LINKING BIOLOGY AND SUSTAINABLE LIVELIHOODS TO THE PROPOSED ESTABLISHMENT OF COMMUNITY-BASED EUCHEUMOID FARMING IN SOUTHERN KENYA

By

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CAPE TOWN

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LINKING BIOLOGY AND SUSTAINABLE LIVELIHOODS TO THE PROPOSED ESTABLISHMENT OF COMMUNITY-BASED EUCHEUMOID FARMING IN SOUTHERN KENYA

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the Department of Biodiversity and Conservation Biology, University of the Western Cape

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DEDICATION

This work is dedicated:

To my dear wife, Jane Nyawira Gacuiri for her love, patience, encouragement, and inspiration.

To my son, Anthony Mureithi Gacuiri and daughter, Christine Wanjiru Gacuiri, for their forbearance and understanding.

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Finally, I wish to warmly express my indebtedness to my dear wife and children, parent, brothers and sisters and their families, as well as my parents in-law, for their encouragement and inspiration.

DECLARATION

I declare that ***Linking biology and sustainable livelihoods to the proposed establishment of community-based eucheumoid farming in southern Kenya*** is my own work, that it has not been submitted before for any degree or examination in any other university, and that all sources I have used or quoted have been indicated and acknowledged by means of complete references.

Joseph Gacuiri Wakibia January 2005

Signed:...

ABSTRACT

Growth rates of three commercial eucheumoids: brown *Eucheuma denticulatum* and green and brown *Kappaphycus alvarezii* were studied at three sites (Gazi Bay, Kibuyuni and Mkwiro) in southern Kenya. The study was conducted using the fixed off-bottom rope technique over a 15 month period from August 2001 to October 2002, in 4 plots (5 m x 1.5 m) set up at each site. The brown *E. denticulatum* had the highest mean growth rate over the entire period of 4.7% day^{-1} compared to the green and brown *K. alvarezii* which were 4.3% day^{-1} and 4.2% day^{-1}, respectively. Mean relative growth rates were highest at Gazi (5.6% day^{-1}), and lowest in Kibuyuni (3.2% day^{-1}) with intermediate values of 4.8% day^{-1} at Mkwiro. Increased water motion was observed to increase thallus nitrogen and hence the growth of eucheumoids. The 'ice-ice' syndrome affected both brown *E. denticulatum* and brown *K. alvarezii* but not green *K. alvarezii*. Mean growth was higher during the southeast monsoon (4.7% day^{-1}) than during the northeast monsoon (4.0% day^{-1}).

The carrageenan characteristics of the three morphotypes were measured for 12 months. The highest carrageenan yield was obtained for green *K. alvarezii* (59.1% dry wt), whereas the average carrageenan yield for brown *K. alvarezii* was 56.5% dry wt and 56.6% dry wt for brown *E. denticulatum*. The plants at Gazi (58.0% dry wt) had a slightly, though significantly, higher carrageenan yield than both those at Kibuyuni (57.1% dry wt) and Mkwiro (57.3% dry wt). However, from a commercial point of view the differences in carrageenan yields were not meaningful. Highest gel strengths were obtained in carrageenans from green *K. alvarezii* (1042.1 g cm^{-2}) and brown *K. alvarezii* (1053.7 g cm^{-2}), whereas low values of 100.8 g cm^{-2} were obtained for brown *E. denticulatum*. The brown *E. denticulatum* had carrageenan with higher viscosity (81.7 mPa.s) and sulphate content (29.1% dry wt) than both green and brown *K. alvarezii*. The gel viscosities of all the morphotypes were higher during the southeast monsoon (67.3 mPa.s) than during the northeast monsoon (46.3 mPa.s) and were positively correlated with gel strengths.

A survey was conducted among households in the three villages, from April to September 2001 to assess their socio-economic characteristics. There were 182 household heads interviewed; about 20% were women. Fishing was the main source of livelihood for about 48% of the household members. In 2001, the average monthly income for the surveyed households was Kshs. 9904 (1 US$=75 Kshs.), with about 67% having less than Kshs. 10 000. The average prevalence of poverty among the households surveyed was 45.1% with 38.8%, 54.8% and 46.7% of households in Gazi, Kibuyuni and Mkwiro villages, respectively, living below the poverty line of Kshs. 1239 per month per adult person.

An economic feasibility study for growing brown *E. denticulatum* and brown *K. alvarezii* in pilot farms of 0.1 ha was conducted at Gazi and Kibuyuni. A higher yield of 793 kg dry wt was obtained for plants grown at Gazi than those at Kibuyuni (793 kg dry wt). The net income derived from *E. denticulatum* was estimated at Kshs. 7549 annually in a 0.1 ha seaweed farm. A higher annual income of Kshs. 49 126 was generated from *K. alvarezii*. The rate of return on investment in farming *E. denticulatum* ranged from 15 to 63%, while 122 to 380% for *K. alvarezii*. The pay back period was shorter for the latter (0.3 to 0.7 years) than the former (1.2 to 2.7 years).

A cross-sectoral policy analysis regarding legislation and policy relevant to the introduction and development of eucheumoid cultivation in Kenya, with particular reference to Kenyan legislation was conducted. The analysis showed that there is no system of promoting or regulating mariculture, though there are fragmented regulations that are scattered among the policies, Acts and regulations of various institutions. Such regulations were not designed specifically for mariculture and as a result they do not fully address the needs of mariculture. The establishment of a national mariculture development programme in Kenya is proposed as a means to develop and manage the farming of marine resources, including seaweeds.

KEY WORDS

Sustainable livelihoods; *Eucheuma*; *Kappaphycus*; eucheumoid; growth; carrageenan; economic feasibility; socio-economic factors; cross-sectoral policy analysis for eucheumoid mariculture; Kenya.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background to the thesis and outline

Kenya has a coastline of about 600 km long in the western Indian Ocean region. In 1997, the estimated coastal population was approximately two million, representing about eight percent of the national population (GOK, 2000). Most of the coastal population relies on the coral reef fishery, the mangroves and subsistence agriculture for their livelihoods (UNEP, 1998). The main fishery along the Kenyan coast is traditional and artisanal supporting 8000 fisherfolk and contributes about 80% of Kenya's coastal fish catch of approximately 8,000 to 16 000 tons annually (McClanahan & Obura, 1995). Most of the fishing is focused on nearshore coral reefs, seagrass beds, and mangroves where traps, spear guns, and nets are used to catch fish. Mangroves are important sources of poles, charcoal and firewood, and also act as breeding grounds for commercial fishery resources. However, the Kenyan coastal environment and its resources are increasingly under pressure from human settlements and development activities (UNEP, 1998).

The degradation of the marine resources and poverty are the two main issues affecting the livelihoods of the coastal communities (GOK, 2002). The fisherfolk have experienced declining fish catches and incomes, and fishing alone rarely supplies sufficient incomes to support households (McClanaham & Obura, 1995). According to the local fisherfolk, the foreign fishermen from Tanzania, coupled with the large number of small-scale fisherfolk in relation to the fishing area and the establishment of marine parks and reserves have considerably reduced the catches in southern Kenya (personal interview). The use of destructive and inappropriate fishing practices such as seining and gill nets, aquarium fishing, use of fishing poisons, and coral collection also contributed to declining catches along the Kenyan coast (McClanaham & Obura, 1995). It has also been reported that Kenyan reefs show signs of overexploitation, while offshore areas are considered under-exploited (McClanaham & Obura, 1995). Other traditional coastal resources such as mangroves have been degraded by overcutting and overharvesting for poles and fuel wood, resulting in a declining supply of firewood and construction materials, loss of economic livelihood for mangrove cutters, loss of breeding habitats for fisheries and associated impacts of declining fish catch (GOK, 2002).

1.1.1 Poverty

One of the major challenges facing the coastal communities in Kenya is the high prevalence of poverty. A socio-economic survey carried out by Central Bureau of Statistics in 1997 revealed that about 62% of the coastal population were living in poverty (highest in the country) as compared to a national poverty level of 52% (GOK, 2000). The causes of poverty among the coastal communities included poor infrastructure including roads, electricity, telecommunications, and water; poor agricultural production due to land tenure problems, and wildlife menace; poor marine fisheries development and coastal and marine resources degradation; high population dependency rate; and lack of credit facilities (GOK, 2002). Women formed the greatest population in the rural areas living in absolute poverty. They engaged in subsistence agriculture to sustain their households but were hardest hit due to droughts and low productivity. Poor farming practices such as the slash and burn system of cultivation exposes large areas of the coastal region to agents of erosion leading to increased surface runoff and decline in soil fertility resulting in depressed agricultural production (GOK, 2002).

The major challenge facing the government is how to generate employment opportunities to absorb the large army of the unemployed, particularly the youth, curb environmental degradation and reduce poverty levels in Kenya, including the coastal communities (GOK, 2003). In order to help the Kenya's coastal fisherfolk rise above their poverty and reduce pressure on coastal and marine resources, several income generating interventions are required. Poverty reduction strategies must be formulated not only to rely on higher economic growth but should also incorporate and target pro-poor marine-based programmes and projects. The interventions should also be environmentally friendly and sustainable. Such intervention strategies could include promotion of offshore fishing, deployment of artificial reefs and introduction of technology for seaweed mariculture. However, most of the fisherfolk have inadequate and poor equipment particularly the boats which lack motors or are not large enough for offshore fishing. The offshore fishing option was attempted at three coastal villages (Kibuyuni, Wasini and Mkwiro) using funding from USAID but failed due to corruption, mismanagement and lack of education (Marine Park Warden, pers. comm.). Artificial reefs are a fishery management tool and serves as shelter and habitat, source of food and breeding grounds for aquatic species in absence of natural habitat (White et al., 1990). However, artificial reef programmes are long term projects requiring huge investments and must be coupled with the introduction of other immediate forms of livelihood. Other options could include locally Marine Protected Areas (MPAs) along with artificial reefs that have been very successful in the Philippines (White et al., 1990). Like in many coastal countries in the developing countries, one potential intervention that could stimulate economic and social development among the coastal communities in Kenya is seaweed farming (Doty, 1987). Seaweed farming is usually carried out on the reef flats and lagoons where villagers, including women, use for gleaning and fishing activities. Seaweed mariculture is a low cost activity that requires simple technology; make use of family labour and locally available materials such as the mangrove poles, and has a short grow out period that allows for cycling (harvesting/replanting a part of the farm every low tide), hence a steady cash flow. The relative non-perishability of seaweed is a particular advantage of seaweed cultivation compared to many other types of aquaculture.

Seaweed farming is a labour intensive activity; it is therefore ideal for developing countries such as Kenya with dense and unemployed or under-employed coastal population. For example, about half a million people in the Philippines benefit from eucheumoid farming (Trono et al., 2000), whereas over 80% of the people farming seaweed in Tanzania are women (Msuya, 1993). Several authors have reported that the communities and families involved in seaweed farming have improved standards of living and income levels (Alih, 1990; Hurtado-Ponce et al., 1996). The operating costs are relatively low; chemicals and fertilizers are not needed to sustain seaweed production. In addition, it has been suggested that increased economic prosperity in the coastal communities due to seaweed farming could reduce the destructive fishing practises as fisherfolk would be involved in the farming activity (Alih, 1990; Mtolera et al., 1992). Commercial eucheumoid cultivation has been described as a sustainable livelihood that offers environmental (Mtolera et al., 1992; Ask, 1999), socio-economic (Doty, 1987; Msuya, 1993; Ask et al., 2003) and political benefits (Alih, 1990; Ask et al., 2003) for coastal communities. However, in establishing a community-based seaweed farming project, a development framework is required to focus on the socio-economic and political characteristics of the community; existing institutional arrangements, biophysical attributes of the coastal resources; and characteristics of the fishing and technologies practiced in the community. The transfer of seaweed farming technologies also requires a participatory approach. Such a participatory framework that focuses on interventions on marine resources and the target beneficiaries is the Sustainable Livelihoods (refer to section 1.1.2).

1.1.2 Sustainable livelihoods

Sustainable livelihoods approach offers both a conceptual and programming framework for poverty reduction in a sustainable manner (Singh & Wanmali, 1998). The concept of sustainable livelihoods (SL) was introduced by the World Commission on Environment and Development, and relates to a way of approaching development that incorporates all aspects of human livelihoods and the means whereby people obtain them to meet basic needs (Keats, 1998; Singh & Gilman, 2000). According to Chambers & Conway (1992), a livelihood comprises the activities, entitlements and assets that enable people to make a living. Activities are things that people do to gain living, and these are based on available assets while entitlements are those things that people demand and appeal for at times of shocks and stresses (Chambers & Conway, 1992; Keats, 1998). The support may take such forms as food, implements, loans, gifts, or work. However, according to Singh & Gilman (2000), entitlements refer to exchange capabilities and human rights, which include economic, social, cultural and political rights, all of which are interdependent and recognised by the international community. There are four types of assets in the sustainable livelihoods context: social and cultural capital (governance structures, decision making power, community and other institutions, participatory process), human assets (knowledge, skills, creativity, adaptive strategies), human made assets (buildings, roads, machinery, crops/livestock), and natural assets (land/soil, water, air, forestry vegetation) (Singh & Gilman, 2000). However, Bebbington (1999) recognized five capital assets: physical, financial, social, natural and human, with the financial capital involving the credit, savings and remittances component of the capital assets. However, some authors argued that financial capital should not be considered;

for instance, they argued that financial capital reflects the values of other capitals and has no value *per se* (Hamilton & Clemens, 1999).

The SL concept also takes into account the several dimensions of sustainability such as the environmental sustainability (ensuring that livelihood activities do not irreversibly degrade natural resources within a given ecosystem); economic sustainability (the use of minimal inputs to generate a given amount of outputs); social sustainability (social imbalances are minimised and social equity maximised); and institutional sustainability (ensuring that prevailing structures and processes continue to perform over the long term) (Singh & Wanmali, 1998). Another dimension of sustainability is the ability to cope with and recover from shocks and stresses. The shocks are impacts which are typically sudden, unpredictable and traumatic, such as droughts, disease outbreaks and collapse of a market, etc., while stresses are pressures which are typically continuous and cumulative, predictable and distressing, such as seasonal shortages, rising populations or declining resources (Wanmali, 1998).

The sustainable livelihoods approach is one of the most innovative approaches which has been developed in response to poverty reduction and sustainable human development (Singh & Gilman, 2000). The SL approach is defined as an integrated package of policy, technology and investment strategies used together with decision-making tools which contribute to livelihoods by building on local adaptive strategies (Singh & Wanmali, 1998). The SL approach includes a defined methodology for implementation. The SL methodology for measuring the components of the SL system (adaptive strategies, policy strategies, technology strategies, and investment strategies) consists of four steps which are not necessary implemented sequentially (Singh & Gilman, 2000). However, Keats (1998) felt that the concept of steps implied that one must be taken before the other, which is the case, and he suggested the term “channel”.

In this study, the term channel will be used to describe the SL methodology according to Keats (1998) as briefly described here. Channel 1 involves a participatory assessment of the assets, entitlements, and activities which people currently use to make their living. The coping and adaptive strategies of individuals, households and communities are also identified using participatory research. Channel 2 involves the analysis of the macro, micro and sectoral policies, and governance arrangements which impinge on people's livelihoods and their adaptive strategies. The methodology involves a policy analysis matrix. Channel 3 involves a participatory assessment of the key technologies contributing to the livelihood systems and determination of the potential contributions of modern science and technology that complement indigenous knowledge systems in order to improve livelihoods. Channel 4 identifies the macro-micro investment strategy, which at the macro level follow an investment led transformation approach based on mobilization of domestic resources. This macro strategy is implemented in harmony with micro finance and traditional saving schemes.

The importance of the SL methodology is that it integrates environmental, social and economic issues into a holistic framework for analysis. This is especially true in identifying not only the types of assets which people use, but also how existing livelihoods can be strengthened with new and appropriate technologies and corresponding social and economic investments. This results in sustainability being brought into the fold and viewed simultaneously through environmental and socio-economic lenses (Wanmali, 1998). Another fundamental principle of the SL approach is that the focus is on community strengths not weaknesses. This is important in building self-esteem and self-reliance and to break the donor-recipient syndrome (Singh & Gilman, 2000).

Having considered that SL approach is an integrated set of policy, technology and investment strategies, this study has considered the development of seaweed farming as a sustainable livelihoods project by applying three of the four channels. A participatory assessment of the assets, activities and coping and adaptive strategies of households was conducted at three coastal fishing villages (Gazi, Kibuyuni and Mkwiro) in southern Kenya (Chapter 3); the current policies, regulations and legislations likely to influence the introduction and development of seaweed farming in Kenya were analysed with some recommendations (Chapter 6) while the technical feasibility of seaweed farming was determined using the fixed off bottom technology (Chapter 2). The micro finance and credit facilities (channel 4) to support seaweed farming were not determined in this study because seaweed cultivation projects are normally promoted and funded by donors or governments or donor recipients (NGOs and academics) and sometimes by the seaweed processors who also purchase the seaweed produced. The SL concept and approach is useful in projects such as commercial eucheumoid development as it acknowledges the diversity of activities that people engage in to survive, and provides a conceptual framework for socio-economic interventions.

1.1.3 Eucheumoid farming

Seaweeds or marine algae are marine resources with many uses. They provide food for humans, fish and other aquatic animals, and are also used in the manufacture of animal feeds and fertilizers. Presently, one of the most important fields of seaweed utilization is for the extraction of cell wall polysaccharides, the most useful ones being agar, alginate, and carrageenan. Agar and carrageenan are extracted exclusively from certain red algae, while alginate comes only from brown seaweeds. Of these polysaccharides, there is a high demand for carrageenans, partly due to their abilities to increase viscosity and gel strength in water solutions resulting in their wide use in several industries (Stanley, 1990).

Carrageenans are produced from various genera of red algae such as *Eucheuma*, *Kappaphycus*, *Betaphycus*, *Chondrus*, *Gigartina*, *Sarcothalia*, *Mazzaella* and *Hypnea*. *Chondrus crispus* Stackhouse (Irish moss) was the principal raw material for carrageenan production until the 1970s when it was replaced by *Eucheuma* and *Kappaphycus* species (Doty, 1987; McHugh, 2003). Today most of the world's supplies of carrageenans are produced from *Eucheuma denticulatum* (Burman) Collins & Hervey (as 'spinosum of commerce') and *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva (as 'cottonii of commerce'). The seaweed *Kappaphycus striatus* (F. Schmitz) Doty ex P.C. Silva was once the principal eucheumoid species but it has been replaced by *K. alvarezii*, which is easier to grow in mariculture operations than the former species (Doty, 1987). In the following discussion, the term 'eucheumoid' will be used to include the different commercial morphotypes of *E. denticulatum* and *K. alvarezii* which were formerly recognized as species of *Eucheuma* (Doty, 1988). The recent taxonomic treatment of eucheumoids by Silva et al. (1996) and Prud'homme van Reine & Trono (2001) will be followed here.

The main sources of carrageenophyte material were previously from the wild but, because of depletion of natural stocks due to overharvesting, *Eucheuma* and *Kappaphycus* cultivation was initiated in the Philippines (Doty, 1973; Parker, 1974).

However, due to the great demand for carrageenans on the world market (McHugh, 2003), combined with insecure supplies of raw material and the strategic risk of concentrating *Eucheuma* farming in the Far East (Lirasan & Twide, 1993), seaweed processors have been promoting cultivation programmes outside Indonesia and the Philippines. Today *K. alvarezii* and *E. denticulatum* are also commercially farmed in Malaysia (Adnan & Porse, 1987), Fiji (Ask et al., 2003), Kiribati (Luxton et al., 1999) and Tanzania (Lirasan & Twide, 1993). All the original eucheumoid strains for cultivation came from the Philippines.

The commercial cultivation of *Eucheuma* and *Kappaphycus* species has so far not been developed in Kenya. The climate and oceanography of the Kenyan coast is similar to that of Tanzania and there have been suggestions that eucheumoid mariculture could be developed here, as in other warm regions (Yarish & Wamukoya, 1990; Oyieke, 1998). However, this has been unrealised to date, and there is a general lack of information on how this resource may be used farmed in Kenya (Oyieke, 1998). The development of eucheumoid farming in Kenya could broaden the livelihood activities of the poor coastal village communities by providing income and employment opportunities. Seaweed farming could also be a source of foreign exchange for the country. However, before commercial eucheumoid farming could be realised in Kenya, the following information is needed: areas potentially supporting commercial growth rates of eucheumoids (Doty, 1987; Trono, 1992a); socio-economic conditions of coastal village communities (Trono, 1992b; Ask, 2003); the quantity and quality of carrageenans from the grown material (Ohno et al., 1996); economic analysis of seaweed farming (Hurtado et al., 2001); and policy and regulations issues that are likely to influence the seaweed development project (Ask et al., 2003, Oliveira & Paula, 2003). Development funding also needs to be addressed in order to establish a seaweed industry in Kenya. The purpose of the present study was to gain the scientific and socio-economic data necessary to assess the potential for commercial eucheumoid farming in Kenya.

1.1.4 Structure of the thesis

This thesis is organized into 7 independent but closely linked chapters that are designed for publication with the exception of Chapters 1 and 7. In chapter 1, a literature review on various aspects of the commercial eucheumoids, and the aim and objectives of this study are presented. The seaweed resources and need for seaweed research in Kenya are also discussed in Chapter 1. Chapter 2 presents the three coastal study sites (Gazi, Kibuyuni and Mkwiro) in southern Kenya and discusses the factors influencing the growth of eucheumoids at the three locations, while Chapter 3 assesses the socio-economic and livelihood conditions of village communities in these areas. In Chapter 4, the carragenan yield and properties of three morphotypes of commercial eucheumoids cultivated in Kenya are analysed. Chapter 5 focuses on the economic feasibility of eucheumoid cultivation at two sites (Gazi and Kibuyuni) by performing a cost/benefit analysis and evaluation of economic indicators. The next Chapter (6) is concerned with the policy issues that are likely to influence the adoption of seaweed farming. Finally, Chapter 7 provides conclusions and recommendations.

1.2 Literature review

1.2.1 Taxonomy and distribution

Several tropical carrageenophytic genera belonging to the family Solieraceae in the order Gigartinales are harvested or cultivated for carrageenan production. These genera mainly include *Eucheuma*, *Kappaphycus* and *Betaphycus*. However, most of the world's carrageenans are extracted from farmed *Eucheuma* and *Kappaphycus* species and only small quantities are obtained from *Betaphycus* species (McHugh, 2003). These seaweeds exhibit the typical triphasic "Polysiphonia-type" life history as illustrated by Dawes (1998) for *Eucheuma isiforme* (C. Agardh) J. Agardh.

The taxonomy of the commercially important genus *Eucheuma* has undergone revision recently. The original genus *Eucheuma* has been subsequently divided into three genera viz. *Eucheuma*, *Kappaphycus*, and *Betaphycus* (Doty, 1995). Members of these genera will be collectively termed 'eucheumoids' in this thesis. The genus *Eucheuma* was established by J. G. Agardh in 1847 on the basis of cartilaginous consistency and three kinds of tissue (Doty, 1985). Recently the genera *Kappaphycus* and *Betaphycus* were segregated from *Eucheuma* primarily on the basis of the type of carrageenan they produced. The genus *Kappaphycus* was created by Doty (1988) on the basis of a combination of gross morphological, anatomical and biochemical characters. The genus *Betaphycus* was created to contain species with beta (β)-carrageenan (Doty, 1995).

However, the name *Betaphycus* was only validated recently because it originally lacked a Latin diagnosis as required for new scientific names (Silva et al., 1996). Although these new genera have been generally accepted by the scientific community, their validity is questionable as recent studies have demonstrated that some members of these genera yielded a mixture of κ-, ι- and β-carrageenans (Knutsen et al., 1994). Also the established genera were based on only a few samples and in some cases on non-reproductive material (Doty, 1995). Probably a systematic approach using a combination of anatomical, biochemical and molecular characters could solve the taxonomy of the family Solieriaceae.

The genera *Eucheuma* and *Kappaphycus* contain species of economic importance, yet their taxonomy and nomenclature are in a rather chaotic state (Doty, 1987; Santos, 1989). However, the situation is clearer in recent times based on their works. Both genera present considerable difficulties to algal taxonomists due, for example, cartilaginous nature of the seaweeds making specimens difficult to dry and preserve them as herbarium specimens, rarity of fertile material, and non-existence of type specimens (Doty, 1985), morphological plasticity (Doty, 1985; Mshigeni, 1987), geographic spread of *Eucheuma* and *Kappaphycus* for mariculture (Zuccarello et al., 2004), and the use of commercial names of convenience (Zuccarello et al., 2004). Nevertheless, the recent works of Doty (1988) have contributed much to the clarification of the taxonomy of commercial species in the genera *Kappaphycus* and *Eucheuma*. However, more detailed investigations involving field transplantations, cell wall chemistry, molecular-based phylogenetic studies, including the traditional morphological-anatomical analyses are needed to verify the delimitation of *Eucheuma* and *Kappaphycus* species.

Of the species of *Eucheuma*, *Kappaphycus* and *Betaphycus* cited in the literature, four are commercially utilised: *E. denticulatum*, *K. alvarezii*, *K. striatus* and *Betaphycus gelatinum* (Esper) Doty. In this thesis, the name *Kappaphycus striatus* will be used instead of *K. striatum* because "phycus" in classical Greek is a neuter noun, but because "-us" is the typical ending of a masculine noun, the International Code of Botanical Nomenclature was altered by the Nomenclature Section of the International Botanical Congress meeting in St. Louis in 1999 to legislate -phycus as a masculine word-element (see Article 62.2 (c)) (ICBN, 2000). Hence, *Kappaphycus striatum* automatically becomes *K. striatus* (P. C. Silva, pers. comm.). However, *E. denticulatum*, *K. alvarezii* and *K. striatus* are the only species that are widely farmed for the phycocolloid carrageenan, and they have been introduced in several countries for experimental or commercial purposes (Ask & Azanza, 2002; Ask et al., 2003). *Eucheuma denticulatum* is the commercial source of iota carrageenan, while *Kappaphycus alvarezii* is the source of kappa carrageenan (Santos, 1989). A variety of forms for each species is used in farming, and ranging from deep red to brown or green in colour with morphologies of slender to very coarse branches (Azanza-Corrales, 1990). Fifteen morphotypes are presently utilized in farming; three are representatives of *E. denticulatum* while the rest are morphotypes of *K. alvarezii* (Trono et al., 2000).

Commercial eucheumoid algae inhabit the tropical waters from the western Indian Ocean region to the Pacific Ocean in Southeast Asia. These plants have also been introduced in Fiji and Kiribati for commercial cultivation. *E. denticulatum* and *K. alvarezii* are generally found in shallow reef flats and in lagoons at a water depth of less than 2 m at high tide (Parker, 1974). *E. denticulatum* grows on sandy-corally to rocky substrata in habitats constantly exposed to moderate to strong water motion. On the other hand, *K. alvarezii* is mostly confined to the sublittoral zone where the thalli are fully submerged in seawater and thrives in reef flats with coarse sandy-corally substrata, where water movement is slow to moderate. The tolerance to aerial exposure appears to regulate the upward littoral distributional limits of both species. However, *E. denticulatum* thrives higher up in the eulittoral zone than *K. alvarezii*, presumably due its tolerance to direct insolation and prolonged desiccation (Mshigeni, 1979; Doty, 1987). The wild and farmed eucheumoids are mostly found naturally in water less than a half meter deep at extreme low tide level (Doty, 1987).

Species of *Eucheuma* and *Kappaphycus* occur naturally in, and are indigenous to, Kenyan coastal habitats, and several authors have studied their taxonomy. Isaac (1967) published the first list of Kenyan marine algae where he included four *Eucheuma* species (*E. denticulatum*, *E. horridum* J. Agardh, *E. serra* (J. Agardh) J. Agardh, and *K. striatus* (as *E. striatum)*. In his second list of marine algae of Kenya, Isaac (1968) added two *Eucheuma* species: *E. chondriforme* J. Agardh and *E. arnoldii* Weber-van Bosse (*as E. cupressoideum*). However, Mshigeni (1987) suggested that the former species be transferred to the genus *Gracilaria* on basis of flattened fronds with marginal projections like some gracilariods. Isaac (1968) also reported that Boergesen identified the material as *E. chondriforme* 'with much doubt'. The presence of *E. arnoldii* in Kenya is also debatable as this species has otherwise only been recorded in the Asiatic waters of Malaysia and Singapore (Kraft, 1972).

