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A multiple-case study of exploring social-ecological resilience of seaweed farming in Unguja

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Declaration

I, Stephanie Degenhardt, declare that this thesis is a result of my research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been appended. This work has not been previously submitted to any other university for award of any type of academic degree.

Signature………………………………..
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Abstract

Seaweed farming has existed in Unguja, Zanzibar for twenty-five years. However, its substantial rise in production and the positive socio-economic impacts it has are now threatened by multiple disturbances, which jeopardize the viability of seaweed farming as a valuable livelihood activity. This thesis examines the challenges and possibilities of seaweed farming as a resilient social-ecological system (SES), in particular in the villages of Matemwe and Paje. Data was collected through semi-standardized interviews with active and non-active seaweed farmers, buying station officers and buying companies, in addition to unstandardized in-depth interviews with a seaweed farmer, the governmental agency and a non-governmental organisation. Complementary data was retrieved from field observations, measurements of phosphorus at the farm sites, analysis of satellite imagery, and unpublished official mariculture statistics. This thesis is guided by the conceptual framework of social ecological resilience, and complemented with an additional perspective provided by the vulnerability concept. The study analyses the complexity of interrelated socio-economic and ecological dynamics over multiple scales that led to a reduced resilience of the SES by identifying key drivers of change and their dynamics. The study finds these to be slow changing environmental conditions that led to unfavourable farming conditions as well as decreasing and unequal spread of knowledge, failed attempts to form cooperatives and monopsonistic market structures leading to higher farmer dependency on existing system structures. The study also finds that disproportional price developments and waning farmer-buyer relationships further fuelled a shift of farming activities away from Unguja. These dynamics have fed back to steadily weaken the system's adaptive capacity and thereby reduce its overall resilience, giving rise to vulnerable conditions and susceptibility to disturbances in the form of widespread disease and seaweed die-off. Furthermore, these dynamics have pressed the system towards one or several critical ecological and socio-economic thresholds, which in light of the lacking adaptability of current management policies, creates great risk of it flipping into a degraded state. Thus, the study concludes by stressing the importance of adaptive management that would allow for development through learning, adaption and transformability.

Acknowledgement

To my family near and far!

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LIST OF ACRONYMS

DFMR	Department of Fisheries and Marine Resources
IMS	Institute of Marine Sciences
KNPA	Kilimanjaro Native Planters' Association
MACEMP	Marine and Coastal Environment Management Projects
MANREC	Ministry of Agriculture, Natural Resources, Environment and Cooperatives (Zanzibar)
PAR	Pressure and Release
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
RC	Refined carrageenan
SES	Social-ecological system
SER	Social-ecological resilience
SRC	Semi-refined carrageenan
SUZA	State University of Zanzibar
SWF	Seaweed farming
UDSM	University of Dar es Salaam
ZaSCI	Zanzibar Seaweed Cluster Initiative

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1. Introduction

1.1. Background

Seaweed farming has long been seen as a relatively benign and sustainable form of mariculture that reduces pressure on overharvested coastal resources and provides a source of livelihood through cash income; constituting a social uplift to coastal communities. Although it is a form of monoculture, seaweed farming in its current state has not negatively impacted coastal eco-systems, nor does it require inputs of fertilizer or pesticides (Eklöf, Msuya, Lyimo, & Buriyo, 2012). Moreover, inexpensive farming methods that require little equipment or education to engage in seaweed farming make it an easily accessible livelihood option for coastal communities. Although covering only a brief period of Zanzibar's history, seaweed farming has had a significant impact on the social and economic life of coastal areas and its populations. Nevertheless, there are several important changes relating to the health of the seaweed and of the farmers. Skewed power relations and aggressive price policies (Bryceson, 2002; Fröcklin, de la Torre-Castro, Lindström, Jiddawi, & Msuya, 2012; Rönnbäck, Bryceson, & Kautsky, 2002) over time have led to questions to whether the system can continue to provide the social and ecological benefits it has been praised for since its early stages. As Eklöf et al. (2012) point out:

> "Seaweed farming has been a first step in the right direction towards aquaculture sustainability. However, we – as others – emphasize that the current form of seaweed farming constitutes a prime example of a "corporate-intensive monoculture" of a "cash crop" […] From this angle, seaweed farming has become worryingly similar to those forms of aquaculture […] that it was originally intended as an alternative to." (p. 229)

Tanzania is the world's fourth largest producer of seaweed used to extract carrageenan. Carrageenan is a polysaccharide hydrocolloid used as a stabiliser, emulsifier or thickening agent in pharmaceuticals, cosmetics and food additives to enhance viscosity and smooth consistency. It is therefore a crucial additive for many consumer products. Although the international value of carrageenan is exploding, cash income for farmers has lost value over the past years. Moreover, production in Unguja, where seaweed cultivation in Tanzania began, has declined to levels not seen since the early 2000s. Fluctuations in seaweed farming are not a new observation. The world's biggest producers of carrageenan, Indonesia and the Philippines have "undergone boom and bust cycles due mainly to disease and price fluctuation" (Sievanen, Crawford, Pollnac, & Lowe, 2005, p. 307). Seaweed farming depends heavily on two factors, namely the carrageenan demand on international markets and the disease prevention on local markets (Richmond, 2011). With the discovery of a wide spread seaweed die-off along the east coast of Unguja, the question arose how vulnerable or how resilient the system is facing disturbances. Never has Zanzibar experienced such a dramatic decline in production and employment.

This thesis largely focuses on the seaweed farming system's complexity and the interconnectedness of the social and natural worlds that create it, it strives to identify the key drivers for these changes. After a short overview of the carrageenan industry and the seaweed farming history in Zanzibar, I will address ecological aspects and challenges, alongside the socio-economic implications of seaweed farming for Tanzania, Zanzibar and Unguja. In particular this thesis seeks to answer the question of current challenges and possibilities towards the resilience of the system.

1.2 Importance of Seaweed Farming

Seaweed and Carrageenan Industry

The seaweed farmed in Tanzania are classified as red algae, of the class Rhodophyceae; macro-algae ranging from a few centimetres to a metre in length

(McHugh, 2003). Besides the use of seaweed directly as food, where nori is the most well-known, red seaweed is used to produce hydrocolloids; a water-soluble substance that enhances viscosity of a solution or smoothens the consistency of solids. Use as a food additive gained importance with the rise of processed food since the 1950s. The two hydrocolloids extracted from red algae are agar and carrageenan. Both are mainly used in the food industry and compete with other stabilizers such as gelatine and gum. Each gel type provides varying features and has diverse applications. Agar, for instance is flavourless, highly sugar reactive and has a high melting temperature. Therefore it is suitable to use in jelly, gelled meat and to reduce the sticky properties of processed food for packaging purposes. Carrageenan is protein reactive, meaning it binds milk protein to form a gel and prevents whey separation. Therefore it is commonly used in dairy products such as cottage cheese, ice cream and chocolate milk. Algae used as a source of carrageenan are called carragenophytes.

The most commonly farmed warm water carragenophytes for commercial value are *Kappaphycus alvarezii* (formerly called *Eucheuma cottonii* and commercially known as cottonii*)* and *Eucheuma denticulatum* (formerly called *Eucheuma spinosum* and commercially known as spinosum). *K. alvarezii* is the main source of the hard-gelling kappa-carrageenan and the strongest of all carrageenan. *E. denticulatum* is the source for the soft gelling iota-carrageenan (Cai, Hishamunda, & Ridler, 2013; McHugh, 2003; Yap, 1999). *K. alvarezii* is produced in the Philippines and is the more popular seaweed due to its higher valued kappa-carrageenan, while *E. denticulatum* is mainly produced in Indonesia and Tanzania (Cai et al., 2013).

To extract carrageen from the seaweed, two methods are commonly used: the semi-refined carrageenan (SRC) or seaweed flour, and the refined carrageenan (RC) (McHugh, 2003). SRC is the cheaper and quicker treatment of the seaweed where, with help of alkali and water, everything but carrageen and cellulose will be dissolved and washed off then dried and ground down to powder. As this powder is not suitable for human consumption it is mostly used for pet food. However, if the seaweed is treated with bleach after the alkali washing, further dried in a closed system then eventually treated with ethanol to keep bacterial count low, it can be made suitable for human consumption. RC on the contrary extracts the carrageenan from the seaweed by applying several processes to separate the cellulose and filter out the high concentrated carrageenan. Hence, it is a more time consuming and cost intensive method.

International Seaweed Market

The world's production of *Eucheuma* seaweed has been expanding from 29,426 tonnes dry weight in 1990 to 94,405 tonnes dry weight in 2000 and 1,036,343 tonnes dry weight in 2013 (Cai et al., 2013) (see appendix FAO Fish Stats). In 2013 the largest producers of carragenophytes, namely Indonesia and the Philippines, had a market share of 80.3% and 14.9% respectively. Followed by Malaysia with 2.6% and Tanzania as the fourth largest producer with a market share of 1.3%. While the Philippines and Malaysia mainly produce *K. alvarezii*, Indonesia and Tanzania nearly exclusively produce *E. denticulatum*. Other important carrageenan producing countries are China, with a global market share of 0.9% in 2013. Other minor producers include Madagascar, the Solomon Islands, India and Mexico.

Mainland Tanzania and Zanzibar Seaweed Market

Tanzania's major seaweed producing regions are in Zanzibar, namely the two large islands of Unguja and Pemba, whereas in mainland Tanzania areas include Tanga, Bagamoya, Mafia Island and the southern districts of Mtwara, Lindi and Kilwa (F. E. Msuya, 2013). Although production in mainland Tanzania has been relatively stable in the 1990s and grew gradually in the 2000s, it's market share stayed below 6% in 2013 (see appendix FAO Fish Stats). Zanzibar on the contrary grew progressively and as of 2013 accounted for 94% of Tanzania's seaweed production. However, in recent years *Eucheuma* production in Zanzibar has undergone fluctuation with the most severe drop in production in 2012 from 15,088 tonnes of dry weight to 11,044 tonnes of dry weight in 2013 (when only considering the variety *E. denticulatum* it is from 14,997 tonnes of dry weight in 2012 to 10,843 tonnes of dry weight in 2013).

History of seaweed culture in Zanzibar

Before Tanzania commoditised seaweed due to its carrageen content it was traditionally used as fish bait and for local medicine. The commodification began in the 1940s when fishers collected fragments of wild seaweed, which had washed ashore and sold it to private businessmen, who further shipped it to Europe (Eklöf et al., 2012).During the beginning of the commercial seaweed trade, export rates increased from 347 tonnes in 1951 to 500-800 tonnes dry seaweed in 1960. However, during the 1970s exports subsequently decreased to less than a third of the export (Eklöf et al., 2012; Sen, 1991).

The dramatic decrease in export rates is thought to be a reaction to different factors, such as structural problems due to a shift from private businesses to the Zanzibar State Trading Corporation (Sen, 1991), competition on the international market and overexploitation of the wild seaweed (Eklöf et al., 2012). Meanwhile, challenges of overexploitation also occurred in the Philippines, combined with a strong demand for seaweed as a raw material on the world market, led to the development of seaweed cultivation in the Philippines in the late 1960s and actual farming in 1973 (Doty, 1987; Yap, 1999). Thereafter, Professor Keto Mshigeni and Professor Adelaida Semesi from the University of Dar es Salaam brought the idea of seaweed farming to Tanzania, after Mishigeni studied in Hawaii under the initiator of seaweed cultivation, Dr. Maxwell Doty, while Semesi had investigated farming efforts in the Philippines (Bryceson, 2002). The first experiments in Tanzania followed in mid-1985 and commercial production began in 1989 (Eklöf et al., 2012; Eklund & Pettersson, 1992). The commercial farming started as a cooperation between the University of Dar es Salaam and the private companies Zanea Seaweeds Ltd. and Zanzibar Agro-Seaweed Company Ltd., which set up pilot plots for seaweed cultivation with the native species *Eucheuma* (Sen, 1991). After these trial farms failed, the native seaweed species *E. denticulatum* was replaced with a more robust strain from the same species obtained from the Philippines and Singapore (Eklöf et al., 2012; Sen, 1991).

The first plots were established in the villages of Jambiani and Paje on the east coast of Unguja, Zanzibar which, provide favourable conditions for farming. From there, farming efforts extended along the east coast as well as to coastal areas in mainland Tanzania; in Tanga and Bagamoyo in 1992 and further in Mtwara, Lindi, Mafia and Kilwa in 1995. After the initial success of farming *K. alvarezii*, it became prone to diseases at most farming sites and therefore decreased enormously from 2003, whilst *E. denticulatum* became the most widely farmed alga, especially in Zanzibar (F. E. Msuya, 2013).

1.3. Environmental Aspects of Seaweed Farming

Environmental Impacts of Seaweed Farming

Mshigeni (1979) conducted important research on identifying species variation and their habitat, which were important guidance for following cultivation. He identified *E. spinosum* as the most abundant variety (later replaced with a South-east Asian strain), followed by *E. striatum* (later replaced by the south-Asian strain *K. alvarezii*). Although *E. striatum* occurred naturally, cultivation of *K. alvarezii* failed in most parts of Zanzibar due to unfavourable environmental conditions, such as too high seawater temperature, and is now restricted to some areas in mainland Tanzania (F. E. Msuya, 2013; Flower E Msuya, 2011).

Seaweed farming is seen as a relatively benign form of mariculture (Bryceson, 2002; Sievanen et al., 2005). However, research on possible negative impacts of seaweed cultivation on seagrass beds and associated macrofauna has been carried out (Eklöf, de la Torre Castro, Adelsköld, Jiddawi, & Kautsky, 2005; Eklöf, Henriksson, & Kautsky, 2006; Ólafsson, Johnstone, & Ndaro, 1995). Accordingly, an often-cited aspect is a decreasing biomass of seagrass due to physical removal of the plants when establishing seaweed farms (Eklöf et al., 2005; Lyimo, Mvungi, & Mgaya, 2008). Conversely, a further study by Eklöf et al. (2006) could not corroborate negative effects due to altered structures of surrounding macrofaunal communities, nor did Ólafsson et al. (1995) find an effect of decreasing macrofaunal density due to toxic substances excreted by seaweed. Also, another study carried out by Lyimo et al. (2006) did not confirm negative effects of seaweed farms on the growth rate of seagrass. On the contrary, although seaweed farming influenced the composition of fish assemblages, it did not affect the fish diversity (Bergman, Svensson, & Öhman, 2001), rather it counter-balanced effects of lessened seagrass beds (Eklöf et al., 2006).

Furthermore, Bryceson (2002) raised associated problems of monoculture farming systems and Halling et al. (2013) proposed that the seaweed farmed in Zanzibar had a narrow genetic variation, all of South-east Asian origin, which has been confirmed by Tano et al. (2015). Both suggest that the South-east Asian *E. denticulatum* is the major type used in farming, at least since 2004. Additionally, Tano et al. (2015) found a dominance of the introduced *E. denticulatum* over the native one outside the farming sites, indicating the invasive properties of the introduced South-east Asian string.

Seaweed Diseases

Doty (1987) conducted pioneering work of seaweed cultivation regarding the capability and challenges of *Eucheuma* farming mostly in Hawaii and the Philippines. Challenges such as grazing, mechanical damage, physical challenges and ice-ice disease are of particular importance for this study. He describes the latter as a "sharp loss of thallus pigmentation until it becomes white"(Doty, 1987, p. 37; 136) as a symptom caused by physio-chemical stress, for instance through sudden changes in temperature or salinity level. The development of ice-ice disease as a result of changing environmental conditions, in particular rising seawater temperature rather than as a micro-organism induced disease has been confirmed by several scholars (Arevalo, Donaire, Ricohermoso, & Simbajon, n.d.; Ask & Azanza, 2002; Hayashi, Hutado Q., Msuya, Bleicher-Lhonneur, & Critchley, 2010; F. E. Msuya, 2013),. Largo et al. (1995) and Largo (2002) however argue the role of pathogenic bacteria as a necessary factor to develop ice-ice disease when the crop is weakened by unfavourable environmental conditions.

Another well-known challenge of *Eucheuma* farming is the regular outbreak of epiphytes and decay, which has been known since the beginning of seaweed farming. Its appearance has been associated with seasonality, in particular during the dry season, which facilitates sudden changes in water temperature, salinity levels and mineral contents (Doty, 1987; Vairappan, 2006). Furthermore Vairappan et al. (2008) identified a severe epiphyte infestation in all carragenophyte-producing countries including Tanzania, which causes secondary bacterial infection, such as outbreaks of ice-ice bacterial disease. Subsequently epiphytism leads to a severe biomass loss through disintegration of tissue, breaking-off of thalli and loosening of the algae from ropes. Furthermore, an epiphyte infestation has a severe impact on carrageenan yield, viscosity and gel strength, which places a serious threat to the productivity of farming efforts (Hayashi et al., 2010; Vairappan et al., 2008).

In order to reduce the occurrence of epiphytes, choosing a suitable farming site with moderate water movement is as important as minimizing their spread through correct farming handling (Doty, 1987; Hayashi et al., 2010; Neish, 2008) and for the industry to communicate better farming practices to the farmers (Vairappan et al., 2008). Msuya et al. (2007) additionally analysed the two common farming methods in Tanzania; namely off-bottom technique and deep-water floating technique. Accordingly, seasonal seaweed die-offs which occur between March and May with the off-bottom methods can be avoided by using deep-water floating methods.

1.4. Seaweed Farming in Zanzibar

Farming Methods

A successful seaweed farming site requires several favourable conditions such as sufficient sunlight and clear water, a white bottom with little competing organisms such as seagrass and a low-tide water depth of less than one metre (Doty, 1987; McHugh, 2003). Furthermore, it needs a seawater salinity of above 30 ppt, ideally 35 ppt, a water temperature between 25-30°C and a moderate water movement. The most common seaweed farming method is the off-bottom technique, however in mainland Tanzania, Pemba and few villages in Unguja the deep-water floating method is practiced (F. E. Msuya, 2006a, 2013). Both farming methods are monocultures using vegetative propagation for seeding. The off-bottom method requires relatively little equipment, namely tie-ties (usually nylon strings, sometimes replaced with pieces of old mosquito nets), ropes, mangrove poles and nylon sacks for packaging. In contrast, the deep-water floating method can be practiced in deeper water using floating container such as recycled plastic bottles to make the seaweed float close to the water surface. Additionally, a boat for farm set-up, maintenance and harvest is required for the floating method (F.E. Msuya et al., 2007).

Thallus fragments of live seaweed obtained from previous harvests are tied at approximately 30 cm intervals on a rope of 4 to 7 metres in length, which is attached between two small poles. The poles are placed in relatively shallow bays or lagoons, approximately 20 – 40 cm above the seabed with a regular water movement. One plot consists of approximately 50 lines. After the grow-out of the thalli the algae can be harvested every fortnight during spring tide by removing the whole plant from the rope and cutting new seedlings of ca. 100 g for a new growth cycle (Cai et al., 2013; Yap, 1999). In ideal conditions, *Eucheuma* has a growth rate of 3-5% per day (Hayashi et al., 2010; McHugh, 2003) and a farming cycle of about 2 to 3 months (McHugh, 2003; Yap, 1999).

After harvesting the seaweed, it is spread out to dry in the sun on mats usually made of coconut-palm leaves, or it is hung to dry from wooden poles for about 2 to 3 days until 80-85% of the water content is removed (Hayashi et al., 2010; Richmond, 2011). In some cases drying machines are used to dry the seaweed in a more effective way, as well as to reduce challenges induced by unfavourable weather conditions or space limitations. After the seaweed is dried and roughly cleaned, the farmers sell it to a local buying station.

Low tide occurs every 14 days for 5 to 7 days and an ebbing interval of 4 hours, during which activities on the farms, such as planting, harvesting and maintaining take place. As maintenance, Neish (2008) includes daily attention in form of replacing loose thalli, shaking off silt, removing drift material on the crop, re-attaching loosening plants and repairing materials. Other activities include post harvest cleaning, drying and packing of the seaweed, which can be done off the farm.

Institutional Structures

When the government and companies established seaweed cultivation they divided the market, with the result that each village was allocated to one specific company (Lange & Jiddawi, 2009). The companies operate in the villages via buying stations where they usually employ a local person as a buying officer, who is the direct contact person for the farmers. After the government loosened the regulation, several buying stations could operate in the same village. After selling the seaweed to the buying station the buying officer cleans the seaweed, weighs it to pay the farmers and stores it until a driver collects it from the villages for transport to the company’s warehouse. There the seaweed is baled and packed for transport overseas for further processing. Whereas the Philippines, Indonesia and Malaysia process the seaweed within their own countries, all the seaweed produced in Zanzibar is exported as raw material.

As of 2011, the local seaweed market in Zanzibar was organised by eight Tanzanian companies; namely *Zanque Aquafarms Ltd.*, *Zanea Seaweed Co.Ltd.*, *C-Weed Corporation Ltd.* and *Kai Trading* operating in Unguja and Pemba; *Zanzibar Shell (ZHS)* and *Zanzibar Agro-Seaweed Company Ltd. (ZaScol)* operating only in Unguja; and *Birr Sea Weed Company* and *SM Rashid* solely operating in Pemba (F. E. Msuya, 2012)(pers. comm. DFMR). Tanzania's main export destinations are Europe, Asia and the USA; in 2011 27% of Tanzania's seaweed exports went to Denmark, 20.7 % to France and 3.8% to Spain; 19.9% went to Vietnam and 8.3% to China; and 18.5% were exported to the USA (Cai et al., 2013).

