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Coastal Aquaculture Developments in Tanzania: Sustainable and Non-sustainable Experiences*

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***Abstract*—**Coastal aquaculture of seaweeds and prawns has developed in Tanzania during the past two decades. Farming of *Eucheuma* seaweeds commenced in 1989 along the east coast of Zanzibar and it has since expanded to other areas. This form of aquaculture does not pollute the environment with feeds, wastes or other chemicals, although there are some negative interactions causing inhibition of surrounding biota, but which appear to be relatively mild. Monoculture may result in some self-inhibition and disease vulnerability over time. The socio-economic impacts of seaweed farming was initially overwhelmingly positive, providing income to women from relatively poor remote villages. Annual production reached 7000 tonnes, constituting an important earning of foreign exchange. However, monopoly control by a few international corporations recent years has led to reduced prices being paid to producers. Aquaculture of penaeid prawns has also been attempted in Tanzania. A huge project was proposed for the Rufiji mangrove delta, but met strong opposition from local communities, government managers, scientists, journalists, lawyers and environmental NGOs. Although it was clear that the consequences of the project would have been seriously deleterious, the government approved it. Conclusions are drawn from the lessons learned through Tanzanian and international experiences, and suggestions are put forward concerning principles for the development of more ecologically viable and socially just aquaculture development.

AQUACULTURE: FROM 'HUNTING AND GATHERING' TO 'FARMING' IN THE SEA

As on land, so too in the sea are many natural resources gathered or hunted, and especially in coastal areas, but there are limits to which these resources can be harvested sustainably. Over-exploitation of scarce resources by hunting and gathering may become a problem when management regimes do not effectively regulate levels of extraction.

As with the development of agriculture on land, so too the development of aquaculture has brought about prosperity and increased food security for many people all over the world: production can be planned and managed to a greater degree.

Various countries with particular environmental conditions, and with distinct histories and cultural traditions, have developed different types of agriculture and aquaculture. Indeed some have actually integrated agriculture and aquaculture. Traditional forms of aquaculture have generally been developed on small scales, with species at low trophic levels (plants, herbivores and detritivores) and at relatively low levels of intensity.

Both agriculture and aquaculture are potentially highly beneficial both socially and economically, but they may also give rise to environmental and social problems if not planned and managed in a

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sustainable way. Pollution of surrounding habitats or impoverishment due to loss of access rights are examples of negative tendencies that may create problems in the context of agricultural or aquacultural development.

International experiences in aquaculture development have shown that the introduction of larger scales of commercial production, the intensification of aquaculture production and the use of species at higher trophic levels (carnivores) all tend to cause greater environmental and social problems. Indeed, some examples of commercial intensive aquaculture of carnivorous species may be characterised as the epitome of non-sustainability.

In the context of globalisation, agricultural and aquacultural cash-crop production in poor countries often brings little benefit to the producers or national economies (only a few local compradors and opportunists profit), while enormous profits are earned by multinational corporations with increasingly monopolistic control over markets.

The question of sustainability is key as to whether aquaculture development succeeds or fails.

THE DEVELOPMENT OF COASTAL AQUACULTURE IN TANZANIA

Although there had been some experience with the development of freshwater aquaculture of tilapia (*Oreochromis niloticus*), there had been essentially no tradition of coastal aquaculture in Tanzania before the 1980s.

Prior to the development of aquaculture in Tanzania, most coastal resources were and are still mainly fished (or 'hunted') and collected (or 'gathered'). For example, wild seaweeds such as *Eucheuma* spp. have been collected for export for decades, particularly from Zanzibar for sale to France, but this practice has now been replaced by seaweed farming. Prawns have been captured using traditional fishing techniques such as *wando* traps offshore from river deltas for centuries and by commercial trawlers since 1969: but prawn farming has yet to contribute significantly to Tanzania's production of prawns.

Tanzania has in recent years witnessed some examples of initiatives towards both sustainable and non-sustainable forms of coastal aquaculture.

The most significant and successful case of coastal aquaculture development has been the introduction of seaweed farming of the red algal species of *Eucheuma denticulatum* and *Kappaphycus alvarezii* for their carrageenan content. This form of aquaculture was introduced at the initiatives of Keto Mshigeni and Adelaida Semesi of the Botany Department of the University of Dar es Salaam after their observations on algal farming in Hawaii and the Philippines.