The most recent field survey of eucheumoids in Kenya was carried out by Yarish & Wamukoya (1990), who identified four *Eucheuma* species: *E. denticulatum*, *E. platycladum* Schmitz, *E. odonthophorum* Borgesen, and *E. horridum*; and two *Kappaphycus* species: *K striatum* and *K. cottonii* (Weber Bosse) Doty ex H.D Nguyen & Q.N. Huyhn. Doty (1988) published the name *K. cottonii* without giving the exact page on which the basionym was named. Nguyen Huu Dinh and Huynh Quang Nang were the first to furnish the pagination; hence the names are appended to the author of this binomial (W.F. Prud'homme van Reine, pers. comm.). Unfortunately none of these specimens are deposited at Kenya Marine & Fisheries Research Institute (KMFRI) as indicated by the authors and consequently, it is difficult to confirm their taxonomic treatment of these species. Furthermore, Yarish & Wamukoya (1990) identified their collections based on taxonomic guides from other areas and hence, there is a need for more studies to confirm some of their species such as *E. odonthophorum*, *E. horridum* and *K. cottonii*.

1.2.2 Carrageenan

Eucheuma and *Kappaphycus* species are commercially farmed as raw material for carragenan production. Carrageenans are biopolymer gels that occur in the cell wall of some red algae (Stanley, 1990). They are widely used in the food, pharmaceutical, and cosmetic, among other industries, as suspending, thickening, stabilising, and emulsifying agents (Stanley, 1990).

Carrageenans are sulphated marine polysaccharides having a repeating structure of alternating 1,3-linked β-D-galactopyranose and 1,4-linked α-D-galactopyranose residues (Figure 1.1) (Anderson et al., 1968). However, the repeating disaccharide units may be substituted or modified with sulphate hemiesters and methyl esters (Craigie, 1990). The 1, 4-linked α-D-galactose 6-sulphate residue is regarded as a biogenetic precursor of 3,6-anhydro-α-D-galactose (3, 6-AG) (Craigie & Wong, 1979). The precursor is catalysed in algal tissues by the enzyme sulphoeliminase (Rees, 1961; Craigie & Wong, 1979) and this process is currently used in commercial extraction of strong gels by the addition of strong alkali such as calcium or potassium hydroxide (Stanley, 1990). Treatment of eucheumoid material with alkali results in a marked increase in gel strength. Anderson et al. (1968) showed that this increased gelling ability was due to conversion ('de-kinking') of the 1,4-linked galactose 6-sulphate units, representing a severe 'kink' in the polymer chain molecule, into the more regular 3,6-AG units. The alkaline modification causes a decrease in viscosity and sulphate content while at the same time increasing gel strength and 3, 6-AG content in *Eucheuma* and *Kappaphycus* carrageenans (Santos, 1989).

The carrageenans have been classified according to the position and structure of the ester sulphate into four families (Craigie, 1990): The kappa (κ)-family consisting of κ, iota (ι), mu (μ), and nu (ν)-carrageenans; the lambda (λ)-family of λ, (xi) ξ and pi (π)-carrageenans, the beta (β)-family consisting of β, alpha (α), omicron (o) and gamma (γ)-carrageenans, and the omega (ω)-family with ω and psi (ψ)-carrageenans (see Knutsen et al., 1994 for the naming authors). In the κ, λ, and ω-families, the 3-linked- β-D-galactopyranosyl residues are sulphated at carbon 4 (C4), C2 and C6, respectively, while sulphate substitution is lacking in the β-family. However, the above classification; based on sulphate substitution has recently been challenged by Knutsen et al. (1994) on the basis of extracted carrageenans with hybrid structures and galactans with mixed agar and carrageenan characteristics. Knutsen et al. (1994) suggested a nomenclature procedure for carrageenans based on their chemical structure. Irrespective of this nomenclatural controversy, only four carrageenans (κ, λ, β, and ι) are available commercially (Craigie, 1990; McHugh, 2003).

The most important properties of carrageenans are the gel strength and viscosity (Stanley, 1990) which are mainly influenced by the 3, 6-AG and the sulphate contents. The production of carrageenan from eucheumoids shows considerable variability in gel yield and properties. These gel characteristics vary with different *Eucheuma* and *Kappaphycus* species, morphotypes, locations, culture techniques, among other factors (Li et al., 1990; Trono & Lluisma, 1992; Hurtado-Ponce, 1995; Ohno et al., 1996). The influence of environmental parameters on carrageenan content and properties has also been reported in eucheumoid algae. For example, the variability in carrageenan characteristics from *Eucheuma* and *Kappaphycus* species has been related to nutrients (Li et al., 1990; Trono & Lluisma, 1992) and water movement (Azanza-Corrales & Sa-a, 1990). Azanza-Corrales & Sa-a (1990) observed that the carrageenan yields of eucheumoids from the Philippines decreased with increasing water movement. Dawes et al. (1974) found pronounced seasonal variations in the carrageenan properties of Florida *Eucheuma* while Buriyo et al. (2001) recorded higher carrageenan content from Tanzanian *E. denticulatum* during the southeast monsoon than in the northeast monsoon. The latter authors also observed that the carrageenan yield correlated inversely with photon fluency rates and temperature. Other possible causes of variations in carrageenan properties include the extraction methods (Miller & Furneaux, 1987) and thallus age (Rivera-Carro et al., 1990).

1.2.3 Physiological ecology

The environment of an organism includes both the biotic and abiotic (physico-chemical) factors. A complex of abiotic and biotic factors have been shown to influence the growth and productivity of seaweeds, including the *Eucheuma* and *Kappaphycus* species (Doty, 1978; 1987). These factors include photon fluency rates, temperature, salinity, water motion, nutrients (nitrogen, phosphorus, and carbon), epiphytes, grazers, and 'ice-ice' syndrome (see later).

Photon fluency rate

Photon fluency rate, normally referred to as irradiance in the literature (Dawes, 1998) or even light intensity is one of the most important abiotic factors regulating growth in marine algae by providing energy for photosynthesis. It also functions as an environmental signal for controlling seaweed development (Lüning, 1990). The photon fluency rate requirement of photosynthesis and growth for eucheumoid varies with species, morphotypes and locations. For example, the photosynthetic irradiance saturation for Tanzanian *E. denticulatum* ranged from 600 to 1000 μmol photon m^{-2} s^{-1} (Collen et al., 1992) while an irradiance saturation of 700 μmol photon m^{-2} s^{-1} was obtained for *K. alvarezii* (Granbom, 2001). Similar values were also observed by Ganzon-Fortes et al. (1993) for a healthy thallus of *K. alvarezii* in the Philippines. However, low photosynthetic irradiance saturation values of 58 to 268 μmol photon m^{-2}

s^{-1} were obtained for green and brown morphotypes of *E. denticulatum* and *K. alvarezii* from the Philippines (Dawes, 1992). For the growth of eucheumoid, optimum photon fluency rate was reported to be 350 μmol photon $m^{-2} s^{-1}$ for *E. denticulatum* (Mtolera et al., 1995) whereas Gerung & Ohno (1997) measured lower optimal photon fluency values of less than 165 μmol photon $m^{-2} s^{-1}$ for growth of brown and green morphotypes of *E. denticulatum* and *K. alvarezii* at 25 °C under laboratory conditions. The variation in photosynthetic and growth optimal photon fluency values for the commercial eucheumoids reported in the literature may be due to differences in nutritional states (Collen et al., 1992), suboptimal nutrient levels in the seawater (Collen et al., 1992), the sample size as well as handling procedures (Dawes, 1979), and probably the difference in productivities within species and morphotypes.

Most eucheumoid algae have a defined photon fluency range for growth but high photon fluency values may cause photoinhibition. Doty (1973) mentioned that elevated photon fluency rates caused ageing of the Philippine *Kappaphycus striatus* (as *Eucheuma striatum*). High photon fluency rates have also been suggested to inhibit the growth of *Eucheuma* species in field studies (Dawes et al., 1974). Furthermore, Mtolera et al. (1995) working with *E. denticulatum* in Tanzania observed that the plants exposed to full solar irradiance had permanent photodamage after photoinhibition. Such inhibition could have involved damage to some components of the photosynthetic apparatus, such as the membranes or electron-transport proteins (Lobban & Harrison, 1994).

Some eucheumoid algae such as *E. denticulatum* inhabit the eulittoral zone while *Kappaphycus* species are common in the upper sublittoral zone of tropical waters, where their optimal photon fluency requirements are often exceeded. Lüning (1990) estimated that the maximum photon fluency in the tropics is about 2500 μmol photon $m^{-2} s^{-1}$, although over 3000 μmol photon $m^{-2} s^{-1}$ have been recorded around *E. denticulatum* beds in Tanzania (Mtolera et al., 1995). Therefore these eucheumoids must have abilities to tolerate the high photon fluency rates. Studies have revealed that these plants often respond to harmful irradiance levels by, increased chlorophyll fluorescence, increased photorespiratory activity, and production of toxic oxygen species such as superoxide, hydrogen peroxide, singlet oxygen and hydroxyl radicals (see Mtolera, 1996). For example, *K. striatus* plants protect themselves against ultraviolet (UV) light by production of UV-absorbing substances (Wood, 1989). However, other factors such as water temperature and nutrients, among others, are also important in maintaining growth in environments with elevated photon fluency rates in culture systems (Collen et al., 1995).

Temperature

Temperature is a fundamental abiotic factor that affects the chemical reactions of seaweeds, including eucheumoids. Although *Eucheuma* and *Kappaphycus* species are distributed in the tropical and subtropical waters of the world, most of them are found in the tropics with temperature controlling this distribution (Mshigeni, 1979; Doty, 1987). Studies on temperature effects on growth and photosynthesis of eucheumoids have been performed both in field and laboratory conditions. Aguirre-von-Wobeser et al. (2001) obtained optimum photosynthetic rates in both green and red morphotypes of *K. alvarezii* at 30°C, which is in agreement with the measured optimum temperature for maximum growth of the plants in field conditions (Hurtado-Ponce, 1992; Ohno et al., 1994). Maximal photosynthetic rates at 30 °C have also been reported for *E. denticulatum* (Dawes, 1979; Glenn & Doty, 1981). In the tropical areas where eucheumoids thrive well, the seawater temperature ranges from 28 to 31 °C (Mshigeni, 1979; Doty, 1987). The optimal growth temperature for eucheumoids seems to range from 28 to 30 °C in field conditions as reported by various authors (Doty, 1987; Hurtado-Ponce, 1992; Ohno et al., 1994). However, Mairh et al. (1986) obtained a broad growth optimum of between 21 and 31°C for *K. striatus* grown in both the laboratory and field environment, which was similar to values of 22- 27°C for *K. alvarezii* in Brazil (Paula et al., 2001).

High temperatures (above 33°C) have been observed to reduce growth rates of eucheumoids in commercial farms in the Philippines (Hurtado-Ponce, 1992), Vietnam (Ohno et al., 1996) and Zanzibar (Lirasan & Twide, 1993). This may be due to the decreased photosynthetic rates of these plants as was also reported for *E. denticulatum* and *K. alvarezii* by Glenn & Doty (1981). The *E. denticulatum* and *K. striatus* plants cultivated in Madagascar became fragile with decreased growth at temperatures of more than 31°C (Mollion & Braud, 1993). Besides the effect of temperature on reduced growth, Hurtado-Ponce (1992) noted that in summer when temperatures were above 35°C, the *K. alvarezii* thalli became stubby and blunt with sparse branching.

Salinity

Salinity of the water may increase due to evaporation brought about by an increase in temperature. Salinity has been reported to influence the local distribution of marine algae (Dawes, 1998). Photosynthetic and growth rates of seaweeds are also affected by salinity. They are few studies on the effects of salinity on photosynthesis and growth rates of commercial eucheumoids (Mairh et al., 1986; Ask & Azanza, 2002). However, the dilution of seawater was identified as the most critical factors influencing growth of natural populations of *Eucheuma* and *Kappaphycus* species in the Philippines (Colina, 1976). A comparison of cited data in the literatures shows that the optimum salinity for growth of eucheumoid algae varies from 33 to 35‰ (Braud & Perez, 1978; Hurtado-Ponce, 1992; Lirasan & Twide, 1993; Ohno et al., 1994).

The growth of marine algae is lowered in elevated salinities because of reduction in photosynthesis due to changes in both osmotic strength and ionic composition of cells, hence lowered activities of enzymes. The reduced turgor pressure also inhibits cell division and thus the lowered growth (Lobban & Harrison, 1994). Salinity less than 32‰, especially during the rainy season, was observed to reduce the growth of *K. alvarezii* and also promoted stubby, blunt and sparse branching and high epiphytism (Hurtado-Ponce, 1992). Paula & Pereira (2003) also reported low growth of *K. alvarezii* grown on rafts in Brazil due to low salinity coinciding with heavy rainfall. Colina (1976) observed that at 30‰, even for a short period, the tips of *K. alvarezii* firstly became white and afterwards the whole plants started to rot or showed ‘ice-ice’ syndrome.

Water movement

The diffusion rate of gases and ions is 10 000 times slower in water than in air (Lüning, 1990). Furthermore, there are boundary layers that limit the diffusion of nutrients and gases into the thalli of seaweeds. The water motion (turbulence, waves, currents) is an important factor that increases the chance of a plant coming into contact with dissolved substances (Wheeler, 1988). Water movement reduces the thickness of the diffusion boundary layer and thus enhances uptake rate by accelerating nutrient transport through this layer adjacent to the plant surface (Wheeler, 1980). Water movement also influences the local distribution and abundance of marine algae (Doty, 1971), and macroalgal community structure via waves, which can physically remove macroalgae and some herbivores, (Kawamata, 1998).

Marine macroalgal photosynthesis, growth, and nutrient uptake increase with increasing water movement (Wheel, 1988; Parker, 1982). Water movement has been observed to influence the growth and production of eucheumoids and thus during site selection, this factor is given primary consideration (Doty, 1978; 1987). Glenn & Doty (1992) obtained highly significant correlations between water motion and growth rate of three eucheumoids grown in Kaneohe Bay, Hawaii. They also found that growth response to water motion in *K. alvarezii* was higher than that in *E. denticulatum*. Water movement was also shown to influence the incidence of epiphyte cover in *Kappaphycus* species. Hurtado et al. (2004) obtained a strong correlation between the occurrence of the epiphyte *Polysiphonia* and water movement in the Philippines. These authors found that locations of low water movement had a higher percentage cover (65%) of *Polysiphonia* than those in more exposed areas (17%). High water movement also promoted high recruitment of *Eucheuma* and *Kappaphycus* species in Tawi-Tawi, Philippines (Azanza et al., 1996).

A moderate current speed of 20-40 m min^{-1} is recommended for good eucheumoid growth (Trono, 1992b). A current speed of more than 40 m min^{-1} is detrimental to farm production, as this tends to break off significant amounts of biomass (Doty, 1987). In contrast, limited water movement restricts productivity by inhibiting a plant's ability to absorb nutrients through enhanced diffusion layers. Hence, a fertile site for eucheumoids is a trade-off between excessive plant breakage and diffusion stresses (Doty, 1978). Thus, the natural habitat of *Eucheuma* and *Kappaphycus* species are always found in such areas in the coral reef flats where the tidal currents are strong and where the water contains the nutrients drained off from the reef, but plants are not exposed to heavy wave force (Doty, 1987).

Nutrients

The growth and photosynthesis of marine plants are determined by the availability of several elements and among these, carbon, nitrogen and phosphorus are particularly important for seaweed growth. Nitrogen and phosphorus are the most critical nutrients that can be limiting to seaweeds in the marine environment (Lüning, 1990; Lobban & Harrison, 1994).

Nitrogen

Nitrogen has been considered to be the major limiting nutrient in the marine environment for seaweeds, including eucheumoid algae. There are various forms of dissolved inorganic and organic nitrogen obtained by seaweeds from the seawater. The inorganic forms are nitrate, nitrite, and ammonia, which have concentrations varying from 0.1 to 43.0, 0.01 to 3.5, and 0.35 to 3.5 μM, respectively, in coastal waters (Dawes, 1998), while urea and amino acids are the main organic forms. There are differences in the abilities of seaweeds to acquire, utilize, and store these forms of nitrogen (Hanisak, 1990). However, in natural conditions, nitrate and ammonium are usually the main forms of nitrogen. Most of the studies on the utilisation of these two forms indicated that growth rate is greater under ammonium than nitrate because seaweeds can take up N as ammonium more quickly than N as nitrate (Laponte & Ryther, 1979). Similar studies on eucheumoids in Zanzibar showed that *E. denticulatum* supplied with ammonium gave higher growth rate than with nitrate (Mtolera et al., 1995). On the other hand, an equal growth rate with these two forms of nitrogen was reported for *Chondrus crispus* (Neish et al., 1977), *Codium fragile* (Hanisak, 1979) and *Gracilaria tikvahiae* (Lapointe & Ryther, 1979).

Ammonium is frequently the preferred nitrogen source for growth of macroalgae because of its ease of assimilation (Hanisak, 1990; Granbom et al., 2004). However, ammonia is usually toxic to seaweeds at high concentrations. For example, Li et al. (1990) observed a reduced growth and breakdown of *K. alvarezii* plants at ammonium concentrations of 35 to 50 mM which they attributed to toxicity of the high ammonium concentrations.

Nitrogen is used to synthesize amino acids and is also a major constituent of photosynthetic pigments such as chlorophyll and phycobiliproteins (Lobban & Harrison, 1994). Hence, nitrogen limitation reduces growth and decreases photosynthetic activities. As nitrogen commonly limits algal growth in the sea environment, seaweeds have evolved mechanisms of storing nitrogen on a short (days) or long term basis (weeks and months) to maintain growth. For example, *K. alvarezii* exhibited surge ammonium uptake and used nutrients excreted by tropical echinoderms (Dy & Yap, 2001). Similarly, Mairh et al. (1999) suggested that *K. striatus* had the ability to accumulate ammonium from low concentrations to maintain its growth.

Phosphorus

Although nitrogen has been considered to be the most limiting nutrient in the marine environment for marine algae (Hanisak, 1979), phosphorus has also been reported to limit seaweed growth in certain coastal areas (Birch et al., 1981). Lapointe (1987) also found that phosphorus rather than nitrogen limited growth of *Gracilaria tikvahiae* in the Florida Keys. Phosphorus occurs in seawater mainly as orthophosphate (HPO_4^{2-}), accounting for 97% of the free phosphorus ions. Seaweeds acquire phosphorus principally as phosphate ions (PO_4^{3-}), which account for less than 1% of total phosphorus in seawater. Other forms of phosphorus are inorganic $H_2PO_4^-$ and organic-phosphorus compounds (Lobban & Harrison, 1994).

Little work has been performed on phosphorus nutrition in eucheumoid algae and most such studies have been carried out using other seaweeds. For example, Sousa-Pinto et al. (1996) obtained a high growth rate for *Gelidium robustum* at a phosphate concentration of 150 µM. As for eucheumoid algae, Glenn & Doty (1990) suggested that a phosphate level of 0.5-1.0 µM could be productive in a commercial farm. Horstman et al. (1977) also reported that fertilizing *K. striatus* (as *Eucheuma striatum*) with phosphate increased growth rates more than with nitrate. However, Friedlander & Ben-Amotz (1991) observed that phosphate levels of approximately 1 mM inhibited productivity in *Gracilaria conferta*. Similarly, Cosson et al. (1995) reported a growth inhibition in *Gigartina teedei* (as *Gigartina teedii*) at a phosphate concentration higher than 10 $\mu mol\ l^{-1}$.

According to Bidwell et al. (1985), phosphate fertilization had little effect on carrageenan content and growth of *Chondrus cripus,* though addition of the nutrient improved the appearance of plants and their resistance to infestation by epiphytes. Moseley (1990) added phosphate in seawater to maintain the growth and health of *C. crispus* in culture. Severe phosphorus depletion has been observed to induce fragmentation of thalli in *C. crispus* (Chopin et al., 1995; Neish et al., 1977) and *G. teedei* (Cosson et al., 1995), as well as other marine algae.

Carbon

Carbon supply is important for seaweed photosynthesis and growth. Adequate carbon nutrition is essential for normal growth of seaweeds, especially in intensive cultivation systems (Bidwell et al., 1985). Seaweeds use inorganic carbon (C_i) as the principal carbon source. There are four forms of dissolved inorganic carbon (DIC) in seawater: carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate (HCO^-_3), and carbonate ($CO_3{}^{2-}$). The relative proportions of the forms of C_i available to macroalgae depend on the seawater pH and salinity (Kerby & Raven, 1985). At pH 7.9 to 8.2 and salinity of 35‰, HCO^-_3 constitutes 92% of the DIC when the natural seawater is in equilibrium with air. The concentration levels of HCO^-_3, CO_2, and $CO_3{}^{2-}$ are about 2 mM, 10 µM and 0.4 µM, respectively (Raven et al., 1985). On the other hand, at pH 9 to 10, the concentrations of CO_2 and HCO^-_3 decreases, and $CO_3{}^{2-}$ constitutes 90% of the available inorganic carbon (Maberly, 1990). All the different forms of inorganic carbon are in equilibrium, and this equilibrium is changed by a change in pH or the removal of amounts of one of the forms of carbon.

Carbon dioxide (CO_2) is the main form of inorganic carbon used by the carbon-fixing enzyme, Ribulose-1, 5-biphosphate carboxylase/oxygenase (RUBISCO) in terrestrial and marine plants (Kerby & Raven, 1985). Collen et al. (1992) suggested that CO_2 is the principal inorganic carbon source for *E. denticulatum*. However, the availability of CO_2 in water is limited by the slow diffusion rate (10^4 times slower than in air), the relatively slow rate of the interconversion between CO_2 and HCO^-_3, and the diffusion resistance of HCO^-_3 through the lipid membrane. Thus seaweed becomes carbon limited in seawater despite a high DIC concentration of 2.2 mM if they use CO_2 as the sole source of inorganic carbon (Larsson & Axelsson, 1999).

Seaweeds have developed strategies to cope with the low available CO_2 concentration. Such strategies include: mechanisms for light energy dissipation (Mtolera, 1996), CO_2 concentrating mechanisms (CCM) (Badger & Price, 1994), and usage of HCO^-_3 (Raven, 1997). There has been much debate over whether or not seaweeds can use bicarbonate (Lobban & Harrison, 1994), and two systems have been proposed: the HCO_3^--dehydration system and the HCO_3^--uptake system (Lobban & Harrison, 1994; Granbom & Pedersen, 1999; Larsson & Axelsson, 1999). The extracellular HCO_3^--dehydration system involves the external carbonic anhydrase (CA) which converts HCO_3^- to CO_2; then the gas diffuses across the plasma membrane. This mechanism has been suggested for several seaweeds, including *Ulva rigida* (Björk et al., 1992) and *E. denticulatum* (Mtolera, 1996; Granbom & Pedersen, 1999). The second pathway for bicarbonate utilisation, the direct active uptake of HCO_3^- has been described for the seaweeds *U. lactuca* and *Gracilaria conferta* (Drechsler & Beer, 1991; Israel & Beers, 1992) and *E. denticulatum* (Granbom & Pedersen, 1999). The exact mechanism of this system is not fully known and it has been based on observations of a gradual increase in net photosynthesis at high pH (Larsson & Axelsson, 1999). This system is in some respects similar to the inducible CCM for green microalgae and is assumed to constitute a direct uptake of HCO_3^- into the cells by specific porter or by a general anion-exchange protein (Badger & Price, 1994; Lobban & Harrison, 1994). The presence of both mechanisms for HCO_3^- use could be a physiological adaptation that enables *E. denticulatum* to grow well in Zanzibar, Tanzania (Granbom & Pedersen, 1999).

Epiphytes

Seaweeds provide anchorage to epiphytic algae and animals due to limited space in the sea (Lobban & Harrison, 1994). However, the epiphyte may become a nuisance to the host species. Epiphytism is one of the major constraints in commercial eucheumoid farming (Trono, 1992b; Ask & Azanza, 2002). Epiphytes on eucheumoid plants have been categorised into two groups: the large algae/seaweeds that grow over the plants and the epiphytic filamentous algae (EFA) (Trono, 1994; Ask, 1999; Ask & Azanza, 2002). The pest weeds commonly observed on *Eucheuma* and *Kappaphycus* farms are species of *Enteromorpha*, *Chaetomorpha*, *Ulva*, *Dictyota, Hydroclathratus*, *Neosiphonia*, *Polysiphonia*, *Hypnea*, and some species of blue-green algae (Trono, 1994; Hurtado et al., 2001; Vairappan, 2004). The EFA include fine filamentous green and red algae which attach to the cortical layer of the anchor species affecting their growth. Epibiota on *Eucheuma* and *Kappaphycus* also include small coralline crusts, encrusting bryozoans and other sessile animals.

Epiphytes are problematic to the host plant because they compete for light, nutrients, gases, and space, hence reducing growth rate of the plant. Mairh et al. (1986) suggested that the poor growth rate of *Kappaphycus striatus* grown in laboratory conditions was due to competition by the epiphyte, *Enteromorpha*. The epiphytic filamentous algae and *Polysiphonia* species were observed to cause stunted, rough and poor branching in eucheumoids (Ask & Azanza, 2002; Hurtado et al., 2004). Vairappan (2004) noted that *Polysiphonia* species penetrated into the cortex of *Kappaphycus alvarezii* thalli and this may probably have caused the change in morphology as observed by the former authors. Epiphytes also reduced the yield of *K. alvarezii* in the Philippines (Hurtado et al., 2001). Other effects of epiphytes on eucheumoid cultivation are increased production cost; as they have to be removed regularly and at harvesting time (Luxton, 1993; Collen et al., 1995), and lowered quality of crop (Trono, 1994; Collen et al., 1995). Hurtado et al. (2004) also reported that the occurrence of *Polysiphonia* on *K. alvarezii* led partly to a reduction in number of seaweed farmers. This was probably due to socio-economic problems associated with less income for their families as a result of low production.

Epiphytes on eucheumoid plants are normally controlled by regular maintenance; it is recommended that farms should be attended at least twice a week (Trono, 1992a). The coarser species of pest weeds are manually removed from the crop. For the fine filamentous algae, the only option is to harvest infested eucheumoid thalli and replace them with uninfested material (Ask & Azanza, 2002). Many marine algae are known to deter epiphytes by production of antibiotic compounds. *Eucheuma* and *Kappaphycus* are seldom covered by epiphytes in nature (Mtolera et al., 1995) and hydrogen peroxide appears to serve as an antifoulant (Collen et al., 1995).

Grazers

Marine algae are constantly grazed by herbivores. Grazing is a severe problem in eucheumoid farming and has even damaged established eucheumoid farms (Doty, 1987). There are three ecological groups of herbivores, based on foraging ranges (Carpenter, 1986): fish (large foraging ranges), sea urchins (intermediate ranges), and mesograzers (small foraging ranges). Similarly, eucheumoid grazers have been classified into four categories on the basis of the type of herbivore damage (see Ask & Azanza, 2002 for more details). Doty (1987) grouped herbivores into two main groups according to size of grazers: micrograzers (< 2cm long) and macrograzers (≥ 5 cm long). Regardless of the classification system used, it appears that there are three major groups of grazers in eucheumoid farms: fish, sea urchins and mesograzers.