The global market for carrageenan is organised by a few multinational corporations that form an oligopsony, a market where the amount of buyers are small whereas the amount of sellers are large. An oligopsony typically results in buyer power where the buyer has a disproportionate influence over prices and other market factors. The largest carrageenan producers are FMC Polymer and JM Huber Corporation, both situated in the USA. JM Huber was formed in 1890 and acquired CP Kelco in 2004, which in turn is a merging of Kelco and Copenhagen Pectin, of which the latter was involved in trial farms for seaweed cultivation in Zanzibar (J.M. Huber Corporation, 2015).

The companies operating in the selected villages at the time of research were Zanea Seaweed Co.Ltd., C-Weed Corporation Ltd. and Zanque Aquafarms Ltd. Zanea is primarily owned by JM Huber and therefore exports solely to JM Huber's subdivision, CP Kelco in Denmark. C-Weed is an independent company that sells to FMC Biopolymer in the USA, Gelymar in Chile and Cargil in France. Similarly, Zanque is an independent company run by locals, but as of 2014 only exports to FMC (pers. com. Zanque).

Throughout the beginning of commercial seaweed farming until the present, the University of Dar es Salaam (UDSM) has played an important role as research facilitator and initiator of farming activities. In particular the Institute of Marine Sciences (IMS) in Zanzibar, provides consultancy services regarding marine science in general, and mariculture in particular. By doing so, IMS is working together with seaweed farmers and local seaweed companies, as well as with governmental institutions to conduct research on problems with seaweed growth, possibilities of cultivation and value adding potentials (F. E. Msuya, 2012, 2013).

The overall management of mariculture in Zanzibar is led by the Department of Fisheries and Marine Resources (DFMR), which operates under the Ministry of Agriculture, Natural Resources, Environment and Cooperatives (MANREC) (). The DFMR plays an important role in the development of mariculture activities and acts as a link between sellers and buyers. The department supports farmers' organisations and assists farmers and buyers with farming activities and keeps statistical records (per. com. DFMR). Additionally it established rules for operating local markets in association with the buyers (Lange & Jiddawi, 2009) and further regulates market entry for new companies (F. E. Msuya, 2013). Through the Marine and Coastal Environment Management Projects (MACEMP) the DFMR is assisting a few villages with purchasing farming equipment and storage facilities.

MACEMP was a project funded through the World Bank and the Global Environmental Facility from 2006 to 2011 (NEMC, 2011) to, amongst other things help farmers with funding and formation of cooperatives to receive training and education (F. E. Msuya, 2013). Among a range of other aid projects, NGOs and farmers associations, the Zanzibar Seaweed Cluster Initiative (ZaSCI) is one of the most relevant contributors. Started in 2006 ZaSCI represents a link between academia, private businesses, governmental institutions and farmers. Its main contributions to provide micro-credits to farmers to promote independence from buying companies, engage in market development through value adding products and finding new market channels in order to increase farming benefits to farmers and the country at large (F. E. Msuya, 2006b). Furthermore, the Paje Seaweed Centre started as a collaboration between the Chalmers School of Entrepreneurship, Intellectual Capital Management Track, the Rylandserska

Foundation, Zanzibar Adventure School, UDSM and local women from Paje with the aim to provide sustainable alternatives by promoting value-added products from seaweed. Accordingly, the Center was run by local women with support by the organizations involved (F. E. Msuya, 2012; Nyberg, 2011).

Socio-Economic Impacts of Seaweed Farming

Seaweed farming has stimulated a wide socio-economic development, especially a transformation of the social landscape through aspects such as improved standards of living. Among other things it has enabled farmers to afford new clothes for their children, pay school fees and buy books and school uniforms. It has also contributed to a higher ownership of items such as clothes, further helped to reduced malnutrition and in general provided a surplus of cash (Eklund & Pettersson, 1992; F. E. Msuya, 2006b). Furthermore, due to the possibility to earn their own income, seaweed farming enabled the predominantly women farmers to earn cash for themselves and their households. In this way, it made a large contribution towards a changed gender role and empowerment of women (Bryceson, 2002; Eklund & Pettersson, 1992; F. E. Msuya, 2006a, 2012, 2013).

Most of the farmers are women. As Msuya (2006; 2012) reported, low prices, irregular income as well as time and labour intensity led men to leave the sector and switch to traditional or new activities, for example in the rising tourism sector. On the contrary, Msuya (2006a) claimed that seaweed farming induced a decline of less lucrative traditional livelihoods, such as subsistence farming, petty trading and fishing. Moreover, Fröcklin et al. (2012) pointed out negative health effects related to farming activities mostly due to poor working conditions. Besides direct influences, such as fatigue, musculoskeletal pain, eye related problems and injuries from hazardous marine animals, they report a general increase in workload related to the need to engage in several livelihoods. Subsequently, this has led to a lower work capacity of the farmers in general.

1.5. The Aim of the Study

The purpose of this study is to analyse the complex socio-economic and ecological dynamics and identify underlying causes for these. By way of this, it aims to investigate the resilience and vulnerability of the seaweed farming system in Unguja, and the researched villages Matemwe and Paje. It further hopes to contribute a better understanding of how the seaweed farming system in Unguja can be managed in a resilient manner, to continuously guarantee benefits for the people that depend upon it.

Research Question

"What are the main challenges to and possibilities for seaweed farming in Unguja as a resilient social-ecological system?"

To address this central research question the study examines five objectives:

Part I:

1. Analyse seaweed farming within a social-ecological resilience context and show the interconnectedness of environmental and social factors and their dynamics on the overall resilience.
2. Identify key dynamics and drivers of change that influence the resilience of seaweed farming.

Part II:

3. Determine critical thresholds of the system by means of using the adaptive cycle.

Part III:

4. Define historical political, socio- economic and ecological dynamics to determine the actors vulnerability.

Part IV:

5. Explore possibilities towards increased social and ecological resilience wherein learning leads to new developments in form of adaptation or transformation by using the concepts of adaptive governance and adaptive management.

1.6. Conceptual framework

Seaweed farming represents an intertwined social-ecological system (SES) (Berkes & Folke, 1998; Chapin, Kofinas, & Folke, 2009), which is constantly shaped by changing social and ecological processes. This study incorporates the concepts of resilience and vulnerability as analytical approaches to understand and assess the linkages between social and ecological dynamics of the seaweed farming system.

Resilience

Social and ecological systems are complex interlinked systems (Berkes & Folke, 1998; Folke et al., 2010) permeated by change, complexity and uncertainty. Social systems do not only depend on ecosystem services in order to function, they continuously influence and shape them, while in return they are also constantly influenced and shaped by them (Berkes, Colding, & Folke, 2003; Chapin et al., 2009). These dynamics result in slow or fast processes of social and ecological change, with positive or negative feedback loops (Berkes & Folke, 1998; Folke et al., 2010), which are characteristics of SESs. However, these changes challenge the functional integrity of the SES (Chapin et al., 2009). Thus, a systems perspective is required to provide a conceptual framework that is flexible and dynamic enough to acknowledge and illuminate the interrelationships of SESs and to integrate their dynamic feedbacks (Berkes & Folke, 1998; Chapin et al., 2009; Walker & Salt, 2006).

Emerging from ecology, ecological resilience was originally conceived by Holling (1973; 1986) as a critique of static single-equilibrium thinking in conventional ecological theory, which emphasises stability and resistance to disturbances. Instead, Holling (1973) proposed a dynamic multiple-equilibrium view, which emphasises the inevitability of change, and regards disturbance as a potential impetus for renewal and innovation. Instead of looking at resilience as a cause and effect system, Holling introduced a non-linear perspective, which focuses on variability rather than stability (Berkes & Folke, 1998; Folke, 2006). Subsequently, resilience ideas have been adopted by other fields of social sciences (Folke, 2006) with the introduction of the concept of social-ecological resilience (SER) (Berkes et al., 2003; Berkes & Folke, 1998; Folke, 2006). The definition utilised for this study interprets SER as

> (1) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction,
> (2) the degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors), and
> (3) the degree to which the system can build and increase the capacity for learning and adaption (Folke, 2006, p. 259).

According to Walker et al. (2004) a resilient system is one that stays in the same basin of attraction, a term to describe conditions that lead to an equilibrium state, while undergoing constant changes. In the resilience concept, changes in the form of disturbances are met with the notion of opportunity and development. When analysing a complex SES within resilience thinking (Folke et al., 2010) the focus lies on the system's adaptive capacity for learning and transformation (Berkes et al., 2003; Folke, 2006). Whereas adaptability describes the ability to respond and adapt with structural changes through learning and development within the same stability (Young et al., 2006); transformability is the ability to create a new stability when current conditions lead to an undesirable state (Walker et al., 2004). Hence, as Folke et al. (2010) point out, the capacity to adapt and transform as a reaction to change are at the core of the resilience of SESs.

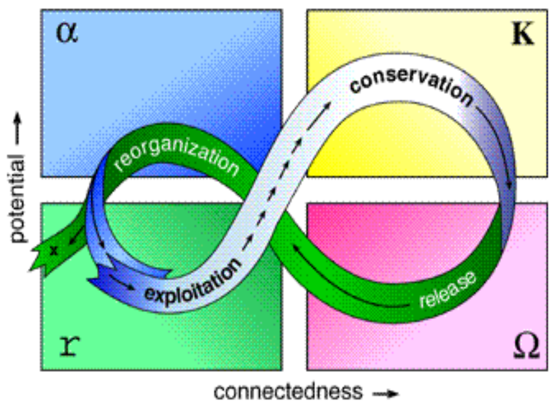

Fig. 1: The adaptive cycle
(Source: Resilience Alliance 2005 modified from Holling, 1986; Holling & Gunderson, 2002)

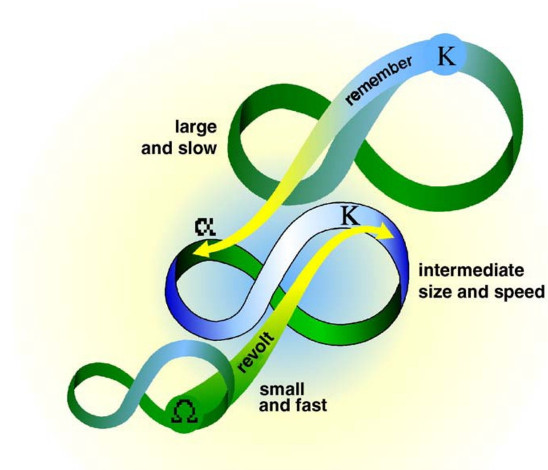

Fig. 2: Panarchy
(Source: Folke, 2006 modified from Gunderson & Holling, 2002)

The adaptive cycle (Figure 1) describes the dynamics of a SES in a four-stage system consisting of the fore loop, namely exploitation (r) and conservation (K); and the back loop, namely release (Ω) and reorganization (α) (Berkes et al., 2003; Gunderson & Holling, 2002; Holling, 1986; Walker & Salt, 2006). The fore loop is characterized as the slow development phase where well-being is increased and dynamics are relatively predictable. The r-phase resembles the growth of a system typically at a stage where resource availability and resilience are high, which then goes over into the K-phase where stability is reached and resources become less accessible whilst resilience begins to decrease. As the system becomes less flexible to disturbances during the end of the K-phase, it is most prone to flip into a chaotic Ω-phase followed rapidly by renewal and reorganisation towards the α-phase, and subsequently into the beginnings of either restarting a similar r-phase, or possibly flipping into a new domain of attraction where it starts a different r-phase. It is often in the back loop that a system crosses a threshold, which causes the system to flip from one equilibrium to another (Berkes & Folke, 1998; Walker et al., 2004; Walker & Salt, 2006). Thus, the back loop is often portrayed as the uncertain phase where the greatest constructive or destructive changes occur (Walker & Salt, 2006). The complexity of a SES requires an expansion of adaptive cycles over scales of time and space.

Such an expansion is described in the conceptualisation of panarchy (Figure 2), which links cycles across small and fast processes with large and slow processes to analyse and illuminate interacting social and ecological dynamics at different scales (Walker & Salt, 2006).

In this study I utilise resilience as a conceptual framework and analytical approach (Folke et al., 2010) to investigate how the seaweed farming system is responding to uncertainties, and to interrogate various interplays, recognising non-linearities, critical thresholds and transformation (Anderies, Folke, Elinoe Ostrom, & Brian Walker, 2012) of the SES seaweed farming. Furthermore, this assessment will help to discuss how adaptive governance, as "a process of creating adaptability and transformability in SESs" (Walker et al., 2004) and adaptive management, as the "emphasis [on] learning and subsequent adaption of management based upon that learning" (Allen & Garmestani, 2015, p. 3) can increase the resilience of seaweed farming.

Vulnerability

Resilience and vulnerability are closely linked concepts. Thus, vulnerability is often described as the absence of resilience (Folke, 2006), or the outcome of the impact of hazards, which are beyond the adaptive capacity of a SES (Bunting, 2013). Although the vulnerability approach has its origin in political economy and is recurrently used in disaster and risk analysis, particularly in relation to natural hazards (Turner et al., 2003; Wisner, 2004), its definition often depends on its domain of use to the social, natural or social-ecological world (Gallopín, 2006). An established definition is given by Wisner (2004) who describes vulnerability in relation to natural hazards by including the social system component as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard". However, Turner et al. (2003) criticise the limitation of vulnerability concepts on perturbation and stress as being too narrow to include system responses. Similarly, Miller et al. (2010) argue that the vulnerability concept is more than a direct outcome of perturbation, and they placed an emphasis on underlying causes for vulnerability through historical and political processes.

In this study I do not intend to use vulnerability as a de-coupled concept, rather I aim to focus on complementary elements to resilience thinking such as the experience of disturbances and responses of SES and their adaptive capacity (Adger, 2006). Hence, the vulnerability of the SES seaweed farming will be analysed in relation to linkages between slow and fast socio-political and ecological dynamics (Miller et al., 2010).

2. METHODS

The research conducted for this work is based on a multiple-case study approach. According to Yin (2008, p. 117)a case study is defined as "an empirical inquiry that investigates a contemporary in depth and within its real-life context." Such a contemporary can be a particular setting, an event or a phenomenon as well as a single person, a group or an entire corporation (Berg & Lune, 2012). The contemporary used in this study is the social-ecological system (SES) of seaweed farming in the villages Matemwe and Paje. A SES can be defined in accordance with the problem it addresses (Chapin et al., 2009), which in this study is the impact of changes on the overall resilience of the system. Thus, the aim is to understand how the system works and how the units of analysis fit in and shape the system (Berg & Lune, 2012). Special emphasis is placed on an event that occurred recently, namely a major seaweed die-off along the east coast of Unguja, which led to a substantial decrease in farming activities. As the occurrence of this event was not known at the beginning of the field research, it triggered a shifting focus from an initially explanatory to an exploratory study. Hence, the aim to understand why the system is more or less resilient shifted to the aim of discovering factors that impact the resilience of the system. The resilience concept is used to guide the discussion and define and analyse key factors and dynamics that influence the seaweed farming system. By choosing two villages the study further adapts a multiple case approach, which has the advantage of being more robust as opposed to a single case approach (Yin, 2008).

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2.1. STUDY SITE

The research was conducted in the villages of Matemwe and Paje, which are both located on the east coast of Unguja, commonly referred to as Zanzibar. Unguja is with 1,666 km^2 and 896,721 inhabitants the biggest island of the semi-autonomous Zanzibar archipelago, situated about 30 km east off mainland Tanzania in the Western Indian Ocean (NBS National Bureau of Statistics, 2013). Unguja's population is a diverse mixture of Africans, Arabs, Indians and Europeans as a result of the East African trading area

Unguja has limited possibilities for agriculture, especially in the eastern coastal areas, and is therefore mostly characterised by small-scale agriculture. Almost 60% of the rural population of Zanzibar is involved in agriculture, but only 22%, predominantly men, are involved in full time activities (NSB, 2013). Another important economic sector for Unguja is the tourism industry. However, due to low literacy rate with 69% of the overall household members and only 37% of the total population attending school in Zanzibar (NSB 2013), job opportunities in the tourism sector have bypassed most of the local population. With the highest density of coastal population in Tanzania (NSB, 2013), Zanzibar's economic activities are widely organized around coastal areas and include artisanal fishery and mariculture. The tropical coral reefs along Tanzania's shallow coast support 70% of the country's artisanal marine fishery (Vice President's Office, 2006), but despite the increasing demand in fish for the growing coastal population and for the expanding tourism industry, the majority of fishermen have not been able to adjust their production or margin and thus remain poor (Vice President's Office, 2006).

The coastal climate and geography provides a vital livelihood base for coastal communities. Whereas two monsoon seasons control the temperature, rainfall and wind of the coast, the semidiurnal tides control the nutrient flow and the distribution of aquatic organisms. The fringing reef at Unguja's east coast where the water surface temperature of between 27°C and 29°C in shallow water, along with low salinity provides ideal conditions for mariculture activities such as seaweed farming (Vice President's Office, 2006). The geographical situation of both villages adjacent to a lagoon on the east coast of Unguja favours intertidal activities such as collecting of bivalves and octopus, fishing and seaweed farming. Furthermore, the emerging tourism sector in Unguja also affects the villages. But whereas Paje is situated closer to other villages with high tourism activities, Matemwe experiences seasonal tourism, which results in less job opportunities for the local population.

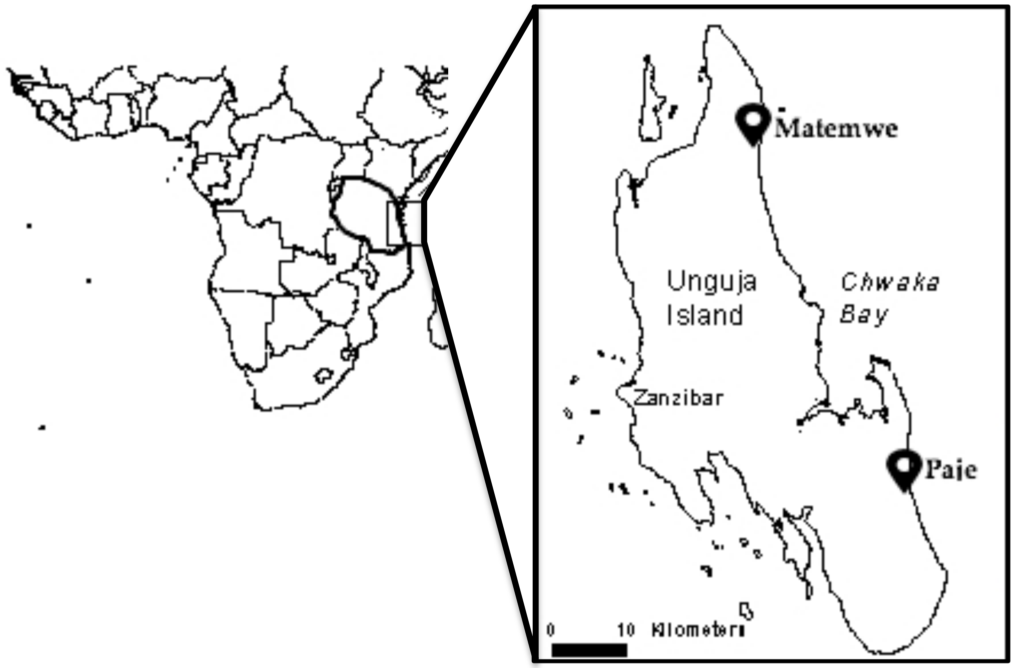


Figure 3: Map of Tanzania and Unguja

Matemwe is located in the Northern District of Unguja (Kaskazini), which counted 7,302 inhabitants with 3770 women in 2002. Seaweed has been farmed in Matemwe since 1994 (Bergman et al., 2001) and 732 women were employed in seaweed farming in 2011 (pers. com. DFMR).

Paje is located in the south district of Unguja (Kusini), which had a population of 2,129 inhabitants with 1119 women in 2002. Paje was among the first villages of the island to adopt seaweed farming in 1989, and 259 women were employed in seaweed farming in 2011 (pers. com. DFMR).

I have chosen these two villages to be able to examine, compare and contrast the seaweed farming system in two areas, which have similar geographical and environmental conditions, but differ in their economical and historical situations. The research mainly took place in the village of Paje, with additional interviews on Paje beach within a stretch of approximately 2 km. The research in Matemwe mainly took place at Matemwe beach within a stretch of approximately 3 km and additionally in Matemwe village.

2.2. Sampling methods

Mixed methods

An important characteristic of a case study analysis is to gain a deep and full understanding of a case, which was sought to achieve by using a mixed methods approach. Whereas qualitative research refers to meanings and quantitative research refers to measures (Berg & Lune, 2012) a mixed methods research approach uses both methods either combined or to complement each other within the analysis of one project (Bryman, 2008). Hence, collecting data by using a mixed methods approach enabled the case study analysis to take a holistic perspective. Furthermore, it encouraged the use of multiple sources of evidences and methods to gain the anticipated deep understanding (Berg & Lune, 2012). However, according to Bryman (2008) there has been a wide discussion about the compatibility of both research methods within one project, which is only feasible by looking at the approaches from a purely technical rather than an epistemological standpoint. Combining qualitative and quantitative measurements can amongst others things generate a higher credibility to the findings or explain them by creating and confirming a hypothesis (Bryman, 2008). Hence, the discovery of the significant decrease of farming activities through interviews and observation was given a higher credibility through the analysis of satellite images and statistical data obtained from DFMR. Further, the reason for the decrease was sought to explain with quantitative measurements of water samples according to the hypothesis that phosphorus pollution through untreated sewage outlets triggered the seaweed die-off.