Less successful have been attempts to introduce the farming of prawns (also referred to as 'shrimps'). The principal species used globally in aquaculture is the giant tiger prawn (*Penaeus monodon*). The first initiatives were made in the mid 1980's by a Norwegian company wishing to develop a medium-sized semi-intensive project on the coast just north of Bagamoyo in a joint venture with the Bagamoyo Development Cooperative, but this project was thwarted by corruption and land speculation. Other small-scale initiatives have recently achieved some production in the same area. A recent proposal for a largescale prawn farm project to be situated in the Rufiji mangroves created a major controversy in Tanzania.

Interesting experimental work has recently been carried out at Makoba, Zanzibar by Mmochi et al. (2001) of the Institute of Marine Sciences of the University of Dar es Salaam with integrated systems including herbivorous and detritivorous fishes, molluscs and algae.

In this paper we have chosen to examine two examples of coastal aquaculture in Tanzania in order to exemplify some differences in relation to issues of sustainability. We discuss these in the context of international experiences and debates on the questions of sustainability or non-sustainability of various forms of coastal aquaculture. These are (1) seaweed farming of *Eucheuma denticulatum* and *Kappaphycus alvarezii* (plant species which do not require feeds and do not load or pollute their surroundings); and (2) prawn farming of *Penaeus monodon* (carnivorous species fed with fish proteins and oils and producing significant amounts of waste products that pollute receiving waters).

A BRIEF HISTORY OF AQUACULTURE OF SEAWEEDS IN TANZANIA

Jaasund (1976) described five species of the genus *Eucheuma* occurring naturally along the coast of Tanzania. The genus has since been split into two genera: *Eucheuma* and *Kappaphycus* (Doty, 1988). These seaweeds were earlier collected from the intertidal zone of coral reefs around Zanzibar and dried for export to France and Denmark where carrageenan was extracted for commercial purposes. *Eucheuma* has a high content of carrageenan, a polysaccharide from its cell walls which is used in foods, cosmetics and pharmaceutical products as a gelling, thickening and emulsifying agent.

Keto Mshigeni studied at the University of Hawaii under Maxwell Doty, the principal pioneer of tropical red seaweed farming, during the early 1970s and under whose influence commercial farming of *Eucheuma* commenced in the Philippines in 1971 (Doty & Alvarez, 1975). Mshigeni (1976) considered the possibility of initiating farming of *Eucheuma* in Tanzania. It was Adelaida Semesi who systematically investigated the carrageenan content of *Eucheuma* in Tanzania (Semesi & Mshigeni, 1977). Professor Semesi observed seaweed farming when she visited the Philippines and then pioneered the introduction of *Eucheuma* farming techniques, especially among women in villages in eastern Zanzibar. Commercial interests from the Philippines and Denmark also played an important role in developing production and markets. Another large corporation from USA, FMC-Biopolymer, has also developed commercial interests in the purchase of farmed seaweeds from Tanzania.

The Philippines is still the world's principal producer of farmed *Eucheuma* and they produce over 600,000 tonnes per year whereas production commenced in Tanzania in 1989, and has reached over 7000 tonnes per year (FAO, 2001).

The two species farmed in Tanzania are *Eucheuma denticulatum (= E. spinosum)* and *Kappaphycus alvarezii (= E. cottonii).* The former contains iota-carrageenan (a weak gel) whereas the latter contains kappa-carrageenan (a strong gel). The previous species names of '*spinosum*' and '*cottonii*' are still in use for commercial purposes. Strains used in farming in Tanzania were apparently introduced from the Philippines (Lirasan & Twide, 1993) without clear consideration of impacts.

The main species now produced in Tanzania is *E. denticulatum* although it currently fetches a lower price than *K. alvarezii*, due to the fact that the latter species now seems to grow poorly and be prone to disease.