The principal herbivorous fishes in eucheumoid farms are rabbitfish (Siganidae), surgeonfish (Acanthuridae), parrotfish (Scaridae) and pufferfish (Tetradontidae) (Russell, 1983; Doty, 1987; Ask & Azanza, 2002). However, rabbitfish was observed to be the most notorious fish among the grazers (Doty, 1987). There are few studies on the effects of grazers on eucheumoid, with the exception of the work of Russell (1983) in Hawaii. He reported that fish ate 10 to 20 tons wet wt of *K. alvarezii* (as *Eucheuma cottonii*) per month from a test farm of 3 m wide by 500 m long. Using caged and uncaged plants, he also showed that fish grazers reduced algal biomass and lowered growth rate. Low growth rates of *K. alvarezii* due to fish predation have also been reported in Brazil (Paula & Pereira, 2003) and Vietnam (Ohno et al., 1996). Similarly, Hurtado-Ponce et al. (2001) attributed a low net yield of *K. alvarezii* farmed using the fixed off-bottom method in the Philippines to excessive grazing by rabbitfish and sea urchins.

The destructive sea urchins on eucheumoid farms are *Echinothrix*, *Diadema* and *Tripneustes* (Doty, 1987). However, observations of eucheumoid predation in the Philippines indicated that *Tripneustes gratila* was the most destructive echinoderm (Trono, 1994). The mesograzers are an important group of herbivores comprising of amphipods, copepods, and polychaetes (Brostoff, 1988). However, this group have rarely been studied because of their small size and difficulty of identification (Lobban & Harrisson, 1994). Mesograzers are important in seaweed cultures because they graze on epiphytic algae on the main crop. Anderson et al. (1998) showed that, when given a choice, isopods preferred the epiphyte rather than the host, whereas experience in tank farming of *Gracilaria* suggests that the same isopods can prove a problem, eating *Gracilaria* when no other seaweed is available (J.J. Bolton, pers. comm.). Other grazers such as starfishes and marine turtles have also reported to consume eucheumoids in commercial farms (Doty, 1987; Ask & Azanza, 2002).

The 'ice-ice' syndrome

At certain times of the year, *Kappaphycus* and *Eucheuma* plants are affected by 'ice-ice' syndrome, a major problem in the intensive seaweed growing areas that causes thalli fragmentation and considerable loss of biomass (Doty & Alvarez, 1975; Doty, 1987; Trono, 1994). The term 'ice-ice' syndrome refers to the white and transparent spots (resembling ice) found within thalli that causes healthy branches to break off (Doty & Alvarezii, 1975). The whitening of the affected portions is probably due to reduced pigment content (Ganzon-Fortes et al., 1993) and hydrolytic enzymes (Largo et al., 1999). Both Doty & Alvarez (1975) and Doty (1987) have described the development of 'ice-ice' in eucheumoids. The precise cause of 'ice-ice' syndrome is not well understood but several reports suggest that it may be caused by either unfavourable ecological conditions or bacteria or both. The development of 'ice-ice' in eucheumoids has been attributed to poor water motion (Mtolera et al., 1995; Largo et al., 1999), low nutrients and salinity (Uyenco et al., 1981; Doty, 1987), high water temperature and photon fluency (Mollion & Braud, 1993; Mtolera et al., 1995), and high epiphyte cover (Uyenco et al., 1981; Hurtado et al., 2004). On the other hand, some authors have isolated certain bacteria that are capable of inducing ice-ice (Uyenco et al., 1981; Largo et al., 1995; Largo et al., 1999). However, none of these bacteria isolated from affected thalli were specifically linked to 'ice-ice' syndrome. It appears that the development of 'ice-ice' is due to a combination of several unfavourable physical, chemical and biological factors that probably weakens the plant defence strategies against marine bacteria and other microorganism such as fungi (Mtolera, 1996; Largo et al., 1999). However, more studies are needed to determine the precise cause of 'ice-ice' syndrome in eucheumoids.

The 'ice-ice' syndrome has serious effects on commercial eucheumoid cultivation. Firstly, the affected portion of thallus dissolves away leading to fragmentation and eventual loss of crop and hence, reduced profit from the farms. Secondly, 'ice-ice' also decreases pigment content and photosynthesis in seaweeds (Ganzon-Fortes et al., 1993), ultimately leading to death of parts of the affected plants. And thirdly, studies have shown that eucheumoid crop affected by 'ice-ice' produces carrageenan of lower quantity and poorer quality (Trono & Lluisma, 1992; Mendoza et al., 2002). At present, there is no control for 'ice-ice' syndrome and the only solution is to harvest all the affected crop. However, from the above discussion, it seems that selection of sites with good water movement could reduce the incidence of 'ice-ice'. Screening of productive morphotypes and varieties that are resistant to the 'ice-ice' syndrome and epiphytism could also be another preventive measure (Collen et al., 1995; Ask & Azanza, 2002).

1.2.4 Socio-economic and ecological aspects of eucheumoid farming

The industrial demand for species of *Eucheuma* and *Kappaphycus* has increased considerably due to their carrageenan content, used as ingredients in many industrial applications. Demand for carrageenan is increasing at a steady rate of about 5% annually, and a continuing increase in demand is predicted (McHugh, 2003). To cope with the demand for carrageenophytic material, eucheumoid farming has been introduced in several tropical and subtropical countries (Ask et al., 2003; Oliveira & Paula, 2003).

Socio-economic factors

Cultivation of *Eucheuma* and *Kappaphycus* has been considered an attractive source of livelihood for poor coastal communities in some tropical countries (McHugh, 2003). Before eucheumoid farming is introduced in an area, reconnaissance surveys should be made and potentially good localities identified and subjected to test planting (Trono, 1992a; Lirasan & Twide, 1993; Ask, 1999). According to these authors the ecological factors used in the preliminary evaluation of sites include: free from freshwater run off, clear and clean water, salinity (>30‰), water movement (20-40 m min^{-1}), and protected areas with > 30 cm water depth at the lowest tide, among other physico-chemical parameters. Growth rate measurements of eucheumoids should then be conducted in the selected areas for a period ranging from 6 to 12 months (Trono, 1992a). Localities supporting a relative growth rate of 3.5% day^{-1} or more are potentially good areas for commercial eucheumoid cultivation (Doty, 1987).

However, aside from the above physico-chemical parameters, socio-economic factors are also considered to influence the success of commercial eucheumoid farming. Thus, in site selection these factors are of primary importance (Lirasan & Twide, 1993; Trono, 1992a; Ask, 2003). In fact, Ask (2003) emphasised that the failure in most commercial eucheumoid farming ventures is principally due to the socio-economic factors such as politics, cultural values, livelihood activities, and demographics, among other human related factors. Ask (1999) suggested that anyone wishing to introduce eucheumoid farming in a village must first study the socio-economic factors of the villagers before embarking on seaweed farming. Namudu & Pickering (2004) have also recommended that a socio-economic survey should be conducted in coastal villages to select the best one for eucheumoid farming.

There are a variety of methods and visualisation techniques used to collect socio-economic data on rural village communities. However, these methods must understand the dynamic of rural life and the complexities of the socio-economic and cultural contexts in which various forms of local livelihood function. Such sensitive and rural research methodologies include an array of the methods known collectively as the participatory rural appraisal (PRA) (Chambers, 1994). The PRA was derived from several related methodologies such as the agro-ecosystem analysis, farming systems research and rapid rural appraisal. A key feature of PRA is its holistic approach, in which the interaction between different elements in the complex people-environment relationship is an important focus. Unlike earlier methodologies, PRA recognises that rural communities are capable of identifying and expressing their needs and aspirations themselves and in their own way (Chambers et al., 1989; Chambers, 1994).

Participatory rural appraisal is a growing family of approaches and techniques, and some of the most useful PRA techniques include: observations, semi-structured interviews, focus groups, discussion with key informants, surveys, transects, timelines, seasonal calendars, Venn diagrams, and ranking (Bunce et al., 2000). Unfortunately the PRA techniques have mostly been used in agricultural or pastoralist communities, with few studies dealing with coastal fishing communities (Keats, 1998). However, recently, Namudu & Pickering (2004) selected suitable coastal village communities for eucheumoid farming in Fiji based on socio-economic factors identified using PRA techniques.

Ecological aspects of seaweed farming

Although there are social, economic and environment benefits from seaweed farming (Ask, 1999), there are also some negative environmental aspects of eucheumoid culture. Such negative effects are: conflict with other coastal activities such as tourism and fishing (Msuya, 1993) and reduced species diversity in seaweed farms due to clearing and removal of seagrasses (Collen et al., 1995; Mtolera, 1996). The impact of the introduced *E. denticulatum* and *K. alvarezii* on the environment is not yet fully understood (Johnstone & Olafsson, 1995; Ask et al., 2003). Studies are needed in areas where commercial eucheumoids have been introduced so that the patterns of spread of these plants and their effects on the local biota could be monitored.

Marine algae have been introduced to other places through several ways. Some have been introduced intentionally for research or commercial purposes while others have been transported by ships or carried along with other introduced aquaculture species accidentally (Ask et al., 2003; Oliveira & Paula, 2003). For example, the invasive *Sargassum muticum* (Yendo) Fensholt was introduced along with the Japanese oyster *Crassostrea gigas* (Ribera & Boudouresque, 1995 in Oliveira & Paula, 2003). Russell (1983) also observed that four algal species (*Acanthophora spicifera* (Vahl) Boerg., *Dictyota acutiloba* J. Ag., *Hypnea musciformis* (Wulfen) Lamour. and *Ulva reticulata* Forsskål) were introduced together with *K. striatus* (as *E. striatum*) and *E. denticulatum* in Kiribati from Hawaii, even after careful consideration. Due to the potential for introduction of undesired organisms with the principal species, actions are now being taken in several countries to curb disruption of the marine environment (Ask et al., 2003; Oliveira & Paula, 2003). Such actions include following the FAO-Technical Guidelines for Responsible Fisheries (1996) and the proposed quarantine procedures by Ask et al. (2003) for introduced eucheumoids.

1.2.5 Methods of *Eucheuma* and *Kappaphycus* farming

The utilization of *Eucheuma* and *Kappaphycus* as carrageenophytic material from the Philippines was started in 1966 as a result of the political situation in Indonesia which prevented the exportation of the seaweeds to the United States (Doty & Alvarez, 1975). The increased use of products using carrageenan in the market today has led to development of eucheumoid farming techniques in order to increase productivity and hence, stabilising the of supply and price of high quality raw material (Doty, 1987). The *Eucheuma* and *Kappaphycus* farmers mostly use the 'tie-tie' system because it is simple, farming inputs are available locally and seaweeds grow well (Ask & Azanza, 2002). In this method, cuttings are tied or attached to ropes using soft plastic tying material, commonly referred to as the 'tie-tie' and hence, the name of the system (Doty & Alvarez, 1975; Trono, 1992a). Presently, the three tie-tie farming techniques used in commercial farms are fixed off-bottom line, floating raft, and floating long line methods (Trono, 1992a). However, due to the cost and time used in the tie-tie system there are attempts to replace it with a non tie-tie system (Ask & Azanza, 2002; Ask, 2004). There are currently several non tie-tie systems on trials, but only the 'Made Loops system' is extensively used on *Kappaphycus* farms in Indonesia, Madagascar, Tanzania and the central Philippines where they have dropped labour cost by 80% over the tie-tie system (E. Ask, pers. comm.). Other non tie-tie techniques such as the bag net and the tube net were experimented over 10 years in the Philippines but are not used today (Lajera & Lirasan, 2001; Ask & Azanza, 2002; Ask, 2004).

Fixed off-bottom line method

The fixed off-bottom line method is the main technique used for commercial eucheumoid cultivation (Trono, 1992a; Hurtado-Ponce & Agbayani, 2000). The advantages of fixed off-bottom method over the other methods are the ease of installing, simple farm maintenance and low cost of the required material. In this method, mangrove stakes or poles are driven into the substratum and a polyethylene rope (PER) or monoline line (4 to 8 mm diameter) is stretched between the stakes/poles (Figure 1.2A.). Selected healthy eucheumoid cuttings (50-100 g) are tied or attached to the monolines at 15 to 25 cm intervals using 'tie-ties'. Plants are grown to approximately 1 kg wet wt before harvesting, which involves complete removal of the thalli. However, the off-bottom method is not suitable in areas with poor water movement or where there is intense grazing and/or seasonality in growth (Trono, 1992a), and therefore other techniques such as the floating methods are used.

Floating raft method

The farming procedure in the floating raft method is similar to the fixed off-bottom line method (Trono, 1992a; Hurtado-Ponce & Agbayani, 2000). A wooden or bamboo frame (4 x 5 m) is constructed and five metre long cultivation ropes, spaced at 20 cm intervals are attached to the frame (Figure 1.2B). Three to four hundred cuttings can be planted on one raft. Five rafts can be joined together as a unit and anchored to the bottom from the corner of each unit using nylon anchor ropes (10 mm diameter) and wooden stakes. This technique is suitable in calm water of about 2 to 7 m deep where water current is weak or where bottom is irregular and the water is too deep for the fixed off-bottom method. It also avoids conflicts with tourism and other reef flat users unlike the off-bottom method. However, this technique is only used in protected areas such as bays because heavy wave action might destroy the raft system.

Floating long line method

The floating long line method has two variations: multiple floating long lines and hanging long line method (Hurtado-Ponce & Agbayani, 2000). The multiple floating long lines method consists of flat plastic binders of 25 to 50 m long. The bamboo poles (10-12 cm diameter and 7-10 m long) are connected to one another with flat binders to which cuttings are tied (Figure 1.3A). Both ends of the farming structure are anchored with polypropylene ropes (14 mm diameter) using steel bars. Styrofoam floats (30 cm diameter) are tied at the middle of every segment of the flat binder after two weeks to keep the seaweeds at a constant depth (25-30 cm) below the water surface (Ask, 1999; Hurtado-Ponce & Agbayani, 2000). In the hanging long line method, both ends of polyethylene ropes (30 to 100 m long) are tied to anchor ropes (14 mm diameter) which are anchored to the bottom with concrete blocks or sand bags (Ask, 1999; Hurtado-Ponce & Agbayani, 2000) (Figure 1.3B). The floating long line method is used in deep waters (>3.5 m) and over large areas. These areas are generally more exposed than that for the floating raft method and water motion is both tidal and wind driven. However, this technique is the most difficult to cultivate eucheumoids, as the construction of the support system, planting and harvesting entails higher labour and material costs, including working from a boat. This method is only practised in the Philippines (Hurtado-Ponce & Agbayani, 2000).

Other methods

Several other eucheumoid farming methods have been tried or are in limited use as described by Ask & Azanza (2002). The pond method has been attempted in Vietnam using *K. alvarezii* in abandoned shrimp ponds (Ohno et al., 1996). The possibilities of eucheumoid polyculture with the grouper *Lates calcarifer* in the Philippines (Hurtado-Ponce, 1992) have been attempted but only on an experimental basis. According to Ask (2004), there has also been a shift to farming *E. denticulatum* using the broadcast method rather than the traditional fixed off-bottom and floating techniques in the Philippines, because it is more efficient in crop production. The broadcasting method is a type of a bottom method and involves throwing the seaweed cuttings into the farm area. The area can be fenced with a net or not. This method is convenient and, in the Philippines over 7000 MT dry wt per year of *E. denticulatum* is produced using this technique (E. Ask, pers. comm.).

1.2.6 Economics of seaweed farming

The exportation of *Kappaphycus* and *Eucheuma* dry biomass has become an attractive source of foreign exchange to tropical countries such as Tanzania and the Philippines (Doty, 1987; McHugh, 2003). Seaweed production is essentially defined in terms of productivity and relative growth rate. Productivity is a measure of net yield of biomass over time and surface area, whereas growth rate is the change in biomass over time and is expressed as daily biomass increase. Thus, productivity is different from relative growth rate (McLachlan & Bird, 1986; McLachlan, 1991).

The productivity data for *Eucheuma* and *Kappaphycus* farming are limited and are mostly reported for *K. alvarezii* (Doty, 1987; Table 1.2). Both the productivity and growth rate values for eucheumoids vary with species, location and culture technique (Table 1.2), as well as environmental factors (Doty, 1987; Hurtado-Ponce et al., 2001). Estimates of growth rates and yields for eucheumoid algae seem to vary from 1.0 to 10% day^{-1} and 20 to 50 t dry wt ha^{-1} yr^{-1}, respectively (Table 1.2). However, these high yield values are extrapolated from small-scale and short-term experimental results and do not reflect the actual farm conditions (Doty, 1987; Hanisak, 1987).

The success of seaweed cultivation is usually assessed by its biomass production and revenues generated. However, to evaluate the economic performance of a seaweed farming operation, production costs and gross revenues are estimated to perform a cost-return analysis (Shang, 1990). The production costs involved in setting up a farming system varies with location, farming system, and size of farm (Doty, 1973, Shang, 1990; Hurtado-Ponce et al., 2001), but generally involves the investment (fixed) and operating (variable) costs. The initial investment costs in *Eucheuma* and *Kappaphycus* farming include boat, engine, polypropylene ropes, steel bars, bull hammer, drying racks, lines, stakes, floating frames, hand tools, baskets, and, sometimes a farm house. The operating costs include items such as seaweed cuttings, labour, 'tie-ties', fuel, and replacement of stakes, lines and maintenance of equipment, among other variable costs (Doty, 1987; Hurtado-Ponce et al., 1996). The economic desirability of eucheumoid farming is also appraised using the payback period and average rate of return (ROI) (Shang, 1990; Hurtado-Ponce et al., 2001). These economic factors are used to select profitable commercial projects, including seaweed resources development.

1.3 Seaweed resources in Kenya

The coastline of Kenya is reported to be about 600 km along the East African coastline, from 1°41'S at the border with Somalia in the north to nearly 4°40'S at the Tanzanian border (UNEP, 1998; Figure 1.4). However, in common with most of the East African region, the Kenyan continental shelf is narrow, and supports a fringing reef which lies about 500 to 2000 m offshore (UNEP, 1998). The extensive fossil reef is raised a few metres above the present sea level and this planation has resulted in areas along the shore with reef flats. There are many lagoons behind the coral reefs which support extensive seagrass beds and a wide variety of marine algae. There are also gaps in the reefs near the mouths of rivers, creeks, bays and estuaries; where an estimated 530 km^2 of mangroves are mostly found (Richmond, 1997; UNEP, 1998).

1.3.1 Climate and oceanography

The coastal belt of Kenya experiences a tropical climate dominated by the seasonal monsoon winds that are driven by the annual north-south migration of the Inter-Tropical Convergence Zone (ITCZ). From April to September, winds flow southeasterly forming the South East Monsoon (SEM) season while for the rest of the year they blow from the northeast forming the North East Monsoon (NEM) season (McClanahan, 1988; Richmond, 1997). The transition period between the two wind regimes varies considerably between years (Mwebesa, 1978), although Johnson et al. (1982) suggested that the switching takes place within 10 days, during which directions are variable. The two seasons are characterised by marked differences in the physical, chemical and biological oceanographic conditions of the coastal waters (McClanahan, 1988, Richmond, 1997). During the SEM period, the winds are strong, irradiance, air and water temperatures are relatively low, duration of sunshine is short, and the cloud cover and relative humidity are high whereas in the NEM season these conditions are reversed. The Kenyan coast has a humid climate with average rainfall of 1058 mm. The temperatures and salinities of the surface coastal waters vary from a minimum and maximum of 24-29°C and 34.5-35.4‰, respectively, depending on the monsoon seasons (UNEP, 1998).

The Kenyan coast is affected by coastal currents, which control the oceanographic conditions in the upper layer of the sea and are in turn affected by the two alternating monsoon winds. The currents are derived from the westerly flowing South Equatorial Current (SEC). The SEC reaches the African coast near Cape Delgado in Mozambique and divides into the southward flowing Madagascar and Mozambique currents and the northerly flowing East African Coastal Current (EACC) (Figure 1.4). During the SEM, the EACC continues north along Kenya coast and extends further north, becoming the Somali current. Under the influence of the NEM, in the northern part of Kenya, the EACC velocities are substantially reduced, before it reverses and flows southwards forming the Somalia Current (Figure 1.4). According to Johnston et al. (1982), the Somali Current penetrates some distance south before meeting the northward flowing EACC (meet at approximately 2 to 3°S, and a depth of about 40 m) and forming a seaward flowing current called the Equatorial Counter Current (ECC). This zone is characterised by upwelling.

The Kenyan coast experiences a semi-diurnal tide regime, with two maxima (high tides) and two minima (low tides) per lunar day (24 h 50 min) (Richmond, 1997). During each month, the coast experiences two spring tides (during full and new moon) and two neap tides (with minimum tidal differences). The maximum tidal range is about 3.9 m.

Except for a limited period of the year, the levels of high and low water of each successive tide varies, and hence the tides are of the mixed semi-diurnal type (Dawes, 1998). During the NEM, the lowest tides occur during the day while lowest tides occur at night during the SEM period. This tide-induced exposure influences the occurrence, distribution and seasonal abundance of the organisms on the Kenyan coast, especially on the intertidal zone, including the seaweeds (McClanahan, 1988; Oyieke, 1998).

1.3.2 Seaweeds of economic potential

Seaweed is one of the marine resources on the Kenya coast, though few studies have been conducted on how it could be exploited. Most of the studies on seaweeds in Kenya have dealt primarily with taxonomic aspects resulting in over 400 identified seaweed species (Isaac, 1968; Yarish & Wamukoya, 1990; Oyieke, 1998). Of these species, *Eucheuma*, *Kappaphycus*, *Hypnea*, *Gracilaria* and *Sargassum*, among others, were identified as seaweeds of economic potential (Yarish & Wamukoya, 1990). The same authors discussed the distribution and natural stocks of *Eucheuma* and *Kappaphycus* species and; further concluded that these populations were insufficient to sustain a carrageenophyte industry. They however, suggested that farming could increase the biomass of eucheumoid and *Gracilaria* species, especially in southern Kenya.

1.3.3 Need for seaweed cultivation

Production of *Eucheuma* and *Kappaphycus* through culture is one of the most productive forms of livelihoods benefiting thousands of coastal inhabitants in countries such as Indonesia, Tanzania, and Philippines, among others (Doty, 1987; Ask, 2003). It is, therefore, of utmost importance that the seaweed resources, especially the eucheumoids, be developed in Kenya in order to provide income and employment to the coastal village communities. The exported crop could also be a source of foreign exchange in Kenya as evident in other tropical countries such as Tanzania and the Philippines (Lirasan & Twide, 1993; Trono, 2000).

Currently, there is no commercial cultivation of *Eucheuma* and *Kappaphycus* in Kenya, although there is considerable potential and interest for its development (Yarish & Wamukoya, 1990; Lirasan & Twide, 1993; Oyieke, 1998; UNEP, 1998). The commercial eucheumoid farming in Kenya appears to be hampered by the lack of both the basic and applied information necessary for its culture (Oyieke, 1998). This study was therefore conducted with the purpose of providing information for the development of *Eucheuma* and *Kappaphycus* farming in Kenya.

1.4 Aim and objectives of the study

The aim of the study was to investigate the feasibility of growing *Eucheuma* and *Kappaphycus* species as a means of broadening the livelihoods of coastal village communities on a sustainable basis, particularly in southern Kenya. The specific objectives were:

1. To assess the socio-economic conditions of the coastal communities in three fishing villages: Gazi, Kibuyuni and Mkwiro.

2. To investigate the growth and productivity of three commercial morphotypes (brown *Eucheuma denticulatum* and brown and green *Kappaphycus alvarezii*) at the three sites.

3. To determine the carrageenan properties of brown *Eucheuma denticulatum* and brown and green *Kappaphycus alvarezii* from the three sites.

4. To determine the economic viability of farming *Eucheuma* and *Kappaphycus* species.

5. To analyse and recommend policies likely to influence the commercial farming of eucheumoids in Kenya.

1.5 References

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Table 1.1 Relative growth rates (% day^{-1}) and production (t dry wt ha^{-1} yr^{-1}) of *Eucheuma denticulatum* and *Kappaphycus alvarezii* grown using various culture techniques in different countries.

Species	Country	Farming system	Growth rate (% day^{-1})	Production (t dw/ha/yr)
Kappaphycus alvarezii	Brazil[1]	Raft	3.6-8.9	
Eucheuma denticulatum	Djibouti[2]	Raft	3.3-5.4	31.8
Kappaphycus alvarezii	Fiji[3]	Off-bottom	2.3-5.3	50.0
Eucheuma denticulatum	Indonesia[4]	Off-bottom	3.0	
Kappaphycus alvarezii			3.0-4.0	
Eucheumoids[a]	Kiribati[5]	Pen cage	3.5-5.1	20.8
Kappaphycus alvarezii	Philippines[6]	Cage	3.7-7.2	39.4
Kappaphycus alvarezii	Philippines[7]	Raft	1.2	30.4
		Off-bottom	2.0	23.2
Kappaphycus alvarezii	Philippines[8]	Off-bottom		27.9
		Long line		21.6
Kappaphycus alvarezii	Philippines[9]	Off-bottom	1.6-9.8	
		Bag net	1.0-4.5	
Eucheuma denticulatum	Tanzania[10]	Off-bottom	5.4-7.0	
Eucheuma denticulatum	Venezuela[11]	Off-bottom	2.3-5.3	
Kappaphycus alvarezii			4.4-7.7	
Kappaphycus alvarezii	Vietnam[12]	Pond	4.0-6.3	
		Off-bottom	3.2-6.5	
		Raft	3.8-5.2	

[1] Paula & Pereira, 2003; [2] Braud & Perez, 1978; [3] Luxton et al., 1987; [4] Adnan & Porse, 1987; [5] Glenn & Doty, 1990; [6] Hurtado-Ponce, 1992; [7] Hurtado-Ponce et al., 1993; [8] Hurtado-Ponce et al., 1996; [9] Lajera & Lirasan, 2001; [10] Lirasan & Twide, 1993; [11] Rincones & Rubio, 1999; [12] Ohno et al., 1996. [a] Biomass not separated into species.

Figure captions

Figure 1.1. Structure of the repeating galactopyranose-4-sulphate (G4S) and 3,6-anhydro-D- galactopyranose (DA) units of κ-carrageenan (A) and galactopyranose-4-sulphate (G4S) and 3,6-anhydro-D- galactopyranose-2-sulphate (DA2S) units of ι-carrageenan (B).

Figure 1.2. Fixed off-bottom line (A) and floating raft (B) culture techniques used in commercial eucheumoid cultivation. After Hurtado-Ponce & Agbayani (2000).

Figure 1.3. Multiple floating long lines (A) and hanging long line (B) culture techniques used in commercial eucheumoid cultivation in the Philippines. After Hurtado-Ponce & Agbayani (2000).

Figure 1.4. Map showing the location of Kenya and the monsoon winds and coastal currents in the Eastern African region. After Richmond (1997).