Triangulation

Furthermore, the use of a mixed methods approach allowed triangulating the research. Triangulation refers to the concept of using quantitative data to verify the qualitative findings and thus, complementarity to provide and back up different aspects on a subject (Bryman, 2008). Through the use of multiple sources of evidence, that is the use of qualitative semi-structured interviews and unstructured interviews of key informants as well as quantitative analysis of statistical data, water tests and satellite images, I could further ensure validity of the research.

Besides the methodological triangulation, the study also has made use of data triangulation. That is the use of different sources of data such as from academia (represented by IMS), from the public sector (represented by farmers and non-farmers), from the private sector (represented by the seaweed trading companies) and from the government (represented by the DFMR).

2.3. Data collection

The fieldwork was conducted during the sampling period of one and a half months in July and October 2014, preceded by initial field visits in June 2014.

In the urban area of Zanzibar town, English is an adequate form of communication. Hence, interviewed institutions mainly situated in Zanzibar's Stonetown, including representatives of the seaweed companies as well as governmental and academic institutions, could be interviewed in English without the need for translation. However, the main language spoken in Unguja is Kiswahili. Therefore a translator was necessary to conduct all individual and group interviews with the seaweed farmers, non-active farmers and buying stations in the rural areas. With recommendation from my supervisor and local supervisor, a female translator with a background in marine biology and experiences in field research was selected. This decision was based on the fact that seaweed farmers in Unguja are predominantly Muslim women, and a female translator was thought to help avoid gender biased communication problems. Further, with a background in marine biology the translator had a good understanding of subject related terms, which facilitated the communication process. Before conducting the research I was kindly assisted in acquiring research permission from the State University of Zanzibar (SUZA) and additionally from each village Sheha in Matemwe and Paje.

Interviews

The interviews are based on a nonprobability sample, because a complete list of the population was impossible to obtain. This is due to the fact that firstly no registration is needed to engage in seaweed farming, hence, a person can receive a patch and simply start farming. Secondly, people are more or less active farmers according to their current life situation and hence, people who stopped farming could still call themselves farmers. Both factors pose a challenge for obtaining an up-to-date list of farmers. The following study therefore identifies active and non-active farmers according to their current farming activity. Due to the use of a nonprobability approach the sampling is not representative of the seaweed farmers in Unguja as a whole.

The aim was to interview active farmers as well as non-active farmers to generate data about their reactions to shocks such as the seaweed die-off and hence, gain information about the resilience of farming activities. Therefore, I have applied a combination of convenience sampling, that is easily accessible subjects were interviewed, and purposive sampling, subjects were selected due to the special knowledge of the researcher (Berg & Lune, 2012). Most farmers only farm during certain hours and certain days during spring low tide periods. In order to include a wide range of farmers, the research was carried out during all days of spring low tide, from its beginning to the end. Whereas I conducted the research in Matemwe only with help of a translator, for the research in Paje my local supervisor advised me to employ a recommended research assistant to gain access to the population. The differences in the accessibility of respondents between Matemwe and Paje are grounded in the higher exposure of Paje to research activities and tourism, along with the timing. The research was conducted during Ramadan, which reduced the farming activities of women during low tide, especially during the end of Ramadan, which coincided with the field research in Paje.

For interviewing single farmers and groups of seaweed farmers, as well as non-active farmers, buying stations and companies, I applied a semi-standardized interview technique. This technique enables the comparison of answers among the respondents, but also leaves room to further explain keep a natural flow of the interview (Berg & Lune, 2012). In total I conducted 25 interviews with active seaweed farmers of which 14 are from Matemwe and 11 are from Paje; 19 interviews with non-active seaweed farmers of which 9 are from Matemwe and 10 are from Paje; 3 group interviews of which 2 are from Matemwe and 1 is from Paje; and 7 interviews with key institutions including the seaweed companies C-Weed, Zanea Seaweed Co Ltd. and Zanque Aquafarms Ltd.

For interviews with key informants as part of the pre-field visits as well as during the research period, I applied unstandardized qualitative interviews. That means a set of topics I was planning to discuss had been prepared, while the actual flow of the interview could be adjusted according to responses. In this sense new questions as well as follow-up questions could be generated during the interview and unknown topics or previous observations could be explored (Berg & Lune, 2012). I conducted 3 interviews with the DFMR, 3 interviews with a key informant seaweed farmer and 3 interviews with key institutions with a seaweed company active in Pemba named Birr Company Ltd. during pre-field visits, and throughout the research period with a representative from the international seaweed buyer named FMC and the Seaweed Centre in Paje.

Observation

Further data was collected through field observations on farming activities during pre-field visits between 28th June and 1st July 2014 as well as mapping of active and inactive farms in Matemwe and Paje with GPS data.

Satellite imagery

Satellite imagery was retrieved from Google Earth 2015 (including its "historical imagery") to analyse changes in farming areas in both villages. The images cover a time period of approximately 10 years and were chosen according to their time of capture to avoid biases in seasonal farming fluctuation. That is because Tanzania's coastal climate is characterised by two monsoon seasons, which control the temperature, rainfall and wind (Vice President's Office, 2006), and hence have a strong influence on seaweed farming. As a full analysis of the study area was too extensive and difficult to achieve due to the low resolution of the imagery, I chose a significant farming area in each village and compared the change of the areal cover over time. The area chosen for Matemwe shows changes from October 2007 to January 2015, and for Paje from September 2005 to October 2015.

Water samplings

Empirical data through water samples was used to further explore challenges for the resilience of seaweed growth on the east coast of Unguja. Water samples were tested for phosphorus levels in order to support or disprove the hypothesis of phosphorus enrichment through untreated sewage outflow. Two sampling sets were collected: the first one by me in October 2014, and the second one in June 2015 by my supervisor Ian Bryceson. The first collection was divided in 4 sampling sites, two in Matemwe and two in Paje with one relatively unpopulated and one populated area respectively. Each sampling consists of 5 samples starting with the first sample at the base of the beach, the second 10 metres from the bottom of the beach slope, the third 20 metres from the beach slope, the fourth 40 metres and the fifth 60 metres. For the first sampling in October I collected the samples during low tide at a site where water was visibly seeping out to the ocean. I took several precautions to avoid contaminating the samples. For example, I made sure to not touch the inside of the cap or the bottle neck, I avoided sediments in the water samples, I avoided standing against the current so that the sampling would not be contaminated by myself, then I pre-rinsed the bottles three times with the seawater before collecting the final sample. Finally I took the sample from about 10 – 20 cm under the water surface. The vials used for the sampling were glass vials with an aluminium cap, which are sought to have little to zero contamination risks (EPA Uited States Environmental Protection Agency, 2012). The vials had a volume of 7 ml, which was insufficient for the later testing that required 10 ml. Therefore one extra sample was used to fill up the missing amount. The samples were stored in a refrigerator until they could be tested within 3 weeks. The testing was carried out with a high range colorimeter (ppm), which resulted in no significant results. Hence, a second testing has been conducted with a handheld ultra-low range colorimeter (0 to populated site with 18 samples (three of each) starting at the base of the beach and then 5 metres, 10 metres, 25 metres, 50 metres and 100 metres away. Due to the distance between Norway and Tanzania, my supervisor, who had the possibility to return to Matemwe, carried out the second sampling and returned the samples to Norway for testing.

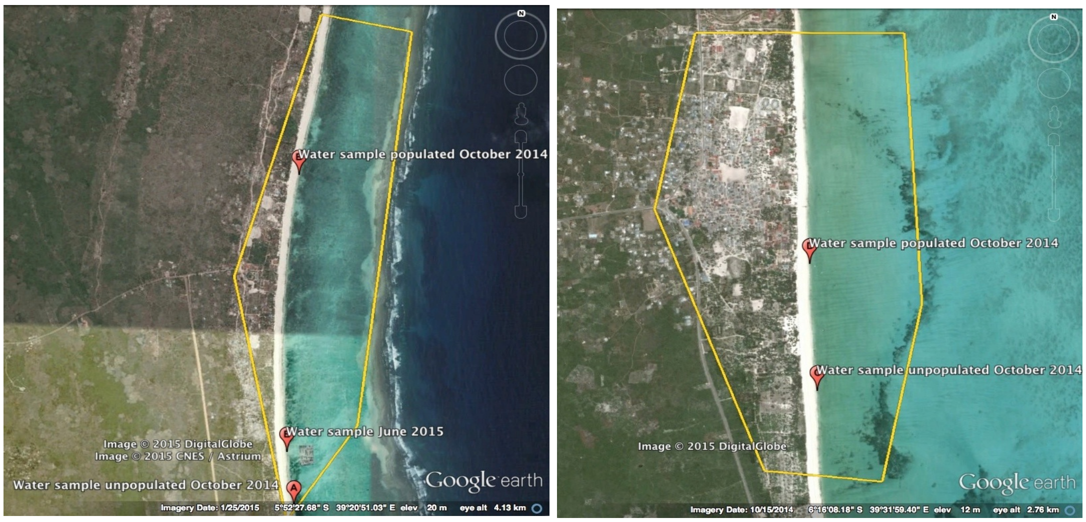


Figure 4: Study Site Matemwe inclusive water samples (left); Study Site Paje inclusive water samples (right)

Picture analysis

Further, I documented visible diseases and destruction of the algae in the field during July and October 2014. The field pictures were taken with a Nikon D3200 Sigma Telephoto 18mm – 250mm lens and a Fujifilm finepix XP70 underwater camera. Additionally I collected algae samples in order to take microscopic pictures, which were taken with an USB microscope Veho VMS 400x.

Secondary data

Additional data included the analysis of unpublished data obtained from DFMR during the time of the research in July and October 2014. Present data on seaweed production and export in Zanzibar was not available through FAO, or any other source, by the time of the research. Therefore, unpublished data obtained from DFMR was used for statistical analysis. However, updated data though FAO was made available during the write up process. A comparison between the unpublished and published data showed a marginal deviation. Therefore, data obtained from FAO was used as the reliable source in the discussion part whenever available.

2.4. Ethical considerations

Though I believe the study does not cover a sensitive topic nor does it ask for sensitive information, I clearly recognise that I am an outsider to the population and participants' lives. Therefore, it is difficult to judge which information is regarded as sensitive and which social or psychological consequences participating in my interviews might have. One example is question 16 when I asked about the main earner in the household, some respondents refused to answer, which can be a sign that it is a sensitive topic. Therefore, in allowance with the notion of doing no harm, I took several measures to avoid physical or emotional (Berg & Lune, 2012) harm to the subjects of my study (Berg & Lune, 2012). I informed all respondents about the purpose of my study as well as the possibility of known or unknown negative consequences of their participation before conducting the interviews. Due to the impracticality of using a signed consent statement at the research site and the possibility of illiterate respondents, I replaced it with a recorded oral agreement. Additionally, I tried to ensure voluntary participation and, especially with regards to the use of a research assistant who introduced me to potential respondents, an exercise of their own choice (Berg & Lune, 2012). Also I made sure that the respondents are of age and hence, allowed to participate. Hence, I stopped one interview with an underage woman after becoming aware of her age. Further measures have been taken to provide data confidentiality, such as the removal or coding of elements, which could help identify the respondents, as well as the secure storage of the collected data (Berg & Lune, 2012). In order to avoid gender related and social biases I used a female translator and I adapted a dress code that could be aligned with religious beliefs of the respondents.

Informed consent

My name is Stephanie Degenhardt, I am a student of the Norwegian University of Life Sciences in Norway and I am conducting research for my master thesis on social and ecological aspects of seaweed farming in Unguja. I would kindly like to ask you to answer questions about your life as a seaweed farmer (former seaweed farmer). Even though I am asking for your name your identity will be handled confidentially and will only be known to me, my translator and my supervisor professor Ian Bryceson. I will lower the risk of identifying you as much as possible however there remain a few risks. The data will be published as part of my study. Do you understand this information? Are you willing to answer my questions as an exercise of your own choice? Do you agree with me recording the interview for further analysis?

2.5. Limitations

The most significant limitation to my research can be seen in the language barrier between the translator, the respondents and myself. Even though I tried to use an understandable language, neither the translator nor I are native English speakers. Hence, misunderstandings in wording as well as information losses may have occurred by translating from Swahili to English and vice versa. Furthermore, the inexperience of the translator in conducting qualitative interviews also posed a limitation to the study. For example after conducting several interviews the translator used common answers as examples or suggestions for answers and hence biased originally open questions. After recognizing this I had to remind her to only translate what I said and what the respondents said. I further tried to minimise the mistakes by listening to the records and pointing out eventual errors.

The field research took place during Ramadan (June 28 to July 27), which, with a predominantly Islamic population, posed a difficulty to the accessibility and availability of the respondents. For instance, hard work was reduced due to the strains of fasting, and women, who are traditionally involved in preparing the food for the feast after sunset, were only available during the daytime, to a limited extent including my translator. In Matemwe, women were accessible mainly at the beach and farming sites and available to be interviewed while they were working, however this limitation posed a bigger problem in Paje. Firstly, the research in Paje took part during the end of Ramadan meaning women were busier preparing for Eid celebration, which reduced their availability. Secondly, farming activities in Paje seemed generally lower and women were engaged in other activities than farming, reducing their accessibility. Hence, a research assistant was employed which led to different sampling methods among the villages. employed which led to different sampling methods among the villages.

With regards to the use of a research assistant the challenge arose in biases of the sampling. Although it seemed that he chose the respondents randomly as instructed, respondents may have felt pressure to participate in the research. I have tried to overcome this ethical and methodological limitation by conducting each interview in absence of the research assistant as well as carefully explaining the purpose of my research and their right of refusing to answer.

The data obtained from DFMR about production figures for Zanzibar was marginally different than the data published by FAO in late 2015. Similarly, GPS data used for mapping active and inactive farms were not reliable due to the inaccuracy of the used GPS measurement.

3. Results

The data presented below incorporates qualitative interviews of active and non-active farmers, buying officers and representatives of local companies, the state and academia as well as own observations; in addition, quantitative measurements of water pollution, analysis of satellite imagery and unpublished statistical data received from DFMR. In order to display the data in a logical manner, which will further help to assess the SES, this section is organised in two parts. The first part presents recent developments of key factors influencing the SES in Matemwe and Paje; the second part will show historical key social-economical and ecological characteristics of the seaweed farming system of Zanzibar.

3.1. Present features of SWF in Matemwe and Paje

Environmental characteristics

Farmed species and varieties of seaweeds

In assessing the farmed species and varieties of seaweed, most respondents and all interviewed companies said they had only used one variety, namely "spinosum" (commercial name for *E. denticulatum*), however they tried to farm "cottonii" (which is the commercial name for *K. alvarezii*) without success. A respondent from Zanea further claimed to use "a variety of Eucheuma called median median, a new species growing in the Philippines", whereas a respondent from Zanque said, "now we found a species with more strength, which is used in Pemba called kikarafuu".

Farming methods

The farming technique used in both villages is called "off-bottom" farming. This method takes place in shallow water using poles and ropes to tie the seaweed on (see Figure 5 A). Although the companies stated that they advise farmers to move their farms to deeper waters during rainy season to avoid a seaweed-die off and be able to keep seedlings for a new farming season, none of the interviewed farmers confirmed to do so. A respondent from C-Weed explained that the reason behind this is that "women cannot swim or are old and weak". However, none of the companies stated to have facilitated such a shifting of farming techniques, nor supported the farmers in Unguja with necessary materials such as a boat. A field visit to Mafia Island in July 2014 showed that seaweed farmers applied the floating technique in which they tie empty plastic bottles are tied to the ropes to enable farming in deeper water (see Figure 5B).

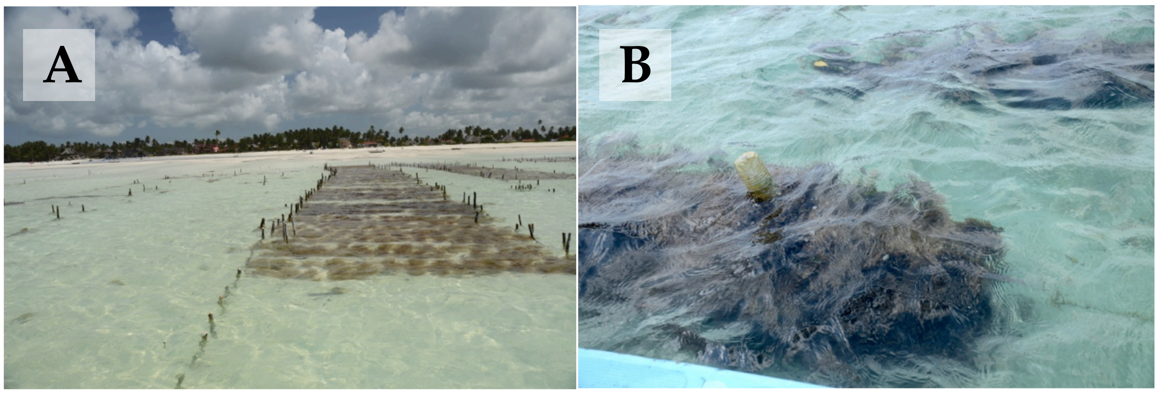


Figure 5: Farming techniques. A: Off-bottom technique in shallow intertidal zone in Paje; B: Floating-line techniques in deeper water in Mafia

The health appearance of seaweeds and disease occurrences

During the time of the field research in July and October 2014 a wide seaweed die-off occurred. In contrast to production and export figures until 2013, little seaweed was farmed in 2014. Thus, empty farms, meaning poles without ropes and seaweed, or farms with very little seaweed could be observed. The seaweed itself was characterized by loosening from the ropes, signs of grazing, bleaching and tissue loss as demonstrated in Figure 6.

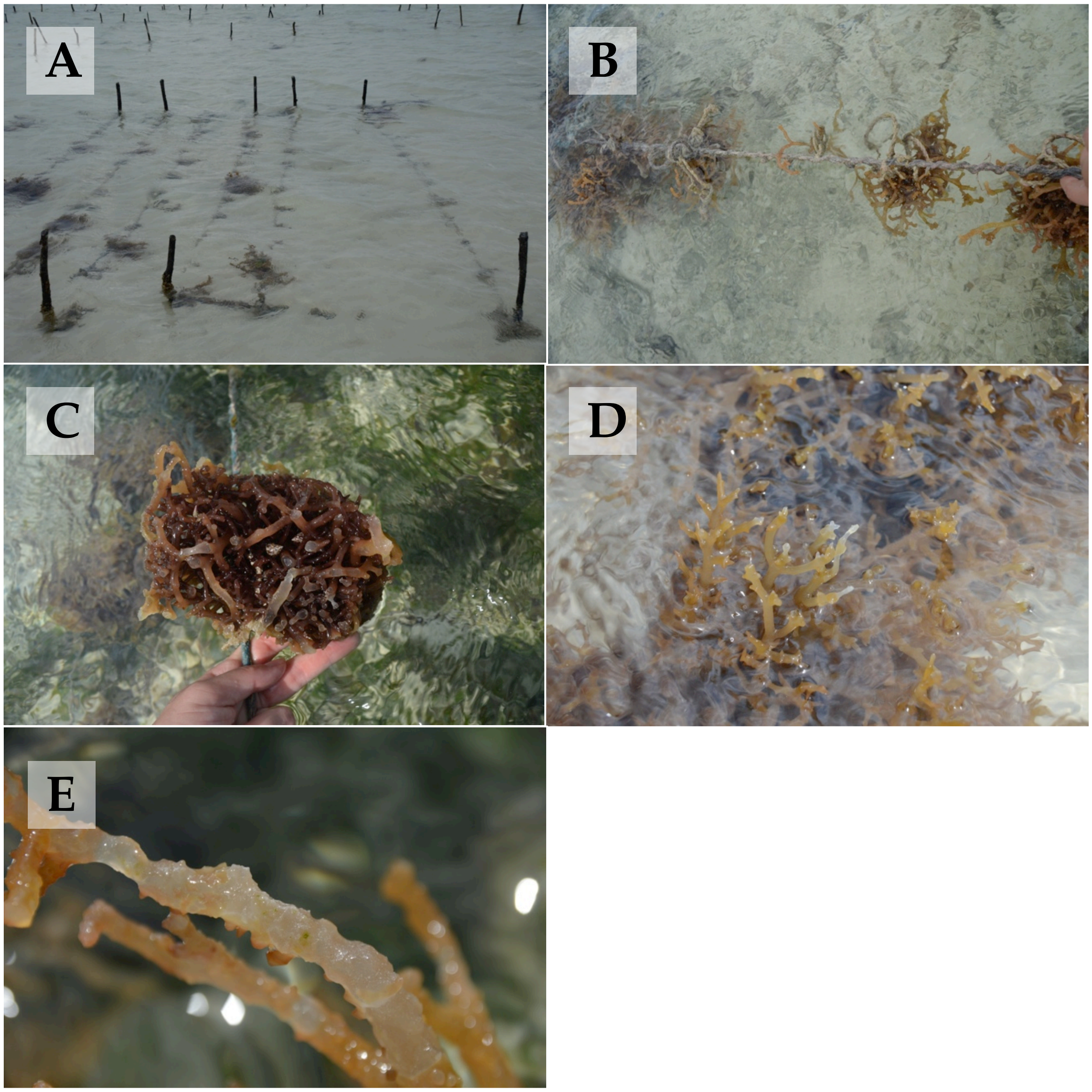


Figure 6: Appearance of *E. denticulatum* in Matemwe, July 2014. A: Abandoned farm with unhealthy seaweed; B: Seaweed loosening from rope; C: Severe signs of grazing with all tips bitten off; D: White tips; E: Severe tissue loss

Similarly, seaweed farms in Paje were scarce and the seaweed found showed signs of bleaching, visible epiphyte infestation and further sand and mud like coverage on the thallus.

