant aquaculture activity that has been ongoing for more than thirty years. Due to the open access to the coastal zone and the relatively easy farming process, seaweed farming is practised in almost all coastal villages in Zanzibar, employing thousands of local women (~ 1% of 900,000 total population; United Repiblic of Tanzania, 2013). Farming of finfish, crab, pearl oyster, sea cucumber, sponge and coral is little developed or in trial stages, with limited national economic importance by employing collectively only a few hundred (< 500) people, yet with local significance. These activities are concentrated mostly in bays or mangrove areas that provide the necessary conditions for farming (e.g. sheltered waters, pond excavation). However, developing mariculture activities, despite the legally open access to the coastal zone, have to abide by local by-laws and government regulations regarding natural resources such as the mangrove cutting prohibition, which also influence their placement. Yet, most of these activities were introduced during the last fifteen years by donor-driven projects, and the areas to host the pilot project were selected by the responsible research institutions or the NGOs. Thus, the initial projects and the subsequent farming and economic constraints that led to reduced interest when the projects ceased, shaped largely the current spatial distribution of other-than-seaweed maricultures in Zanzibar. Overall, when considering the significance of small-scale aquaculture apart from food provision and direct economic gain, activities such as seaweed and mollusc farming are known to provide a variety of ecosystem services (e.g. nutrient uptake, habitat provision) but their valuation and incorporation into markets is globaly rare (Naylor et al., 2021) and yet absent in Zanzibar.

When it comes to gender balance and task sharing, mariculture activities in Zanzibar differ. Seaweed farming is generally considered a female job and an individual or family labour. The other maricultures, however, are performed by cooperative groups of farmers represented

by both sexes, since the capital investment and the nature of the work require sharing and men and women may undertake different tasks in the group (e.g. in pearl farming men maintain the farms while women process the half-pearls into jewellery).

The question of "who farms" in Zanzibar has, however, a common denominator. Mariculture farmers face serious economic limitations that have not enabled them to improve their farming techniques and infrastructure, leading to small and irregular production, which cannot support reliable remuneration creating a vicious cycle. As a result, mariculture is part-time labour, outcompeted by other already established activities that cover food needs (e.g. agriculture and fishing). Aquaculture farmers in Zanzibar resemble the "poor fish farmers" in Ghana described by Kassam and Dorward (2017), who without the ability to adopt Best Management Practices and to receive training, are unlikely to increase their income based on aquaculture.

Technological innovation and appropriate training at farm level, together with coordinated efforts to support non-farm value chain segments, are paramount to increase profitability. There are multiple examples of innovation at farm level such as the use of pelleted feeds, higher fingerling stockings and deeper excavation of ponds in fish farming (Belton et al., 2017), the shift to pond cultures instead of dive-in cages in crab farming (Mirera, 2011; Mirera et al., 2014) and the use of protective cylinders in half-pearl production (Johnston et al., 2020). However, the simultaneous evolution of upstream and downstream non-farm enterprises that provide vital input (such as seed and feed), logistical support and trade are necessary for the aquaculture production supply to grow (Belton et al., 2018; Bush et al., 2019; Hernandez et al., 2018; Kaminski et al., 2018). In Zanzibar, aspects of value chain upgrade should be considered in conjunction with aquaculture development. Government interventions at initial stages could play an important role to support the establishment of aquaculture value chains and providing technical advice in collaboration with research institutions (e.g. Belton et al., 2017; Hernandez et al., 2018; Galappaththi and Berkes, 2015). Regarding farm inputs, a first step has been made in Zanzibar with the construction of a government-led marine hatchery aiming at producing milkfish, crab and sea cucumber seedlings. However, for Zanzibarian mariculture products, trade and access to both domestic and international markets is another critical aspect. In particular, a support mechanism is needed to strengthen and diversify seaweed trade, as well as the establishment of clear market outlets and trade routes to large urban markets, both in Zanzibar and on the mainland, for fish, crab, pearl oysters and export agreements for sea cucumbers. Accordingly, coherence with other national trade policies should not be neglected in the process (Brugere et al., 2021). Moreover, particular consideration should be given to the role of local women in processing, trading and marketing of mariculture products, since it has proven significant in other African countries (e.g.(Kaminski et al., 2018; Kassam and Dorward, 2017)).

Due to economic, technical and institutional limitations in Sub-Saharan Africa, the potential of both inland (Brummett et al., 2008) and marine aquaculture (Ateweberhan et al., 2018; Mmochi, 2015) has largely not been realised. Approaches to overcome these limitations by moving from small-scale artisanal cultures to more integrated units such as Small and Medium Enterprises (SME) have been proposed (Brummett et al., 2008). In the case of Zanzibar, according to Zanzibar Aquaculture Development strategy and the Action Plan (ZADSAP) (RGoZ, 2015a), the move towards larger business units might be one way forward. However, a value chain approach considering also indirect benefits from aquaculture and market multipliers should be considered when policies to support business models are developed. In the case of freshwater aquaculture in Ghana, for example, Kassam and Dorward (2017) found that even if SMEs' impact on fish production and the economy is significant, small-scale farmers with the ability to adopt BMP might have greater potential to reduce poverty by creating higher market multiplier effects. Yet, which scale and model of aquaculture development would be the most advantageous for local people in Zanzibar remains, to our knowledge, unstudied.

Effective mariculture governance determines whether the sector fulfils its goal to produce food and economic growth without significant environmental degradation (Davies et al., 2019). Many Sub-Saharan countries, including Tanzania, have been characterized by Davies et al. (2019) as "at risk" to develop marine aquaculture due to low capital, unclear property rights and higher risk to impact the environment. In Zanzibar, there are no formal regulations regarding mariculture and no coastal zoning to set tenure rights. The community-based management to regulate coastal resources might have been enough so far considering the small scale of the sector. However, a shift to formal regulations and planning might be necessary when considering expansion. A support mechanism to aid the implementation of regulatory measures might be needed to strengthen the efficiency of mariculture governance in Zanzibar. Galappaththi and Berkes (2015) describe a participatory institutional structure, where a three-level farmers' association network, from local to national level, played a key role in Sri-Lankan shrimp aquaculture to control common water resources and shrimp disease. Zanzibar has a bottom-up system to manage environmental resources and in this respect, a similar participatory governance framework, where farmers' associations are organized at local level with their own by-law to national level working together with the government and other value chain stakeholders, might be appropriate. In Zanzibar, the establishment of, yet dysfunctional, Zanzibar Seaweed Farmers Association (ZASEFA), could be further supported and used as a building block to strengthen mariculture governance, production development and innovation in the entire sector.

This study highlights several challenges in the social and economic dimensions of sustainable development of coastal aquaculture in Zanzibar, but also potential solutions. However, the most important aspect of the development of coastal aquaculture is that the practices must be developed to be operational within the ecological/environmental boundaries of our planet. To be able to address and adapt coastal aquaculture to operate sustainably, frequent monitoring and thorough investigations of positive and negative environmental impact are needed. Identifying social and economically viable solutions that improve rather than degrade the environment should be a priority.

Author statement

Conceptualization: LMN & SC with input from all authors; Data curation: SC; Formal analysis: SC; Maps: KvS; Funding acquisition: LMN; Investigation: SC with help from KvS & TL; Methodology SC, LMN with input from NJ, MG & CH; Supervision: LMN; Writing – original draft: SC led the writing, all authors contributed; Writing – review & editing: SC led the revision, all authors contributed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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