Figure 1.1 Wakibia

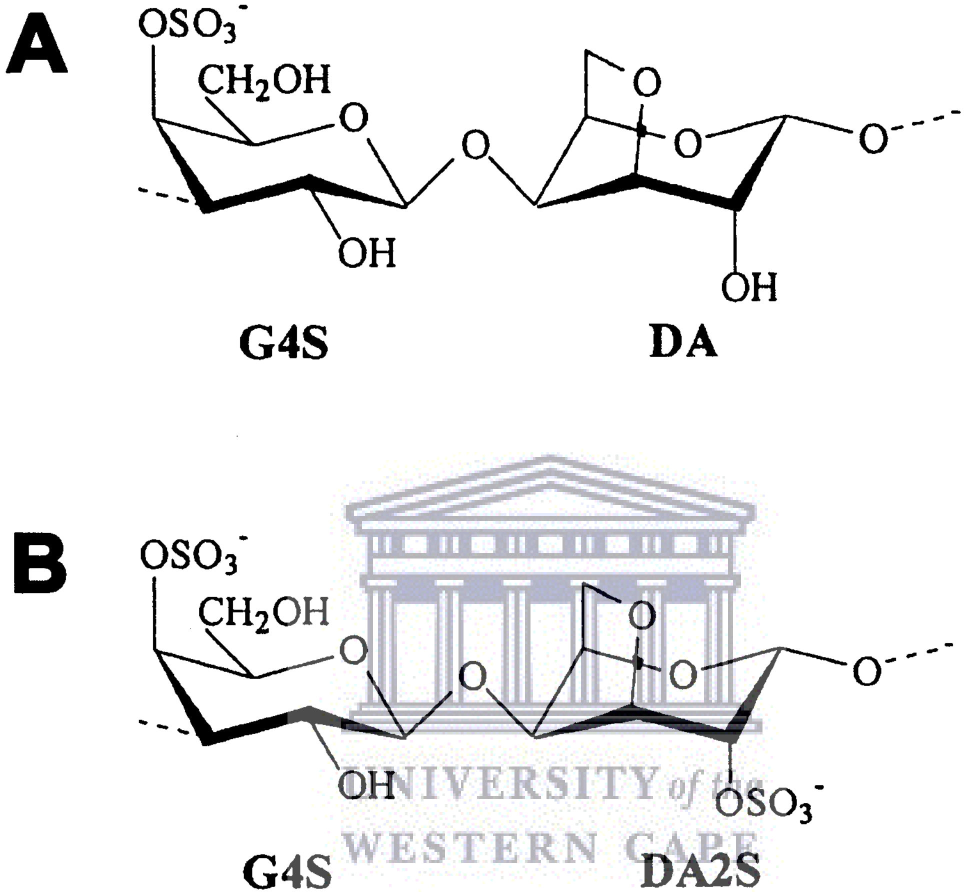
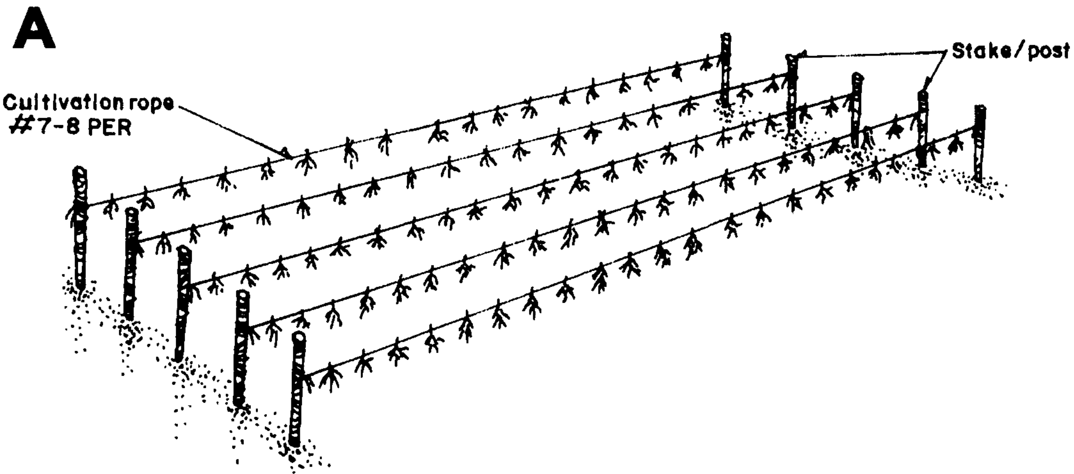


Figure 1.2 Wakibia



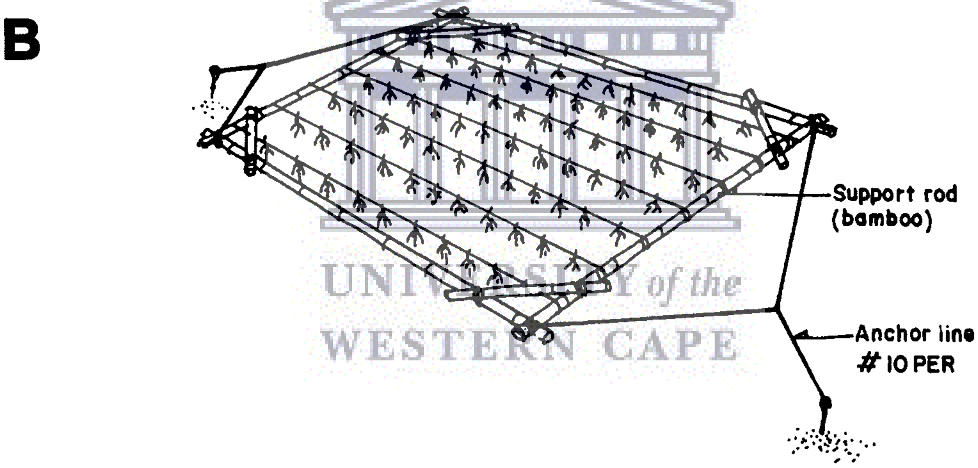


Figure 1.3 Wakibia

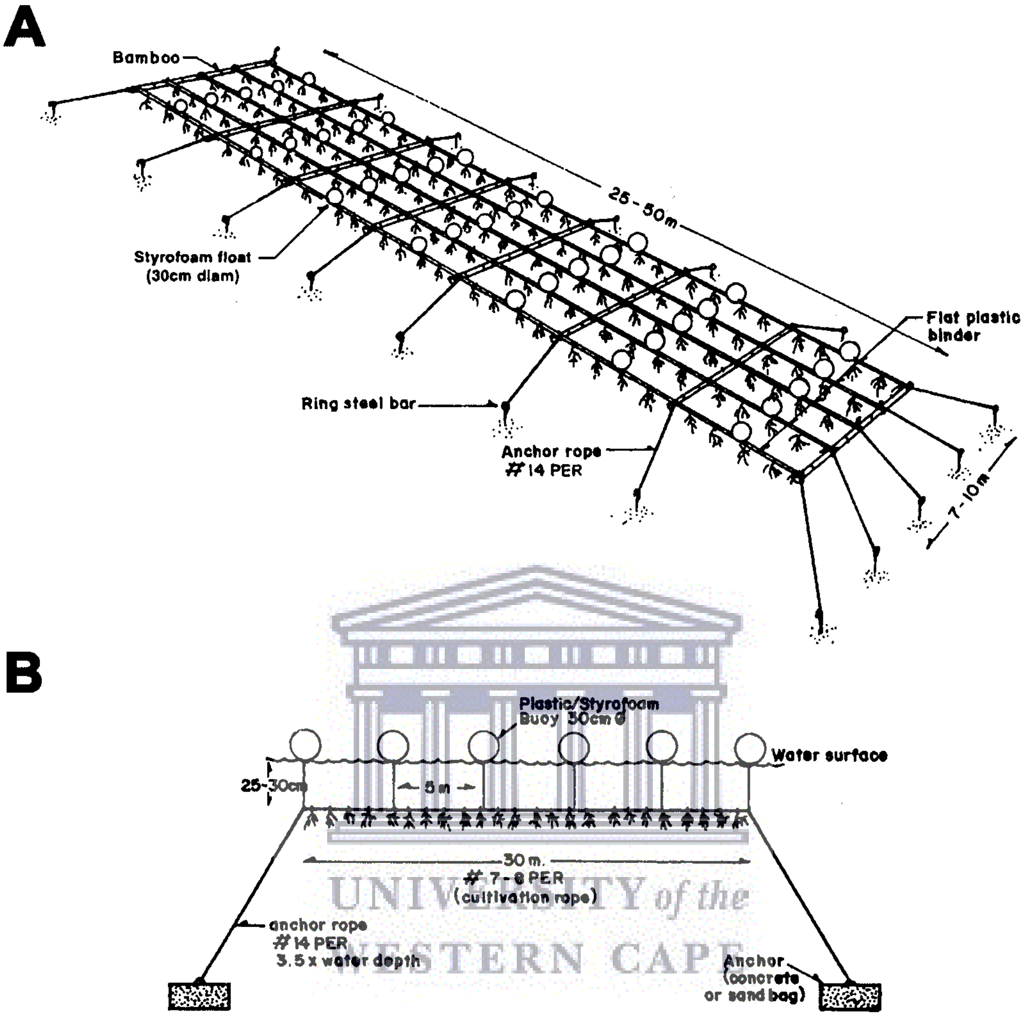
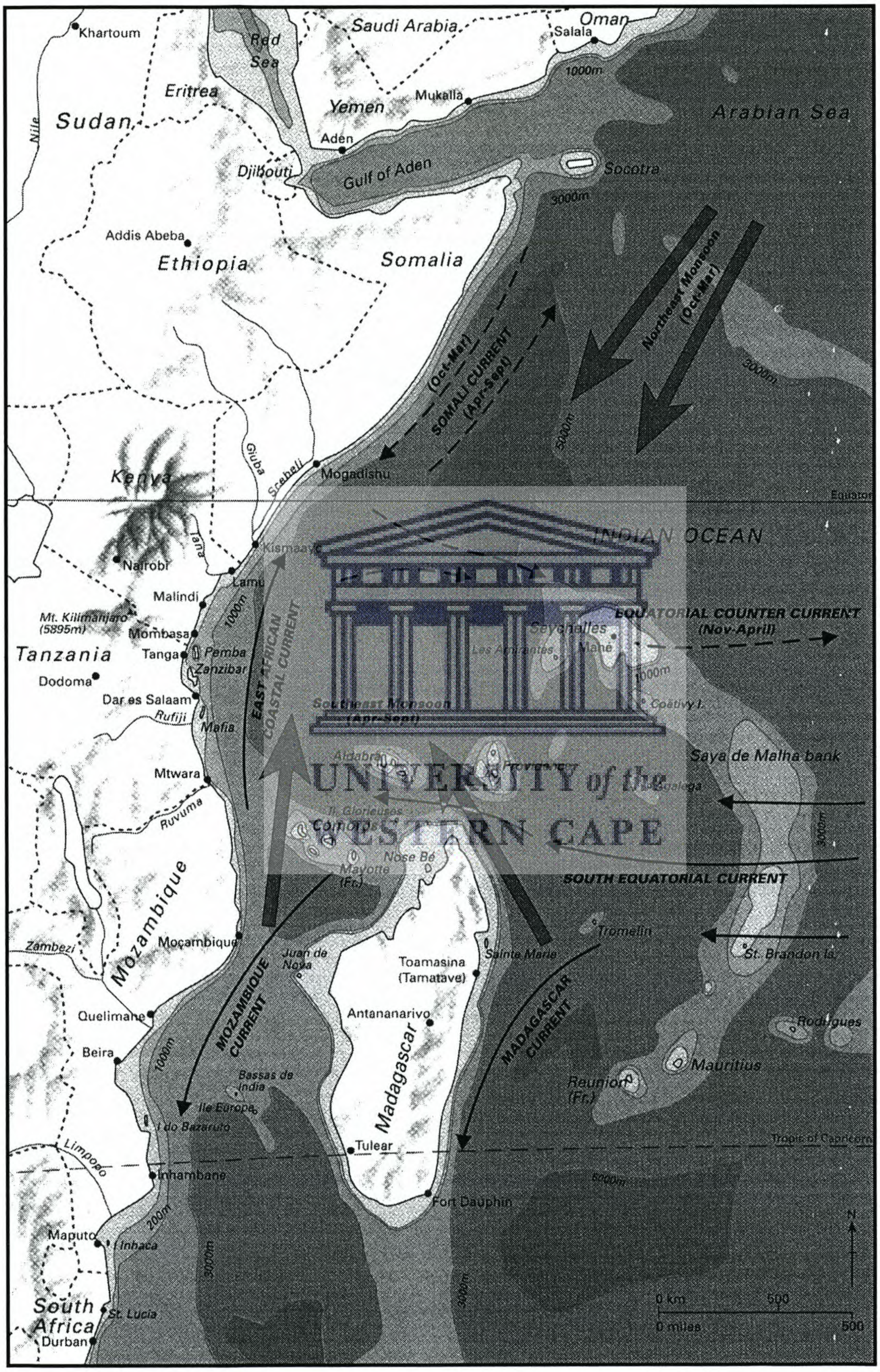


Figure 1.4 Wakibia



CHAPTER 2

FACTORS INFLUENCING GROWTH RATES OF THREE COMMERCIAL EUCHEUMOIDS AT COASTAL SITES IN SOUTHERN KENYA[1]

Abstract

As a possible means of improving the livelihoods of local villagers, off-bottom rope cultivation of commercial eucheumoids was investigated on the southern Kenyan coast at three sites, representative of the variety of environments. Three commercial morphotypes were used: brown *Eucheuma denticulatum* and green and brown *Kappaphycus alvarezii*. The study was carried out over a 15 month period from August 2001 until October 2002. Mean relative growth rates were highest at a sandy flat in a mangrove system (Gazi; 5.6% day^{-1}), and lowest in an intertidal reef flat (Kibuyuni; 3.2% day^{-1}) with a lagoon being intermediate (Mkwiro; 4.8% day^{-1}). Brown *E. denticulatum* had the highest mean growth rate of 4.7% day^{-1} compared to the green and brown *K. alvarezii* which were 4.3% day^{-1} and 4.2% day^{-1}, respectively. Growth was more variable at Kibuyuni and Mkwiro than at Gazi. Mean growth was higher during the southeast monsoon (4.7% day^{-1}) than during the northeast monsoon (4.0% day^{-1}). The effects of water motion, salinity, temperature, thallus nitrogen, and 'ice-ice' syndrome on growth of morphotypes is discussed. The water motion was observed to increase thallus nitrogen and hence the growth of eucheumoids. The 'ice-ice' condition affected both brown *E. denticulatum* and brown *K. alvarezii* but not green *K. alvarezii*. The results suggest that commercial cultivation of eucheumoids in Kenya will be feasible.

Key words: *Eucheuma denticulatum*; *Kappaphycus alvarezii*; growth; mariculture; Kenya.

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2.1 Introduction

The marine algae, *Eucheuma denticulatum* (Burman) Collins & Hervey and *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva are important carrageenan-yielding seaweeds (carrageenophytes). However, several morphological and pigment forms of each species are used in farming which makes the taxonomy and naming of commercial *Kappaphycus* and *Eucheuma* species problematic (Doty, 1987). The term "eucheumoid" (by adding "oid" to the genus *Eucheuma*, as is the case with gracilarioid) is used for both *E. denticulatum* and *K. alvarezii* and their associated forms. This term has been used by other authors when referring to the red algal genera *Kappaphycus* and *Eucheuma* (Glenn & Doty, 1990; Ask et al., 2003). The species *E. denticulatum* and *K. alvarezii* are the main carrageenophytes and their cell walls are rich in carrageenans. In 2001, these species accounted for over 88% of the world's raw material for carrageenan extraction, with the Philippines, Indonesia and Tanzania producing 115 000, 25 000 and 8 000 t dry wt, respectively (McHugh, 2003). Carrageenans are used extensively as binding, gelling, stabilising and thickening agents in food, pharmaceutical, cosmetic, and biotechnology industries (McHugh, 2003).

The high demand for carrageenan has been increasing over the years, and to meet this requirement (and possibly at a lower cost), carrageenan producers, donors and governments have been promoting the geographic spread of eucheumoids to locations such as Indonesia, Tanzania, Madagascar, Fiji and Kiribati, among other areas (Ask et al., 2003). In addition, the mariculture of eucheumoids is also gaining popularity in developing countries as means of broadening the livelihoods for coastal communities (Ask et al., 2003). For example, in the Philippines, about 180 000 families (Hurtado & Cheney, 2003) and 20 000 people in Tanzania (Mtolera, 1996) benefit from seaweed cultivation. Commercial farming of eucheumoids is also an important source of foreign exchange. However, the effects of the introduction of eucheumoids on the local environment have not yet been determined.

The attractive economic opportunities of eucheumoid farming in the Philippines and Tanzania have stimulated the cultivation of these species in East African countries such as Madagascar (Ask et al., 2003; Mollion & Braud, 1993) and recently in Mozambique (R. Piezas, pers. comm.). Although Kenya has similar environmental conditions to

Tanzania (McClanahan, 1988; UNEP, 1998), there is no commercial exploitation or farming of marine algae. Coppejans (1989) reported that there is little suitable shallow water area (compared to Tanzania) for seaweed cultivation in Kenya. He also suggested that there might be conflicts for water space with other reef users. However, there are no figures available of suitable area for seaweed cultivation in Kenya. Furthermore, some farming systems such as the floating raft and long line methods are used in deep waters to avert water space conflicts, among other reasons (Hurtado-Ponce et al., 2001; Paula & Pereira, 2003). Yarish & Wamukoya (1990) found no suitable natural sources and concluded that utilisation of eucheumoids in Kenya could only be realised by mariculture. Other reports have suggested that Kenya holds a potential for eucheumoid farming (Lirasan & Twide, 1993; Oyieke, 1998; UNEP, 1998; Wakibia, 2001). However, McHugh (2002) did not consider that Kenya had good prospects for a seaweed industry. He felt that the pilot studies were not promising but he did not reference these studies.

The oceanographic conditions of the Kenyan coastal waters seem ideal to support commercial growth of *Eucheuma* and *Kappaphycus*. However, to date, there is no information about the ecology of these plants in Kenya, particularly on their growth potential. The lack of information may partly have limited the commercial development of eucheumoid farming in Kenya. The purpose of this study was to evaluate the feasibility of growing three commercial morphotypes (brown *E. denticulatum* and brown and green *K. alvarezii*) under field conditions in Kenya.

2.2 Materials and methods

2.2.1 Study sites

Based on a preliminary survey of potential study sites along the southern Kenya coast, three areas: Gazi Bay, Kibuyuni and Mkwiro (Figure 2.1) were selected because they are sheltered from wave action, accessible, and represent a range of environmental conditions in Kenya. Gazi Bay (4°25′S, 39°30′E) is a shallow mangrove system which receives freshwater from rivers. However, both a shoreward wind and tidal currents mix the water in the bay, leading to seawater with near oceanic salinity (Kitheka, 1996). A prominent seagrass bed of *Thalassia hemprichii* (Ehrenberg) Ascherson exists at the centre of the bay. However, at the cultivation sandy flat, only *Halodule*, *Halophila* and *Cymodocea* were common. *Gracilaria* and *Hypnea* species were encountered growing on pebbles and mangrove roots. The major substratum consisted of a mixture of sand and silt. The sandy flat was covered with approximately 20-30 cm of water at the lowest tide and 3.8 m at the highest tide. The area is highly fished and women were observed gleaning for prawns and oysters.

Kibuyuni (4°38′S, 39°20′E) is a large intertidal reef flat covered by a belt of seagrass *Thalassodendron ciliatum* (Forsskål) den Hartog with epiphytic *Gracilaria corticata* J. Agardh and *Dictyota* sp. on its leaves and stems. Patches of *E. denticulatum* and *Kappaphycus striatus* (F. Schmitz) Doty ex P.C. Silva, of local origin, were also common in this area. The material was however, insufficient and too seasonal for the study. The substratum at the study site consisted of coral rubble and small pockets of sand. The reef-flat was covered with 10 cm of seawater at the lowest tide and 3.2 m at the highest tide. The dominant animals were soft corals, large sponges, starfishes, brittle stars, sea urchins and rabbit fish. The area is highly fished by local and foreign fisherfolk from Tanzania.

Mkwiro (4°40′S, 39°23′E) is located on the eastern side of Wasini Island, about 2 km from the mainland. It is a lagoon characterized by a sandy substratum where *Thalassia hemprichii, Syringodium isoetifolium* (Ashers.) Dandy, *Turbinaria*, *Sargassum* predominate, with occasional coral heads. *Eucheuma platycladum* Schmitz was found growing in patches. Numerous sea urchins, starfishes, brittle stars, and soft corals were also evident at the site. The main livelihood for the local inhabitants is fishing and reef gleaning.

2.2.2 Plant materials

Three morphotypes from two species: brown *Eucheuma denticulatum*, green and brown *Kappaphycus alvarezii* were collected from a seaweed farm in Zanzibar (about 80 km from the study sites), originally having come from Bohol, Philippines. The plant materials (2.5 kg for each morphotype) were washed clean of silt, associated animals and plants, and transported in styrofoam boxes to Mombasa, Kenya. The materials were placed in outdoor culture tanks at Kenya Marine Fisheries Research Institute (KMFRI) for 4 weeks, inspected and cleaned of any other foreign organisms before use. The morphotypes were distinguished by thallus colour and consistency, and the branching pattern. The branching of brown *E. denticulatum* is whorled/spinous with a brittle cartilaginous thallus; green *K. alvarezii* is divaricately dichotomous with a cartilaginous thallus, while the branching of brown *K. alvarezii* is unilateral to irregular with a cartilaginous thallus (Doty, 1987).

2.2.3 Cultivation method and growth experiments

The fixed off-bottom rope technique as described by Lirasan & Twide (1993) was used in the culture of the three morphotypes. In order to compare the growth rates of the three morphotypes, 4 plots (5 m x 1.5 m) were set up at each site; each containing four polypropylene ropes (one for each morphotype and an empty rope) stocked with twenty healthy cuttings, each weighing between 80 and 100 g. The cuttings were tied to the rope using 'tie-ties' (plastic straws) at spacing interval of 25 cm. The empty rope was used as a control for weights of sand and filamentous epiphytes. The plots were maintained at least twice a week by removing epiphytes and tightening loose stakes, ropes and cuttings. At the end of each culture period (about 30 days), stocked ropes were untied, water drained by shaking for 30 seconds, and weighed. The weight of each rope with its cuttings, less the weight of the empty rope, was averaged to the number of cuttings remaining on the rope. The number of missing cuttings and those with 'ice-ice' syndrome (white, soft and partly dissolved thallus) on every rope were recorded. Healthy cuttings from each plot were used for each succeeding culture period.

The growth study was performed from August 2001 to October 2002. However, due to logistical problems it was not possible to collect data at Mkwiro from May to July 2002. The relative growth rate (RGR), expressed as percent increase in wet weight per day was determined for each rope according to the following formula:

$$RGR = [(Wt/Wo)^{1/t} - 1] \times 100$$

Where Wo = average cutting wet weight at start, Wt = average cutting wet weight at time t and t = time intervals (days). The number of plants lost and the occurrence of 'ice-ice' syndrome were expressed as percentage. Grazing damage was not measured but observations were made on predated plants.

In an attempt to determine the appropriate starting weight of cuttings, four different starting weights (50, 100, 200, and 400 g) from brown *K. alvarezii* were used at Kibuyuni in July 2001. A similar experimental design as described above was used in this study. Four plots (5 m x 2.0 m), each containing five polypropylene ropes (one for each starting weight and an empty rope) stocked with twenty healthy cuttings were established. The cuttings were grown for 30 days before weighing. The maintenance and weighing followed the above procedures.

2.2.4 Plant tissue analysis

The harvested materials were sun dried for three days, oven dried at 45°C to constant weight and stored in polythene bags for carrageenan extraction (data not presented here) and nitrogen and phosphorus tissue analysis. The material for N and P analysis was rinsed in distilled water, oven dried at 60°C for 24 h, and ground in a Wiley mill (40-mesh size). Prior to analysis, the milled powders were redried to constant weight at 60°C and cooled in a desiccator over silica gel. Total N was determined with a LECO FP528 Nitrogen Analyzer. For total P, 0.5 g of seaweed sample was dry ashed at 450°C. The ash was wetted with deionised water, dissolved in 1:1 HCl (5 ml) and diluted to 50 ml. The total P concentration was determined with a Varian Vista-MPX ICP Spectrophometer. The N and P analyses were carried out by Bemlab (Somerset West, South Africa).

2.2.5 Environmental factors

Various environmental factors were recorded from each site once every two weeks both during the flood and ebb tides. These factors were measured at the depth where the plants were growing. Water temperature and salinity readings were determined using a mercury thermometer and a refractometer (Atago, Japan), respectively. Photon fluency rate was measured using a LI-193SA Spherical Quantum Sensor and LI-1400 Datalogger (Li-Cor, USA). Water pH and dissolved oxygen were measured using a portable pH meter (Beckman Instruments, USA) and WTW Multline P4 Universal meter (Germany), respectively. The water motion was determined by the dissolution of spherical plaster of Paris balls according to a clod card method modified from Doty (1971). The balls were made by pouring a mixture of water and plaster of Paris (1:1) into tennis ball moulds (about 5 cm diameter) and then inserting a stick (15 cm long, 0.5 cm diameter) into each ball. The moulds were removed after the hardening of plaster balls and the rough surfaces smoothed with sand paper. Duplicate balls (each weighing about 30 g) were mounted at each site by threading the stick through the lay of 4 mm polypropylene ropes. They were collected after 24 h, rinsed in freshwater, dried and weighed. The diffusion factor (DF) was determined by the ratio of weight lost in the field compared to duplicate plaster balls that had been kept in 20 L of still seawater for four days.

Two surface seawater samples for the determination of nitrate and phosphate levels were collected (one at each tidal time) at each site using 250 ml polyethylene bottles. The samples were stored in a cool box at 4°C and transported to KMFRI laboratory. Water samples were filtered through Whatman GF/C filters and analysed for nitrate and phosphate by the modified automated method of Parsons et al. (1984) using the continuous flow analyzer as applied in the Technicon Auto Analyzer II system. Two similar water samples were also collected with 4 L plastic bottles to determine total suspended matter (TSM). The water was filtered through previously dried and weighed Whatman GF/C filter papers which were then dried and re-weighed to measure the TSM content of the water.

Data on maximum and minimum air temperature measurements were obtained from the Kenya Meteorological weather station at Matuga, about 40 km from the study sites. Data analyses were made by General Linear Model Procedures (GLM) followed by determining differences among individual mean values by Least Significant Difference (LSD) test at $p<0.05$. Pearson's product moment correlation test was used to determine the linear relationship between treatments. Statistical analyses were performed using the SAS Program (SAS, 1999).

2.3 Results

2.3.1 Growth rate

The preliminary growth results (Table 2.1) showed that cuttings with a starting weight of 50 and 100 g were significantly higher relative growth rates (P< 0. 01) than those of 200 and 400 g. The starting weight of 400 g had the lowest relative growth rate.

The monthly relative growth rates (RGRs) of three commercial morphotypes are presented in Figure 2.2. Results for all the morphotypes at the three sites followed a general pattern of initial high growth rates followed by a decline, with the lowest RGR of 1.0 ± 0.2% day^{-1} being recorded for brown *K. alvarezii* in February 2002. There was a general increased growth rate in most of the morphotypes from March to August/September, followed by a decline again. The low growth rate at Kibuyuni from July to September was probably due to grazing by fish and the sea urchin, *Tripneustes gratilla*. The growth rate of morphotypes was more variable at both Mkwiro and Kibuyuni than at Gazi, where grazers were not abundant. The RGRs were highest at Gazi (5.6 ± 0.1% day^{-1}), and lowest at Kibuyuni (3.2 ± 0.1% day^{-1}) with Mkwiro (4.8 ± 0.2% day^{-1}) being intermediate (Table 2.2).

There were significant (p<0. 01) differences in growth rates among the three morphotypes. The brown *E. denticulatum* had the highest growth rate, whereas the green and brown *K. alvarezii* RGRs were similar and lower (Table 2.3). According to the above results, there was a significant difference in growth rate between the two species, *E. denticulatum* and *K. alvarezii.*

The growth rates of the morphotypes at the three sites were higher (p<0.01) during the southeast monsoon (SEM) (4.7 ± 1.7% day^{-1}) than during the northeast monsoon (NEM) (4.0 ± 1.8% day^{-1}). The month of August 2001 (6.0 ± 0.3% day^{-1}) had the highest RGR followed by September 2001 (5.4 ± 0.4% day^{-1}) whereas the lowest growth was recorded in January 2002 (3.1 ± 0.3% day^{-1}). Growth of eucheumoids seemed to vary from one year to another as the RGR values for August to October in 2001 were significantly higher (p<0.01) than those in August to October 2002. No data were available for Mkwiro from April to July 2002 due to logistical problems.