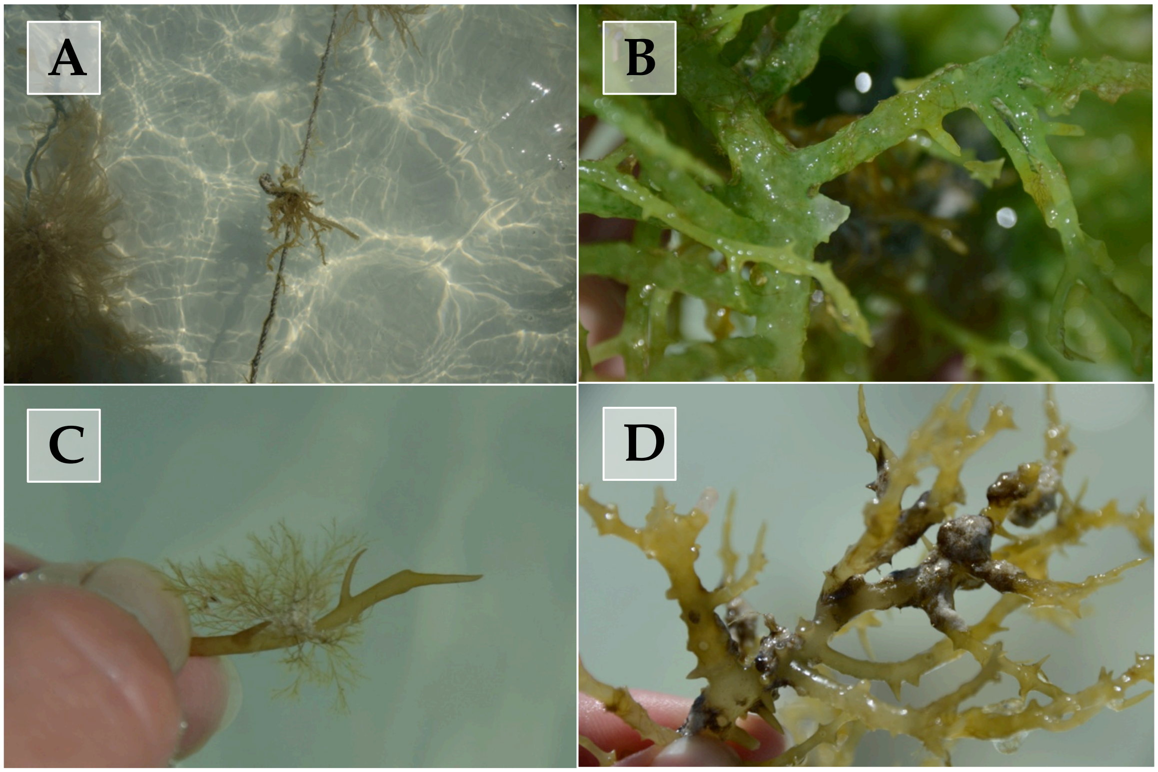


Figure 7: Appearance of *E. denticulatum* in Paje July 2014. A: Slow growth of seaweed and loosening from the rope; B: Signs of bleaching; C: Severe growth of epiphytes; D: Silting

Seaweed collected in Matemwe in October 2014 was further photographed through a microscope to document its health appearance (see Figure 8). Reccuring signs of unhealthy seaweed included bleaching of thallus tips, tissue loss, epiphyte infestation and signs of grazing with flat removal of tissue as well as lost tips.

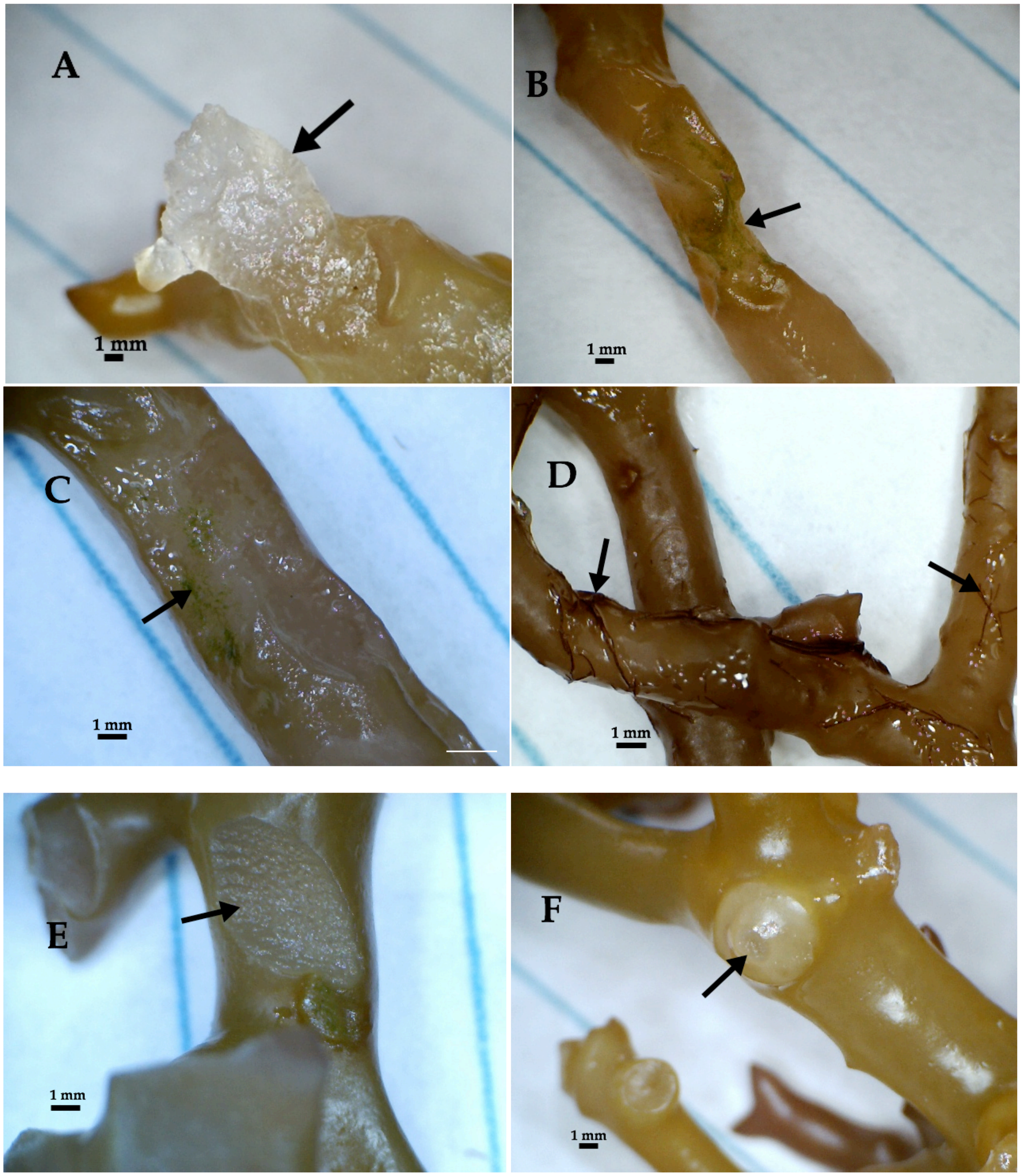


Figure 8: Microscopic pictures of *E. denticulatum* in Matemwe October 2014. A: Bleaching of ends; B: Loss of tissue; C: Epiphytes in its beginning growth level; D: Severe growth of epiphytes; E: Flat removal of tissue; F: Tips are bitten off.

Furthermore, several snails and hermit crabs were found in the middle of some seaweed plants, as shown in Figure 9. One farmer in Matemwe identified sea urchins of the species *Tripneustes gratilla* as a grazer on her seaweed farms. In addition, the same type as well as another common sea during observations. Both species are abundant at the east coast of Unguja, especially in Matemwe.

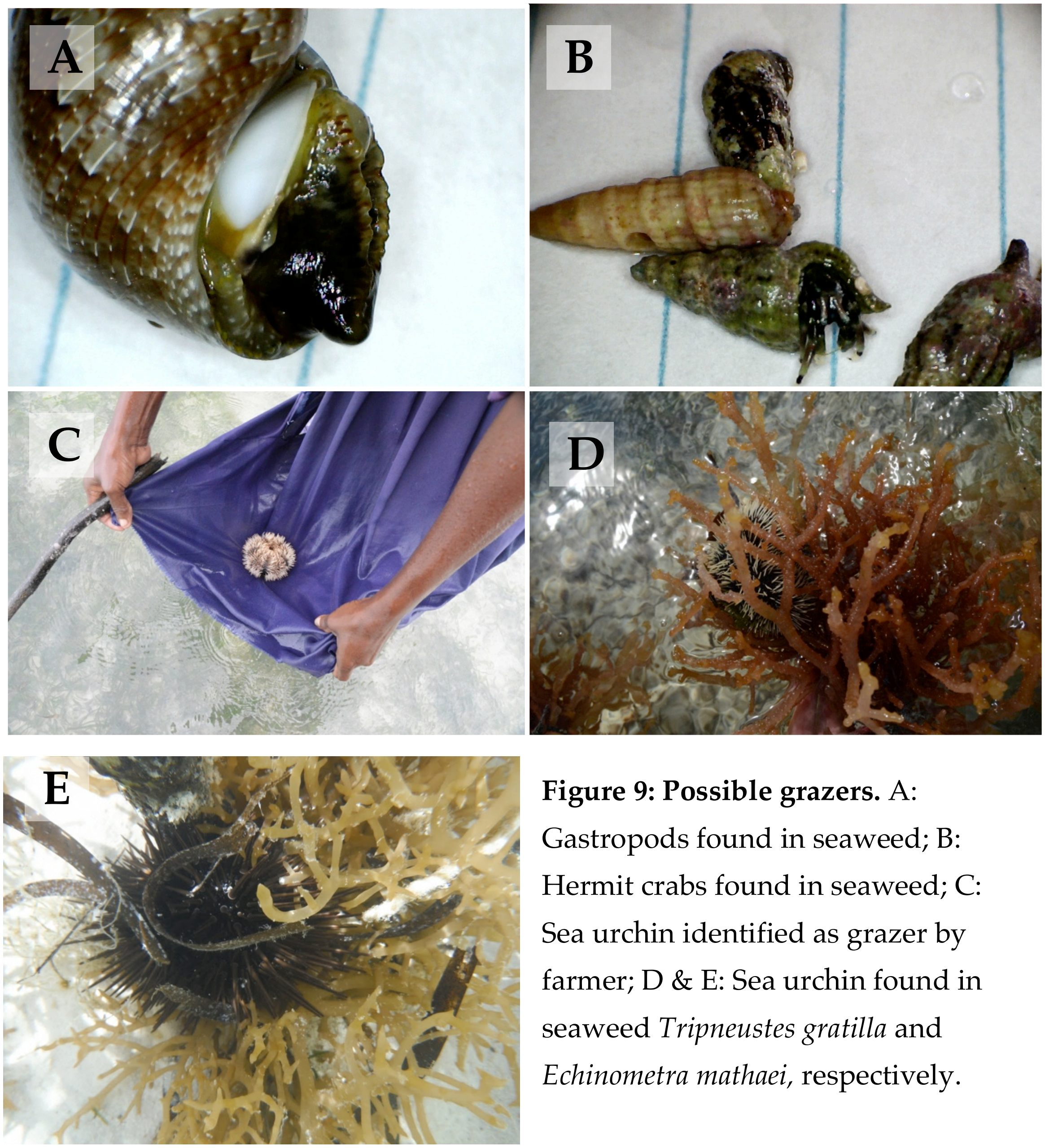


Figure 9: Possible grazers. A: Gastropods found in seaweed; B: Hermit crabs found in seaweed; C: Sea urchin identified as grazer by farmer; D & E: Sea urchin found in seaweed *Tripneustes gratilla* and *Echinometra mathaei*, respectively.

Farmers were asked if they had experiences with seaweed disease and how they would describe them (see Figure 10). Overwhelmingly, all farmers had experienced seaweed diseases and die-offs. Some respondents, as well as representants of some companies made remarks that diseases are a seasonal occurrence, which happens approximately 2 – 3 months per year, meaning during the rainy season. An in-depth interview with a key respondent revealed that a similar seaweed die-off occurred in 2012, however it did not multiple answers to describe the experienced disease, which were very similar in both villages. However, as Figure 10 shows Matemwe experienced more frequent signs of bleaching and occurence of grazers, whereas Paje showed higher epiphyte infestation, resulting in a mud or sand like consistency on the surface of the seaweed. These descriptions confirm some of the results on seaweed disease and possible grazers as shown in Figure 9. Whereas the farmers could not answer the question why these diseases and die-offs occur, a representative of Zanque said that the problem was caused by a mixture of factors such as “changes in water temperature, rainwater, shallow water, sunlight and probably wind”.

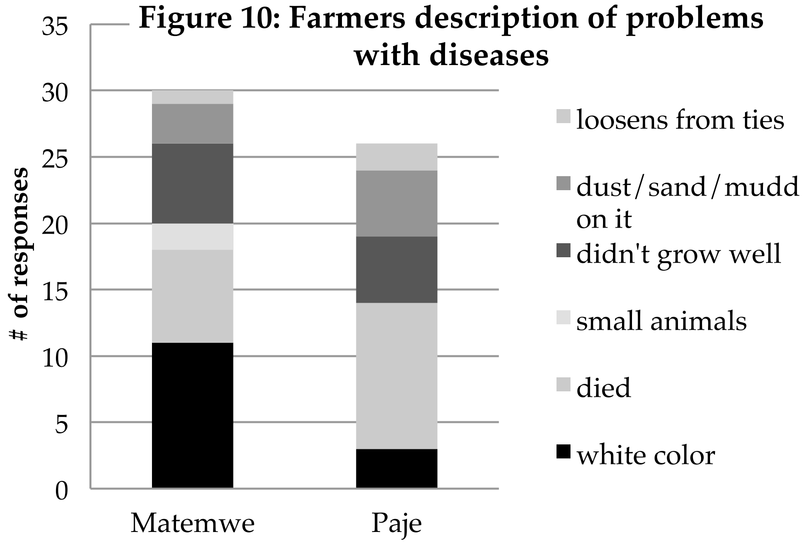
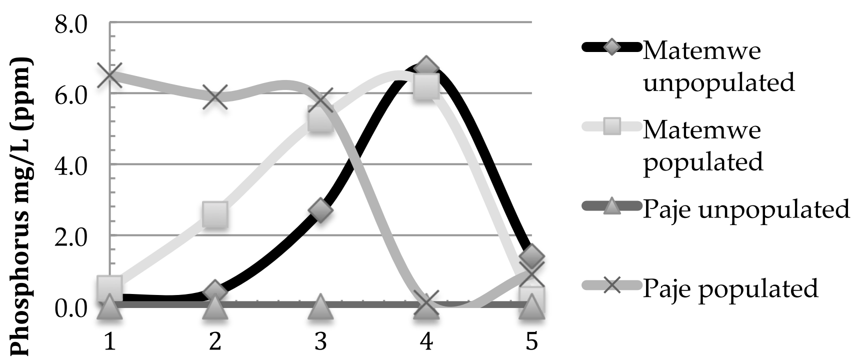


Figure 10: Farmers description of problems with diseases

<u>Phosphorus levels</u>

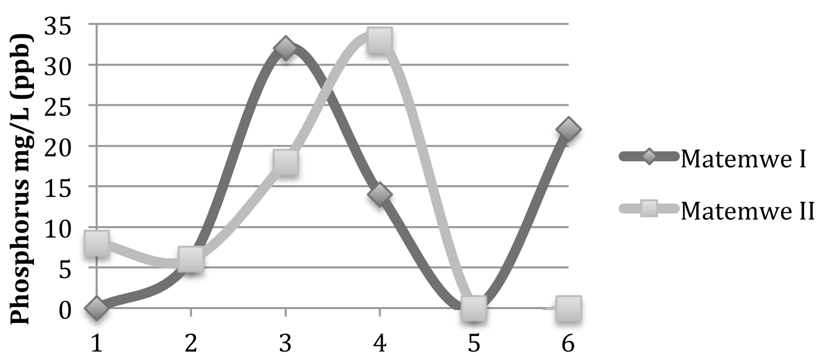
A total of five phosphorus measurements were carried out to analyse the water for phosphorus enrichments in populated and unpopulated areas in Matemwe and Paje, respectively (see Figure 11 and 12). The first samples taken in October 2014 did not show a substantial enrichment in P. The sample “Matemwe populated” showed a P value of 0.5 ppm at the bottom of the beach slope, and increased with growing distance from the beach into the water up to 6.2 ppm at 40 meters, before it dropped to 0.2 ppm at 60 meters. In contrast, the sample “Paje populated” had a high P value of 6.5 ppm at the bottom of the beach slope up to a distance of 20 meters into the water, but suddenly dropped to a P value of 0.1 and 0.9 at 40 meters and 60 meters from the beachslope, respectively. After receiving results with inconsistencies and partly very low P values in October 2014, a fifth sample was taken in June 2015 in Matemwe with a more sensitive measurement of ppb. A significant P enrichment was further absent in the new sample. Thus, P concentration showed a value between 0 and 8 ppb at the bottom of the beach slope up to 10 meters into the water. Although the value increased to 33 ppb at 20 to 40 meters from the beach slope it fell again to 0 ppb at 60 meters.

Figure 11: Measurements of total phosphorus (ppm), October 2014



Distances are 20 meter beginning with the bottom of the beach slope.

Figure 12: Measurements of total phosphorus (ppb), Matemwe June 2015

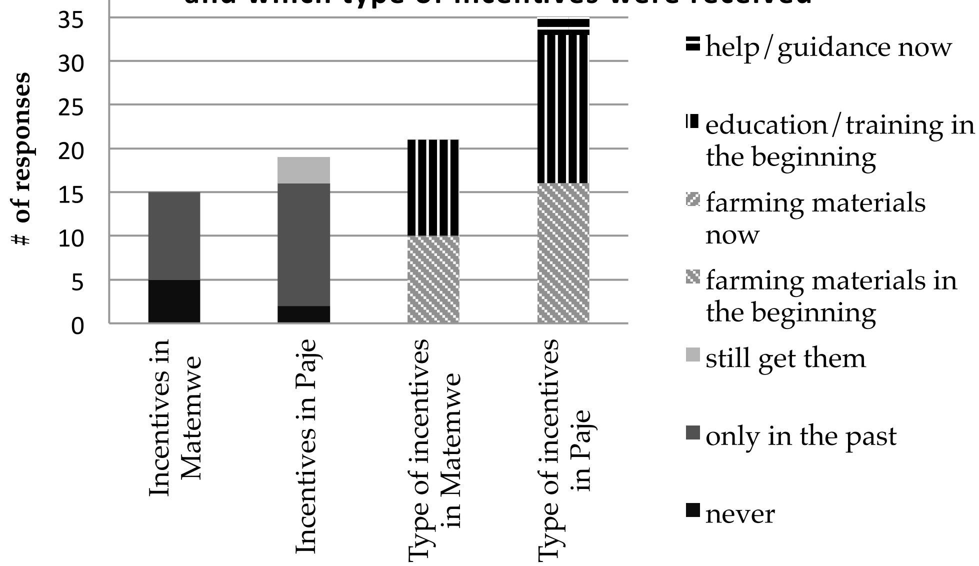


Knowledge

<u>Knowledge transfer</u>

When seaweed farming was introduced to Unguja in 1989, farmers were trained on how to farm using the off-bottom technique and given farming equipment to set up farms. As farming activities spread along the east coast of Unguja, people began to learn farming from each other. Thus, seaweed experience or training. Therefore, it is surprising that only 2 respondents said that they continue to get help and guidance, as opposed to 28 farmers who only received help at the beginning of their farming activities. In particular, when asked if they received help with the current seaweed die-off some respondents said that the companies knew about the problem, but they did not help them. Similarly, none of the farmers stated that they currently receive farming materials, which were given out at the beginning of farming activities in Unguja and included ropes and tie-ties.