The method of farming is the 'tie-tie' system whereby fronds of *Eucheuma* are tied to strings stretched between wooden pegs. These are situated in shallow intertidal lagoons inside the fringing reefs, mainly off the eastern coast of Zanzibar, and spreading to other parts of Tanzania and neighbouring Mozambique and Kenya. Other systems, such as floating lines and rafts, that require deeper water have not been used. Elisabeth Lundsør recently tested a 'broadcast' system of in net enclosures at the suggestion of Erick Ask of FMC-Biopolymer (Lundsør, 2002).

Eucheuma seaweeds normally grow at an impressive rate of 4–12% per day. They are tended and harvested at spring low tides that occur at two weekly intervals.

Eucheuma grow best in warm (30 ºC), salty (35‰) seawater with adequate water movement (but very strong currents present a problem by breaking pieces off). Clear water also allows for maximum light exposure.

Growth and survival may be hampered by unfavourable environmental factors such as temperature or salinity fluctuations, or by pollutants (heavy metals, herbicides, etc.). Physiologically stressed *Eucheuma* takes on a white appearance called 'ice-ice' and it may then become prone to bacterial or fungal infections. *Eucheuma* produces volatile halogenated organic compounds when it is under stress (Mtolera et al., 1996) and these may inhibit epiphytes or other organisms in their vicinity (Johnstone & Olafsson, 1995). Herbivores may occasionally graze on *Eucheuma*: these include fishes such as juvenile *Siganus* spp. during seasons (Bi Jiddawa of Paje, pers. comm.) (Bergmann et al., 2001) and echinoids such as *Echinometra mathaei* and *Tripneustes gratilla*, but there generally appears to be relatively little presence of herbivores in the seaweed farms. Sware Semesi has made interesting

observations in her current research on the interactions between farmed *Eucheuma* and surrounding flora and fauna (Semesi, 2002).

Socially and economically the farming of *Eucheuma* initially represented an excellent opportunity for poor people, particularly women, in remote villages to earn money (Msuya, 1993; 1995) and it was most encouraging to witness the improved standards of living apparent in the villages. It also represents an important source of foreign exchange for the national economy.

The major importers of *Eucheuma* are corporations based in Denmark, UK and USA. The total value of carrageenan products made by a few multinational corporations is about $10 billion and growing at about 3–5% per year (Borgeson et al., 1999; Taylor, 2000). A relatively new high-value product group of 'nutraceutical additives' is also emerging from carrageenan products. One can order lower grade carrageenan products over the internet for a price of about $ 50 per kg (Alexander Essentials Ltd., 2001) or $ 30 per kg (PhilImportExport Inc., 2001). Corporations such as FMC-Biopolymer also deal in other high value products from farmed seaweeds, such as agarose, that are priced as high as $ 4240 per kilogramme.

In stark contrast: the price paid to seaweed farmers in Tanzania has now been lowered to a meagre $ 0.$\underline{09}$ per kg.

Despite recent trends showing that the demand and market price for carrageenan is increasing (also confirmed by FMC-Biopolymer, 2001) they continue to press down prices paid to the producers. This is due to the fact that a few multinational corporations monopolise the world market for carrageenan. These corporations have a philosophy that is starkly shown in a quotation from Ask (2000) of FMC-Biopolymer based in USA:

> "As a potential seaweed supplier trying to find the best village to work in, you should be delighted to find a village populated by consumers with no or little livelihood options. In this case we call *cottonii* and *spinosum* farming the livelihood of last resort. Today we find the most productive and consistent farmers from villages like these…. In these places it is too arid to farm or the soil is unsuitable and the reefs have been destroyed and fish stocks decimated …. Your ultimate goal is to make seaweed farming become a way of life for the villagers. This happens after five or so years. At this stage people don't think too much about price, they just farm because they have always farmed. Their children will follow them into that career."

In eastern Zanzibar many women have completely despaired in the face of lowered prices (Bi Fatuma Abdulla of Jambiani, pers. comm.), and abandoned seaweed farming, except for some such as widows or divorcees or the poorest persons who have no livelihoods alternatives.