2.3.2 Tissue analysis and seaweed factors

The thallus nitrogen and phosphorus contents and the percentage plant loss and 'ice-ice' syndrome for the three morphotypes are presented in Table 2.3. The highest thallus P values were obtained for brown *E. denticulatum* while both brown and green *K. alvarezii* had the same levels. Thallus N levels were similar for all the three morphotypes. However, significant differences in thallus N and P contents were observed between sites (Table 2.2). Thallus N levels were highest in Gazi plants, and lowest in Kibuyuni plants with those at Mkwiro having an intermediate content. Thallus P content was higher in Mkwiro plants than in those at Kibuyuni (0.082% dry wt) and Gazi (Table 2.2). Highest thallus N (1.10 ± 0.04% dry wt) and P (0.087 ±0.003 % dry wt) levels were observed during the southeast monsoon while lowest values of 0.94 ± 0.02 and 0.079 ± 0.003% dry wt were recorded during the northeast monsoon for thallus N and P, in that order. There were no differences in plant loss among the morphotypes (Table 2.3) but there were between the sites (Table 2.2). The plant loss and 'ice-ice' occurrence at Kibuyuni was higher than at Mkwiro, whereas there was no incidence of 'ice-ice' at Gazi.

2.3.3 Environmental parameters

Table 2.4 shows the summary of environmental factors determined during the study period. Phosphate and nitrate levels were both higher at Kibuyuni and Mkwiro than at Gazi. The high nutrient levels at both sites was presumably due to nutrient excretions by the numerous echinoderms such as, sea urchins, starfishes and brittle stars at both sites as observed in the Philippines by Dy and Yap (2000). The cyanobacterium, *Lyngbya majuscula* Harvey ex Gomont known to fix nitrogen (Jones, 1990) was also common. However, though Gazi had slightly lower levels of nutrients, the greater water motion apparently made more nutrients available to the plants.

Salinity varied slightly over the study period at each site (Table 2.4). Relatively higher salinities were recorded at both Kibuyuni and Mkwiro than at Gazi. The relatively low salinity at Gazi was presumably due to dilution with freshwater. The total annual rainfall data recorded at Gazi were 1578 and 1661 mm for 2001 and 2002, respectively. The diffusion factors calculated for Gazi were significantly higher than those for

Mkwiro and Kibuyuni (Table 2.4). The high total suspended matter and low pH at Gazi were probably due to the influence of incoming run-off and sediments that were brought to the Bay during the rain. Water temperature, photon fluency, and dissolved oxygen were all similar at all the study sites (Table 2.4).

Among the environmental factors recorded at the study sites, only water temperature, salinity, minimum and maximum air temperatures exhibited seasonality. These factors were significantly higher ($p<0.01$) during the NEM than in SEM. Average readings for water, minimum and maximum temperatures, and salinity were 29.8°C, 23.1°C, 31.7°C, and 35.8‰, during NEM, and 27.8°C, 21.6°C, 29.2°C and 34.9‰ during SEM, respectively.

Several epiphytes and grazers were observed at the study sites. The most common epiphytes were *Enteromorpha ramulosa* (J. E. Smith) Hooker and the blue-green alga, *Lyngbya majuscula*. The *E. ramulosa* was abundant in the cooler months of May to July while *L. majuscula* was abundant during the NEM. Both epiphytes grew and formed mats over the eucheumoid thalli. Other epiphytes such as *Ulva*, *Hypnea*, *Enteromorpha* and *Dictyota* grew on the ropes and stakes. However, a fine red filamentous epiphytic alga (not identified) grew on eucheumoid thalli, especially on green *K. alvarezii*. This filamentous alga was abundant during the colder season though it was also common during the warmer period. In March 2002, a phytoplankton bloom developed in southern Kenya but it did not affect the plants negatively as this period showed an unexpectedly high growth for most of the plants (Figure 2.2). Some fishes, starfishes and sea urchins were found feeding on eucheumoids. The most destructive grazers were the rabbit fishes (Siganidae) and an echinoderm, *Tripneustes gratilla*. The experimental plants at Kibuyuni were heavily grazed in July-Sept 2002, resulting in the low growth rates recorded during this period.

2.3.4 Correlation analyses

Table 2.5 shows the correlation coefficients between growth rates of brown *E. denticulatum*, green and brown *K. alvarezii,* environmental factors and plant tissue parameters. Positive correlations ($p< 0.01$) between growth rates of the three morphotypes and both water motion (DF) and thallus nitrogen content were observed.

Hence, high relative growth rates were associated with high levels of thallus N and water motion. None of the morphotypes showed any significant correlation with thallus P level. Both the brown *E. denticulatum* and brown *K. alvarezii* growth rates were inversely correlated with maximum air temperature and salinity at $p<0.05$, whereas brown *K. alvarezii* growth rate was also negatively correlated with minimum temperature. None of the other nine factors, including, the seawater nitrate and phosphate concentrations had significant ($p>0.05$) correlations with growth rates of the eucheumoids. On the other hand, negative significant correlations were obtained between the growth rates of both the brown *E. denticulatum* and brown *K. alvarezii* and percent 'ice-ice' but none for green *K. alvarezii* (Table 2.5). Thallus N contents of brown *E. denticulatum* and brown *K. alvarezii* were inversely correlated with 'ice-ice' ($r=-0.361$, $p<0.05$ and $r=-0.523$, $p<0.01$, respectively), whereas very little disease symptoms were observed for green *K. alvarezii* ($r=-0.187$, $p>0.05$).

2.4 Discussion

The growth rates of eucheumoids have been observed to vary with species and morphotypes (Doty, 1987). The growth rates of all morphotypes in Kenya (Table 2.3) were above the recommended commercial value of 3.5% day^{-1} for eucheumoid farming (Doty, 1987). These growth values were similar to those observed for eucheumoids in other regions (Braud & Perez, 1978; Glenn & Doty, 1990; Lirasan & Twide, 1993; Dawes et al., 1994; Ohno et al., 1996; Hurtado et al., 2001; Paula & Pereira, 2003). The maximum growth rates (6.9 to 7.8% day^{-1}) reported in this study are lower than the maximum values of 10.6 and 11.0% day^{-1} recorded for *K. alvarezii* (Azanza-Corrales & Aliaza, 1999) and *Eucheuma uncinatum* (Polne et al., 1981), respectively. The growth difference was probably due to the small starting weights used by both authors. On the other hand, the growth rates obtained were higher than those for both *E. denticulatum* and *K. striatus* (mean of 1.4% day^{-1}) grown in Madagascar (Mollion & Braud, 1993).

The growth rates of commercial morphotypes vary with species as observed in this study where higher growth was obtained for brown *E. denticulatum* than with both brown and green morphotypes of *K. alvarezii* (Table 2.3). Similar observation has have been reported by Russell (1982) in Fiji waters where the growth rate of *E. denticulatum* was higher (7.5% day^{-1}) than that of *K. striatus* (6.1% day^{-1}). However, several authors have reported higher growth rates for *K. alvarezii* than in *E. denticulatum*. They attributed high growth of *K. alvarezii* to its wide range of tolerances to ecological factors (Dawes et al., 1994; Gerung & Ohno, 1997; Ask & Azanza, 2002), greater response to water motion (Glenn & Doty, 1992), and morphological variability (Doty, 1987; Dawes, 1992). On the other hand, no significant difference in growth rate was found between *E. denticulatum* and *K. striatus* by Mollion & Braud (1993). The higher growth rates for *E. denticulatum* than the two forms of *K. alvarezii* in the present study may partly be due to its response to the great water motion and the tidal flushing as was observed in Zanzibar (Mshigeni, 1994) and its better tolerance to the adverse conditions, as well as other factors. The high tidal amplitude (4 m) in Kenya (McClanahan, 1988) may have enhanced more diffusion of nutrients in the study areas. Kraft (1969) found that *E. denticulatum* (as *E. muricatum*) tolerated higher rates of water movement than *K. alvarezii* (as *E. striatum*) at Panagatan, Philippines. The algal responses to different water motion levels and other relative factors may vary between species (Glenn & Doty, 1990; Hurd, 2000). The high production of *E. denticulatum* in Indonesia has been attributed to its greater tolerance to desiccation than *K. alvarezii* (Luxton, 1993). The brown and green morphotypes of *K. alvarezii* had similar growth rates in this study as observed by other authors (Dawes et al., 1994; Ohno et al., 1994; Hurtado-Ponce et al., 2001).

There were distinct differences in eucheumoid growth at the three sites (Table 2.2). The variation in growth rates obtained for the morphotypes can possibly be explained by differences in water motion at the three sites (Table 2.5). Similar results of growth differences at different sites due to water motion have been reported for *E. denticulatum*, *K. alvarezii* and *K. striatus* in Kaneohe Bay, Hawaii (Glenn & Doty, 1992). In Zanzibar, Mtolera et al. (1995) attributed the differences in growth rates for *E. denticulatum* at four sites to variations in inorganic carbon due to water movement. However, water motion was not measured at the sites. It has been suggested that water motion enhances growth rates of seaweeds by reducing the extent of the diffusion boundary layer around the algal surface (Wheeler, 1988). The decreased boundary layer then increases the supply of inorganic carbon, phosphate, nitrate and other micronutrients to the thallus (Wheeler, 1988; Hurd, 2000), and facilitates the removal of algal metabolic products such as O_2 and OH^- ions (Gonen et al., 1995) and excess hydrogen peroxide and halogenated organic compounds (Mtolera et al., 1995) away from the plant surface. In addition at Gazi Bay, there were strong tidal currents reaching velocities up to 0.60 m s^{-1} with far-reaching effects on nutrient and material exchanges (Kitheka, 1996), and hence, probably the high growth rates.

The high growth rates at Gazi may be attributed to an increased supply of inorganic nitrate level to the morphotypes due to high water motion as shown by the high thallus N level (Table 2.2 & 2.5). The critical level of nitrogen and phosphorus required for maximum growth has been observed for several seaweeds (Hanisak, 1990; Lewis & Hanisak, 1996; Mairh et al., 1999). A critical N level of 1.00% dry wt has been observed for *K. alvarezii* (Li et al., 1990) and between 1.19 and 2.53% dry wt for *K. striatus* (Mairh et al., 1999). Consequently, slower growing plants at Kibuyuni with thallus N value of 0.83% dry wt were presumably N-limited. Similar observations of N-limited eucheumoids have been reported by Hurtado-Ponce (1995) and Mollion & Braud (1993). Thallus P content was not correlated with plant growth at any site, suggesting that the plants were probably not P-limited. Results of critical P levels for eucheumoids are uncommon. Lewis & Hanisak (1996) reported that production of *Gracilaria* strain G-16s cultured under various nutrient levels was P-limited at thallus P content of 0.07% dry wt. All the plants at all sites in this study had a similar or higher thallus P content. Lower thallus P values of 0.04 and 0.03% dry wt were reported, respectively, for *E. denticulatum* and *Kappaphycus* from thalli that had been rinsed to remove surface salt (Doty, 1987). However, the critical level of N and P varies with photon fluency, nutrients and temperature, as well as other factors (Lobban & Harrison, 1994).

The highest average water (30.6°C) and maximum air temperatures (33.0°C) were measured in February (northeast monsoon), coinciding with periods of low growth rates. During this time, the lowest tides occurred around the mid-day, when the effects of heating and desiccation can be lethal for eucheumoids. The high temperature and tide-induced exposure probably stressed the plants, thus affecting their growth. On the other hand, high growth values were obtained in August/September (southeast monsoon) when the average monthly water and maximum temperature readings were 28.4 and 29.1°C, respectively. It appears that temperatures between 28 and 30.6°C were favourable for growth of the three morphophytes in this study. Optimum temperatures for the growth of eucheumoids in field conditions have been suggested to be between

28°C and 30°C (Doty, 1987; Hurtado-Ponce, 1992; Ohno et al., 1994) and coincided with the optimal temperature for the nitrate reductase enzyme (Granbom et al., 2004). The maximum rates of photosynthesis for both red and green morphotypes of *K. alvarezii* were also observed at 30°C (Aguirre-von-Wobeser, et al., 2001). Pauli and Pereira (2003) showed that temperature was the main factor influencing growth of brown *K. alvarezii* grown on a raft in Brazil. High temperatures (>31°C) have been observed to reduce the growth rates of eucheumoids in this study, as well as in other tropical areas, such as Vietnam (Ohno et al., 1996) and Madagascar (Mollion & Braud, 1993).

Low growth rates of eucheumoids were recorded at Kibuyuni where high 'ice-ice' occurrence was observed. The cause of 'ice-ice' syndrome is not well understood but there has been a general consensus that 'ice-ice' is due to physical and chemical stresses (Uyenco et al., 1981; Doty, 1987; Largo et al., 1995; Mtolera et al., 1995). High 'ice-ice' occurrence was observed at Kibuyuni from November to January, coinciding with the period of high temperature and salinity. Grazing of the plants and presence of the blue-green alga, *Lyngbya majuscula* forming mats on thalli were also observed during this time. It appeared that the high 'ice-ice' syndrome at the site was promoted by a combination of environmental (high temperature/low salinity and low water motion) and biological factors (grazers and epiphytes). Grazing by tip nipping and removing of cortical layers from thallus especially by sea urchins probably reduced the photosynthetic capacity of the plants (Ganzon-Fortes et al., 1993), and the left wounds that were potential sites for pathogen infection. The covering of plants by epiphytes could also have limited the amount of available light for the seaweeds, hence low growth. An inverse significant correlation between 'ice-ice' and growth of both brown *E. denticulatum* and brown *K. alvarezii* was observed but none for the green *K. alvarezii* (Table 5), implying that the green morphotype was 'ice-ice' resistant. A significant correlation between percent 'ice-ice' occurrence and thallus nitrogen content of both brown *E. denticulatum* and brown *K. alvarezii* was also obtained (see results) but none for the green morphophyte. Low thallus N content was reputed to promote 'ice-ice' in Madagascan eucheumoids when thallus N content was 0.88% dry wt (Mollion & Braud, 1993), comparable to a mean value of 0.83% dry wt for morphotypes at Kibuyuni (Table 2.2). Growth of eucheumoids may also have been affected by the presence of seagrasses, competitors for nutrients and space as observed for *E. denticulatum* in

Zanzibar (Mtolera et al., 1995). The growth patterns of eucheumoids at the three sites support the complex multifactorial theory of Doty (1987) which suggests that light, water motion, temperature and water quality determines the suitability of a site for seaweed growth. However, other factors, such as epiphytes and grazers should also be incorporated in the model as observed in this study.

In conclusion, results of the present study indicate good prospects for commercial cultivation of eucheumoids at three sites in southern Kenya, including a mangrove bay environment. However, it is apparent that attention should be given to a survey of potential sites for commercial eucheumoid farming along the Kenyan coast, with water motion, temperature and salinity, among other criteria being considered. Selection of local eucheumoid strains with good growth and carrageenan properties should also be given priority.

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Table 2.1 Duncan's Multiple Range Test for the relative growth rates (% day^{-1}) of cuttings with different starting weights from brown *K. alvarezii* grown at Kibuyuni in July 2001 (mean ± SE). Means with the same letter are not significantly different at $p<0.05$.

Starting weight of cuttings (grams)	N	Relative growth rate (% day^{-1})	Duncan's grouping
50	4	4.8 ± 0.2	A
100	4	4.6 ± 0.2	A
200	4	4.0 ± 0.2	B
400	4	3.2 ± 0.1	C

Table 2.2 N and P thallus content (% of dry wt) and seaweed parameters of eucheumoids grown at three sites in southern Kenya (mean ± SE, n=39-117). Means with the same letter in each row are not significantly different at $p<0.05$.

Parameter	Gazi	Kibuyuni	Mkwiro
Thallus N	1.22 ± 0.03^a	0.83 ± 0.02^c	1.02 ± 0.03^b
Thallus P	0.077 ± 0.004^c	0.082 ± 0.003^b	0.090 ± 0.005^a
% Plant loss	2.4 ± 0.7^b	5.4 ± 0.6^a	3.5 ± 0.6^b
% Ice-ice syndrome	0.0^c	2.5 ± 0.5^a	1.4 ± 0.4^b
Relative growth rate (% d^{-1})	5.6 ± 0.1^a	3.2 ± 0.1^c	4.8 ± 0.2^b

Table 2.3 N and P thallus content (% of dry wt) and seaweed parameters of three eucheumoids grown at three sites in southern Kenya (mean ± SE, n=34-133). Means with the same letter in each row are not significantly different at $p<0.05$.

Parameter	Brown *E. denticulatum*	Brown *K. alvarezii*	Green *K. alvarezii*
Thallus P	0.101 ± 0.003^{a}	0.074 ± 0.002^{b}	0.068 ± 0.002^{b}
Thallus N	1.00 ± 0.03^{a}	1.01 ± 0.04^{a}	1.02 ± 0.04^{a}
% Plant loss	3.7 ± 0.5^{a}	4.7 ± 0.7^{a}	3.5 ± 0.7^{a}
% Ice-ice syndrome	0.8 ± 0.2^{b}	3.4 ± 0.7^{a}	0.1 ± 0.1^{b}
Relative growth rate (% d^{-1})	4.7 ± 0.2^{a}	4.2 ± 0.1^{b}	4.3 ± 0.2^{b}

Table 2.4 Environmental factors measured at three study sites in southern Kenya (mean ± SE, n = 9-15). Means with the same letter in each row are not significantly different at $p<0.05$.

	Sites		
Environmental parameter	Gazi	Kibuyuni	Mkwiro
Nitrate (µM)	1.39 ± 0.27^{b}	2.76 ± 0.57^{a}	2.43 ± 0.43^{a}
Phosphate (µM)	0.77 ± 0.14^{c}	1.33 ± 0.18^{b}	1.49 ± 0.25^{a}
Water temperature (^{o}C)	29.3 ± 0.6^{a}	28.5 ± 0.4^{b}	28.6 ± 0.5^{ab}
Salinity (‰)	34.8 ± 0.5^{b}	35.6 ± 0.3^{a}	35.6 ± 0.3^{a}
Water motion (diffusion factor)	6.16 ± 0.31^{a}	4.72 ± 0.21^{c}	5.54 ± 0.28^{b}
Photon fluency (µmol photon m^{-2} s^{-1})	1042 ± 77^{b}	1254 ± 186^{ab}	1317 ± 324^{a}
PH	7.74 ± 0.05^{b}	8.19 ± 0.11^{a}	8.15 ± 0.08^{a}
Dissolved oxygen (mgl^{-1})	5.48 ± 0.53^{a}	6.09 ± 0.37^{a}	6.56 ± 0.64^{a}
Total suspended matter (mgl^{-1})	13.2 ± 0.7^{a}	12.8 ± 2.0^{a}	8.7 ± 1.0^{b}

Table 2.5 Correlation coefficients of three eucheumoids growth rates with thallus N and P (% dry wt) and environmental factors measured in southern Kenya.

Parameter	Brown *E. denticulatum*	Brown *K. alvarezii*	Green *K. alvarezii*
Water nitrate	-0.138	-0.209	0.005
Water phosphate	0.055	0.101	0.073
Maximum air temperature	-0.333*	-0.413**	0.021
Minimum air temperature	-0.246	-0.393*	0.022
Water temperature	-0.152	-0.214	0.074
Diffusion factor	0.518**	0.591**	0.489**
Salinity	-0.391*	-0.363*	-0.180
Photon fluency rate	-0.208	-0.339	0.065
pH	-0.137	-0.176	-0.337
Dissolved oxygen	-0.040	-0.231	-0.056
Total suspended matter	-0.087	-0.084	-0.252
Thalls N	0.623**	0.790**	0.534**
Thallus P	-0.023	0.242	-0.121
% Ice-ice syndrome	-0.472**	-0.611**	-0.098

* Significant at $p<0.05$, ** Significant at $p<0.01$

Figure caption

Figure 2.1. Map of Kenya showing the three study sites: Gazi Bay, Kibuyuni and Mkwiro.

Figure 2.2. Monthly relative growth rates (RGRs) of three morphotypes, brown *Eucheuma denticulatum* (prism), green (triangle) and brown (square) *Kappaphycus alvarezii* grown at three sites (A=Mkwiro; B=Kibuyuni; C=Gazi) in southern Kenya (mean ± SE, n=3).

Figure 2.1 Wakibia

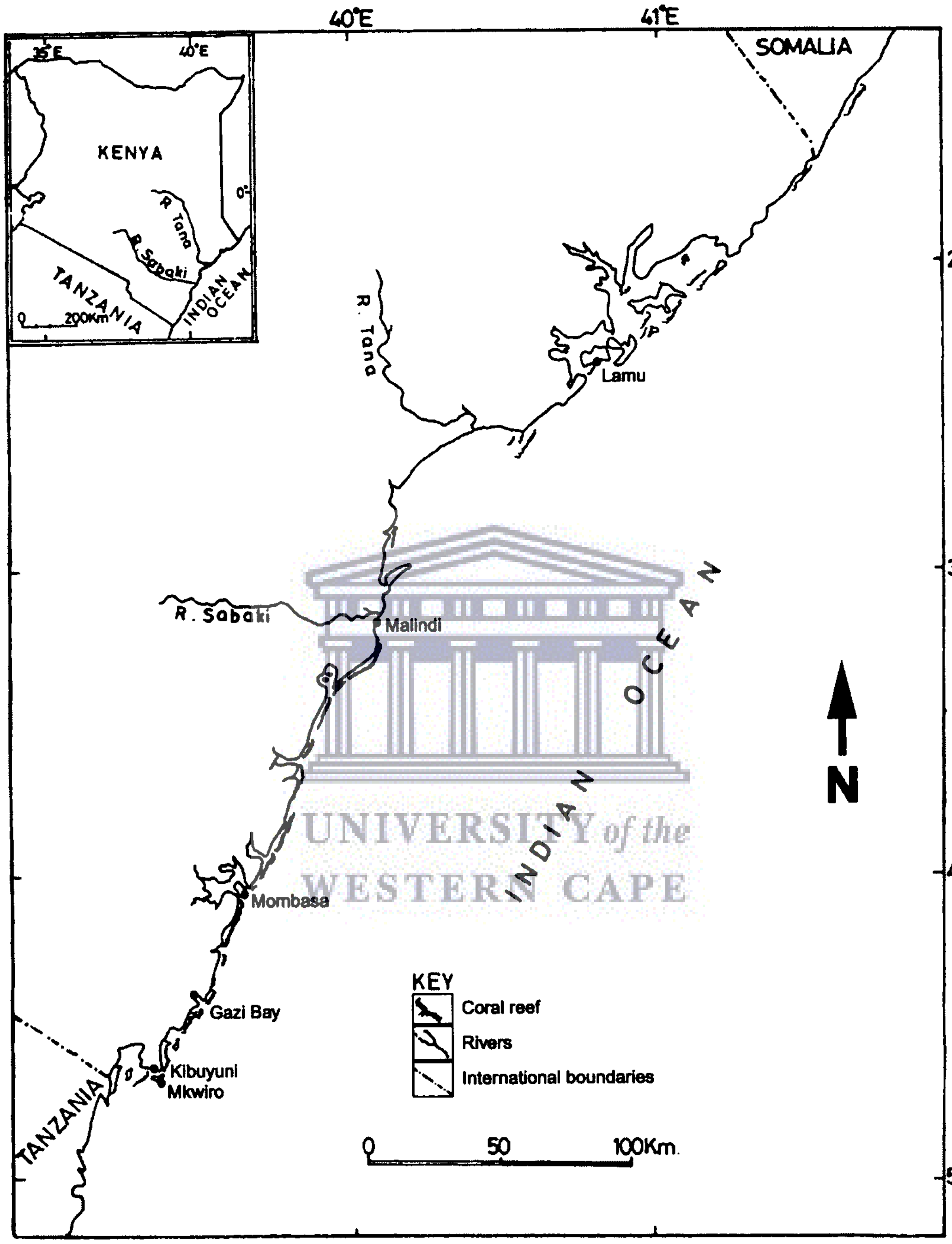
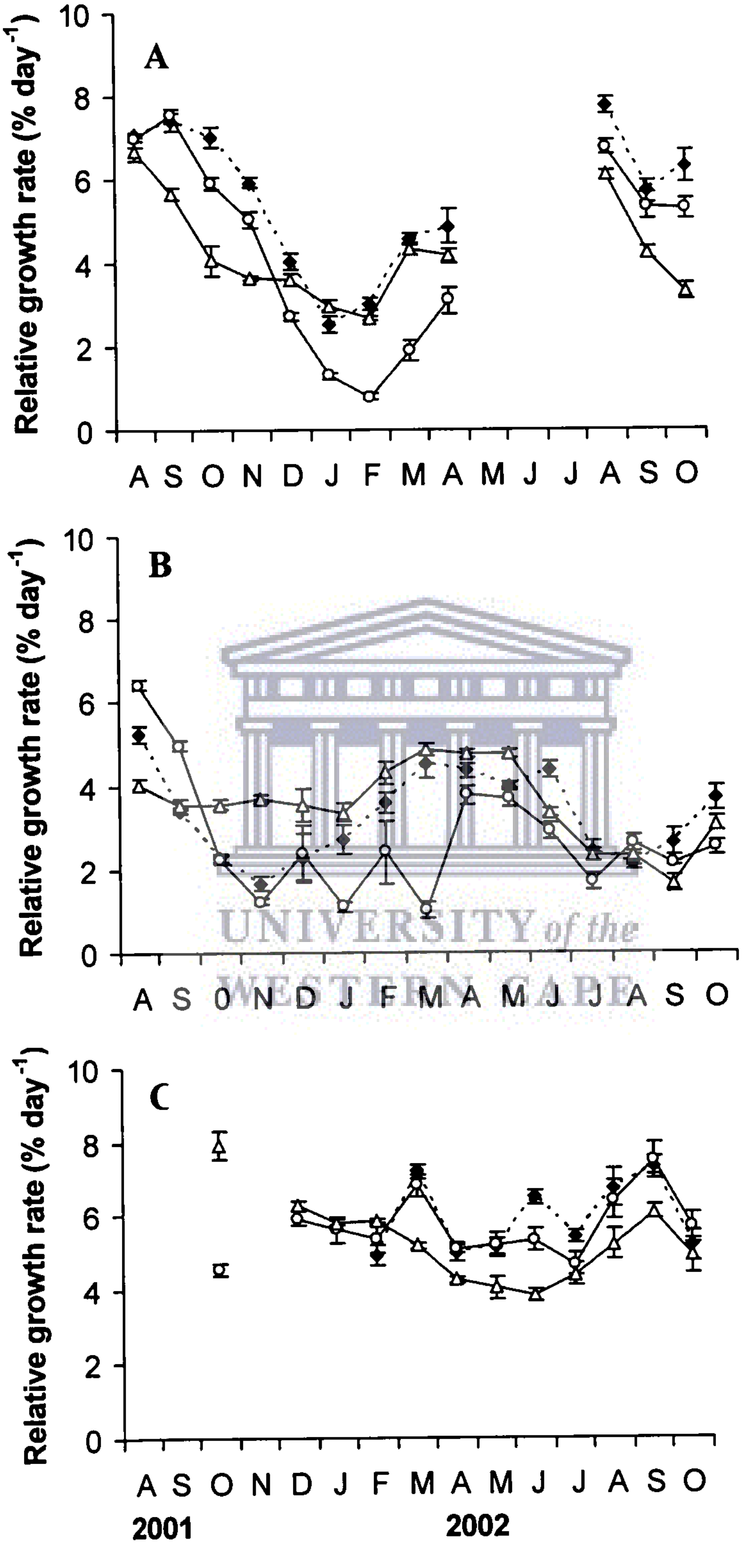


Figure 2.2 Wakibia



CHAPTER 3

DEMOGRAPHIC AND SOCIO-ECONOMIC FACTORS FOR CONSIDERATION IN DEVELOPING A COMMUNITY-BASED EUCHEUMOID CULTIVATION PROJECT IN SOUTHERN KENYA[3]

Abstract

There is a growing interest in commercial eucheumoid cultivation in Kenya as a means of broadening the livelihoods of coastal village communities. To select a suitable community for seaweed farming, a socio-economic survey was conducted in three coastal villages in southern Kenya: Gazi, Kibuyuni, and Mkwiro, from April to September 2001. The average household size for the villages was 6.2 and a significant proportion of the household members (76%) was below 30 years of age. There was a high proportion (41%) of young children (0-14 years) coupled with elderly people (65 years +), which indicates a high dependency on the economically active population. The households depended on a variety of livelihoods but the main one reported was fishing (over 48%). The average monthly income for the surveyed households was Kshs. 9904 (1 US$=75 Kshs. in 2001). No significant differences were apparent for household income among the villages and between the male and female-headed households. However, the female respondents had lower educational attainment levels and less assets than the male respondents. The majority (66.5%) of the households had a monthly income of less than Kshs. 10 000. The prevalence of poverty among the households surveyed was 45.1% with 38.8%, 54.8% and 46.7% of households in Gazi, Kibuyuni and Mkwiro villages, respectively, living below the poverty line (Kshs. 1239 per month per adult person). No significant difference in poverty incidence was obtained for the villages. The study describes some of the strategies that villagers used to cope with shocks and stresses. Based on the socio-economic factors and ecological factors, Kibuyuni village would be most likely to benefit from piloting eucheumoid cultivation because the average household size was large with a high percentage of economically active members to provide labour. The low educational levels also limited

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their employment opportunities while lack of microfinance facilities prevented or limited other economic activities.