Figure 13: Farming incentives divided by whether and which type of incentives were received



A representative from C-Weed confirmed that training on how to farm and dry the seaweed was given at the beginning of farming efforts, however not anymore. He went on to say that they stopped providing materials, which they used to give out for free for increased farming efforts. However, a spokesperson from Zanque noted to provide continuous training and guidance on farming and post handling in Pemba, where the company further "gives out rainboots and rubber boats for harvesting and additionally supports the communities by building stairs, water wells and schools" (pers. com.). When asked if similar incentives are carried out in Unguja, he said they were not.

Another form of incentive and knowledge transfer is the facilitation of technological improvements. A reccuring problem mentioned by all actors have problems drying the seaweed, especially during rainy season, buying officers and company representatives claimed to receive insufficiently dried or unclean seaweed. One buying officer claimed that some farmers deliberately sell insufficiently dried seaweed to receive more money due to the higher weight of the seaweed. Further, one company spokesperson from Zanque mentioned having had problems with selling the seaweed due to low quality caused by inadequate drying and cleaning processes. However, besides education on post-harvest handling of the seaweed, none of the interviewed farmers had access to adequate drying locations, cleaning tables or a drying machine such as that present in the Seaweed Center in Paje (see Figure 14 B). Hence, farmers stated to usually dry the seaweed either by hanging it over a pole or by placing it on a coconut mat on the floor, or on stones to avoid mixing it with sand.

Figure 14: Drying of seaweed. A: Drying of seaweed in Paje village; B: Drying machine in Paje Seaweed Center.

Institutional structures

<u>Institutions</u>

A regulation on free trade, which broke down the monopsony character of local markets by allowing several companies to enter one village, was identified by all interviewed companies as the starting point for deceasing markets shares in Unguja. All respondents agreed that with the regulation in 2006 all buyers stopped providing material to the farmers and as a result the production in Unguja declined. According to spokespersons from C-Weed and Zanea, the reason behind withdrawing from providing equipment was that other companies who were not investing in that village would buy seaweed for a higher price. That was possible, firstly because they would not have expenses for buying expensive farming materials; and secondly farmers were not loyal to the company they received the materials from and hence sell their seaweed to the one who could offer the highest price.

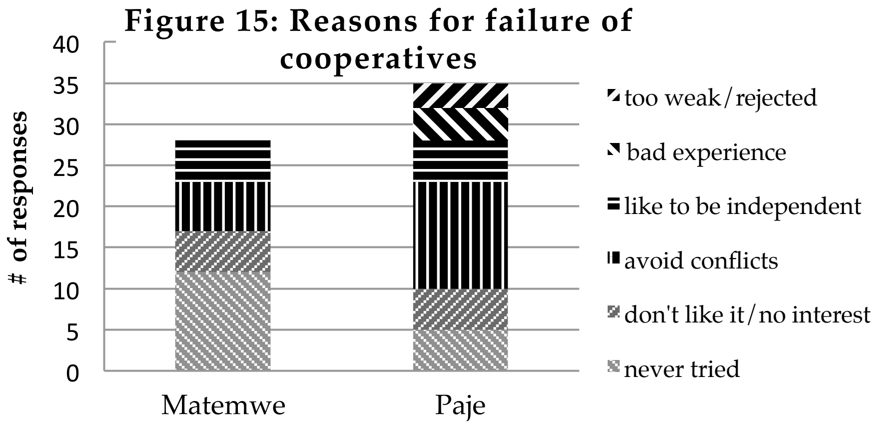
The DFMR represents an important link between farmers and buyers. According to a DFMR representative the government encouraged and facilitated the formation of farmers organisations, such as a seaweed committee. He pointed out that the committee was sought to assist farmers to work properly and transform into a unit rather than imposing a cooperative. But after being successful at beginning, lack of education of the leadership on how to maintain the committee broke it up.

Cooperatives among farmers

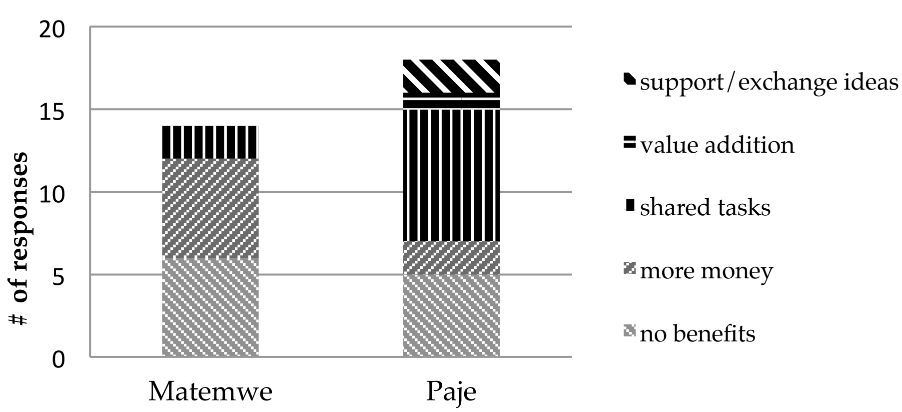
It was a common occurrence that farmers would either farm alone or with a relative, which was supported by a farmer's statement that everyone farms alone and they are lacking unity. Further, the common perception of farmers' cooperatives was predominantly negative even though none of the farmers interviewed were part of a cooperative and only three respondents had been in a cooperative before, namely Furahia Onawaka Group and Paje women's cooperative. When asked for the reasons behind why so many farmers rejected cooperatives, lack of interest as well as avoiding conflicts and misunderstanding were among the most frequent answers (see Figure 15). A key respondent in Matemwe also mentioned bad experience with cooperatives in which farmers lost all their investments due to corruption as a reason to neglect further participation. Similarly, farmers in Paje said to know other farmers who were involved in the Seaweed Center in Paje[1] but were kicked out after the Center was restructured. Further, some respondents went along by saying "I do not like it, because some people are lazy", indicating selfish reasons or expressing insecurity by saying "I am too weak, I want to

[1] After personal communication with a representative of the Center they clarified that the centre is not a cooperative, but a private entity and as such, they had to decrease their number of staff due to economical reason. However, they mentioned a correspondent NGO as the major shareholder of the Center. However, none of the interviewed women in Paje was involved in the Centre's activities nor had access to their facilities. Moreover, anticipations towards the Centre were mainly negative. Whereas the conflict between both parties needs a

decide on my own when to farm" (interview active farmers in Matemwe and Paje, respectively).



Besides the negative perception of cooperatives and the notion that more than one third of the respondents did not see any benefits of them as shown in Figure 16, respondents also associated a higher income and shared tasks with cooperatives.



Farmer-buyer relationship

Attitudes encountered between the farmers and buyers were generally characterized by bad communication or even blaming. For instance, one buying officer working for C-Weed stated he get blamed from farmers for low prices, but also from the company over inadequately dried and cleaned seaweed. Another repeteadly occurring example was that farmers often felt left alone with the seaweed die-off even though they reported the problems to buying officers. The companies however felt they gave them support as they were searching for solutions, for example by working together with IMS.

Similarly, whereas farmers stated to not have received help with seaweed die-offs, buying officers and companies claimed to encourage farmers to shift farms and train them how to tie seaweed in high tides. In that notion one company representative from Zanque said that contrary to farmers in Unguja, farmers in Pemba adapt help.

Furthermore, all spokesmen from the three companies went on to point out their disappointment with farmers in Unguja by saying that farmers here were more discouraged to farm because they have money now, or other means of income. One spokesman from Zanea claimed farmers in Unguja are disloyal as they would sell their seaweed to the person with the highest price. A similar statement was made by a farm technician who said about farmers in Unguja that "farmers can earn 50,000 – 75,000 TZS per month, but what they do is a hobby, not serious farming" (pers. com, FMC representative).

Socio-economical characteristics

Profitability

The value addition of seaweed farming takes place at the refining process in which carrageenan is extracted. Whereas 1 kg of dried seaweed raw material is sold for 0.31 USD, the price for 1 kg refined *E. denticulatum* was 560 USD as of 2014 (per. com. Birr). However, no refining processes, and hence value addition, were taking place in Tanzania by July 2014. When asking the companies for reasons behind this, they said that it required big investments in semi-processing as well as a bigger quantity of raw seaweed to make the processing profitable.

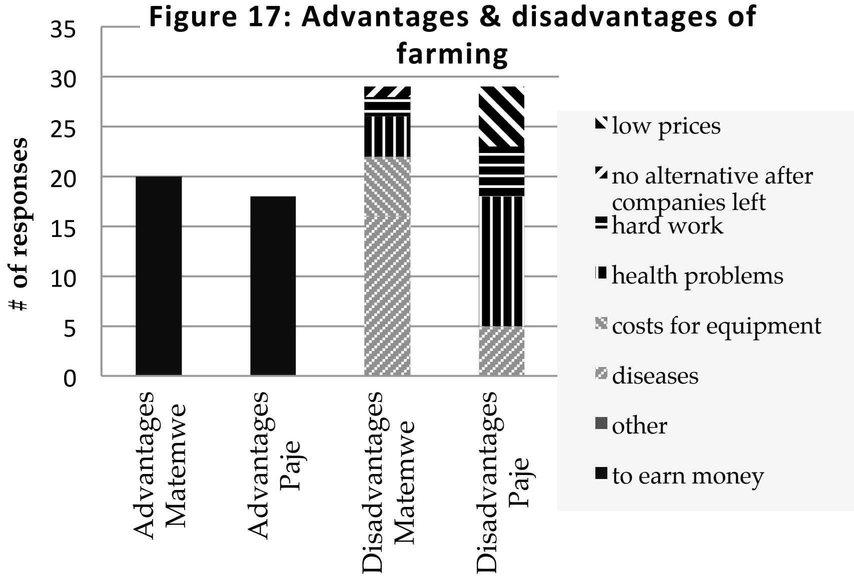
Seaweed production in Unguja is relatively low compared to Pemba. However, a spokesperson from DFMR stated that the production in Unguja was not going down, rather it was continuously low. On the contrary, companies claimed to invest a lot in Unguja, partly because Unguja was more favourable due to imposed transport costs implied in the production in Pemba. As a representative from C-Weed pointed out, the international harbour is in Unguja, such that the companies could not leave there entirely.

However, all three interviewed companies saw a profitable alternative in Pemba, where already 80% to 95% of their production took place. Besides the already mentioned perception that farmers in Pemba were more productive, a reason for the shift was to avoid conflict with the tourism industry which already took some areas for farming away (pers. com. farm technician FMC).

Motivation

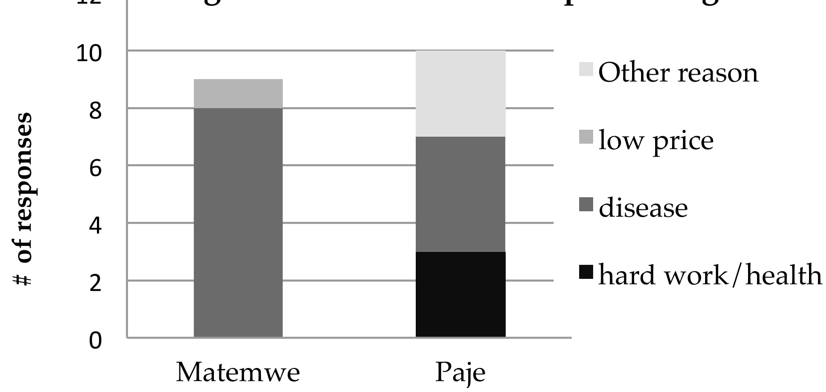
Across all interviewed farmers, active as well as non-active farmers in Matemwe and Paje, they named earning money as an advantage of farming seaweed. On the contrary, low prices and high equipment costs were identified as a problem, however, even more so were health problems associated with farming activities and disease outbreakes.

Figure 17: Advantages & disadvantages of farming



Although income was pointed out as a clear advantage of farming and low prices are considered a disadvantage, low prices were named as a less common reason to stop farming. Rather, seaweed diseases were pointed out as one of the driving causes with 8 out of 9 responses in Matemwe and 4 out of 10 responses in Paje.

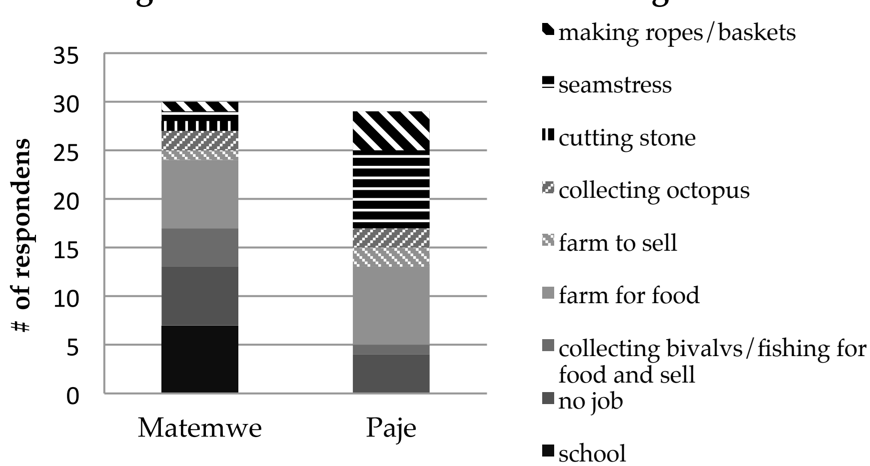
Figure 18: Reasons to stop farming



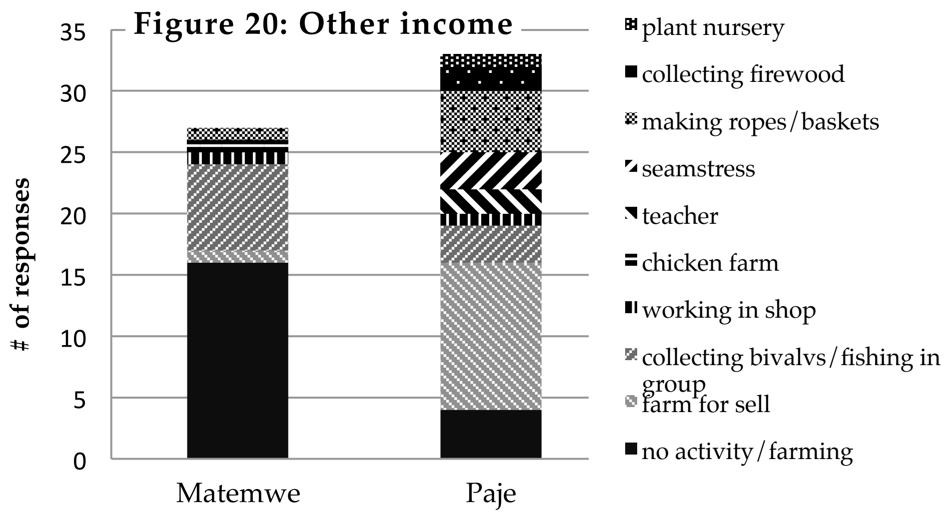
<u>Profitable alternatives</u>

Farmers, both active and non-active, were asked what activities they were engaged in before and during, or after farming. As shown in Figure 19 the majority of respondents in Matemwe and half of the respondents in Paje only engaged in non-income generating activities before farming, displayed without a pattern. Such activities were typically farming on the fields for food or collecting bivalves also for food only. Typical income generating activities were petty businesses such as working as a seamstress, making ropes and baskets or collecting octopus to sell.

Figure 19: Activities before farming



Although the number of respondents who did not engage in any income generating activity after stopping farming was still high, especially in Matemwe, there seemed to be a general increase in alternative activities. The group, as displayed in Figure 20. Further, activities in Paje seemed to be more diverse and respondents often engaged in more than one other activity.

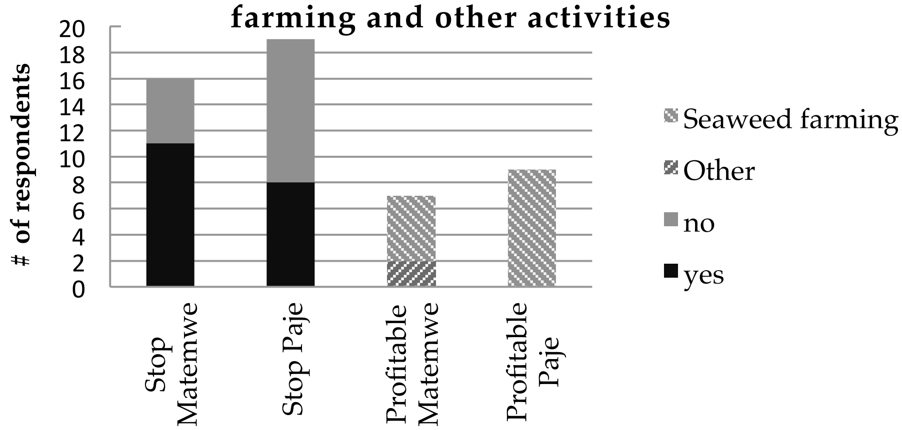


Women who fished together in a group also stated to have started fishing together when the seaweed die-off occured. Accordingly, all women decided together to stop farming and start fishing as a group. Observations of the women fishing showed that they went during low tide to fish in the fringing reef by making a big circle and chasing the catch into the net through movements and noises. Afterwards, the women shared the catch equally among each participant and further divide the revenue of the more valuable catch.

Figure 21: Women fishing group in Matemwe. A: Fishing women in Matemwe; B: The catch and revenue is divided among all

Farmers were further asked if they would stop seaweed farming if they had another activity, which would bring in an equal income. The displayed Figure 22 shows that approximately two thirds of the respondents would stop seaweed farming if they had an equal income-generating activity, whereas in Paje less than half would stop. Accordingly, one farmer in Paje went on to say that people cannot rely on only one job and hence she would not stop farming. Despite the high number of respondents who would stop farming almost all stated that seaweed farming was the activity which generated the highest income. However, some also mentioned that seaweed farming used to generate more income, especially when they did not have to buy their own farming materials.

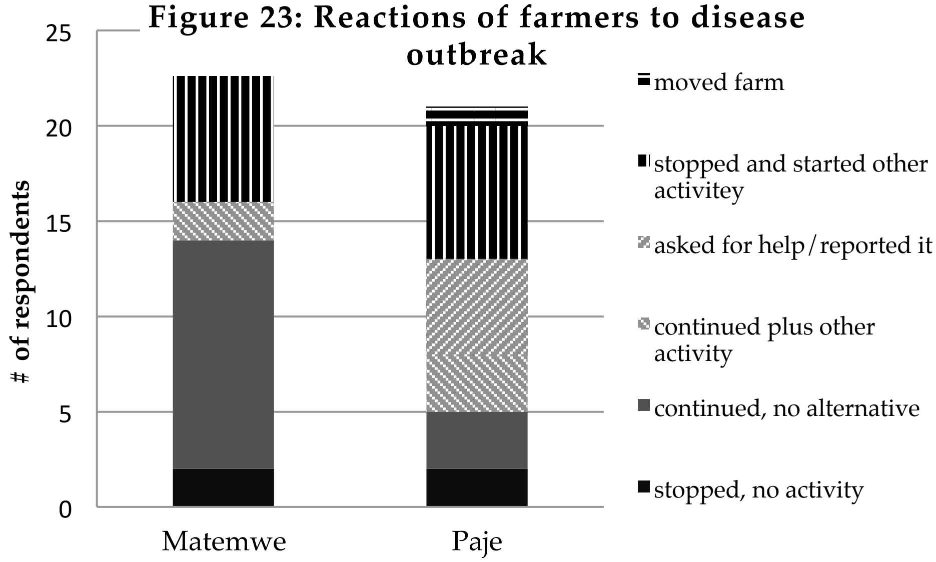
Figure 22: Comparison of profitability of farming and other activities



Disturbances

All active and non-active farmers interviewed mentioned that they experienced seaweed disease of some form. Figure 23 displays how the respondents reacted to disease outbreaks. The columns without pattern show non-monetary alternatives to seaweed farming, such as stopping without having another form of income or continuing farming despite the problems. Overwhelmingly more than half of the respondents from Matemwe stated they did not engage in other income generating activities. The columns with pattern show income generating alternatives, such as continuing farming plus engaging in other activities or stopping farming to start another activity. In contrast to Matemwe, three quarters of the respondents in Paje stated to engage in other activities. The buying companies on the contrary react to shocks by giving advice to the farmers through their buying officers and additionally work together with IMS to find solutions on tackling specific diseases such as ice-ice, as stated by a representative from Zanque. However, all three companies explained that they mainly produced in Pemba, which does not experience diseases.