A BRIEF HISTORY OF AQUACULTURE OF PRAWNS IN TANZANIA

Prior to aquaculture, prawns have been captured by fisherfolk along the Tanzanian coast for centuries. Among various methods, *wando* traps are typically erected outside the edge of mangrove forests off river deltas, and the prawns are trapped with the receding tides as they attempt to migrate out of the mangrove nursery areas when they have become large enough to move towards the open sea. Since 1969 commercial trawlers have captured prawns by dragging large trawls across the shallow bottoms—destroying benthic habitats, uprooting seagrass beds and often damaging traditional fishing gears. Japanese trawlers were the first, but later, other foreign (and for a brief period national TAFICO) fleets have been given licences. Local fisherfolk have experienced dramatic declines in their own catches with the commencement of industrial trawling and they have witnessed huge quantities of fish being dumped dead by the trawlers as 'trash fish' by-catch although many such fish are considered palatable and marketable along the coast. Although prawns are traditionally consumed and marketed locally, industrially captured prawns are mainly exported to Japan, Europe and USA as a luxury food item.

Given the ecologically and socially undesirable impacts of prawn trawling, it would seem appealing to be able to farm prawns instead. Indeed, prawn farming has been carried out traditionally in extensive systems in southeastern and southern Asia for centuries. Juvenile prawns have been raised to an edible size in coastal ponds in the vicinity of mangroves where natural

productivity is high and these detritus-feeders thrive. Other traditional systems produced rice in rainy seasons and prawns in the same paddies during dry seasons (Shiva & Karir, 1997; Vivekanandan & Kurien, 1997).

Modern commercial prawn aquaculture in semi-intensive and intensive systems developed rapidly and optimistically during the late 1970s and 1980s. Taiwan was the main producer until 1989, but problems began to emerge due to self-pollution and excessive extraction of groundwater. Catastrophic diseases broke out in 1988 and production collapsed. China took over next as the main producer, and production collapsed there in 1993. Philippines, Indonesia, Thailand, Sri Lanka, India, Bangladesh and Vietnam have all experienced disease outbreaks and falls in production (Primavera, 1991; 1997). World prawn aquaculture production has continued to fall for the last 7 years due to such self-pollution and disease (FAO, 2001).

Beyond the undesirable aspects of a 'boom and bust' production, the prawn farming industry has caused serious ecological problems:

- enormous areas of mangrove forests have been destroyed, natural productivity has fallen and biodiversity has decreased;
- huge tracts of agricultural land and groundwater have been rendered salty by intrusion of seawater;
- massive amounts of leached and uneaten prawn-feed and faecal wastes have caused eutrophication of receiving waters;
- prawn diseases have become rampant, causing major collapses in production in many countries and infecting natural populations;
- toxic chemicals and antibiotics have polluted surrounding areas, waters and biota, both from hatcheries and farms (Gräslund & Bengtsson, 2001);
- large quantities of fish have to be caught for prawnfeed, affecting fish communities and trophic relationships;
- capture of wild prawn larvae involves killing huge numbers of other species' larvae.

In addition, prawn farming has also caused many social, economic, political and cultural problems (Primavera, 1997; Kurien, 1997):

- local communities have lost access to common property mangrove resources;
- multiple mangrove ecosystem services are severely diminished;
- land grabbing and privatisation pauperises and marginalises people;
- salinisation of groundwater and agricultural land drives people out then urban poverty and unemployment is often the only alternative for such people;
- large quantities of fish are taken from the market for prawn-feed, thus affecting food prices and food security for poor people;
- benefits are short-term and only accrued by a few 'get-rich-quick' opportunists;
- after a few years, polluted and diseased sites are abandoned, leaving deforested and polluted wastelands and impoverished local communities behind.

In Tanzania, attempts were initiated in 1986, while prawn farming was still in an early and optimistic stage of development by a Norwegian company, Bartz Group (with which this author was involved), proposing a joint venture with the Bagamoyo Development Cooperative. They proposed to develop a medium-sized semi-intensive prawn farm to be developed just north of Bagamoyo behind the mangrove forest area in the Ruvu delta. Despite support from the district and regional authorities and by the Fisheries Division, the project was thwarted by an Austrian land speculator with influential contacts deciding over land allocations. Other medium-scale commercial initiatives have recently commenced production in the same area.