3.1 Introduction

The cultivation of seaweeds belonging to the genera *Eucheuma* and *Kappaphycus* seaweeds (commercial eucheumoids) has received a lot of attention in several tropical countries due to their ecological, economic and social significance (1, 2, 3). Farming of eucheumoids is influenced by a number of ecological and non-ecological factors. The ecological factors mainly include: water temperature, water motion, salinity, irradiance, 'ice-ice' syndrome, epiphytes and grazers (1, 4, 5) whereas socio-economics and demographics are non-ecological factors (1, 3, 6). Other factors related to eucheumoid cultivation are the availability of suitable areas (7), and lack of market and price fluctuation (2).

Although most studies on eucheumoid cultivation have concentrated more on the ecological factors (8-10), the human factors are also very important (4). Introductions of *Eucheuma* and *Kappaphycus* species for commercial cultivation have been attempted in many areas (over 20 countries) but only five countries have succeeded commercially (annual production of about 1000 t dry wt or more) (11). The high failure rate has been attributed to human factors rather than ecological factors (3). Several authors have reported cases where eucheumoid cultivation has been limited or has failed due to human factors such as unreliable seaweed buyers (12), cultural aspects (11), political interferences (11, 12), disagreements over employment and working conditions (2) and seaweed farmers shifting to short lived boom fishery (e.g. octopus season) and more lucrative livelihoods (11, 13). The key to successful eucheumoid cultivation in Tanzania and the Philippines has been attributed to the willingness of the local communities to grow seaweeds because of their social and economic conditions (1, 14). The importance of human factors in seaweed cultivation is emphasized by Ask (4) who suggests that eucheumoid cultivation is 90% psychology and 10% phycology. Yet, to date, the above issues have not been adequately addressed by researchers, who tend to focus more on the technical and environmental details of eucheumoid cultivation rather than a combination of all factors including, the socio-economic aspects (15) and politics (4).

The socio-economic factors likely to influence the adoption of commercial eucheumoid cultivation in any area are outlined by various authors (1, 3, 6) and the need to study the livelihoods of villagers before introducing seaweed farming in their areas has also been recommended (4). A livelihood encompasses the activities, assets and entitlements required for a means of living (16). Among the three components of livelihood, the portfolio asset is the most complex and generally given more attention. Assets consist of natural resources, abilities, knowledge, skills and employment opportunities. Assets also include social institutions, and services and facilities (17). Activities are things that people do to gain living, and these are based on available assets while entitlements are those things that people demand and appeal for at times of shocks and stresses. The support may take such forms as food, implements, loans, gifts, or work (16). A livelihood is sustainable when it allows people to make a living and improve their quality of life without jeopardizing the livelihood opportunities for present and future generations. Sustainable livelihoods also deal with how people avoid or cope with shocks and stresses and adapt to changes that affect their livelihoods (18). The shocks are impacts which are typically sudden, unpredictable and traumatic, such as droughts, disease outbreaks and collapse of a market, etc., while stresses are pressures which are typically continuous and cumulative, predictable and distressing, such as seasonal shortages, rising populations or declining resources (16). The sustainable livelihood concept is useful in project such as seaweed development as it acknowledges the diversity of activities that people engage in to survive, and provides a conceptual framework for socio-economic interventions.

Most socio-economic surveys have traditionally focused on rural communities engaged in subsistence agriculture, while coastal village communities, including those involved in eucheumoid farming, have received little attention (6, 15, 19, 20). Besides, the limited surveys have only emphasized the social and economic impacts of seaweed farming with little information on the various forms of livelihoods for coastal communities. In addition, the existing socio-economic assessments of seaweed farmers are site specific, and have often focused on the Asia-Pacific countries such as Fiji (6), Kiribati (21) and the Philippines (1). These countries have different social and cultural factors than the eucheumoid farmers in the Western Indian Ocean areas such as Tanzania, Madagascar and Mozambique. Although Tanzania is a major producer of eucheumoids, there is very little information on the non-ecological factors influencing the development of seaweed farming (19). However, Eklund and Pettersson (19) and Msuya (2) assessed the socio-economic impacts of *Eucheuma* farming on communities in Zanzibar. It has been reported that the development of eucheumoid farming in Zanzibar was influenced by the social and economic structure of Zanzibar (14). However, all these studies were conducted after eucheumoid farming was already established in Zanzibar.

There is a growing interest in the potential for *Eucheuma* and *Kappaphycus* farming in Kenya (22, 23). However, an assessment of the socio-economic conditions of coastal village communities needs to be conducted before introducing eucheumoid farming in Kenya. The existing information on social and economic characteristics of coastal fishing communities in Kenya is limited. Both Juma (24) and Malleret-King (25) conducted surveys on the socio-economic profiles of fishing households in southern Kenya. However, these authors did not deal with the physical, social and human assets of these households. There is also a lack of knowledge of and insight into patterns of livelihoods among fisherfolk on the south coast of Kenya and how they cope with shocks and stresses such as freshwater shortages and diseases (26, 27). Little knowledge exists about the household income and income composition of fisherfolk though it is believed to vary greatly between fishing villages and within villages (24). This study aimed to report on a socio-economic survey of three coastal fishing communities in southern Kenya with the purpose of providing information for the identification and selection of coastal villages suitable for eucheumoid cultivation. Such information could also serve as a baseline profile of households prior to the development of eucheumoid farming.

3.2 Materials and methods

A socio-economic survey was conducted among households in three coastal villages in Kwale District, southern Kenya. Administratively, Kenya is divided into eight provinces. Each province is divided into districts which are further subdivided into divisions. Locations and sublocations are the smallest administrative units. Each sublocation is under an assistant chief who represents the government. There are several villages in a sublocation each headed by a chairman or headman who together with elders run the village affairs. The elders are respected old men who together with the chairman form a village council. The role of the village council is limited to resolving petty issues within the village, particularly those of family importance, which are not handled by the assistant chief or police. The three villages were: Gazi (mangrove bay) (4°25′S, 39°30′E), Kibuyuni (raised reef platform) (4°38′S, 39°20′E), and Mkwiro (Island) (4°40′S, 39°23′E). The villages were selected because they are located in sites where there was an ongoing experiment on seaweed cultivation (see Chapter 2). The sites were also representative of different ecological conditions. A reconnaissance survey was initially conducted to carry out a general household census in each village and identify key informants in order to build a sampling frame. The household census was conducted with the assistance of the village chairman who was the head of the village.

The household is commonly used as the unit for analysis in socio-economic surveys because it is a convenient policy tool (16, 28, 29), and is assumed to be the level at which resources are pooled together, and acts as a decision making unit (30). However, the male and female access to and control over resources are relatively independent of the household structure (31, 32). Thus, some authors have advocated the use of individuals within households rather than households as sampling units in economic surveys (28, 31). Nevertheless, several investigations have used household as the sampling unit in the assessment of coping strategies (20, 29, 30), sustainable livelihoods (20), and food security (25). According to Preston (33), a household is a basic socio-economic unit in which members interact and organize themselves for shelter, sustenance and reproduction. In this study, a household was defined as a social and economic unit of members living, cooking and eating together in a house and sharing resources and tasks. It is generally accepted that individuals are gregarious and act in association with others, except in extreme situations (33). However, it is necessary to acknowledge the intra-household differences in access to resources and decision-making ability among members (29, 30).

In this study, participatory research methods and techniques were used to gather data in the villages and included direct observation, key informant interviews, semi-structured interviews based on a set of open-ended questions, and focus group interviews. The validity of the findings was verified by means of cross checking and replication (16,17) and the presence of a research assistant who knew the informants well.

To obtain information on topics pertaining to agriculture, fisheries, health and education in the villages the following key informants were interviewed: village chairman, a medical officer, a headmaster of the local primary school, a fisheries officer, and an agricultural officer. These people were selected because they had special knowledge in the area ranging from health status to educational issues in the village. Direct observations were conducted throughout the study period, particularly during the household census and interviews. These observations provided insight into livelihood activities, housing structures and household assets and also helped gain trust of the villagers. Detailed observations were also made of the community services and facilities through a series of transect walks across the villages.

During the household census, a total of 160, 84 and 120 households were listed for Gazi, Kibuyuni and Mkwiro villages, respectively. The entire households in each village were assigned numbers (1 to 160, 1 to 84 and 1 to 120 for Gazi, Kibuyuni and Mkwiro villages, respectively) that were later used to select a representative sample for interviews. Household semi-structured interviews were conducted in 80, 42 and 60 of the households at Gazi, Kibuyuni and Mkwiro, respectively, representing 50% of the total listed households. The household sample size used for each village was based on established tables for various population group sizes by Bunce and others (17). The households interviewed for each village were randomly selected using generated random numbers from a Microsoft Excel spreadsheet program.

Once households were selected, a pre-tested household interview guide was used to interview the head of household or the spouse or other household members in a face-to-face situation. The interview guide covered the following aspects: socio-demographic composition, economic activities, assets and possessions, and shocks, stresses and coping and adaptive strategies in each household (see Appendix 1). Several of the questions were open-ended to encourage two-way interactions, including exchanges of information between the facilitator and respondent. The total monthly income for each household was also estimated. Total income here refers to the sum of cash income for all sources of livelihoods by household members and household consumption of agricultural produce and natural resources (mainly fish). The value of subsistence was based on the prevailing market value at the nearby shopping centre. The collection of income data is a sensitive matter that requires the building of trust between investigators and the household members (29). The trust and confidence in this study was established by recruiting a field assistant with secondary level of education who was a resident in the village and respected by village members. The assistant also made a follow-up study for information on daily income, consumption and expenditure patterns in the selected households. A repeat visit was also carried out to follow up with conflicting details with the other household members. Each household interview lasted between 1 and 1.5 hours, and 182 household interviews were conducted in total.

To get information on shocks and stresses, and coping and adaptive strategies in each village, a focus group interview composed of the 5 to 6 village elders (the village council) was used. The focal group discussion also provided useful information on social, economic and political situation of the village life that did not emerge directly from interviews with household respondents. The discussion lasted for about two hours. Some relevant data were collected from government department records and reports, census, and survey statistics at Kwale District headquarters, about 50 km away from the study sites.

The survey was conducted for a period of 6 months, from April to September 2001, and included the hunger (April-June) and the harvest (July-September) periods. All interviews were conducted in Swahili. The data from the survey were qualitatively and quantitatively analysed. Statistical analysis was carried out using the SAS Program, Version 8.2 and presented in the form of tables and figures. Numerical data were analysed by General Linear Model Procedures (GLM) followed by determining differences among individual mean values by Least Significant Difference (LSD) test at $p<0.05$. Categorical data were analysed using cross tabulations to calculate the χ^2 statistic.

3.3 Results

3.3.1 Socio-demographic characteristics

The socio-cultural characteristics of the household heads in three villages are presented in Table 3.1. The ages of the household head ranged from 23 to 70 years, with an average age of 43.2 years. The educational attainment level of the female household heads was significantly lower than the male heads (Table 3.2). About 31% had no formal education, 53% reached various levels in primary school and only 4% had post secondary education. A significant difference in the level of formal education among the household heads in the three villages was also observed. The respondents in Gazi and Mkwiro had attended schools for more years ($p<0.05$) than those from Mkwiro village (Table 3.1). Of the 182 household heads surveyed, about 80% were married while only 3.3% were not. The majority of the inhabitants in Gazi and Kibuyuni village were of Digo tribe while those in Mkwiro village were of Shirazi tribe (Table 3.1). Some members of the Wapemba tribe from Tanzania were also present in all the villages. The 'others category' included 13 ethnic groups. Most of the surveyed respondents were Muslims while most of those in Gazi and Kibuyuni believed in the existence of witchcraft. The acceptance of family planning among the surveyed households was very low particularly in Mkwiro (Table 3.1).

Table 3.2 shows the socio-economic characteristics of the male and female heads of households while Table 3.3 presents the demographic characteristics of household members in surveyed households. The average household size and working members were similar in female and male headed households (Table 3.2). However, the number of active members were higher in female-headed households than those of male-headed ($p<0.05$). The average household size for the villages was 6.2 individuals, with households in Kibuyuni and Mkwiro villages having more members per household than those in Gazi village ($p<0.05$). The economically active members were more than both the children and elderly members (Table 3.3) while a significant proportion of the household members (76%) were below 30 years. The number of working members in the surveyed households was higher in Kibuyuni village than in Mkwiro and Gazi, According to the gender ratio in the surveyed households, females outnumbered males with the exception of members in Gazi village where males slightly outnumbered females (Table 3.3). The ratio of female to male for the total population was roughly 1.2:1.

3.3.2 Livelihood activities

Respondent households depended on a variety of livelihoods. The main livelihoods for households in the three villages are presented in Figure 3.1. For the purpose of this study, the main livelihood was an activity from which a household generally derived over 50% of its livelihood. However, there were five households where the main livelihood was 45 to 49% of the total, due to livelihood diversification. Among the surveyed households over 48% reported fishing as their main livelihood. In Kibuyuni village, 76% of the surveyed households derived their main livelihood from fishing, followed by 52% in Mkwiro whereas Gazi was the least fishing dependent community (31%). Whilst the majority of household members in Kibuyuni village depended mainly on fishing as their main source of livelihood, about 20% of residents in Gazi and Mkwiro were also dependent on small business and employment (Figure 3.1). In the small-scale business livelihood, members were involved in retail shops, mat making, catering, and transport services whereas the salaried jobs were mostly teachers, civil servants, and employees in the tourism and private industries. Hired labour was mainly in the farming and transport services. The rest of the household members had other main livelihoods such as mangrove pole production, pension and money transfer (remittances). Farming was a main livelihood to a few households in Kibuyuni and Gazi with none in Mkwiro. Subsistence farming was practised more in Kibuyuni where the traditional slash and burn agriculture was used and a majority of the households possessed farming tools (Table 3.4). The main food crops were maize, cassava, cowpeas, and millet.

No significant differences were apparent for household monthly income between female and male-headed households (Table 3.2) and among the villages (Table 3.3). The average total income per month for surveyed households was about Kshs. 9904 and varied from Kshs. 1200 to 57 600. The average monthly income classes for villages are presented in Figure 3.2. The majority (66.5%) of the households had a monthly income of less than Kshs. 10 000. More households in Gazi village had a monthly income of less than Kshs. 5000 and ≥ Kshs. 30 000 than Kibuyuni and Mkwiro villages (Figure 3.2), hence the higher standard error (Table 3.3).

Using the absolute rural poverty line of Kshs. 1239 per month per adult person (34), about 39%, 55% and 47% of the household members in Gazi, Kibuyuni and Mkwiro, respectively, lived below the rural poverty line (Table 3.3). The average poverty incidence was about 45% among the households surveyed, with more than half of households in Kibuyuni village living below the poverty line. However, no significant differences were apparent for the percentages of households living below the poverty line among the villages.

3.3.3 Household assets and amenities

The three villages exhibited strikingly different household assets and amenities. Table 3.4 provides data on assets and tools in the surveyed households. Land is of paramount importance in rural communities and most respondents in the villages cited lack of land as a problem. More than half of the surveyed households were squatters with the majority of them found in Gazi village while most of the landowners were from Kibuyuni and Mkwiro villages (Table 3.4). Among the land owners only 30% had title deeds while the rest had allocation letters. The land was acquired through inheritance from family members (50.6%), allocated by government and village councils (34.2%) or purchased from other villagers (15.2%). The surveyed households had chicken and goats. A few cows were observed in Gazi and Mkwiro villages. More households in Kibuyuni had chicken and goats than in the other villages (Table 3.4).

Fishing was the main source of livelihood for most of the villagers. However, the fisherfolk were engaged in artisanal fishing which was largely dependent on traditional fishing gears and equipment. The most popular fishing gears among the fisherfolk were handlines followed by fish traps (Table 3.4). The basket trap (*malema*) and the fence trap (*uzio*) were the most common fish traps. A significant portion of the households that engaged in fishing did not own boats as only 17.6% had small boats of less than one ton capacity and mostly non-mechanized. About 10% of the fisherfolk used gill nets. Destructive gears such as seine nets and ring nets were also observed at Gazi where there was a large number of fisherfolk from Pemba, Tanzania.

Figure 3.3 shows the skills prevalent in the surveyed households. The three commonly possessed skills were fishing, farming and business. Other skills included masonary, fish gear repairing and making, tailoring, mangrove cutting, quarrying and midwifery. Of the village households surveyed in Kibuyuni, over 90% had fishing and farming skills while over 60% of those in Mkwiro had fishing and business skills. There were more household members with business, cooking, teaching and weaving skills in Mkwiro village while driving skill was more prevalent in Gazi households (Figure 3.3).

The total number of skills per household varied among the villages with more skills in Kibuyuni (3.1) and Mkwiro (2.9) than in Gazi (2.2) ($p<0.05$). However, there were no significant differences in the total number of skills between the female-and male-headed households (Table 3.2).

Table 3.5 shows the types of houses and household amenities in Gazi, Kibuyuni and Gazi villages. A variety of houses was observed in the study areas. The Swahili houses hereby referred to as temporary structures had a thatched roof of *makuti* (coconut palm leaves) and walls made of mangrove poles placed close together and plastered with mud. The semi-permanent houses were roofed with *makuti* while the walls were made of coral stones and cement whereas the permanent types had stone walls with a roof made of iron sheets. Of the counted shelter structures, the majority of the temporary houses were in Kibuyuni village while most permanent houses were in Mkwiro village. The average number of rooms per house was 3.2. Among the surveyed 182 households, only about 40% houses had toilet facilities with over 57% of them recorded in Gazi village. In Kibuyuni village, the majority of the houses had no latrines (Table 3.5).

The majority of the households (more than 50%) had amenities such as a radio, lamp and beds (Table 3.5) whereas only a few of them (9-15%) owned basic amenities such as televisions or telephones. Some households possessed bicycles that were used as a means of transport particularly in Kibuyuni and Mkwiro where the roads were impassable by motor vehicles. A considerable proportion of households in Kibuyuni and Mkwiro had had jewellery which was sold to cope with shocks and stresses.

3.3.4 Shocks, stresses and coping strategies

According to the household semi-structured interviews and focal discussions with village elders, the following were identified as the most common stresses experienced by household members in the three villages: lack of land, food shortage, prevalence of diseases, fresh water shortage, wildlife menace, lack of livelihood opportunities, over-fishing and use of destructive fishing methods, low and fluctuating market price for agricultural and marine products, lack of credit facilities, and poor government services and facilities. During the study period, members of Kibuyuni and Mkwiro villages experienced two major shocks. In April, the month with the heaviest rainfall in the area, there was an outbreak of cholera and six villagers died while hundreds were hospitalised. Consequently, the government closed all the food stores and hotels for two months resulting in a major loss of livelihoods for the villagers. According to the local medical officers at Mkwiro and Kibuyuni, the outbreak of cholera was due to usage of untreated water from boreholes and underground tanks. However, according to the villagers, the disease was 'brought' to the villages by fisherfolk from Pemba. It appeared that due to lack of toilet facilities in the two villagers (see Table 3.5), most of the villagers use the forests as their natural toilets and hence the flowing rainwater swept their waste into the water reservoirs. Villagers from Kibuyuni and Mkwiro experienced another shock in September 2001 when a prominent politician 'grabbed' Kisite/Mpunguti Marine Reserve (the major fishing grounds for the fisherfolk) and sold it to a foreign business person. However, the illegal acquisition of the Islands was revoked by a presidential degree in 2002 (J. Kaleha, Warden of Kisite/Mpunguti Marine Park & Reserve, pers. comm.) after all the villagers threatened to relocate to Tanzania.

According to the household interviews, the villagers coped with stresses using various strategies (Table 3.6). Most of the household members saved money while about 79% borrowed money from family, relatives and friends. The money was mainly saved for food (during the hunger months of March-June), school fees, medical and wedding expenses. Other reasons given for saving money were: for buying boats, building houses and emergency cases such as deaths. About 68% of the household members saved money in boxes in the house while 17% saved in banks (Table 3.6). None of the households in Kibuyuni saved money in banks because most of their income was derived from fishery and agricultural products and was used mainly for food. This was unlike in Gazi and Mkwiro where some household's members derived their income from formal employment. Whilst fishing was the main livelihood in the villages, the majority (74%) of households depended upon two or more activities as a coping strategy. To cope with food shortages, households skip meals, sell assets and store food, among other strategies (Table 3.6). The availability of credit facilities in the villages was limited to two non-governmental organizations, one employer co-operative society and the 'merry-go-round' credit system (Table 3.6). According to the local fisheries officers all the fisheries co-operative societies in the area had collapsed due to corruption and mismanagement. Very few households in Kibuyuni and Mkwiro were members of the formal micro finance institutions, presumably due to poor transport infrastructure, among other reasons. However, a major portion of household members in Mkwiro belonged to a traditional 'merry-go-round' credit system. In this informal credit system, each member contributed Kshs. 100 every month and the total receipts is paid to one member in a rotational basis. To cope with diseases in the area most of the villagers attend hospitals though a considerable number of them visited traditional healers. Piped water was very scarce in the villages and the main source of drinking water was boreholes. At Mkwiro, large basins or underground tanks (*birika*) have been dug to store captured rainwater for domestic use.

3.4 Discussion

The study areas have a young population with more than three-quarters of the surveyed members being less than 30 years old. Based on the household census (364 households) established at the beginning of the study and an average household size of 6.2 members, the estimated population in the three villages was total 2244 people. However, this population is expected to increase at a growth rate of 2.6% per annum according to population growth projections for Kwale District (35). In this study, a higher proportion of economically active population was obtained than the combined youth and aged members (Table 3.3). This was contrary to the National Population and Housing Census held in August 1999 (35) which showed a higher number of both young children (0-14 years) and elderly people (65 years +). Differences in the results may be attributed to the concept of what is a household and on household selection, among other factors. The National Population and Housing Census selected households that were easily accessible and considered as household members only those living in the house, unlike in the current study where members living, cooking and eating together and sharing resources and tasks constituted a household, including students who were away. In this study, about 58.8% of the household members were productive (Table 3.3) representing a total population of about 1319 economically active members with a presumably higher number of females than males according to the measured female: male ratio of 1.2: 1. Both (35) and (36) reported a similar female: male ratio of 1.1: 1 for Kwale District and attributed the higher number of females to high migration of males to urban centres in search of employment.

In this study most households were composed of 6-7 members, a household size that was generally similar to the 5-6 members reported for Kwale District during the 1999 National Population and Housing Census (35). The average household sizes in Kibuyuni and Mkwiro were significantly higher than those in Gazi and apparently the majority of the households in the former villages were engaged in fishing (Figure 3.1). This situation suggests that households with more members presumably tended to take up fishing because they had access to more labour, a clear need for self-employment. A similar observation of households with more members engaging in fishing or fish culture in freshwater lakes has been reported in Zimbabwe (37).

The average total income of households was approximately Kshs. 9904 per month with the majority of households earning less than Kshs. 10 000 (Figure 3.2) (Kshs. 75=1US$). In the study sites, the average household monthly income was lower than the mean household monthly income of Kshs. 15 000 and Kshs. 39 000 reported by GOK (36) and HSEDCO (38), respectively, for villages in Kwale District. A monthly income ranging from Kshs. 500 to slightly over Kshs. 10 000 was reported for household heads in fishing communities including those in Gazi village (24). In another study, McClanahan and his colleagues (39) estimated that the net monthly income per fisher in southern Kenya was Kshs. 5900. The latter authors based their estimates on 24 fishing days per month and did not take into account the fish consumed in the fisherfolk's household. Deriving accurate monthly household income figures is complicated and data generated should be treated with caution (40). This is mainly because respondents lack bookkeeping or recording skills and cannot always recall figures accurately (24). Agricultural and marine products tend to either be under-or overestimated at market prices (31, 34, 38). Some informants consider such information as being very personal and are suspicious of taxation (17, 28). The gathering of household income data is also an extremely time consuming exercise (34). In this study, to obtain fairly accurate income figures, trust was established between the investigators and the household members in part due to a highly respected field assistant who was recruited as mentioned earlier. However, due to difficulties in quantifying the value of agricultural and fishery products as well as remittances, the total household income per month may have been underestimated. The seasonality in income was also not taken into consideration.

In the present study, the average monthly income were similar between the female and male headed households (Table 3.2). This was probably due to the fact that the household income was a sum from all members and not from the individual household head. However, the household size, number of working members, number of livelihood sources and skills in both the female and male-headed households were similar (Table 3.2). The main livelihood activity for the men was fishing. However, even women were observed to collect shellfish, sea cucumber, octopus and shells on the reef; prawns, oysters and crabs on mangrove bays for food and selling. Women were also involved in small businesses of frying fish, selling snacks to fisherfolk, making mats, caps and ropes using coconut leaves. They were also involved in farming activities, particularly those at Kibuyuni where the land was fertile and expansive. Probably, these diverse livelihood activities by the female members contributed to the similarity in the income levels between the male and female-headed households in the present study areas.

In the study area, 45.1% of the total households surveyed were living below the absolute rural poverty line. The percentage of household members living below the poverty line was similar to the national rural poverty of 46.4%, but lower than the Kwale District and Coast Provincial poverty values of 51.5%and 52.0%, respectively (34). The overall lower poverty level in the villages was probably due to several strategies (Table 3.5) adopted by households, among other reasons. However, although households in Kibuyuni had a larger number of working members and skills, they experienced a higher level of poverty (54.8%) than the regional (52.0) and national (46.4%) poverty levels. The high prevalence of poverty in Kibuyuni was manifested by the low numbers of modern and permanent houses (2.4%) and toilet facilities (14.3%) (Table 3.5). The high poverty level could probably be attributed to the household head's low education level (Table 3.1) and high household size (Table 3.3). Results from the third Welfare Monitoring Survey carried out by the Kenyan government showed that poverty among households increased as the head's level of education decreased and the situation was reversed when the level of education increased (34). The survey also demonstrated that households with a large number of members had higher rates of poverty.

Poverty among the Kenyan population including the coastal communities is increasing rapidly (41). Poverty reduction strategies and programmes must therefore target the coastal populations, including the poor fishing communities such as those in Gazi, Kibuyuni and Mkwiro villages. This could be achieved by promoting offshore fishing, artificial reef programmes and mariculture in southern Kenya (26, 42). Fishing in offshore waters deeper than 3 m beyond reef edge, should be encouraged by promoting the use of offshore fishing equipment by local fisherfolk (42). However, to undertake offshore fishing the fisherfolk need credit services or donor support to buy strong boats, engines and fishing nets. Credit facilities are not available to these groups and donor support may collapse due to corruption, mismanagement and lack of education as was evident in the USAID programme in Kibuyuni, Wasini and Mkwiro villages according to village elders in those areas. Artificial reef programmes are long term projects requiring huge investments and must be coupled with the introduction of other immediate forms of livelihood. These could come in the form of seafarming and land-based activities. Such a livelihood activity worth exploring is seaweed farming particularly because of its community-based orientation. Seaweed farming could help alleviate the poverty of these villages and help create employment opportunities.