Figure 23: Reactions of farmers to disease outbreak

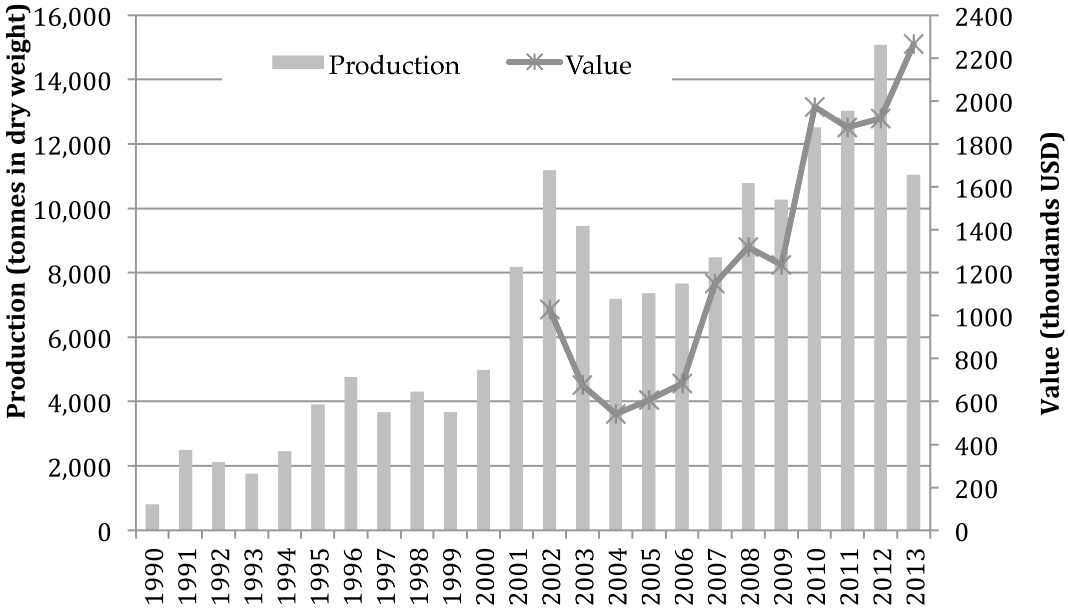


3.2. Historical development of key characteristics

Seaweed production

Seaweed production in Zanzibar grew steadily from 808 tonnes dry weight in 1990 to a high of 15,087 tonnes in 2012. However, fluctuation in production are visible throughout the 13 years of farming. Figure 24 shows that each new high in production is follwed by a decline, for instance minor declines in 1993 to 1,768 tonnes and in 1997 to 3,667 tonnes, but also more drastic declines in 2004 and 2013 when production dropped to 7,186 tonnes and 11,056 tonnes, respectively. Simultaniously, the production value steadily increased to a maximum of 2.2 million USD (3.7 billion TZS) in 2013.

Figure 24: Seaweed production in Zanzibar



(Source: Adapted from DFMR and FAO FishStats)

The seaweed production in 2013 totalled 8,418 tonnes dry weight. Most of it was produced in Pemba where seaweed farming began in 2002, and has steadily increased since. Only 2,637 tonnes dry weight were produced in Unguja, 109 tonnes of which were farmed in Matemwe and 56 tonnes in Paje. Zanea and C-Weed were the only companies which were actively producing seaweed in the villages of Matemwe and Paje in 2013 and 2014. In comparison, in 2012 four companies, namely Zanea, C-Weed, ZaScol and ZHS, and in 2011 five companies, namely Zanea, C-Weed, ZaScol, ZHS and Kai, produced seaweed in Paje and Matemwe.

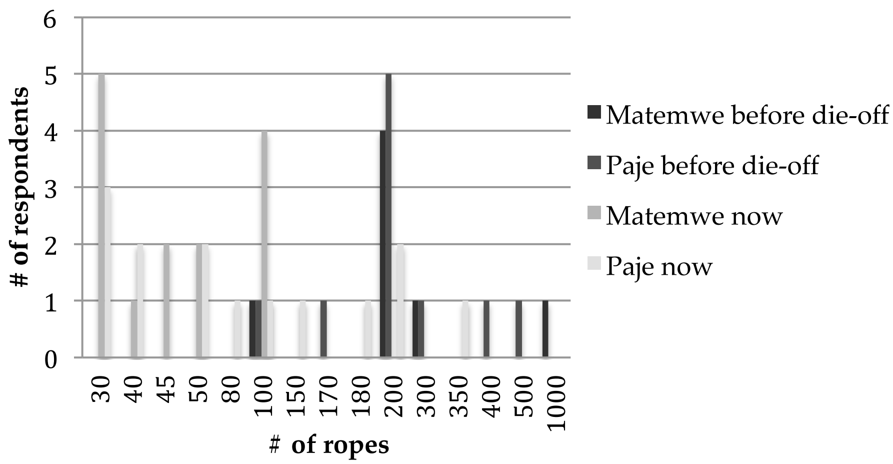
Year	Zanzibar	Unguja	Pemba	Matemwe	Paje
2013	11,055.89	2,637.74	8,418.15	109.96	56.06

Table 1: Production of seaweed in tonnes dry weight in 2013

(Source: Adapted from DFMR)

Farmers were asked to state their farm size before the seaweed die-off which occurred between 1 and 3 years ago, compared to at the time of the research. As Figure 25 shows, the majority managed more than 200 ropes before the outbreak of the seaweed die-off. As of July 2014 most farmers in Paje and all famers in Matemwe had less than 100 ropes, most of which were not used for farming, but to keep seedlings for a new start when the farming conditions would improve.

Figure 25: Farm size before the seaweed die-off and during time of research



Number of farms and farmers

In 2011 the DFMR counted 732 seaweed farmers in Matemwe and 259 farmers in Paje, all of whom were women (DFMR pers. com.). However, observations during the research period in July and October 2014 showed a much smaller number of farmers. Women participating in bivalve and octopus collection, along with fishing in women's groups, have dominated the activities in the intertidal zone during low tide (own observation). Similarly, larger numbers of inactive than active seaweed farms were observed as demonstrated in Figure 26.

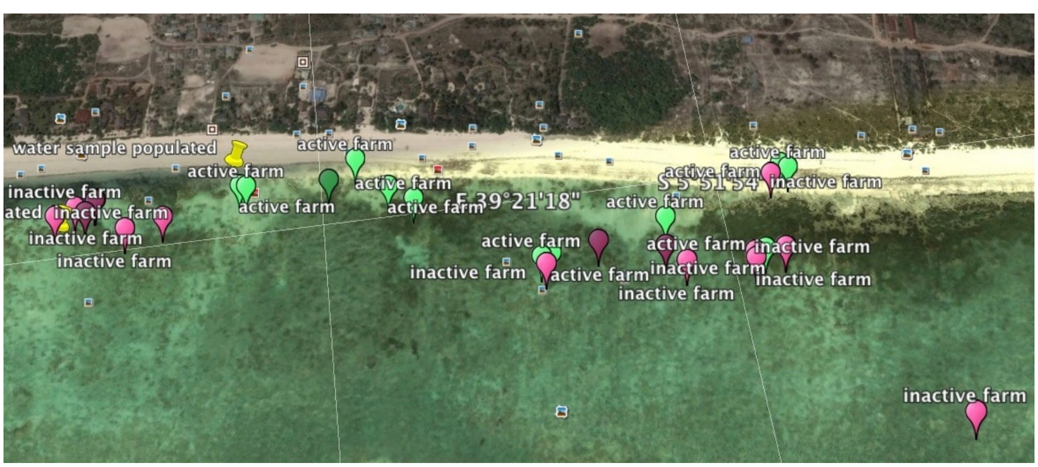


Figure 26: Active and inactive seaweed farms documented with GPS in Matemwe in July 2014

A comparison of satellite imagery retrieved from Google Earth from 2005 to 2015 showed the decrease in farming activities (see Figure 27). Whereas fluctuations occured over time a stark contrast was visible in the time period 2012 to 2015. Seaweed farms which have been relatively stable within a time period of 7 to 8 years virtually disappeared from 2012 to 2015.

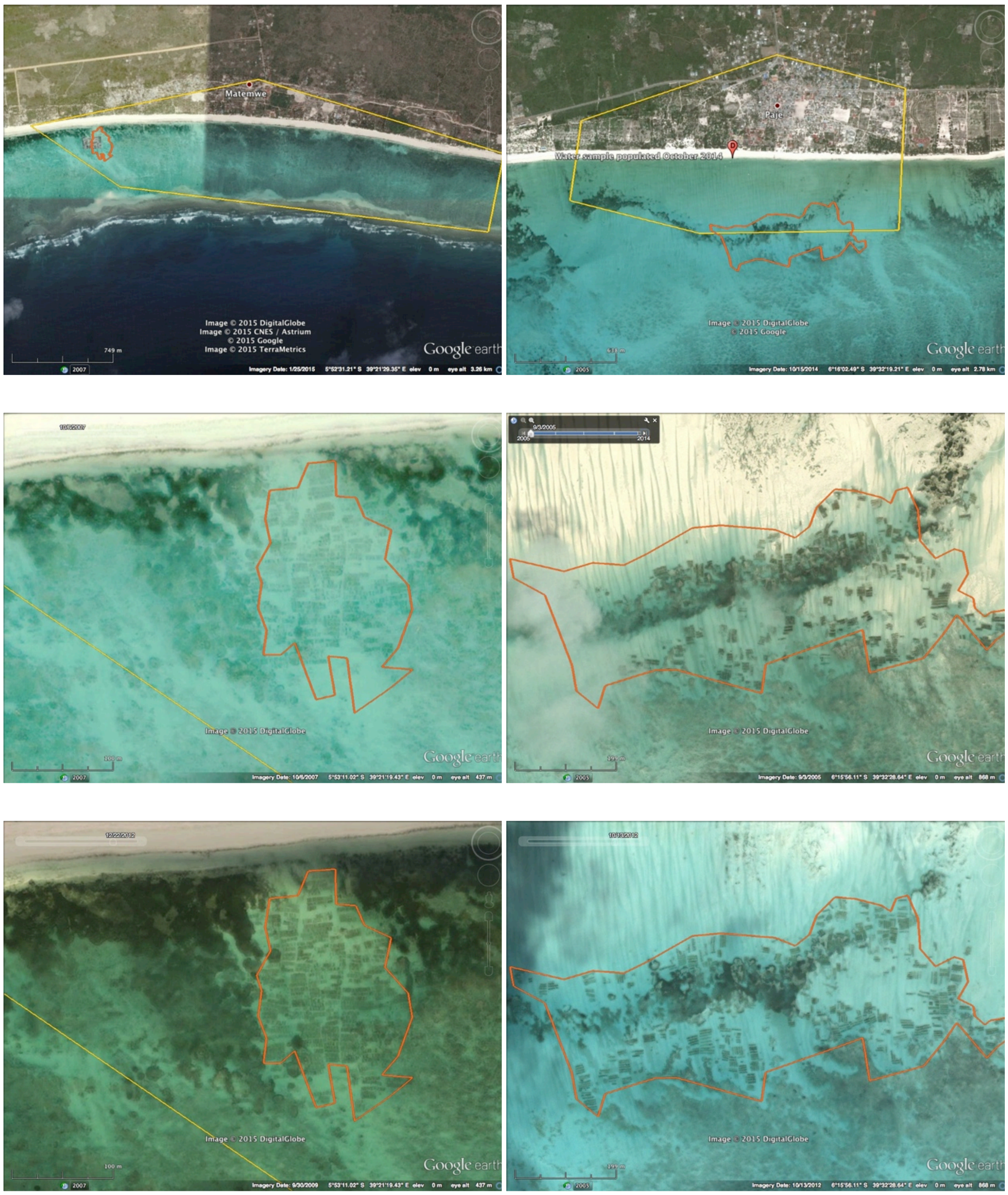
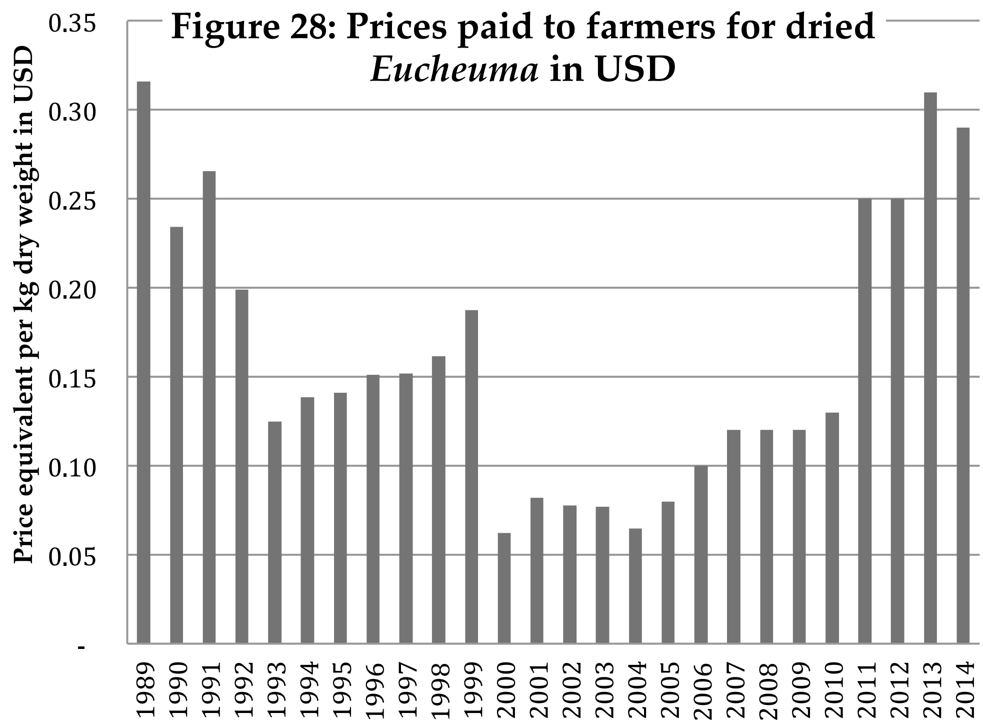
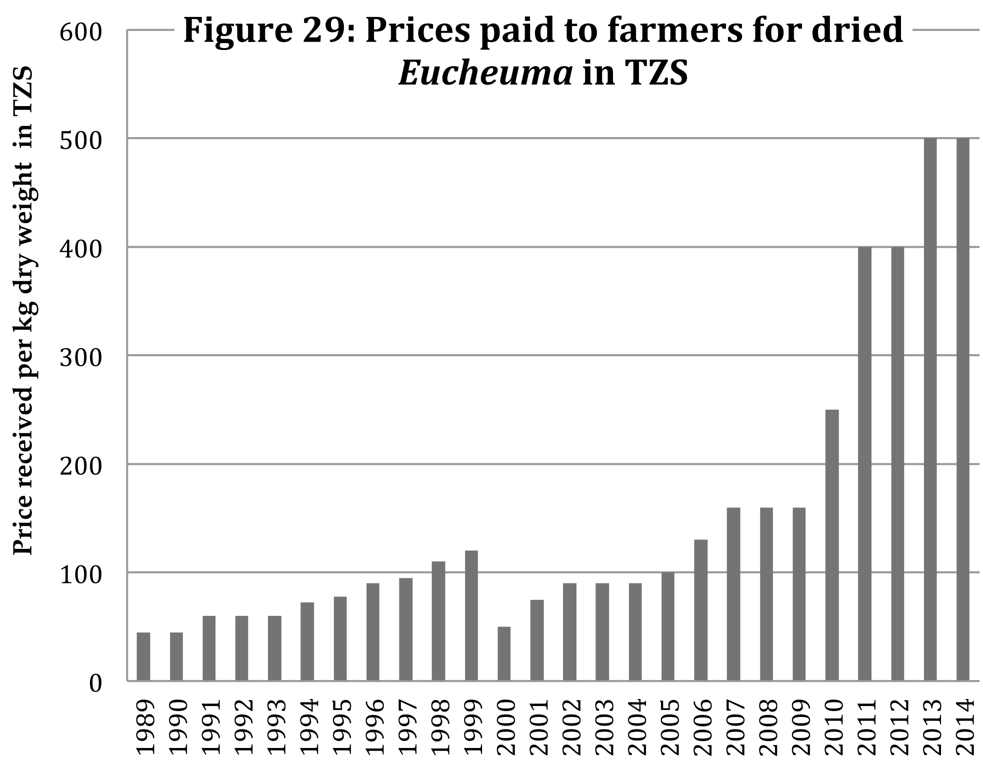


Figure 27: Seaweed farms in Matemwe and Paje. A: Area of analysis in Matemwe; B: Google image October 2007; C: Google image December 2012; D: Google image January 2015; E: Area of analysis in Paje; F: Google image September 2005; G: Google image October 2012; H: Google image October 2014

Seaweed prices

Although prices per kg of dried *E. denticulatum* steadily increased from 45 TZS in 1990 to 500 TZS in 2014, the inflation rate of TZS also rose, with a high of 19,8% in 2012. As illustrated in Figure 28 and Figure 29 a price of 45 TZS per kg seaweed paid to the farmers in 1990 was equivalent to 0.23 USD, whereas a price of 500 TZS per kg in 2014 only accounted for 0.29 USD.





(Source: Adapted from DFMR & FAO FishStats)

4. Discussion

Superficially seaweed farming in Unguja seems resilient, considering its economic importance as a valuable mariculture product and livelihood activity in the coastal areas. As a resilient SES it would be capable of absorbing external shocks and adapting to changes of a social and environmental nature (Adger, Kelly, & Nguyen, 2001). However, when faced with a major shock, such as the disease at the time of research, the SES reveals its weaknesses. As Young et al. (2006) point out:

> Resilience of the SES allows for temporary changes in functioning and dynamics, as long as the system remains within the same stability domain. Vulnerability refers to situations in which neither robustness nor resilience enables a system to survive without structural changes (p. 305-306).

Resilience and vulnerability are properties that are the results of complex processes, which are influenced by a variety of dynamics. This study identifies key drivers influencing the system's adaptive capacity; affecting its resilience and its vulnerability in various ways. Identifying and understanding these processes and feedbacks, their challenges and possible development is important in order to manage the system within a particular domain of attraction.

4.1 Dynamics and Feedbacks that Influence the Resilience of the SES

The complexity of the cyclic change of a SES is captured within Hollings (1986) adaptive cycle. However, this single-cycle model does not cover the characteristics and dynamic responses of multiple cycles at different scales and thus, the panarchy is used to illustrate and explain connections across scales of space and time (Holling & Gunderson, 2002; Berkes et al. 2003).

In this study's attempt to illuminate the resilience and vulnerability of the system, key characteristics are broken down into sections and analysed according to the panarchy concept to investigate and assess their influences.

Environmental drivers

<u>Environmental conditions</u>

The resilience of seaweed farming depends heavily on the ecological functioning of the system. Unfavourable or changing environmental conditions can impact the crop's health and thus, the success of seaweed cultivation (Doty, 1987; McHugh, 2003; Neish, 2009) as experienced with the seaweed *K. alvarezii* (Msuya, 2012; 2013). As cultivation of *K. alvarezii* failed and farmers, especially men, dropped out of seaweed farming the overall production declined. The remaining variety *E. denticulatum* had a lower market price and consequently farmers received less money for the same amount of work (Msuya, 2012). Although the failed *K. alvarezii* cultivation cascaded several negative feedbacks to the SES the availability of a second variety acted like an insurance in that it performed the same function and thus, represented what Siemonsen et al.(2012) call functional redundancy.

Seaweed farming itself also impacts environmental conditions, which in turn might feedback and challenge the system's functioning. Although environmental degradation in the form of sea grass bed clearing (Eklöf et al., 2005; 2006; Olafsson et al., 1995; Msuya, 2012) was considered to affect the ecosystem negatively, only marginal alterations are known. Thus, the introduction of non-native seaweed strings may alter the ecosystem slowly, however, if these changes will trigger positive or negative feedbacks to the resilience of the SES is not known. Until now these changes seemed to be absorbed by the adaptive capacity of the system.

Monoculture

The use of a low diversity of the South-east Asian *E. denticulatum* in Unguja may lower the resilience through several dynamics and feedbacks. Firstly, the introduction of non-native seaweeds carries the risk of them becoming invasive (Cai et al., 2013)which could subsequently alter or even degrade surrounding ecosystems (Tano et al., 2015). As a side effect the native seaweed might decline (Tano et al., 2015) and eliminate the possibility to diversify farming with native strains (Halling et al., 2013). Secondly, due to a low genetic variation the system may become susceptible to diseases and negative aspects of changing environmental conditions (Halling et al., 2013), which could further result in a decreasing crop yield and quality (Bryceson, 2002; Msuya; 2012). Contemplating that ecological diversity can enhance resilience by providing response diversity[2] (Siemonsen et al.; 2012) the absence of diversity in monoculture systems may on the contrary lower the resilience.

Another form of monoculture is the use of just one of the two previously described farming methods. Although moving the cultivation to deeper waters can increase the production of the more valuable *K. alvarezii*, prevent a seaweed die-off during rainy seasons (Msuya et al., 2007; Neish, 2009) and possibly address problems related to a sea level decline (Benjaminsen, Bryceson, & Maganga, 2008; F. E. Msuya, 2012), very few of farmers in Unguja (and none of the respondents in the researched villages) engaged in deep-water farming. A resulting challenge of seaweed die-offs during rainy seasons is the low production after the threat until seeds are fully grown again (Msuya et al., 2007). Superficially, adaption to changes, during seasonal fluctuation or slowly changing environmental conditions, appeared low. However, farmers seemed to anticipate the fluctuations and engaged in other activities while keeping seed stocks to continue farming, indicating a good adaptability to fast changes. Moreover, a common activity was small-scale agriculture, which was only sufficient during rainy season.

[2] Response diversity is understood as „differences in the size and scale of the components performing a particular function give them different strengths and weaknesses, so that a particular disturbance is unlikely to present the same risk to all components“ (Siemonsen et al., 2012, p. 4).