A major controversy emerged in 1996–1997 in Tanzania, with the exposure of a secret new proposal for a giant-sized prawn farm project that was to be situated in the Rufiji mangrove forest conservation area. A worst-case scenario appeared to be looming (Bryceson, 1997) in which Reginald John Nolan, an Irish weapons dealer involved in several legal disputes in Tanzania (Lissu, 1998) was attempting to gain control over a 19,000-hectare tract of land in Rufiji. Nolan was proposing the construction of the world's biggest prawn farm there. Extraordinarily, the Tanzanian Government approved the project in 1998 including a clause

allowing Nolan to import arms worth $ 570,000 each year into the country (Africa Confidential, 1998; Wood & Peleman, 2001).

Fortunately the proposed project was finally halted in 1999–2000 by the joint efforts of many people:

- village communities in the Rufiji mangrove delta area immediately recognised the threat that the project would pose to their livelihoods and opposed it (apart from a small number who were given 'incentives' by the project proponents);
- dedicated forestry managers working in the Rufiji alerted others despite attempted intimidation (e.g. Alphonse Lubango, pers. comm., who tragically died in a vehicle accident in the Rufiji), and researchers raised questions (Sørensen & Fottland, 1996);
- the National Environmental Management Council (NEMC) played an exemplary role and rejected the bogus EIA process;
- a public letter of protest (Bryceson, 1997) was given wide press coverage with the assistance of committed journalists, including members of Journalists' Environmental Association of Tanzania (JET);
- university staff members (such as Prof. Seithy Chachage) publicly exposed attempts by the project proponents to intimidate them;
- the Institute for Resource Assessment (IRA) conducted a public hearing on the project that contributed to increased popular awareness and opposition;
- JET and other journalists tirelessly investigated and exposed scandals surrounding the project despite attempts to politically intimidate them;
- the Lawyers' Environmental Association of Tanzania (LEAT) energetically investigated and wrote accounts of legal aspects of the project;
- together with Prof. Adelaida Semesi, we publicly raised the issue of corruption in connection with the project (JET News, 1999);
- legal action by villagers with support by the Lawyers' Environmental Action Team (LEAT) and Prof. Issa Shivji gained a legal injunction against the project.

This case represented a historic victory in favour of popular opposition against an ecologically and socially deliterious project proposal: It was the first of its kind in Tanzania creating an important precedent against other such proposed projects.

SOME LESSONS LEARNED FROM TANZANIA'S AQUACULTURE EXPERIENCES

Lessons learned from twelve years of seaweed farming in coastal Tanzania:

- seaweed culture does not seem to have serious negative environmental impacts since neither artificial feed nor chemicals are employed;
- there does however appear to be some impacts on surrounding biota and on the growth rates of farmed seaweeds themselves in monoculture that deserve further research;
- villagers are interested in innovative new livelihood activities if they are shown to be practicable and viable;
- the benefits to villagers, particularly women farmers, are important for poverty eradication as long as they are paid fair prices for their produce;
- multinational corporations cynically commence with attractive prices paid to producers, but then lower them when they consider that they have made people sufficiently dependent upon such income;
- Producers in the Philippines earn more by doing the processing themselves instead of exporting raw dried seaweed.

Lessons learned from the struggle to halt the Rufiji prawn project:

- the essentiality of good management plans (such as the Mangrove Management Plan (Semesi, 1991)) and coastal zone management planning processes (e.g. Tanzania Coastal Management Partnership, TCMP) and well-trained managers;
- the strength of participatory management based upon genuine villagers' key involvement in natural resource utilisation and mangrove conservation;
- the importance of freedom of information,

along with transparent and accountable planning processes (including access to all environ-mental and social impact assessments);
- the need for investigations of ecological, social and legal aspects by principled and honest researchers (in the Rufiji case a few scientists and international NGOs were tempted to write compromising EIA reports for lucrative fees);
- the strength in unity between local communities, responsible and dedicated managers, committed researchers and scientists, journalists, lawyers and principled environmental NGOs;
- the democratic usefulness and credibility of holding a public hearing or tribunal in the case of such a controversial project;
- the importance of learning from parallel experiences and struggles in other countries and of exchanging ideas and building international solidarity with them.