Cultivation of seaweeds has been considered as an attractive source of livelihood for poor coastal communities in tropical countries (3). Numerous authors have suggested the introduction of *Eucheuma* and *Kappaphycus* farming in Kenya as an alternative source of livelihood for coastal communities in southern Kenya, including the present areas of study (22, 23, 26). Seaweed faming is a source of employment and income for fishing communities in Kiribati (21), Tanzania (2, 7, 19), Fiji (11) and the Philippines (1). Seaweed farming has created a lot of socio-economic changes to seaweed farmers due to increased monthly income. Income derived from seaweed farming showed an increased purchasing power of the basic needs (better housing, clothing, food, and education) and recreational needs. An improvement in the standard of living among the planters has been demonstrated through the purchase of video cassette players, radio cassettes, bicycles, better furniture and clothing, and livestock (2, 14). A shift from fishing to seaweed farming has also been reported and assumed to reduce fishing pressure in over fished waters, thereby permitting fishery resources to recover (4, 43).

Eucheumoid cultivation seems to have strengthened the position of women in society on the east coast of Zanzibar. Seaweed farming is mainly an activity carried out by women and children as they represent more than 90% of the seaweed farmers (2). Women are now able to contribute financially not only to their own well-being but also to the household needs as they earn income either equal or more than that of their husband from farmed seaweeds. There are also indications of women who are making use of their formal rights to divorce, when they are able to pay back the bride-wealth in this dominant Muslim community (14). Women are also selecting their future husbands without being dependent on their ability to support a family as is the tradition with the Muslim community. There are also speculations that families are more secure and stable with less divorcees than before the introduction of eucheumoid farming since women are independent economically (2, 19).

Among the surveyed villages, the Kibuyuni area appears to be a good site for seaweed farming because the average household size was large with a high percentage of economically active members (Table 3.3). The low educational levels also limited employment opportunities for villagers in Kibuyuni unlike in Mkwiro and Gazi where about 20% of the household heads had salaried jobs (Figure 3.1). The employment and small-scale businesses were essential components in the household economies in both Gazi and Mkwiro villages. According to Ask (4), commercial projects growing eucheumoids should have a farmer base of about 300 to 500 farmers. In Kibuyuni village, there were 344 productive residents (>15 and <65 years). The site also has expansive farmable areas, while results from an ongoing research at the site indicate that the seaweed material produced is of very high carrageenan quality (see Chapter 4). However, before commercial seaweed farming could be introduced in Kibuyuni, socio-economic factors such as the possibility of seasonality of livelihoods, particularly the subsistence agriculture and businesses should be investigated. Other factors to be taken into consideration if seaweed is to be introduced at chosen sites such as the Kibuyuni area are the availability of water space, seaweed buyers and favourable government policy for investment in mariculture. Conflicts for water space with other reef users, the setting up of marine reserves and allocation of coastal land for tourism (see Chapter 6) and growth rates (see Chapter 2) should also be given attention before establishing eucheumoid farms in Kenya.

In conclusion, the socio-economic survey in the three coastal villages revealed that the prevalence of poverty is high among fishing households in southern Kenya and poverty reduction strategies and new livelihood projects such as seaweed farming should be implemented to improve their welfare. However, plans of action should take into consideration the existing activities, assets and entitlements of communities to reinforce their livelihood strategies. More socio-economic surveys should also be conducted in other villages on the Kenyan coast to explore the factors likely to influence the adoption of projects and programmes for broadening their livelihoods.

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Table 3.1 Socio-cultural characteristics of household heads in three villages in southern Kenya.

Characteristic	Village Gazi N=80	 Kibuyuni N=42	 Mkwiro N=60	 Total N=182
Sex (%)				
Female	21.3	7.1	26.7	19.8
Male	78.7	92.9	73.3	80.2
Age (yr)*	43.7 (1.3)^a	42.0 (2.0)^a	43.3 (1.3)^a	43.2 (0.8)
Educational attainment (yr)*	6.0 (0.5)^a	3.6 (0.6)^b	5.3 (0.6)^a	5.2 (0.3)
Marital status (%)				
Divorced	8.7	4.8	10.0	8.2
Married	77.5	83.3	80.0	79.7
Never married	3.8	7.1	0.0	3.3
Widowed	10.0	4.8	10.0	8.8
Ethnic group (%)				
Digo	56.3	95.2	0.0	46.7
Shirazi	0.0	2.4	81.7	27.5
Pemba	10.0	2.4	5.0	6.6
Others	33.7	0.0	13.3	19.2
Religion (%)				
Christian	3.8	0.0	1.7	2.2
Islam	96.2	100.0	98.3	97.8
Cultural values (%)				
Accept family planning	15.0	19.1	5.0	12.6
Belief in witchcraft	61.2	85.7	8.3	49.5

*Data are mean with standard error in parentheses. Means with the same letter in each row are not significantly different at $p<0.05$.

Table 3.2 Socio-economic characteristics of household heads by gender in three villages in southern Kenya. Data are mean with standard error in parentheses. Means with the same letter in each row are not significantly different at $p<0.05$.

Characteristic	Female	Male
Sex (%)	20	80
Age (yr)	47.7 (9.5)^{a}	42.0 (11.2)^{b}
Educational attainment (yr)	2.5 (3.1)^{b}	5.9 (4.3)^{a}
Household size	6.6 (3.0)^{a}	6.1 (2.6)^{a}
Number of active members	4.3 (2.3)^{a}	3.5 (2.0)^{b}
Working members	2.2 (1.1)^{a}	2.2 (1.4)^{a}
Average monthly income (Kshs.)	8033 (1160)^{a}	10 365 (643)^{a}
Number of livelihood sources	2.1 (0.9)^{a}	2.0 (0.8)^{a}
Total assets	1.0 (1.0)^{b}	2.2 (1.6)^{a}
Number of skills	2.7 (1.1)^{a}	2.6 (1.2)^{a}

Table 3.3 Socio-economic characteristics of surveyed households in three villages in southern Kenya.

Characteristic	Village			
	Gazi N=80	Kibuyuni N=42	Mkwiro N=60	Total N=182
Sex (%)				
Female	49.4	50.7	60.2	53.8
Male	50.6	49.3	39.8	46.2
Age category (%)				
Children (0-14 yr)	41.2	34.1	39.5	38.8
Active members (15-64 yr)	57.4	62.3	57.9	58.8
Elderly members (65 yr +)	1.4	3.6	2.6	2.4
Young members (>30 yr)	74.9	78.6	76.0	76.2
Household size*	5.3 (0.3)[b]	6.6 (0.5)[a]	7.0 (0.3)[a]	6.2 (0.2)
Working members*	1.7 (0.1)[b]	3.3 (0.3)[a]	2.1 (0.1)[b]	2.2 (0.1)
Average monthly income (Kshs.)*	10 106 (1127)[a]	8534 (846)[a]	10 592 (805)[a]	9904 (595)
Poverty incidence (%)[c]	38.8	54.8	46.7	45.1

*Data are mean with standard error in parentheses. Means with the same letter in each row are not significantly different at $p<0.05$.

[c] Based on GOK (34) which pegged absolute rural poverty line at Kshs. 1239 per month per adult person in 2000.

Table 3.4 Ownership of productive household assets at three villages in southern Kenya.

	Village			
Asset	Gazi N=80	Kibuyuni N=42	Mkwiro N=60	Total N=182
Land tenure (%)				
Owner	10.0	73.8	66.7	43.4
Squatter	83.7	21.4	33.3	52.7
Tenant	6.3	4.8	0.0	3.9
Animals (%)				
Poultry	32.5	73.8	45.0	46.2
Goats	27.5	45.2	38.3	35.2
Tools/equipment (%)				
Farm tools	45.0	92.9	5.0	42.9
Boats	5.0	28.6	26.7	17.6
Fish traps	2.5	33.3	31.7	19.2
Handlines	15.0	59.5	30.0	30.2
Fish nets	7.5	14.3	10.0	9.9

Table 3.5 Shelter types and household amenities in three villages in southern Kenya.

	Village			
Shelter and	Gazi	Kibuyuni	Mkwiro	Total
amenity	N=80	N=42	N=60	N=182
House type (%)				
Permanent	25.0	2.4	38.3	24.2
Semi-permanent	36.3	23.8	38.3	34.1
Temporary	38.7	73.8	23.4	41.7
Toilet facility (%)				
Present	57.5	14.3	35.0	40.1
Absent	42.5	83.3	65.0	59.3
Missing data	0.0	2.4	0.0	0.6
Number of rooms*	3.2 (0.2)	2.9 (0.2)	3.3 (0.2)	3.2 (0.1)
Amenities (%)				
Radio	81.3	59.5	60.0	69.2
Television	21.3	4.8	8.3	13.2
Sewing machine	10.0	9.5	10.0	9.9
Lantern lamp	80.0	28.6	80.0	68.1
Tin lamp	87.5	100.0	78.3	87.4
Telephone	13.8	2.4	6.7	8.8
Carpented bed	90.0	38.1	81.7	75.3
Rope bed	30.0	85.7	63.3	53.9
Jewellery	10.0	40.5	36.67	25.8
Bicycle	32.5	26.2	10.0	23.6

*Data are mean with standard error in parentheses.

Table 3.6 Coping strategies by household members in three villages in southern Kenya.

Coping strategy (% of households)	Village			
	Gazi N=80	Kibuyuni N=42	Mkwiro N=60	Total N=182
Borrow money	62.5	95.2	90	79.1
Save money	87.5	88.1	76.7	84.1
Method of saving money				
Box	60.0	88.1	63.3	67.6
Bank	28.8	0.0	13.3	17.0
None	11.2	11.9	23.3	15.4
Livelihood diversification (more than one livelihood)	63.8	88.1	78.3	74.2
Sell assets	25.0	57.1	58.3	43.4
Skip meals	52.5	31.0	41.7	44.0
Store food	37.5	69.1	1.7	33.0
Membership in micro credit institution:				
Choice International	7.5	0.0	0.0	3.3
Cooperative society	5.0	0.0	3.3	3.3
Kenya Women Finance Trust	13.8	16.7	0.0	9.9
'Merry-go-round' credit system	7.5	9.5	58.3	24.7
Attend hospitals	92.5	76.19	93.3	89.0
Seek traditional healers	63.8	59.5	46.7	57.14

Figure captions

Figure 3.1 Main livelihood activities of surveyed households in Gazi (dark bar), Kibuyuni (stripped bar) and Mkwiro (white bar) villages, southern Kenya.

Figure 3.2 Average household income per month in Gazi (dark bar), Kibuyuni (stripped bar) and Mkwiro (white bar) villages, southern Kenya.

Figure 3.3 Skills of surveyed household members in Gazi (dark bar), Kibuyuni (stripped bar) and Mkwiro (white bar) villages, southern Kenya.

Figure 3.1 Wakibia

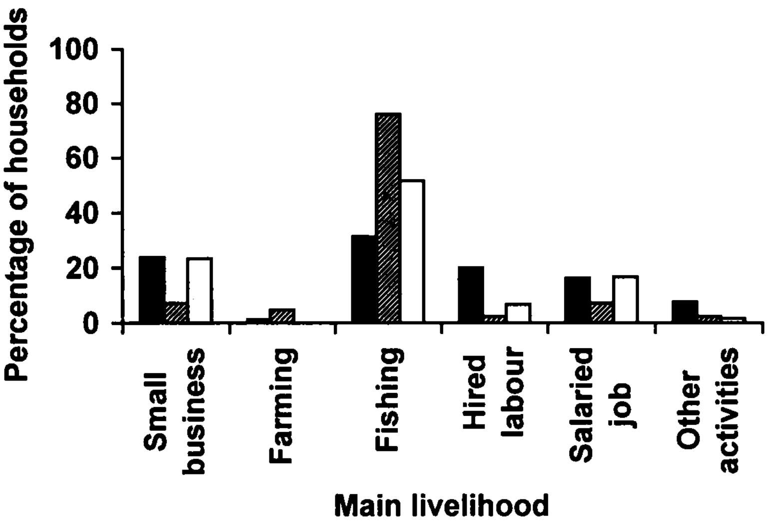


Figure 3.2 Wakibia

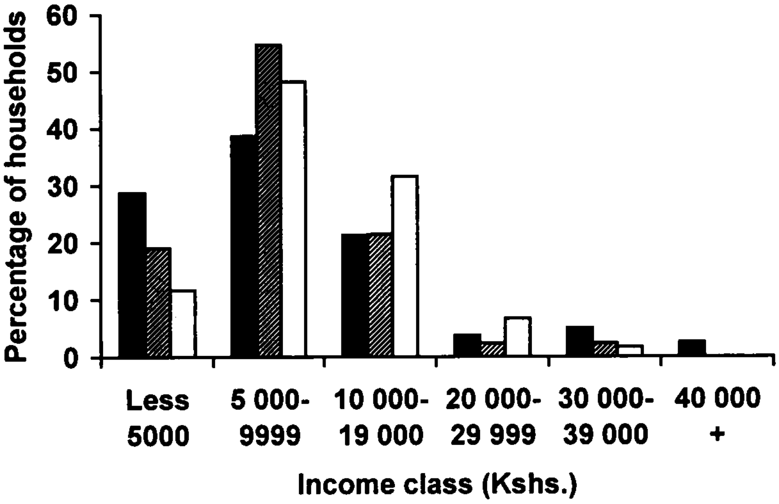
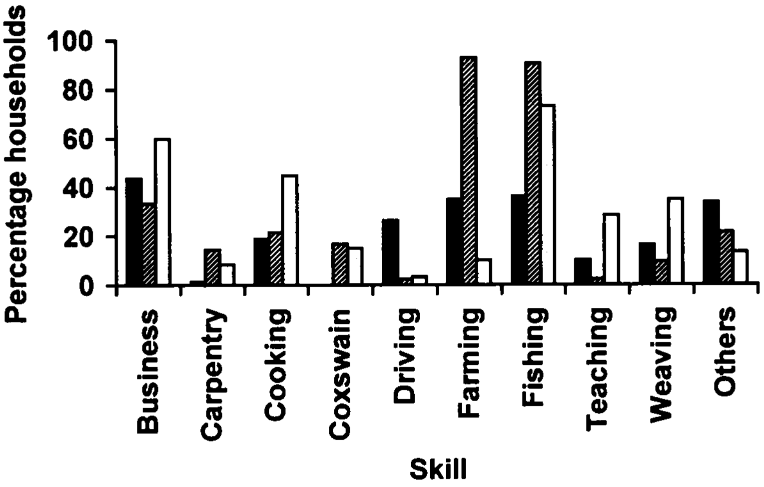


Figure 3.3 Wakibia



CHAPTER 4

CARRAGEENAN YIELD AND GEL PROPERTIES FROM THREE COMMERCIAL EUCHEUMOIDS GROWN IN SOUTHERN KENYA[4]

Abstract

Three commercial morphotypes (brown *Eucheuma denticulatum*, green and brown *Kappaphycus alvarezii*) were examined for carrageenan properties at three sites in southern Kenya, monthly for 12 months. The mean carrageenan yield was significantly higher for green *K. alvarezii* (59.1% dry wt) than both brown *E. denticulatum* (56.6% dry wt) and brown *K. alvarezii* (56.5% dry wt). Plants at Gazi (58.0% dry wt) had a significantly higher carrageenan yield than both those at Kibuyuni (57.1% dry wt) and Mkwiro (57.3% dry wt). However, the difference does not appear meaningful commercially. The carrageenan yields of brown *E. denticulatum* were inversely correlated with dry weights, and positively correlated with relative growth rates while in green *K. alvarezii*, the gel yields were inversely correlated with gel strengths, and positively correlated with viscosities and water motion. Both green and brown *K. alvarezii* exhibited higher gel strengths of 1042.1 g cm^{-2}and 1053.7 g cm^{-2}, respectively than brown *E. denticulatum* (100.8 g cm^{-2}). Plants at Kibuyuni showed higher gel strengths 783.0 g cm^{-2} than those at Gazi site (690.1 g cm^{-2}) while those at Mkwiro had intermediate values of 747.8 g cm^{-2}. In both green and brown *K. alvarezii*, the gel strengths were positively correlated with photon fluency rates while the gel strengths of brown *K. alvarezii* showed an inverse correlation with both the relative growth rates and percentage 'ice-ice' syndrome. The brown *E. denticulatum* had carrageenan with higher viscosity (81.7 mPa.s) and sulphate content (29.1% dry wt) than both green and brown *K. alvarezii*. The gel viscosities of all the morphotypes were higher during the southeast monsoon (67.3 mPa.s) than during the northeast monsoon (46.3 mPa.s) and were positively correlated with gel strengths. The differences in carrageenan properties among the morphotypes and sites are discussed. The results show that the three morphotypes produced carrageenans of commercial quality.

Key words: Carrageenan; yield; quality; sites; *Eucheuma*; *Kappaphycus*; Kenya.

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[4] Prepared in the format of the Journal: Botanica Marina

4.1 Introduction

Red seaweeds of the genera *Kappaphycus* and *Eucheuma* (commercial eucheumoids) are cultivated in tropical countries for the commercially important phycocolloid, carrageenan. Carrageenans are galactan polysaccharides in the cell wall of red seaweeds, providing structural support in response to water currents and wave action resulting in elasticity and rigidity of the plants (Kloareg and Quatrano 1988). Phycocolloids may also act as a fluid medium in which cells can slide past one another as they grow and divide (Craigie 1990). Carrageenans are sulphated polysaccharides with a common structural framework of alternatively 4-linked α-D-galactopyranosyl and 3-linked β-D-galactopyranosyl units (Anderson et al. 1968). There are several carrageenan types but only the κ-, λ-, ι- and β-carrageenans are available commercially (Craigie 1990, McHugh 2003). The naturally occurring κ- and ι-carrageenans contain μ- and ν-precursor residues, respectively, with 4-linked α-D-galactopyranosyl-6-sulphate or 2,6-disulphate units and alkali extraction is used to increase their gel strengths (Stanley 1990). Phycocolloids, also referred to as hydrocolloids due to their ability to dissolve in water, possess unique functional properties. The gel properties and viscosities of carrageenans from eucheumoids have made them commercially important as water binders, gellants, stabilizers, and thickeners in food, cosmetic, pharmaceutical, and textile industries (Stanley 1990). Carrageenans also have considerable potential in biotechnology, as well as microencapsulation and immobilisation of drugs and enzymes (McHugh 2003).

The carrageenan industry has a total market value of about US$ 300 million with an estimated increase in demand for carrageenan growing at 5% annually (McHugh 2003). This high demand for carrageenans in the world market has encouraged the introduction of commercial eucheumoid farming in several tropical countries (Doty 1987, Ask et al. 2003). Although the carrageenan industry's concern for eucheumoids is based on their hydrocolloids, the information on carragenan yield and quality from these plants is limited (Doty 1987, Ohno et al. 1996, Muñoz et al. 2004). The lack of information for carrageenan properties for the introduced commercial eucheumoids is even more marked. There are some published data on carrageenan characteristics of introduced eucheumoids in the subtropical waters of Japan (Ohno et al. 1994) and Brazil (Paula et al. 1999), and tropical waters of Vietnam (Ohno et al. 1996) and Mexico (Muñoz et al. 2004). However, these reports do not provide year-long data on carrageenan properties in these areas.

Commercial cultivation of the introduced cultivars of endemic eucheumoid is now well established in the West Indian Ocean and Central Pacific regions in areas such as Tanzania, Fiji Islands, Kiribati and Madagascar (Ask et al. 2003). However, to date, little has been published regarding the carrageenan properties of introduced eucheumoids in the Western Indian Ocean region; indeed, no such studies have been published on *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva. Except for the work of Braud and Perez (1978) on introduced *Eucheuma denticulatum* (as *Eucheuma spinosum*) (Burman) Collins & Hervey in Djibouti waters, most of the studies performed on carrageenan properties in the region are from naturally growing *E. denticulatum* and *Kappaphycus striatus* (F. Schmitz) Doty ex P.C. Silva in Tanzania (Buriyo et al. 2001) and Madagascar (Mollion and Braud 1993). The influence of local environmental factors on carrageenan yield and quality from these introduced eucheumoids is not known or inadequately documented. Such information is useful in siting eucheumoids farms to yield the best quality carrageenan (Ohno et al. 1996). It has been reported that the chemical and physical properties of carrageenans from eucheumoids vary with species and morphotypes (Trono and Lluisma 1992, Hurtado-Ponce, 1995), season (Trono and Lluisma 1992, Buriyo et al., 2001), physiological state (Trono and Lluisma 1992; Mendozoa et al. 2002), life history (Paula et al. 1999), environmental factors (Azanza-Corrales and Sa-a 1990, Li et al., 1990), and methods of extraction (Dawes et al. 1977). Ohno et al. (1996) also observed differences in carrageenan properties from *K. alvarezii* grown in different sites in Vietnam.

As there is an ongoing research project investigating the feasibility of eucheumoid cultivation in southern Kenya (Chapter 2), it is apparent that attention should be given to the chemical nature of the cultivated material. This study was conducted to determine the carrageenan yield and quality of three commercial eucheumoids grown at three sites with different environmental conditions (see Chapter 2). The carrageenan quality factors measured were gel strength, viscosity and sulphate content because they are important in food and non-food industries. The purpose of the study was to provide information on carrageenan properties of the cultivated material to assess their commercial potential.

4.2 Materials and methods

4.2.1 Collection and drying of seaweed materials

Samples of three morphotypes (brown and green *Kappaphycus alvarezii* and brown *Eucheuma denticulatum*), each weighing about one kilogram (wet weight) were collected monthly for 12 months from the harvested material at study sites in southern Kenya (see Chapter 2). Three samples (20.0 g each) of fresh seaweed for each morphotype were rinsed with seawater, blotted dry and oven dried at 60°C to constant weight to determine dry wt (% fresh algal weight). The remaining plant material was sun-dried for three days, oven dried at 45°C to constant weight and stored in polythene bags for nitrogen and phosphorus tissue analysis (data presented in Chapter 2) and carrageenan analysis. For carrageenan analysis, the stored algal samples were thoroughly washed and cleaned with tap water to remove salt, sand, epiphytes and other impurities, and oven dried at 60°C for 24 h.

4.2.2 Carrageenan extraction

Prior to carrageenan analyses the chopped seaweeds were redried to a constant weight at 60°C and cooled in a desiccator over silica gel. The techniques for carrageenan extraction and analysis in this study were developed in association with Drs H.J. Bixler (Ingredients Solutions, Inc., Searsport, USA) and D.J. Stancioff (FMC BioPolymer, Philadelphia, USA). A preliminary study was carried out to determine the best duration of extraction for each species by using the following extraction time: 3, 8, 13, 18 and 23 h. The preliminary results showed that extraction for 18 h and 8 h produced relatively high carrageenan yield and gel strength values for *K. alvarezii* and *E. denticulatum* morphotypes, respectively than the other extraction time, hence these extraction times were used in this study. To evaluate the commercial value of the grown plant material, the extraction was performed using alkaline pretreatment.

Carrageenan extraction was done by soaking 20.0 g of the chopped seaweeds to 700 ml of hot distilled water in a 2-l stainless steel beaker and adding 4 g of calcium hydroxide (Ca $(OH)_2$). The mixture was heated with mild agitation in a water bath (95 ± 2°C) for 30 min, blended to a paste and 300 ml of hot water added to the mixture. The paste was then thoroughly mixed with a magnetic stirrer. The steel beaker was capped with aluminium foil (to reduce evaporation) and placed in a water bath (95 ± 2°C) for 8 h and 18 h for *E. denticulatum* and *K. alvarezii* samples, respectively. To each of the hot mixtures, 20.0 g Celite 545 was added and stirred for 30 min, and the hot slurry pressure filtered through Whatman filter paper # 2 in a preheated stainless steel pressure filter holder (Sartorius GmbH, Goettingen, Germany). The residue was then removed from the filter paper, placed in 200 ml boiling distilled water and pressure filtered as above. The resulting hot filtrate was adjusted to pH 8.5 ± 0.5 with diluted reagent grade HCL (w/v, 10%). The filtrate was poured into two litres of 99% reagent grade isopropanol in a steady stream while stirring the alcohol gently until the carrageenan coagulum had completely formed and hardened as much as possible. The coagulum was drained on a 100 mesh sieve, squeezed and kneaded to remove as much liquid as possible. The coagulum was spread out in a glass Petri dish to allow alcohol evaporate in a ventilated fume chamber for an hour. The coagulum was oven-dried at 60°C to constant weight, cooled in a desiccator over silica gel and weighed to calculate carrageenan yield (% algal dry wt). The dried carrageenan was then ground to a powder using a Wiley mill (40 mesh size), placed in a bottle with a lid and stored in a dry place (2 months) for carrageenan quality analysis. Each sample was extracted in duplicate for carrageenan yield determinations.

4.2.3 Carrageenan quality analysis

The physical properties (gel strength and viscosity) were determined in duplicate using a 1.5% gel carrageenan in 0.2% potassium chloride (KCL). Water gel of the carrageenan was made up using 1.5 g extract, 0.2 g KCL, and 100 ml of deionised water. The mixture was weighed and heated in a boiling water bath with constant stirring until the carrageenan was dissolved (30 min). The solution was maintained at 80°C for 10 min. The volume was adjusted to initial weight using hot deionised water followed by stirring to incorporate the added water. The hot gel was poured into a crystallizing dish (70 x 50 mm) and allowed to stand for 20 min at room temperature (25°C). The crystallizing dish was covered with a plastic film and allowed to gel overnight in a10°C incubator. The resulting gel was inverted in the crystallizing dish to expose the fresh surface of the gel to the gel testing plunger. The gel strength was determined (g cm^{-2}) in duplicate, with a laboratory made apparatus that measures the force required to break the gel surface. The apparatus consists of 1 cm^{-2} stainless steel cylindrical probe connected to a motor drive and, a Sartorius balance (BP 4100) attached to a PC with Winwedge ® version 1.2 software (Wakibia et al. 2001). Viscosity was determined by soaking 9.0 g of the extract in 600 ml of 0.2% KCL. The solution was allowed to cool and at 75°C, viscosity was measured (mPa.s) with a Brookfield DV-II viscometer (Brookfield Engineering Labs. Inc., Middleboro) using the spindle No.1 at 30 rpm. For purposes of comparison (reference), gel strength and viscosity measurements were made of a 1.5% gel containing 0.2% KCL prepared from commercial samples (Sigma): κ-carrageenan (Lot No. 41K1413) and ι-carrageenan (Lot No. 41K1424).

The sulphate content of the carrageenan extract was determined by digesting 0.5 g of each sample with concentrated nitric acid. After the hydrolysis, the sample was diluted to 50 ml. The sulphur concentration was determined with a Varian Vista-MPX ICP Spectrometer. Percentage sulphur was then converted into percentage sulphate. The sulphur analysis was carried out by Bemlab (Somerset West, South Africa). The study was performed from October 2001 to October 2002. However, due to logistical problems it was not possible to collect samples at Mkwiro from May to July, and July at Kibuyuni.

4.2.4 Statistical analysis

The carrageenan properties (gel strength, viscosity and sulphate content) of the carrageenan measured in the present study were compared with environmental and seaweed factors (see table 4.3) that were determined in a previous study (see Chapter 2.2.5). Data analyses were made by General Linear Model Procedures (GLM) followed by determining differences among individual mean values by Least Significant Difference (LSD) test at $p<0.05$. Pearson's product moment correlation test was used to determine the linear relationship between treatments. Statistical analyses were performed using the SAS Program (SAS, 1999).