Diseases

A functioning ecosystem that provides healthy and high quality seaweed is one of the pillars for a resilient system. Although the rainy season from March to May precipitates a low production and possibly seaweed die-offs during and shortly after a rainy season (Msuya et al., 2007), my research (during July and October 2014) found severe health problems and extremely low production in both villages. The seaweed observed at the study sites showed what Neish (2009) describes as a red condition; symptoms of bleaching (Figure 6D; Figure 7B; Figure 8A), signs of grazing (Figure 6C; 8E & 8F; Figure 9) and weeds, epiphytes, epizoa and diseases (Figure 6E; Figure 7C & 7D; Figure 8B, 8C & 8D). Whereas sea urchins and possibly siganids eat the seaweed, gastropods and hermit crabs found in the seaweed cause severe wounds to the tissue (Msuya, 2006). Additionally, the epiphyte infestation and the sharp loss of thallus pigmentation, which indicated the ice-ice disease, lead to severe biomass loss (Vairappan et al., 2008) as illustrated in Figure 6A & B and Figure 7A. Furthermore, epiphytism impacts the productivity and quality of the seaweed negatively by lowering its carrageenan yield, viscosity and gel strength (Vairappan et al., 2008; Hayashi, 2010).

The occurrence of this massive seaweed die-off beyond regular seasonal fluctuations, underlined by its severity, denotes not only a low resilience of the farming system, but further indicates a passing threshold. Ice-ice disease is considered to be the biggest production constraint in the Philippines and Indonesia (Sievanan et al., 2009), and similarly Tanzania already had experienced failing cultivation of *K. alvarezii* due to similar conditions (Msuya, 2012).

The seaweed die-off might also be related to slow environmental changes. That is, besides the reported sediment shifting (Neish, 2009; Msuya, 2012), an uplift of the coral reef (Benjaminsen et al., 2008) might be a stressor the farming system inducing a declining sea level (Msuya, 2012, key respondent) and thus altering seawater temperature of the reef.

Knowledge Transfer

Revising existing knowledge is an essential feature of a SES to adapt to continuously changing ecological, social and economic conditions (Siemonsen et al., 2012). Knowledge in the forms of education, monitoring, research and innovation of new technologies must be made available to all actors in the system. As Variappan et al. (2008) point out, good farming practices entail regular training of the farmers, including regular visits to the farm sites, monitoring and education. As my research has shown, only a few farmers got continuous help and guidance of good farming practices and handling of current challenges. However, research on prevention of seaweed disease is only useful for the system if it is transmitted to the farmers. This is particularly important for the resilience of the system in the face of recent disease out-break, which reduced the seaweed quantity and quality and further the number of farmers. Thus, the above mentioned epiphyte outbreak could have been reduced by regular farm maintenance, healthy seedlings and shifting cultivation (Variappan et al., 2008). In the light of seasonal disease outbreaks the lack of education, both in the form of good farming practices as well as post disease farm handling, places an enormous burden on the resilience of the system.

An unequal spread of knowledge or technology was further evident through the inaccessibility of drying facilities. Moisture content is crucial for obtaining high quality seaweed (Hayashi et al., 2010) in such that lacking access to drying facilities could hinder drying related challenges. Various projects within the ZaSCI and the Paje Seaweed Center aimed to increase market development and find new market channels for seaweed through developing value-added products such as soaps (Msuya, 2013). However, whilst these projects were restricted to only a few villages a spread to a wider audience would be necessary to profit the whole farming system. Hence, if applied correctly, knowledge can increase the resilience through development and adaption. As Siemonsen et al. (2012) point out, well connected systems can increase information sharing among different social groups, such as researcher and farmer, and thus, enhance resilience through their ability to overcome disturbances quicker. On the contrary, the lack of knowledge cascades feedbacks that inevitably reduce resilience and eventually expose the system's vulnerability.

Power Relations

Institutional Structures and Cooperatives

The aforementioned allocation of companies to a specific village created a monopsony market structure, a market in which the availability of only one buyer compared to a large amount of seller assigns high market power, for example over prices, to the buyer. This market structure could provide positive aspects, such as the buyers had to provide farming material to each farmer free of charge and guarantee to buy the seaweed at a fixed price, thus assuring the buyers a stable supply (Lange & Jiddawi, 2009; Msuya, 2013). However, it also implied that farmers were bound to sell only to the allocated company and could not negotiate higher prices from alternative potential buyers (Lange & Jiddawi, 2009; Msuya, 2013). This structure became particularly problematic when the costs of living increased rapidly while the income of the farmers increased only marginally (Figure 27&28; Lange & Jiddawi, 2009). As a consequence the government resolved the monopsony to use market forces, which were thought to create competition leading to higher prices (pers. com. DFMR). However, as my results showed this free trade regulation prompted buyers to stop providing farming materials to the farmers, who now were selling their seaweed partly to companies that did not invest in the area and thus could offer higher prices. Consequently, farmers who could not afford expensive materials had to farm less and the overall production declined.

Further, due to the limited capacity of farmers to find other buyers than the ones available in their village the power remained with the buyers in an oligopsony structure, a market in which few buyers are available to a large amount of farmers. Msuya (2013) critiqued the new regulation as a precarious development for farmers who depend on the few buyers by pointing out that "the country cannot afford to lose the buyers and therefore free trade must be approached as a process rather than an action".

Subsequently, the market structure is the key factor to facilitate power relations (Neish, 2009). Changing market structures along with a skewed power relation of farmers and buyers cascaded into negative feedbacks slowly influencing the productivity and the relationship among actors, as will be discussed in the following. A first step to adapt to such trajectories is to understand how single actors react to changes, such as the farmers' reaction to low income and the buyers' reaction to competition. Furthermore, in order to manage slow changes and subsequently lower the risk of a degrading resilience, institutions and policies that acknowledge complex and unpredictable reactions need to be established (Siemonsen et al., 2012).

Farmers cooperatives have a solid history in Tanzania which began with the formation of Kilimanjaro Native Planters' Association (KNPA) in 1925, when farmers of coffee and cotton cash-crops attempted to receive higher prices by eliminating the middlemen. KNPA functioned as an institution that regulated and channelled production to the markets while at the same time protecting farmers' interests, providing equipment and technology, assisting with guidance, disease control and sales of produce at the highest possible prices (Lyimo, 2012). Farmers' organization can provide farmers with various advantages, most importantly a stronger bargaining power and if the market structure makes it possible, bypassing middlemen to increase margins (Hayashi et al., 2010). Whereas in Indonesia the seaweed market is governed by strong farmers' cooperatives who negotiate directly with the processors, farmers in Tanzania have no possibility to eliminate the middlemen since processing facilities are not situated within the country (Neish, 2009). The lack of other channels in which to sell their seaweed to bounded farmers to unappealing low prices.

Seaweed as a cash-crop has a similar market structure as coffee and cotton markets, though in contrast to the statement made by Msuya (2013) that "most farmers – especially in Zanzibar – have organized themselves into associations" this study did not find any farmers who were involved in cooperatives at the time of research. Rather, misunderstandings, conflicts and bad experiences led to the separation of cooperatives and subsequently, resentment towards new ones. Some respondent identified bad experiences with the Seaweed Center in Paje as a reason to not wanting to engage in cooperatives anymore, a key respondent claimed having lost all their saved up money due to a corrupt bank and Msuya (2013) reported protracted funds provided by MACEMP as a reason for discouragement. Similarly, the DFMR promoted a platform for farmers and buyers to communicate and encouraged farmers to form associations (Msuya 2013). Although successful at the beginning a lacking leadership led to a separation of these committees (per com DFMR).

Next to financial challenges and competition among members, member support is the most challenging factor for sustaining successful cooperatives. Although once in place, cooperatives can advance bargaining power, create solidarity among members and improve farmers' social image (Lyimo, 2012), many of the interviewed farmers did not see any benefits in cooperatives. Thus, several disturbances in form of failed attempts to form and bad experiences of maintaining cooperatives and farmers associations diminished the development of new institutional structures and a shift to more balanced power relations. Accordingly, farmers' dependencies on the government or the buying companies to represent and fulfil their interests remained high and thus, decreased their ability to absorb shocks or changes.

<u>Farmer-Buyer Relationship</u>

This research found, whereas farmers repeatedly complained about low compensation for their high farming efforts, buying companies justified their low prices with high investment costs in farming materials (Cai et al., 2013). On the contrary when farmer were free to sell to any buyer and subsequently buyers stopped providing materials, investment costs were passed on to the farmers, who were still dependent on the availability of buyers in their village. Farmers found themselves trapped and either lowered their farming efforts or started another activity. The decreasing production led buyers to provide material again although farmers were not bound to them any longer and would partly sell to other buyers. As a side effect companies shifted their production to Pemba, where farmers were loyal and highly motivated to farm.

With the history of farmers-buyers interaction in mind it is unsurprising that the relationship between both parties suffered immensely. In addition to problems related to skewed power relations, lack of honesty, trust and reliability are key challenges. As this research highlights, unsatisfactory execution of tasks fuelled the already battered relationship. From the farmers' perspective these included lacking support from the buying companies with continuous training and guidance, supplying security equipment to lessen health risks as well as providing adequate drying and storage facilities. The buying companies on the contrary expected a high and regular supply of high quality seaweed. High quality seaweed refers to conflicts with farmers who tried to receive more money by selling seaweed with high moisture content or mixed with sand or stones (Msuya, 2006). The possibility to shift to a different market, i.e. Pemba[3], posed an additional threat in form of decreased efforts to support farming activities in Unguja. Hence, the decreasing farming activity in Unguja is a consequence of cascading dynamics and feedbacks of institutional structures and power relations, slowly lowering the farmers-buyers relationship and degrading the overall resilience of the SES.

Socio-Economic Drivers

Profitability for Exporter

The carrageenan value chain consists of four stages: production of raw material, post-harvest treatment, transaction and processing (Cai et al., 2013). The latter stage adds the highest value to the product. Rising popularity of cheaper and less demanding SRC processes has opened up opportunities for small processors to

[3] Reasons for the different attitude towards seaweed farming in Pemba are yet to be explored. Presumably key factors are the lack of alternative livelihoods, better farmer organisation, better support from the buying companies contrary to those provided in Unguja.

enter the market (Cai et al., 2013). Thus, processing of the seaweed could increase the profitability for local companies and farmers and in addition, decrease dependencies on international processors. Therefore, such a vertical integration can be seen as a possibility to transform the existing market structures and increase the resilience of the SES. However, whereas some countries, such as the Philippines and in part, Indonesia, include all stages of the value chain (Cai et al, 2013), Tanzania does not have any processing facilities. As the research highlights, low and unstable production in Unguja imposes too high investment costs for building processing facilities. Additionally, dependencies of local companies on international buyer who do not have any interest in SRC imposes a further challenges.

Profitability is further influenced by production costs. Lange & Jiddawi (2009) pointed out that companies have very low profit margins and barely are covering their capital costs. This might among others be due to the oligopsonic market structure of the exporters-processor market. As pointed out by a company representative, the international market dictates the price for the raw material, leaving little power over prices to the exporters. Furthermore, increasing shipping costs, from Pemba to the international harbour in Unguja and further to international processors, put additional pressure on the exporters profit margin (Cai et al., 2013, pers com. with exporters). Consequently, several dynamics lower the profitability of buying companies, which further impact the profitability of the farmers and subsequently threaten the functioning of the farming system.

Profitability for Farmers

Similarly to exporters, farming has to be profitable for farmers to engage in the activity. A farm technician from FMC confirmed that farming can be lucrative and accordingly, this research highlighted that earning money was the main motivation for farmers to engage in seaweed cultivation. Correspondingly, the amount of cash available to the local population has increased with the introduction of seaweed farming, together with the general standards of living

(Msuya, 2006) and social empowerment of women (Msuya, 2007; 2012). As for example a key respondent reported that she paid the school education of all her kids from the money she earned with seaweed farming. However, the mentioned disproportional price development, which farmers expressed by saying seaweed money used to be good money, but it is not anymore, have increased the opportunity costs of farmers to engage in farming (Bryceson, 2002, Lange & Jiddawi, 2009; Msuya, 2012) and thus triggered a movement away from farming.

As a side effect the empowerment of women and the rising tourism industry in some villages has further decreased seaweed cultivation. As for example observed by Msuya (2012) opportunities in the tourism industry influenced the number of farmers in Paje, which increased from 500 farmers in 1993 to 1,400 farmers in 1998 and then dropped dramatically to 150 farmers in 2010. Additionally, conflicts between buyers and farmers as well as increasing health problems as a result of farming activities and lacking safety equipment (Fröcklin et al., 2012) have influenced the system negatively over time. As an overall result farmers have adapted to the changing socio-economic conditions and their farming activities have decreased correspondingly.

However, seaweed farming was by time of research a popular activity, partly due to the higher income it generated compared to other available livelihoods and partly due to the lack of alternatives and possibly also due to the abandoning of traditional activities (Msuya 2006; Fröcklin et al., 2012). The lack of alternatives gives reason to conclude that seaweed farming often remained the activity of the last resort for those who do not have other income generating alternatives. Thus, although seaweed farming has been a continuous activity, disturbances and negative feedbacks have lowered its resilience. In combination with other external circumstances, such as more profitable means of income, the system is pushed towards a critical threshold and is at risk of flipping to a less desirable state, for example a lower production. Although the study found that farmers in Paje were more resilient to disturbances, because of a better adaption to changing condition by engaging in other activities and market development, the overall resilience of the system seemed excessively low.

Connections between different adaptive cycles are responsible for keeping the SES in a particular basin of attraction. These connections explain how the outlined disturbances in form of fast and small changes can stimulate recombination within the SES without causing it to collapse and switch to another equilibrium. The stabilizing character of larger and slower cycles helps to counteract disturbances and stimulate a faster recovery (Siemonsen et al., 2012).

For the seaweed farming system in Unguja that implies fast changes such as the failed cultivation of *K. alvarezii* generated a reorganization of the market in that most of the men stopped farming followed by a severe decline in production and income for the remaining farmers. However, it did not trigger a cascading collapse of the system due to the stabilizing effect of larger cycles nested in the hierarchy (Resilience Allience, 2015). In such the availability of the alternative variety *E. denticulatum*, the lack of alternative livelihoods for women and the comparably high income generated from seaweed farming could absorb the loss of *K. alvarezii* farming and allow the overall system to recover. Similarly, slower changes for example the decreasing value of income could be stabilized within the panarchy through the lack of alternative profitable livelihoods and the lack of alternative market channels to sell the seaweed to. However, several dynamics and feedbacks, such as slowly changing environmental conditions and the slowly decreasing relationship between farmers and buyers, weakened the resilience and hence the stabilizing effect, and pushed the system towards critical ecological and socio-economic thresholds.

4.2. Adaptive cycle

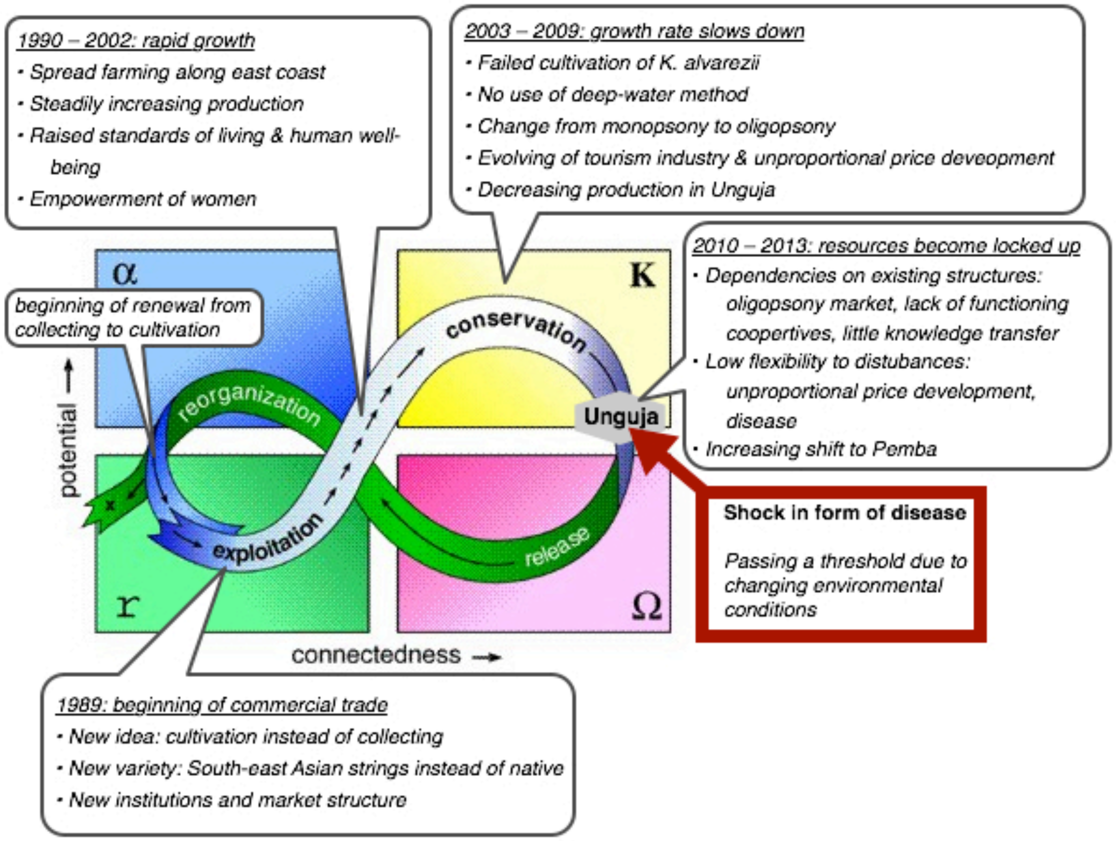


Figure 30: Adaptive cycle for SWF in Unguja (Adapted from Holling 1986)

The adaptive cycle itself consists of the consecutive phases of growth, conservation, release and reorganisation (Gunderson & Holling, 2002), which describe the changes and how the SES responds to such changes over time (Walker & Salt, 2006).

The SES of seaweed farming emerged from the collapsed SES of native seaweed collection. The collection of native seaweed started in the 1940s, went through an exploitation phase from 1951 to 1960, began to decline in 1973 due to several feedbacks resulting from market structures, competition and resource depletion due to overexploitation and soon after, underwent a release-phase of termination. During the release phase, novel inventions, such as newly developed cultivation techniques, arose from related cycles in the panarchy (international markets) and eventually experiments on seaweed cultivation in

Zanzibar 1985 led to a reorganisation of the SES with new dynamics and attractors.

With the successful cultivation a new r-phase began, characterised by new components such as monopsonistic market structures and a new variety to farm. The early phase represented a period of rapid growth in that the production tripled within the first year of cultivation and continued to grow until it peaked in 2002. New opportunities and resources were exploited and seaweed farming spread along the east coast of Unguja providing income to poor households, offering alternatives to traditional livelihoods and engaging women as well as men in farming activities. The employment of women responded in positive feedbacks of independency from their husbands and subsequently their empowerment, which fuelled the engagement in farming activities.

The market entry of Pemba, which represents a new cycle in itself, indicated exploitation of new markets and continuous growth of the seaweed market in Zanzibar. Reliable production figures for Pemba are not available, however, the presence of positive feedbacks (such as an increasing market share, the use of different farming methods, the lack of disease related challenges as well as the provision of extension services through the companies), which are lacking in Unguja, indicated a high resilience of the system. Therefore the farming system of Pemba can be placed in the early K-phase, subsequently with the overall farming system of Zanzibar. When separating Unguja, and in particular the villages Matemwe and Paje, the market entry in Pemba heralded the end of the r-phase and a transition to the K-phase in which growth slowed down.

The transition to the K-phase is gradual and represents a long and slow progression in which the system becomes more complex. As Walker & Salt (2006) point out, connections between actors increase, the system becomes more efficient and new methods and innovations are excluded. Thus, as the research has shown, new farming methods to prevent seaweed die-offs, such as the deep-water farming methods, were not adopted. Similarly, new regulations and a restructuring of the market did not succeed to counteract price developments.

As the conservation phase continues, resources become locked up and the system is less flexible to disturbances (Walker et al., 2004; Young, 2006). The lack of knowledge, strong farmers associations and diversity in farming methods, varieties and gender involved in farming made the system unable to counteract disturbances such as a high inflation rates, seaweed die-offs and buyers migrating to Pemba. Furthermore, farmers became increasingly dependent on existing structures, for example provision of farming materials and market channels, which made the system more rigid and the overall resilience declined. The longer the SES remains in the end of the K-phase, even a minor disturbance is sufficient to push it into the back loop (Walker & Salt, 2006).

Such a disturbance could be the disease outbreak which was happening at the time of research. As the research in the villages Matemwe and Paje highlighted, farming activities and the presence of buying companies were extremely low and further declining. Additionally, severe health problems in the form of epiphytism, ice-ice disease and signs of grazing were found at the seaweed farms, outside the regular time for diseases. Although farmers and buying companies were willing to engage in farming as soon as the seaweed recovered, the socio-economic challenges outlined previously may have lowered the resilience of the SES enough so that when combined with the disease it could soon flip into the back loop. While the renewal-phase can be a chance for development and initiation of novel cycles, in the case of seaweed farming in Unguja, and particularly in the researched villages, it is reasonable to posit the flip may lead into a degraded state.