The overall lessons from these experiences seem to emphasise the importance of a broad holistic and interdisciplinary approach to understanding of issues, and the need for combining traditional, local and modern scientific knowledge in the endeavour. Evidence has demonstrated the need for local and global solidarity alliances against the forces of corporate globalisation, corruption and opportunism.

Some research questions specifically related to seaweed farming that may be suggested include:
- further research on the impacts of *Eucheuma* on surrounding flora and fauna;
- impacts of detached branches of *Eucheuma* proliferating in subtidal coral reefs;
- self-impact of monoculture of *Eucheuma* on growth and susceptibility to disease;
- biodiversity impacts and genetic distortions caused by introduced foreign strains;
- socioeconomic research on the distribution of benefits between producers, intermediaries and monopoly multinational corporations.

Some research questions related to prawn farming that may be suggested include:
- possibilities for introducing traditional-style Asian ecologically benign forms of coastal polyculture (incorporating prawns among various other floral and faunal components);
- careful and diligent ecological, pathogenic and socio-economic monitoring of any ill-advised monoculture prawn farm initiatives in case they should be approved by the government.

TOWARDS GREATER SUSTAINABILITY IN COASTAL AQUACULTURE

Important lessons about the development of sustainable aquaculture can be learned from other countries with ancient traditions in aquaculture.

The principles of incorporating several species that occupy different ecological niches in systems of polyculture (such as Chinese carp farming in inland freshwater ponds) are very instructive. Polyculture is also applied in several countries' coastal saltwater systems, for example:
- Indian *pokali* rainy season coastal rice paddy with fish and dry season extensive fish and prawn culture;
- Indonesian *tambak* ponds with planted mangroves, fish and prawns;
- Philippine *tumpang sari* ponds with mangroves, fish, prawns, molluscs.
- Vietnamese experiments with combined mangroves, fishes, prawns, crabs, gastropods, bivalves, holothurians, algae, etc.

Integration of aquaculture with agriculture is easier in freshwater systems, such as the Vietnamese *vuon-ao-chuong* system of combining aquaculture with horticulture and animal husbandry since freshwater can be used for irrigation. However, in coastal systems, mangrove-based aquaculture can be also combined with harvesting of fodder, wood, medicines, honey and birds' eggs.

Williams (1997), Naylor, et al. (2000; 2001) and Kautsky et al. (1997; 2000; 2001) outline important principles and lessons regarding sustainability in aquaculture. They convincingly show that while some forms for aquaculture contribute positively to world fish supplies, others constitute a loss (2–5 kg of captured fish is used to provide feed to produce 1 kg of carnivorous fish such as salmon or prawns). Pauly et al. (2001) also raise the problem concerning the inherent non-

sustainability implicit in trends of fishing down the food web and simultaneously farming up the food web.

In conclusion, we choose to identify two main paths for aquaculture systems: we call these Small-Scale Integrated Polyculture (SIP) and Corporate Intensive Monoculture (CIM) and present a simplified table below (Table 1) to juxtaposition their characteristics.

We hope that scientists, producers and decision-makers in Tanzania will emphasise SIP type systems to the broad benefit of coastal peoples and the environment, and oppose CIM type systems that only enrich a few people for a short time and which are inherently non-sustainable.

Table 1. Comparison of small-scale integrated polyculture and corporate intensive monoculture aquaculture systems

Small-scale integrated polyculture (SIP)	Corporate intensive monoculture (CIM)
Traditional holistic knowledge	Reductionistic technology
Multi-species polyculture	Single-species monoculture
Plants, herbivores, detritivores	Carnivores: fish-protein and fish-oil
Integrated production systems	Disconnected production systems
No or low incidence of diseases	Prone to disease problems
No or low medicines or chemical use	Widespread use of medicines
Wastes utilised through integration	Wastes causes serious pollution
Environmentally benign	Destruction of the environment
Under control of local people	Conflict over land and sea rights
Products for various markets	Luxury products for export
Enables people to leave poverty	Benefits only a few rich people
Supports struggles for livelihood rights	WTO trade liberalisation in fish products

REFERENCES

Africa Confidential (1998) Tanzania: Gunning for prawns. *Africa Confidential*, 9 October 1998, vol. **39:** 3.