Moreover, the slowly changing environmental conditions provide another challenge to the SES. That is, the system is approaching a threshold in which current farming practices might become unmanageable. The declining sea level alters the physical conditions needed for farming, such as water temperature and water movement and thus, the SES might shift in a different direction. Once the threshold is crossed it becomes difficult to return to the previous equilibrium (, Walker & Salt, 2006).

4.3. Factors Influencing the Vulnerability of Seaweed Farming

Positioning the SES of seaweed farming in Unguja in the end of the conservation phase is accompanied by a low resilience. According to Folke (2006), a low resilience is the initial situation for vulnerability to occur. Although through applying the resilience concept I have already analysed slow drivers of change, the concept of vulnerability emphasises underlying social, political and economical processes over time (Miller et al., 2010). This can therefore add important insights in understanding the responses of the SES to change. Thus, the lens of the vulnerability is applied as an additional perspective to complement my analysis build upon the resilience concept.

To illustrate factors that impact the vulnerability of the SES, the "Pressure and Release" model (PAR) is applied to guide this discussion. Wisner et al.'s (2004) PAR model is a tool that shows "how disasters occur when natural hazards affect vulnerable people" (p. 46). Although the studied SES has not been affected by a natural hazard per se, the wide spread disease has caused massive seaweed die-off, which has altered the market conditions of the system and threatened the livelihoods of the people, and thus, intensified their vulnerability. In that, the seaweed die-off as a natural event exposed, to a varying degree vulnerable, people to a disaster. The disaster, in this case the destruction of the livelihoods of farmers, occurs when vulnerable people and a hazard converge. The PAR model also allows for explaining disaster by linking the impact of the seaweed disease and die-off with underlying social factors and processes (Wisner et al., 2004). Additionally, phosphorus pollution was thought to be a possible stressor that might have contributed to the seaweed die-off, but as illustrated in the results however, no phosphorus enrichment could be found.

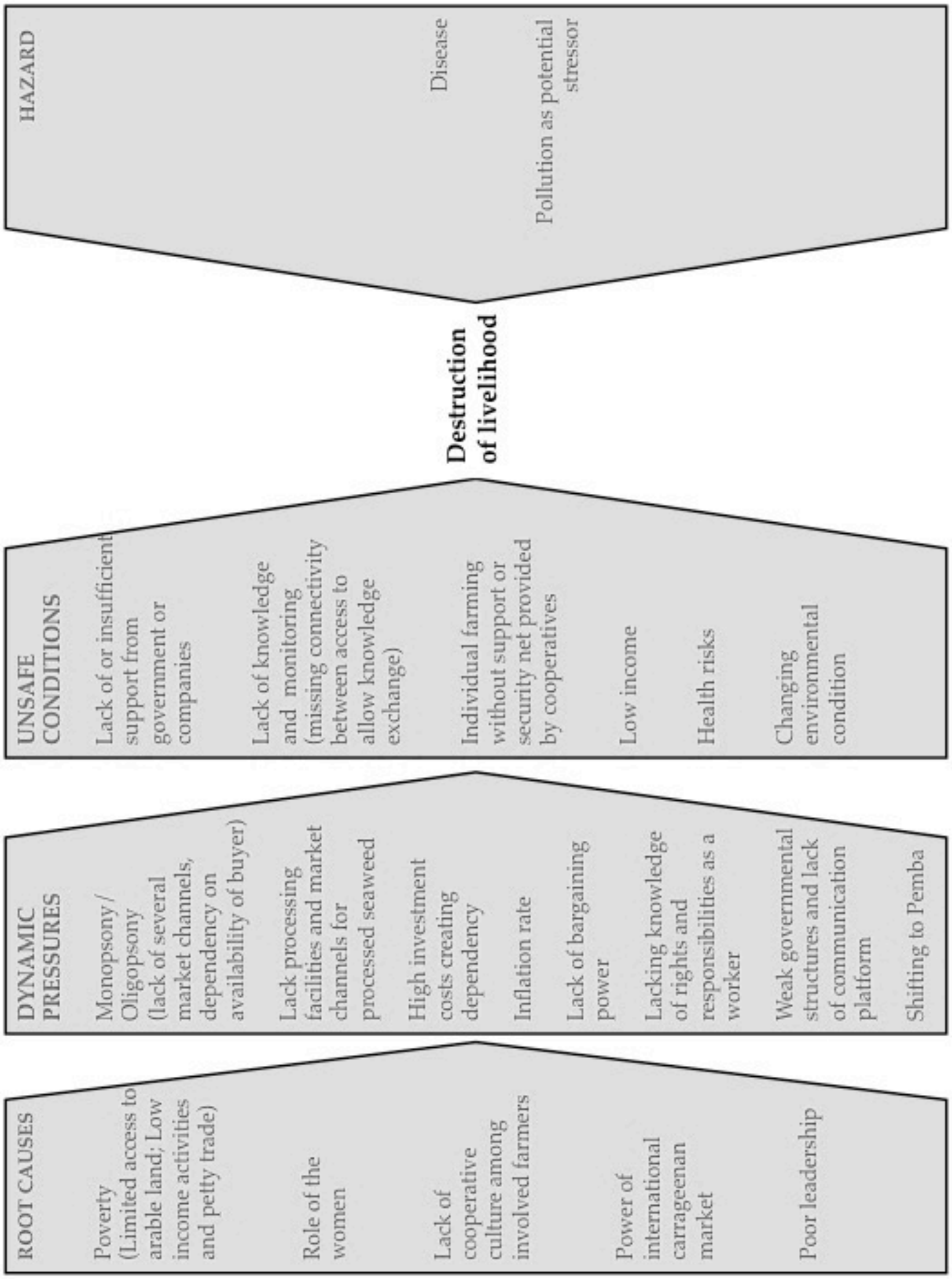


Figure 31: PAR-model of the SWF in Unguja (Adapted from Wisner et al. 2004)

Root Causes

As illustrated in Figure 31, root causes are distant socio-economic processes that reflect power relations (Wisner et al., 2004). Poverty and limited access to arable land as well as low-income livelihoods and petty trade have been identified as key root causes. With 33.6 % of the population living below the poverty line of basic needs in 2007 (NBS, 2013), Tanzania is categorised as one of the poorest countries in the world. Among other reasons, the poor quality of soil and lack of moisture provided by the uplifted fossil-coral terrestrial surface, leaves coastal communities in Unguja only with low-income livelihoods such as subsistence farming, small-scale fisheries and mariculture (Msuya, 2012). Women in particular, who have traditionally been responsible for household activities rather than earning income, have previously depended on their husbands to provide for basic needs. Furthermore, the lack of organisational experience for a cooperative culture, which has proficiencies for saving money and making investments together, was evident among the social group that represents the seaweed farmers.

On the contrary, there was a high concentration of power with the international stakeholders on the carrageenan market. Few multinational corporations control most of the international as well as the local market as outlined in this thesis. Consequently, these actors strongly influenced the prices paid for the raw seaweed, which affected local companies as well as the farmers (Lange & Jiddawi, 2009; Bryceso, 2002). Combined with a weak governmental leadership that was unable to create strong institutions and policies, this led to a much skewed power distribution.

Furthermore, international markets are controlled through a price mechanism, and international competition may be a major cause in market fluctuation such as price and export rates. Whilst export prices between 2000 and 2011 have been stable for *E. denticulatum,* they doubled for *K. alvarezii* (FAO 580). Tanzania mainly exports the first, while international demand is higher for the latter.

Although root causes are difficult to link as causal connections to unsafe conditions (Wisner et al. 2004), they can add understandings of underlying political and economical processes cascading pressure and release phases, which are not thoroughly covered by the resilience concept. As such they are important consideration when managing the SES, as will be explained in the following section.

Dynamic Pressures

Subsequently, the outlined root causes create dynamic pressures, which I have already analyzed according to the resilience criteria, and thus shall not discuss here in great detail. Furthermore, dynamic pressures led to particular forms of unsafe conditions (Wisner et al., 2004). Forces of dynamic pressure arose through the already mentioned market structure, which prevented farmers from selling their seaweed to a buyer free of choice, either through regulation or lacking availability of alternative buyers. Concurrently, oligopsonistic international market structures prevented local companies from moving up the value chain towards processing the seaweed. Furthermore, poverty forced farmers to engage in contract farming due to relatively expensive investment costs in farming materials. Farmers were particularly locked into this poverty trap in the face of doubled costs of living from 2002 to 2012 (NBS, 2012), whilst their income rose disproportionally. Other forces were the lack of bargaining power of farmers, partly due to weak enforcements of market regulation policies, and the failures of farmers' associations and seaweed committees. The lack of experiences in working as a cooperative additionally reinforced their paucity of knowledge about rights and responsibilities of seaweed farmers. As hitherto outlined, these factors cascaded a shift of seaweed farming activities from Unguja to Pemba.

Unsafe Conditions

This shift exposed farmers in Unguja to unsafe conditions, which exacerbated their vulnerability in the face of the seaweed die-off. Besides the previously discussed low income and health, one of the most conspicuous unsafe conditions was the lack of support to the farmers in the researched villages. Although the interviewed companies and their local buying officers, in addition to governmental organisations and researchers, knew about the disease and the subsequent seaweed die-off, none of the key actors seemed to engage in monitoring the scale and occurrence of the disease, nor applying measures to prevent further damages. The overall strategy seemed to be to wait passively in anticipation of farming becoming manageable again. However, in the meantime, the buying companies shifted their production to Pemba, which they reported has not been hit by the disease. None of the interviewed farmers had received education on how to handle the die-off or how to engage in better farming practices. Since all of the interviewed farmers farmed alone, none of them received support through any organisation and thus, they either went back to activities they engaged in before they started seaweed farming, or they were left without any income-generating activity. Some farmers in Matemwe formed a women's fishing group through which they could provide food for their households or even some cash from the revenues earned. However, most farmers expressed their hope that they were still waiting for the seaweed to recover and grow back, in order for them to continue farming.

4.4. Management and Governance of the SES

As outlined above, the SES behaves in a complex manner over multiple scales and is characterized by uncertainty (Walters 1986, Allen & Garmestani 2015). Against the notion of conventional management practices, which tend to focus on managing one component according to a maximum sustainable yield premise, a complex system management requires the acknowledgement of interactions between several components (Walker et al., 2004, Folke, 1998). Feedbacks, thresholds and surprises arise through these interactions, which constantly change the system and create a high degree of uncertainty (Berkes et al., 2003). Due to these changes, complexities and uncertainties a focus on adaptation in governance as well as management is needed to enhance the resilience of the SES (Walker et al., 2004).

Whereas adaptive governance refers to the process of creating policies and institutional structure that can enhance resilience (Biggs, Schlüter, & Schoon, 2015; Walker et al., 2004), adaptive management refers to its actualization and accomplishment through learning (Allen & Garmestani, 2015; Biggs et al., 2015; Walker et al., 2004; Walters, 1986). Therefore, adaptive governance can be seen as the social-political framework (Allen & Garmestani, 2015) which facilitates adaptive management. As the study highlighted, local seaweed committees created by the DFMR dissolved after a short successful time due to the lack of leadership skills. Similarly, some farmers organisations arising under the development program MACEMP ended due to the lack of funding (Msuya, 2013). In addition, some local farmers cooperatives stopped because of bad experiences and miscommunication. Considering that Gunderson (2015) emphasises adaptive management as the opposite of a trial and error approach, these experiences should be used as understanding, monitoring and learning experiments in order to create better policies and institutions.

As earlier presented, the dominance of monopsonistic market structures has undermined the power of the farmers and created unwanted dependencies. Although the government has altered these structures in the face of changing market conditions, the researched villages had oligopsonistic, if not monopsonistic market structures. Thus, understanding of and learning from management decisions did not seem to be present. Berkely and Gunderson (2015) stress the importance of a collective-decision making, both for governmental as well as non-governmental organizations. Consequently, the involvement and inclusion of seaweed farmers, companies, managers and researchers is vital for the development and implementation of adaptive management as an iterative process of building knowledge.

To the time of research no measures had been taken to minimize the spread of the disease. According to Neish (2009), severe health risks, such as those found in the researched villages, call for immediate action and improved agronomic practices to prevent or diminish the disease. Considering that the management of the farming system is an important component of the SES the lack of action reveals a lack of adaptability to disturbances.

5. Conclusion

5.1 Summary

This study has added to a volume of research that contemplates social and ecological aspects of seaweed farming in Unguja, in particular through illustration of the system's complexity. Attention has been on political, socio-economic and ecological key drivers and dynamics of change affecting the system's resilience, in addition to vulnerability through cross-scale feedbacks. Identified fast changes and positive feedbacks, such as the socio-economic uplift of farmers' standards of living and empowerment of the women, have reinforced the systems resilience to withstand brief disturbances. Examples include seasonal seaweed die-offs, failed cultivation of the more valuable *K. alvarezii* and failed farmers associations. Further dynamics, such as the disproportional price development, monopsonistic market structures and insufficient farmer cooperatives, have reinforced the farmers' dependencies on existing market structures and subsequently lowered their resilience. Although these dynamics ensured the functioning of the SES, they have cascaded into a reduced resilience of the overall system. This has occurred through the slowly decreasing farmer-buyer relationship, the lowered efforts to invest in Unguja, and the shifting production to Pemba. Furthermore, these dynamics and feedbacks have given rise to the SES movement towards a critical threshold.

The occurrence of these dynamics were better understood by identifying underlying political and socio-economic processes, such as gender relations, poverty and international market structures. Although not directly linked to the low resilience of the SES, these processes facilitated the skewed power relations, accelerating vulnerable conditions. These conditions were met with additional challenges posed by the slowly changing coastal environment. Widespread seaweed die-off shocked the system, commencing the loss of farmers' livelihoods.

Both, the socio-economic and ecological challenges increase the likelihood of the SES to flip into a different domain of attraction. Although such a flip can be a chance for development and renewal for the SES, it may also lead to a degraded state. Particularly in the researched villages, factors such as low adaptability lack of flexible governance structures and insufficient management of stabilising slow variables of the farming system in Unguja can result in this degradation. It is therefore crucial to improve current management practices and apply measures that can adapt to dynamics' complexities and rapidly changing cycles.

5.2 The Way Forward

This study has highlighted the complexity of dynamic drivers of change over multiple scales, with their interaction leading to a high degree of uncertainty. In order to manage the resilience of such a system, it is crucial to discard the concept of a maximum sustainable yield, in which one component can be managed according to a stationary equilibrium (Gunderson, 2015). Therefore, the control and command approach of the 'corporate-intensive monoculture' should be replaced with an adaptive management approach that expects uncertainties, and encourages development through learning, adaption and transformability.

To facilitate adaptive management, policies and institutions must be created that can apply adaptive assessments and experiments (Gunderson, 2015). For the outlined SES of seaweed farming, that implies the need for key people in leadership roles to strengthen the governance of the system, as well as the application of collective-decision making involving all key stakeholders.

Furthermore, an adaptive management approach must allow for learning and development through building on experiences and conducting experiments. An example of this is the failed formation of seaweed committees and establishment of local market structures. By doing so, underlying challenges can be understood and learned from to create improved policies and institutions, rather than treating them as trial and error approaches. Monitoring and assessing then becomes a crucial tool for creating and spreading knowledge. In the case of failed farmers associations and cooperatives, such knowledge in the form of education and increased awareness about farmers' rights and responsibilities, would have been key to create successful cooperatives (Lyimo, 2012). This could have cascaded, leading to increased bargaining power and independency of farmers and therefore a higher resilience towards external disturbances.

Subsequently, a further consideration of managing the SES's resilience, is the decision of what to manage and how to manage it (Biggs et.al., 2015; Siemonsen et al., 2012; Miller et al., 2010). The increased bargaining power and independency would imply a loss of what the system in its current state is built upon: a skewed power distribution. Thus, trade-offs between multiple groups and components lead to a decreased resilience of one component, when enhancing the resilience of another. However, in the light of the system's already low resilience and threat of it flipping into a degraded domain of attraction, keeping the current management approaches and priorities will not lead to a higher resilience of any stakeholder. Management tools should rather be used to create innovation and restructuring in order to manage a change to a different basin of attraction (Walker & Salt, 2006).

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Appendix

A1: Interview guide unstructured interviews, companies pre-field visit

<u>Social-ecological resilience of seaweed farming in Unguja</u>

Interview number:

Date/time:

Place:

1. Can you tell me about seaweed farming in Zanzibar? (structure national and international, price developments, employment relations, challenges)

A2: Interview guide unstructured interviews, key informant

<u>Social-ecological resilience of seaweed farming in Unguja</u>

Interview number:

Date/time:

Place:

1. Can you tell me about seaweed farming in Zanzibar? (your life as farmer, price developments, challenges)

Follow up

1.Can you describe how the swf has developed within the past months (from July – October)

2. Can you describe what you have been doing/acivity in the past months?

A3: Interview guide unstructured interviews, key institution

Social-ecological resilience of seaweed farming in Unguja

Interview number:

Date/time:

Place:

1. Can you describe the work of the seaweed center? (purpose, development, impact, structure)

2. Can you say more about the structure of the seaweed center, are you working together with other companies or institutions?

3. Can you describe your relationship to the sw farmers from the village?

A4: Interview guide semi-structured interviews- companies

Social-ecological system of seaweed farming in Unguja

Interview number: Date/time: Place:

1.What is your name?

2. What is the company you are working for?

3. What is your position?

4. Can you describe your job/activity?

5. Can you tell me something about the structure of your company? (connected to whom, competition national-intern., other institution to work together with, how big company, in which villages)

6.What is your main business and do you diversify the production/value chain, how?

7.What does the buying/selling process look like? (who, how often, organization of buying)

8.How much do you export and what is your main export country?

9.How much do you pay for 1Kg dried seaweed? And how did it develop over time?

10.How is the price defined, by whom?

11.How are the farmers organized? (structure, history, cooperatives))

12. What is the relationship between farmer and buyer? (employee, how

contact, how find new people to expand, historical)

13.Do you provide incentives to the farmers to work/sell to your company? (education, material, knowledge, techniques, equipment)

14.What are challenges for your job/seaweed farming business, how do you handle these?

15. Which species and their varieties do you use/have used? (K. alvarezii (tambalang), K. cottonii (adik or Sacol Island), E. denticulatum (spinosum))

16. How important is the quality of the seaweed and how do you monitor it? (esp environmental aspect – controls of farms etc.)

17.How do you manage the current spread of diseases and what are the possible plans to overcome challenges? (esp. workers health – protective clothing and equipment)

18. Do you also have a production site in Pemba and if yes, can you compare it to the farming here in Unguja?

A5: Interview guide semi-structured interviews: seaweed farmer, non-farmer, groups

<u>Social-ecological resilience of seaweed farming in Unguja</u>

General

Interview number / ID:

Date/time:

Place:

1.What is your name?

2.How old are you?

3.What is your marital status?

4. How many children do you have?

5.What is your education level?

Development of seaweed farming

(Are you a seaweed farmer?) *-not if obvious*

6.When did you start/stop farming?

7.What are the reasons that you started/stopped seaweed farming? (why)

8.How big is/was your farm? (how many plots, lengths of each plot)

9.How much time does/did seaweed farming take up? (hours, days)

Livelihoods:

10.What did you do before seaweed farming?

11.What do you like/d about seaweed farming?

12.What are/were the main challenges of seaweed farming?

13.How much do/did you get for 1 kg of dried seaweed?

14.How often do/did you sell (each tide?) and how much?

15.Is there anything in particular you are/were using the money for?

16.Who brings in the main source of income in your household, how? (consider other household members)

17.Do you have any other income generating activities and if yes, which generates more income?

18.What would you do if you had enough income from any activity seaweed or other? (quit seaweed farming or invest more)
(if the other activity brings in more, would you stop farming to concentrate on the other? / If you compare both activities, which do you prefer?)

Structure of seaweed farming in Unguja:

19.Where do/did you get your materials from and how much do they cost per month?

20.Can you describe how the selling process looks like?

Cooperatives:

21.Do/did you farm alone or in a group?

22a.Alone: What are the reasons for farming alone? / Would you prefer farming in a group/cooperative?

22b.Group: Who do you farm with, how is it organised, since when?

23.What benefits do you think you get from a cooperative? (general)

Environment:

24.Have you had problems with diseases recently? (And has it happened before?)

25a. If yes, since when?

25b. If yes, what did you do? (farm anyway, change activity, do nothing)

26.Do you think the quality/weight/yield of your seaweed is getting less over the period of time? Why?

27.Which species do you farm, and have you tried farming different varieties of seaweed, with which results?

28.Do you have/have you had health problems from seaweed farming, which?

A6: Interview guide semi-structured interviews – buying station

<u>Social-ecological resilience of seaweed farming in Unguja</u>

General:

Interview number:

Date/time:

Place:

1.What is your name and gender?

2.What is your position?

3.What is the company you are working for?

4.Can you describe your job/activity?

5.What does the buying/selling process look like?

6.How much do you pay for 1Kg dried seaweed? And how did it develop over time?

7.Who defines the price?

8.How often do you buy?

9.What are challenges for your job – buying/selling?

10.Do you get a regular income or do you work individually?

11.Can you tell me something about the structure of your company?

12.How are the farmers organized? (structure, history, cooperatives)

13.Do you give them incentives? (education, material, knowledge, techniques, equipment)

14.Do you see possibilities to overcome the current challenges? Are there plans?

A7 Fish stats Production in Zanzibar