Alexander Essentials Ltd (2001) *Carrageenan sales*. http://www.alexander-essentials.com/.

Ask (2000) *Suggestions for* cottonii *and* spinosum *suppliers*. FMC Biopolymer publication, Philadelphia, USA. 21 pp.

Bergman, K.C., Svensson, S. & Öhman, M.C. (2001) Influences of algal farming on fish assemblages. *Mar. Poll. Bull.* **42:** 1379–1389.

Borgeson, N., Brunner, B. & Sakota, K. (1999) Food Additives. http://scup.sric.sri.com/Public/Reports/FOODA000/Navigation.html.

Bryceson, I. (1997) Shrimp farm threatens Tanzanian coast and people. *Development Today* **7:** 11.

Bryceson, I. (1998) Public plea to the Tanzanian government to reject Rufiji prawn project. *Samudra* **19:** 54–56.

Doty M. S. (1987) The production and use of *Eucheuma*. *In:* Doty, M.S., Caddy, J.F. & Santelices, B. (eds), Case studies of seven commercial seaweed resources. *FAO Fish. Tech. Pape*r **281:** 123–161.

Doty, M.S. (1988) Prodromus ad systematica Eucheumatoideorum: a tribe of commercial seaweeds related to *Eucheuma* (Solieriaceae, Gigartinales). *In:* Abbott, I. A. (ed.), Taxonomy of economic seaweeds with special reference to Pacific and Caribbean species. Volume 11. California. Sea Grant College Program Rep. No. T-CSGCP-018. pp. 159–207.

Doty, M.S. & Alvarez, V.B. (1975) Status, problems, advances and economics of *Eucheuma* farms. *Mar. Technol. Soc. J.* **9:** 30–35.

FAO, (2001) *World Aquaculture Production Statistics.* http://www.fao.org

FMC-Biopolymer (2001) http://www.fmcbiopolymer.com.

Fottland, H. & Sorensen, C. (1996) Issues related to

the establishment of prawn farms in Tanzania with an example from the Rufiji Delta. Catchment Forestry Report, 1996. **4.**

Gräslund, S. & Bengtsson, B. (2001) Chemicals and biological products used in south-east Asian shrimp farming, and their potential impact on the environment – a review. *The Sci. Total Environ.* **280:** 93–131.

Jaasund (1976) *Intertidal seaweeds in Tanzania: A field guide*. University of Tromsø, Norway. 160 pp.

JET News (1999) Rufiji Shrimp Project Saga: Dons commend Jet for standing firm, they say deal is shrouded with corruption. *Newsl. Journal. Environ. Assoc. Tanzania*, February 1999, pp. 1–3.

Johnstone, R.W. & Olafsson, E. (1995) Some environmetal aspects of open-water algal cultivation: Zanzibar, Tanzania. *Ambio* **24:** 465–469.

Kautsky, N., Berg, H., Folke, C., Larsson, J. & Troell, M. (1997) Ecological footprint as a means for the assessment of resource use and development limitations in shrimp and tilapia aquaculture. *Aquaculture Research* **28:** 753–766.

Kautsky, N., Folke, C., Rönnbäck, P., Troell, M., Beveridge, M. & Primavera, J. (2001) Aquaculture. *In:* Levin, S. (ed.) Encyclopedia of biodiversity. Vol. 1. Academic Press. pp. 185–197.

Kautsky, N., Rönnbäck, P., Tedengren, M. & Troell, M. (2000) Ecosystem perspectives on management of disease in shrimp pond farming. *Aquaculture* **191:** 145–161.

Kurien, J. (1997) State and shrimp: A preliminary analysis of the economic and ecological consequences of India's fishery policies. Paper presented at the FAO Technical Consultation on Policies for Sustainable Shrimp Aquaculture, Bangkok, 8–11 December, 1997.

Lirasan T. & Twide P. (1993) Farming *Eucheuma* in Zanzibar, Tanzania. *Hydrobiologia* **260/261:** 353–355.

Lissu, T.A.M. (1998) *The mad rush for "pink gold": A socio-legal study of the Rufiji delta prawn farming project in Tanzania.* Study presented at African Centre for Technology Studies (ACTS), Nairobi, Kenya. 91 pp.

Lundsør, E. (2002) *Eucheuma* farming in Zanzibar: Broadcast system, an alternative method for seaweed farming? Cand. Sc. thesis, University of Bergen. 96 pp.

Mmochi, A., Mozes, N, Kite-Powell, H.L., Dubi, A.M., Gordin, H., Jiddawi, N., Kissil, G., Msuya, F. & Mwangamilo, J. (2001) Design and preliminary results of an integrated mariculture pond system at Makoba, Zanzibar, Tanzania. *In:* Richmond, M. D. & Francis, J. (eds) *Marine Science Development in Tanzania and East Africa.* Proceedings o the 20th Anniversary Conference on Advances in Marine Science in Tanzania. 28 June – 1 July 1999. Zanzibar,Tanzania. pp. 431–449

Mshigeni (1976) Seaweed farming: a possibility in Tanzania's coastal ujamma villages. *Tanzania Notes and Records* **79–80:** 99–105.

Msuya, F. (1993) Seaweed farming in Zanzibar: An amazing story. *ALCOM News* **11:** 11–15.

Msuya, F. (1995) Socio-economic and environmental impact of seaweed farming in the east coast of Unguja, Tanzania. *In:* Proceedings of a National Workshop on Integrated Coastal Zone Management in Tanzania. Zanzibar, 9–12 May 1995. 24 pp.

Mtolera, M., Collen, J., Pedersen, M., Ekdahl, A., Abrahamsson, K. & Semesi, A.K. (1996) Stress induced production of volatile halogenated organic compounds in *Eucheuma denticulatum* (Rhodophyta) caused by elevated pH and high light intensities. *Eur. J. Phycol.* **31:** 89–95.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. (2000) Effect of aquaculture on world fish supplies. *Nature* **405:** 1017–1024.

Naylor, R.L., Goldburg, R.J., Troell, M., Beveridge, M.C.M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Mooney, H. & Primavera, J.H. (2001) Is aquaculture a net loss? *Conservation Biology* **2:** 20–21.

Pauly, D., Tyedmers, P., Froese, R. & Liu, L.Y. (2001) Down with fisheries and up with aquaculture. Paper presented at American Association for the Advancement of Science Meeting, San Francisco, 2001.

PhilImportExport Inc. (2001) *Carrageenan products*. http://www.philimportexport.com.

Primavera, J.H. (1991) Intensive prawn farming in the Philippines: Ecological, social and economic implications. *Ambio* **20:** 28–33.

Primavera, J.H. (1997) Socio-economic impacts of shrimp culture. *Aquaculture Research* **28:** 815–827.

Semesi, A.K. (1991) Management plan for the mangrove ecosystem of mainland Tanzania. Report from a NORAD funded project under the Ministry of Tourism, Natural Resources and Environment, Tanzania.

Semesi, A.K. (1998) Mangrove management and utilisation in eastern Africa. *Ambio* **27:** 620–626.

Semesi, S. (2002) Ecological and socio-economic impacts of farmed *Eucheuma* seaweeds in Zanzibar, Tanzania. MSc thesis, Agricultural University of Norway. 97 pp.

Semesi, A.K. & Mshigeni, K.E. (1977) Studies on the carrageenans from economic red algal genus

Eucheuma in Tanzania. *Botanica Marina* **20:** 239–242.

Shiva, V. & Karir, G. (1997*) Towards sustainable aquaculture: Chenmmeenkettu*. Research Foundation for Science, Technology and Ecology, New Delhi. 133 pp.

Taylor, D. (2000) *Mindanao seaweed growers, traders organize to prop up industry*. http://www.mindanao.org/news/0009/18.htm \z "/images/busiworld.gif".

Vivekanandan, V. & Kurien, J. (1997) Socio-economic and political dimensions of shrimp culture development in India: The case of Andhra Pradesh. Paper presented at Second International Symposium on Sustainable Aquaculture, Oslo, Norway, November 1997.

Wood, B & Peleman, W. (2001) *The arms fixers: Controlling the brokers and shipping agents*. http://www.nisat.org/publications/armsfixers/default.htm.