4.3 Results

4.3.1 Carrageenan yield

The monthly variations in carrageenan yields of three eucheumoid morphotypes at three sites are presented in Figure 4.1. The monthly average carrageenan yield varied between 49% and 63% dry wt. Although no regular seasonal pattern in carrageenan yield was observed, a decrease in carrageenan content in April and increase from August was evident for the morphotypes (Figure 4.1). The carrageenan yield was higher for the green morphotype of *K. alvarezii* than for both brown *E. denticulatum* and brown *K. alvarezii* (Table 4.1). There were also significant differences ($p<0.05$) in dry wt among the three morphotypes and at the three sites. The brown *E. denticulatum* showed the highest dry weight while the brown *K. alvarezii* had the lowest value (Table 4.1). The highest dry wt was obtained from plants at Kibuyuni while those at Gazi had the lowest dry wt (Table 4.2). On the contrary, Gazi plants had the highest carrageenan yields with those at Kibuyuni having the lowest values (Table 4.2). There were significant differences in carrageenan yields between the two morphotypes of *K. alvarezii* with the green morphotypes having higher yield values than the brown morphotype (Table 4.1). The three morphotypes showed no difference in carrageenan yields between the northeast monsoon (NEM, 57% of dry wt) and southeast monsoon (SEM, 57% of dry wt).

4.3.2 Carrageenan quality properties

The monthly average carrageenan gel strengths of the three eucheumoid morphotypes are shown in Figure 4.2. The gel strengths for the brown *E. denticulatum* varied from 80 to 130 g cm^{-2}) while those of both *K. alvarezii* morphotypes generally varied from 600 to 1400 g cm^{-2} with the exception of the extremely low gel strength of about 200 g cm^{-2} recorded in November and December for both green and brown *K. alvarezii* at Kibuyuni and Mkwiro sites (Figure 4.2). The gel strengths of carrageenans differed among the morphotypes and sites. Both green and brown morphotypes of *K. alvarezii* exhibited significantly higher gel strengths than the brown morphotype of *E. denticulatum* (Table 4.1). However, the gel strengths of the two *K. alvarezii* morphotypes were similar. Plants at Kibuyuni site showed higher gel strengths than those at Gazi (Table 4.2). The three morphotypes showed similar gel strengths of carrageenans between the SEM (764 g cm^{-2}) and NEM (724 g cm^{-2}).

Gel viscosities of carrageenans varied among species but not between sites (Tables 4.1, 4.2). The brown *E. denticulatum* had carrageenan with significantly higher viscosity ($p<0.05$) than both green and brown *K. alvarezii* (Table 4.1). The carrageenan viscosities of the three morphotypes varied significantly between the seasons, with higher values ($p<0.05$) during the SEM (67.3 ± 5.3 mPa.s) than during the NEM (46.3 ± 4.4 mPa.s). Significant differences in monthly average sulphate contents of carrageenans were exhibited in the three morphotypes. Among the three morphotypes, brown *E. denticulatum* recorded the highest sulphate content with the lowest mean value in green *K. alvarezii* (Table 4.1). However, the three morphotypes showed similar sulphate contents among the three sites and between the two seasons. The 1.5% gel solution under the laboratory conditions provided the following gel properties: gel strengths for commercial κ-and ι-carrageenans from Sigma Chemicals Co. (St. Louis, U.S.A) were 1600.1 ± 56.6 and 82.8 ± 5.7 g cm^{-2}, respectively, and viscosities were 61.4 ± 4.9 and 54.3 ± 4.2 mPa.s for κ-and ι-carrageenans, respectively.

4.3.3 Correlations

Table 4.3 shows the correlation coefficients of carrageenan yield (% algal dry wt) of three morphotypes with environmental factors, seaweed parameters, and carrageenan quality factors. Among the environmental factors, water motion showed positive correlation with carrageenan yield from green *K. alvarezii*. In brown *E. denticulatum*, the carrageenan yields were inversely correlated with dry wt levels, and positively correlated with relative growth rates ($p<0.05$, Table 4.3). In green *K. alvarezii*, the carrageenan yields were inversely correlated with gel strengths, and positively correlated with viscosities ($p<0.05$, Table 4.3).

Table 4.4 presents the correlation coefficients between gel strengths of carrageenans of three morphotypes and environmental, seaweed, and carrageenan quality factors. In both the green and brown morphotypes of *K. alvarezii*, the gel strengths were positively correlated with photon fluency. The gel strengths of brown *K. alvarezii* showed an inverse correlation with both the relative growth rates and percentage 'ice-ice' syndrome ($p<0.05$, Table 4.4). In the three morphotypes, the viscosities were positively correlated with gel strengths ($p<0.01$, Table 4.4). The gel viscosity values of both brown *E. denticulatum* and green *K. alvarezii* were inversely correlated with water temperatures ($r=-0.365$ and $r=-0.441$, $p<0.05$, respectively). However, the carrageenan gel strengths from the three morphotypes showed no significant correlations with the sulphate contents (Table 4.4).

4.4 Discussion

4.4.1 Carrageenan yield

The production of carrageenans by eucheumoids varies with species and morphotypes, as well as other factors. A wide range of carrageenan yields from *Eucheuma* and *Kappaphycus* species are reported by several authors (Dawes et al. 1977, Doty 1987, Azanza-Corrales and Sa-a 1990, Muñoz et al. 2004). In the present study, the average monthly carrageenan yields from brown *E. denticulatum*, brown and green *K. alvarezii* varied from about 49 to 63% dry wt (Figure 4.1). These yields were higher than those obtained for *K. alvarezii* morphotypes (8 to 12%) in the Philippines (Hurtado-Ponce 1995), but lower than 47-80% of Floridian *Eucheuma* species (Dawes et al. 1977). Muñoz et al. (2004) obtained 30-41% carrageenan yield for red, green and brown morphotypes of *K. alvarezii* in Mexico. The carrageenan yields obtained in the present work were similar to gel values of eucheumoids grown in the Philippines (Trono and Lluisma 1992), Vietnam (Ohno et al. 1996), China (Li et al. 1990) and Brazil (Paula et al. 1999). Buriyo et al. (2001) reported a range of 44-59% of carrageenan yields from natural stocks of *E. denticulatum* in Tanzania. The green morphotype of *K. alvarezii* had a higher carrageenan yield than the brown *K. alvarezii* (Table 4.1) as similarly observed by Trono and Lluisma (1992). Conversely, Hurtado-Ponce (1995) obtained higher carrageenan yields for brown morphotypes of *K. alvarezii* than the green morphotypes, whereas Muñoz et al. (2004) found no significant differences among three *K. alvarezii* morphotypes.

Although no seasonal pattern was evident to distinguish carrageenan levels between the NEM (October-March) and the SEM (April-September), there was a general gel yield increase from July to September (Figure 4.1), corresponding to the period of high relative growth rate (see Chapter 2). In brown *E. denticulatum*, the carrageenan yield was positively correlated with relative growth rate (Table 4.3). Similar increased phycocolloid content with increasing growth rates have been obtained in eucheumoids (Li et al. 1990, Trono and Lluisma 1992) and other commercial *Gelidium* species (Carter and Anderson 1986, Mouradi-Givernaud et al. 1992) and *Gracilaria* species (Oyieke 1993). Conversely, numerous authors have reported an inverse relationship between phycocolloid yields and growth rates in several agarophytes and carrageenophytes (Dawes et al. 1974, Bird et al. 1981, Guist et al. 1982). It has been suggested that during the active growth of algae, sufficient nitrogen levels promote the synthesis of proteins and protoplasmic constituents at the expense of deposition of cell wall materials, including phycocolloids (Fogg 1964, Dawes et al. 1974). However, reduced phycocolloids may also be due to carbon limitation as plants in most culture systems grow under suboptimal inorganic carbon availability (Moseley, 1990). Thus, if both nitrogen and carbon are in sufficient supply, it may be possible to have seaweeds with both high growth and phycocolloid levels as was observed in the field culture of *K. alvarezii* by Li et al. (1990) and in this study at Gazi site.

Results obtained from this investigation showed significant differences in carrageenan yields and dry wt values among the three sites, with the highest gel yields observed in Gazi plants and the lowest in Kibuyuni plants while the dry wt values were reversed (Table 4.2). The phycocolloid yields in seaweeds have been reported to vary with sites (Wang and Yang 1980, Ohno et al. 1996, Oliveira et al. 1996, Zinoun and Cosson 1996). On the Normandy coast (France), *Calliblepharis jubata* (Goodenough & Woodward) Kützing plants collected in West Cotentin had a higher carrageenan yield (52%) than those from North Cotentin (36%), the difference being attributed to different temperatures and turbidity of water (Zinoun and Cosson 1996). Length of sunshine in various locations was considered to affect the agar yields extracted from *Gracilaria* species cultivated in Taiwanese ponds (Wang and Yang 1980). Oliveira et al. (1996) obtained higher agar yields of Brazilian *Pterocladia capillacea* (S.G. Gmelin) Santelices &Hommersand from an exposed site (22.4% dry wt) than a sheltered one (18.8% dry wt) and attributed the agar differences to turbulent waters. In the present study, it appears that the variation in carrageenan yields among the sites was probably due to differences in water movement. In Vietnam, Ohno et al. (1996) obtained higher carrageenan yield for *K. alvarezii* plants grown in offshore waters (53.2%) than those in lagoons (51.9%,) and ponds (47.1%). Although no data on water motion were provided, these authors reported that the offshore cultivation area had a strong water current. In the current study, higher water motion was measured at Gazi than Kibuyuni (see Chapter 2) and consequently, the plants at Gazi could have adapted to the strong water environment by synthesising additional structural cell wall polysaccharides. Hence an increase in carrageenan yield in Gazi plants than those in other sites. Oliveira et al. (1996) suggested that *Pterocladia capillacea* plants growing in exposed areas invested in agar deposition between cell walls to withstand turbulent waters. Phycocolloids are structural cell wall polysaccharides that provide structural support in response to water currents and wave action in seaweeds (Kloareg and Quatrano 1988). However, strong water currents at Gazi could also have provided sufficient carbon and nitrogen to support high relative growth rates and high carrageenan yields.

During the study period, the lowest carrageenan levels were obtained in Kibuyuni from October to December, particularly for brown *E. denticulatum* and green *K. alvarezii* (Figure 4.1), a period of low relative growth rates as plants were affected by the 'ice-ice' syndrome (Chapter 2, Figure 2.2). Similar low carrageenan yields due to ice-iced plants have been reported for commercial eucheumoids in the Philippines (Trono and Lluisma 1992, Mendoza et al. 2002). On the other side, plants at Kibuyuni had the highest dry wt compared with those at both Gazi and Mkwiro (Table 4.2). The carrageenan content in the brown *E. denticulatum* was inversely correlated with the dry weight (Table 4.3) suggesting that carrageenan synthesis occurred at the expense of dry matter production. A similar relationship has been observed in *Gelidium spinosum* (S.G. Gmelin) P.C. Silva (as *G. latifolium*) (Mouradi-Givernaud et al., 1992).

4.4.2 Carrageenan quality

Kappaphycus plant produces kappa carrageenan while *Eucheuma* plant produces iota carrageenan. The former is harder than the latter. Gel strength is one of the important indices of carrageenan quality. *Kappaphycus* and *Eucheuma* species generally produce carrageenans with gel strengths of about 1000 g cm^{-2} and 100 g cm^{-2}, respectively (Santos 1989). The gel strengths obtained in the present study are within these ranges but lower than those reported for *K. alvarezii* grown in Japanese (Ohno et al. 1994) and

Vietnamese waters (Ohno et al. 1996). Higher gel strengths were obtained in the present study compared to those reported for eucheumoids in China (Li et al. 1990), Tanzania (Buriyo et al. 2001) and the Philippines (Azanza-Corales and Sa-a 1990, Hurtado-Ponce 1995). There was no significant difference in the gel strength of carrageenans between the brown and green morphotypes of *K. alvarezii* as similarly observed by Azanza-Corrales and Sa-a (1990). In contrast to the above observations, however, a higher gel strength was obtained for the green *K. alvarezii* than the brown counterpart by Hurtado-Ponce (1995). The higher gel strengths obtained in the present study may be attributed to the strong alkali used (20% of the weight of the 20 g of seaweed) and the long duration of extraction.

The gel strengths for the eucheumoid morphotypes showed variation among the sites, with the highest values observed in plants at Kibuyuni and those at Gazi having the lowest values (Table 4.2). This difference may be due to the site characteristics such as the photon fluency rates. The photon fluency rates were significantly higher at Kibuyuni (1254 μmol photon m^{-2} s^{-1}) than at Gazi (1042 μmol photon m^{-2} s^{-1}) (Chapter 2). In both brown and green morphotypes of *K. alvarezii*, the gel strengths were positively correlated to photon fluency (Table 4.4). Wang & Yang (1980) also observed that the location and sunlight affected the gel strengths of agars from *Gracilaria* species cultivated in Taiwan, with areas experiencing more sunlight producing gels with high gel strengths.

It has been suggested that algae cultivated under growth-promoting conditions synthesise high concentrations of polysaccharide precursors which form strong gels on alkali treatment (Craigie and Wen 1984, Lahaye and Yaphe 1988). The gel strength of carrageenan from brown *K. alvarezii* was inversely correlated with relative growth rate (Table 4.4), indicating that the slow growing plants at Kibuyuni had higher gel strengths than the fast growing plants at Gazi. Thus the current model of biosynthesis of sulphated polysaccharides in red algae relating strong gels to alkali treatment of actively growing tissues (Craigie and Wen 1984, Lahaye and Yaphe 1988), cannot explain the gel strength difference between these sites. Christiaen et al. (1987) related the gel strength of agar in *Gracilaria* to cell growth and showed that high agar quality was obtained from plants growing under adverse winter conditions. Similarly, Cancino et al. (1987) reported that slow growing *Gracilaria gracilis* (as *G. verrucosa*) plants with a high a degree of epiphytism produced stronger gels than those with few epiphytes. With respect to the present study, low growth rates of eucheumoids were recorded at Kibuyuni where adverse conditions such as 'ice-ice' syndrome and epiphytes were observed. The interaction of epiphytism and 'ice-ice' syndrome may probably explain the higher gel strength for Kibuyuni plants. An inverse relationship was found between carrageenan yield and gel strength in green *K. alvarezii* (Table 4.3), presumably to save energy required for adaptation to these extreme conditions by reducing carrageenan production. *Eucheuma* plants have been shown to use energy for hydrogen peroxide production to keep their surface clean of epiphytes and pathogens (Collen et al. 1995). Increased gel strength has also been reported in *Gracilaria* species as a means of resisting pathogens (Lahaye and Yaphe 1988).

High sulphate content is usually associated with phycocolloids of low gel strength (Anderson et al. 1968, Craigie 1990). The morphotype with the highest sulphate content of carrageenan was *E. denticulatum* which also had the lowest gel strength. There was a significant difference in the sulphate content between brown and green *K. alvarezii* but no differences in gel strengths (Table 4.1). However, Hurtado-Ponce (1995) found higher gel strength in carrageenans from the green morphotype *K. alvarezii* with low sulphate content, whereas that of the brown *K. alvarezii* had higher sulphate with lower gel strength. Lower sulphate contents were measured than those reported by Azanza-Corrales and Sa-a (1990) for *E. denticulatum* morphotypes (34-50%) and *K. alvarezii* morphotypes (28-39%), probably due to the strong alkali used in the present study.

The formation of gels is reported to involve a coil-helix transition of the gel molecules, followed by aggregation and network formation (Morris et al. 1980). According to Rees (1969), sulphates in the cell wall polysaccharide cause kinks in the helical structure responsible for gel formation resulting in phycocolloid of lower gel strength. An inverse relationship was observed between carrageenan sulphate content and gel strength for morphotypes of *K. alvarezii* (Hurtado-Ponce 1995). On the contrary, no significant relationship was observed between sulphate content and gel strength in the present investigation as also observed by Azanza-Corrales and Sa-a (1990) for *Eucheuma* and *Kappaphycus* morphotypes. Similarly, Mouradi-Givernaud et al. (1992) did not find any significant correlation between sulphate and gel strength in *Gelidium spinosum*. It appears that other factors rather than sulphate content probably play a role in gel formation as evident in this study where a significant difference in sulphate contents between the brown and green *K. alvarezii* did not result in different gel strengths (Table 4.1). The lack of firm relationships between sulphate content and gel strength may probably be due to the complex nature of the cell wall polysaccharides. It has been suggested that the length of phycocolloids may be related to the gel strength, with longer chains interacting with each other to form gels of higher strengths and reverse for shorter chains (Mouradi-Givernaud et al. 1992, Mendoza et al. 2002).

The viscosity values for carrageenans extracted from the brown *E. denticulatum* were higher than those found from both the brown and green *K. alvarezii* (Table 4.1). The higher viscosity in carrageenan from *E. denticulatum* may be due to its higher sulphate (Dawes et al. 1977). In the present study, higher viscosities were measured for *K. alvarezii* morphotypes than for *K. alvarezii* morphotypes grown in the Philippines (Hurtado-Ponce 1995) but lower than for *K. alvarezii* morphotypes grown in Mexico (Muñoz et al. 2004), Japan (Ohno et al. 1994) and the Philippines (Azanza-Corrales and Sa-a 1990). There was no significant difference in the viscosity of carrageenan between the brown and the green morphotypes of *K. alvarezii* as similarly observed by Azanza-Corrales and Sa-a (1990) and Muñoz et al. (2004).

In this work, positive correlations were observed between gel strengths and viscosities in the three eucheumoids (Table 4.4). Both the carrageenan from *Gymnogongrus griffithsiae* (Turner) Martius (Breden and Bird 1994) and agar from *G. spinosum* (Mouradi-Givernaud et al. 1992) showed similar patterns. In contrast to these observations, an inverse relationship between gel strength and viscosity was observed for three members of the family Cystocloniaceae (Cosson et al. 1990) and *Gigartina teedei* (Roth) Lamouroux (Zinoun et al. 1993). The difference in the relationships may be due to the type of carrageenans and their molecular weights, among other factors (Stanley, 1990). Mendoza et al. (2002) observed low gel strength and viscosity of 'ice-ice' infected carrageenans due to its low molecular weight. In the present investigation, similar low gel strengths were observed at Kibuyuni during the October-December period when plants were infected with 'ice-ice' syndrome (Figure 4.2). A negative relationship was obtained between viscosity and the 'ice-ice' syndrome (see Table 4.3). Gel viscosities were also inversely correlated with water temperature (as aforementioned in the results), and were higher during the southeast monsoon than during the northeast monsoon. These results corroborated findings of Braud and Perez (1978) which indicated higher viscosity of carrageenan of *E. denticulatum* during the cold season in Djibouti waters.

The gel strength and viscosity of phycocolloids depend on the method of extraction, the measurement device, and concentration of the gels, as well as growth conditions and other factors (Levy et al. 1990, Stanley, 1990). For reference purposes, it has been suggested that the quality of gel extract should be compared to a standard commercial gel in order to relate its quality to a standard product (Levy et al. 1990). The carrageenans extracted from the three morphotypes in the present study, showed that the gel strengths and viscosities were comparable to the Sigma commercial carrageenans (see results). All the three carrageenan extracts had sulphate levels which fit the US Food and Drug Administration purity standard of 20-40% (dry wt) and meet the industrial requirements of minimum carrageenan yield and viscosity value of 39% (dry wt) and 5 mPa.s, respectively (Bixler, 1996). From the growth data (Chapter 2), socio-economic information (Chapter 3) and carrageenan data presented here, eucheumoid cultivation in Kenya appears feasible and could be a source of livelihoods for the coastal communities. However, information on economics of eucheumoid cultivation is needed before commercial farms are established. Attention should also be given to site selection particularly if high quality carrageenans are required.

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Table 4.1 Carrageenan properties and dry weight (% algal fresh wt) of three commercial eucheumoids grown in southern Kenya (mean ± SE, n=35-93). Means with the same letter in each row are not significantly different at $p<0.05$.

Parameter	Brown *E. denticulatum*	Brown *K. alvarezii*	Green *K. alvarezii*
Yield (% algal dry wt)	56.6 ± 0.3^b	56.5 ± 0.3^b	59.1 ± 0.4^a
Gel strength (g cm^{-2})	100.8 ± 1.8^b	1053.7 ± 36.0^a	1042.1 ± 39.0^a
Viscosity (mPa.s)	81.7 ± 7.7^a	40.0 ± 3.3^b	46.0 ± 3.9^b
Sulphate (% gel dry wt)	29.1 ± 0.4^a	26.5 ± 0.5^b	20.9 ± 0.2^c
Dry wt (% algal fresh wt)	11.5 ± 0.1^a	9.0 ± 0.1^c	9.6 ± 0.1^b

Table 4.2 Carrageenan properties and dry weight (% algal fresh wt) of eucheumoids grown at three sites in southern Kenya (mean ± SE, n=35-93). Means with the same letter in each row are not significantly different at $p<0.05$.

Carrageenan parameter	Gazi	Kibuyuni	Mkwiro
Yield (% algal dry wt)	58.0 ± 0.35^{a}	57.1 ± 0.35^{b}	57.3 ± 0.36^{b}
Gel strength (g cm^{-2})	690.1 ± 52.2^{b}	783.0 ± 66.2^{a}	747.8 ± 70.6^{ab}
Viscosity (mPa.s)	55.3 ± 5.9^{a}	53.7 ± 5.6^{a}	57.8 ± 7.2^{a}
Sulphate (% gel dry wt)	25.4 ± 0.7^{a}	25.4 ± 0.7^{a}	25.5 ± 0.7^{a}
Dry wt (% algal fresh wt)	9.0 ± 0.1^{c}	10.7 ± 0.1^{a}	10.0 ± 0.2^{b}

Table 4.3 Correlation coefficients of carrageenan yield (% algal dry wt) of three morphotypes with environmental, seaweed, and carrageenan quality factors in southern Kenya.

Factor	Brown *E. denticulatum*	Brown *K. alvarezii*	Green *K. alvarezii*
Environmental factor			
Water temperature (^{o}C)	0.078	0.038	0.055
Water motion (diffusion factor)	0.300	0.016	0.408*
Salinity (‰)	-0.329	0.097	0.045
Photon fluency (µmol photon m^{-2} s^{-1})	-0.270	-0.451	-0.242
Seaweed factor			
Relative growth rate (% d^{-1})	0.361*	0.203	0.067
Dry weight (% algal fresh wt)	-0.506**	-0.083	-0.159
Thallus N (% of dry wt)	0.151	0.067	0.130
Thallus P (% of dry wt)	-0.183	-0.237	0.170
% 'Ice-ice' syndrome	-0.206	-0.251	0.239
Carrageenan quality factor			
Gel strength (g cm^{-2})	0.066	-0.207	-0.400*
Viscosity (mPa.s)	0.107	-0.096	0.392*
Sulphate (% gel dry wt)	-0.173	0.047	-0.020

* Significant at $p<0.05$, ** Significant at $p<0.01$

Table 4.4 Correlation coefficients of gel strength (g cm^{-2}) of carrageenans of three morphotypes with environmental, seaweed, and carrageenan quality factors in southern Kenya.

Factor	Brown *E. denticulatum*	Brown *K. alvarezii*	Green *K. alvarezii*
Environmental factor			
Water temperature (°C)	-0.196	-0.195	-0.284
Water motion (diffusion factor)	0.107	0.041	0.282
Salinity (‰)	0.120	0.109	-0.006
Photon fluency (μmol photon m^{-2} s^{-1})	-0.142	0.606*	0.518*
Seaweed factor			
Relative growth rate (% d^{-1})	-0.145	-0.440*	-0.221
Dry weight (% algal fresh wt)	-0.298	0.331	-0.213
Thalls N (% of dry wt)	0.260	-0.368	-0.120
% 'Ice-ice' syndrome	0.076	-0.368*	0.141
Carrageenan quality factor			
Yield (% algal dry wt)	0.066	-0.207	-0.400*
Viscosity (mPa.s)	0.873**	0.673**	0.626**
Sulphate (% gel dry wt)	-0.092	-0.199	-0.031

* Significant at $p<0.05$, ** Significant at $p<0.01$

Figure captions

Figure 1. Mean monthly carrageenan yields (% dry wt) of three morphotypes, brown *Eucheuma denticulatum* (prism), green (triangle) and brown (square) *Kappaphycus* alvarezii at three sites (A=Mkwiro; B=Kibuyuni; C=Gazi) in southern Kenya from October 2001 to October 2002 (mean ± SE, n=2).

Figure 2. Mean monthly gel strength g cm^{-2} of three morphotypes, brown *Eucheuma. denticulatum* (prism), green (triangle) and brown (square) *Kappaphycus alvarezii* at three sites (A=Mkwiro; B=Kibuyuni; C=Gazi) in southern Kenya from October 2001 to October 2002 (mean ± SE, n=2).

Figure 4.1 Wakibia

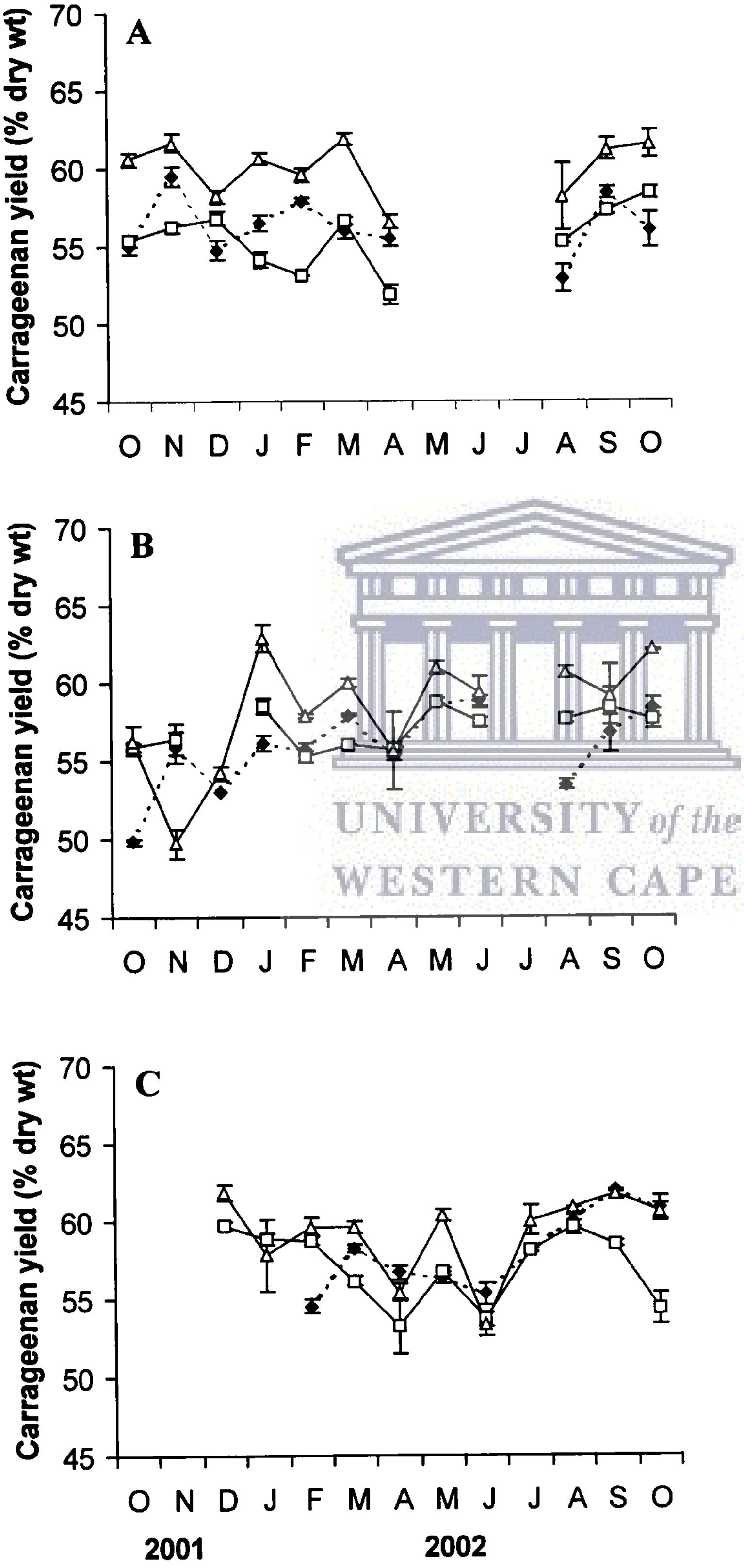
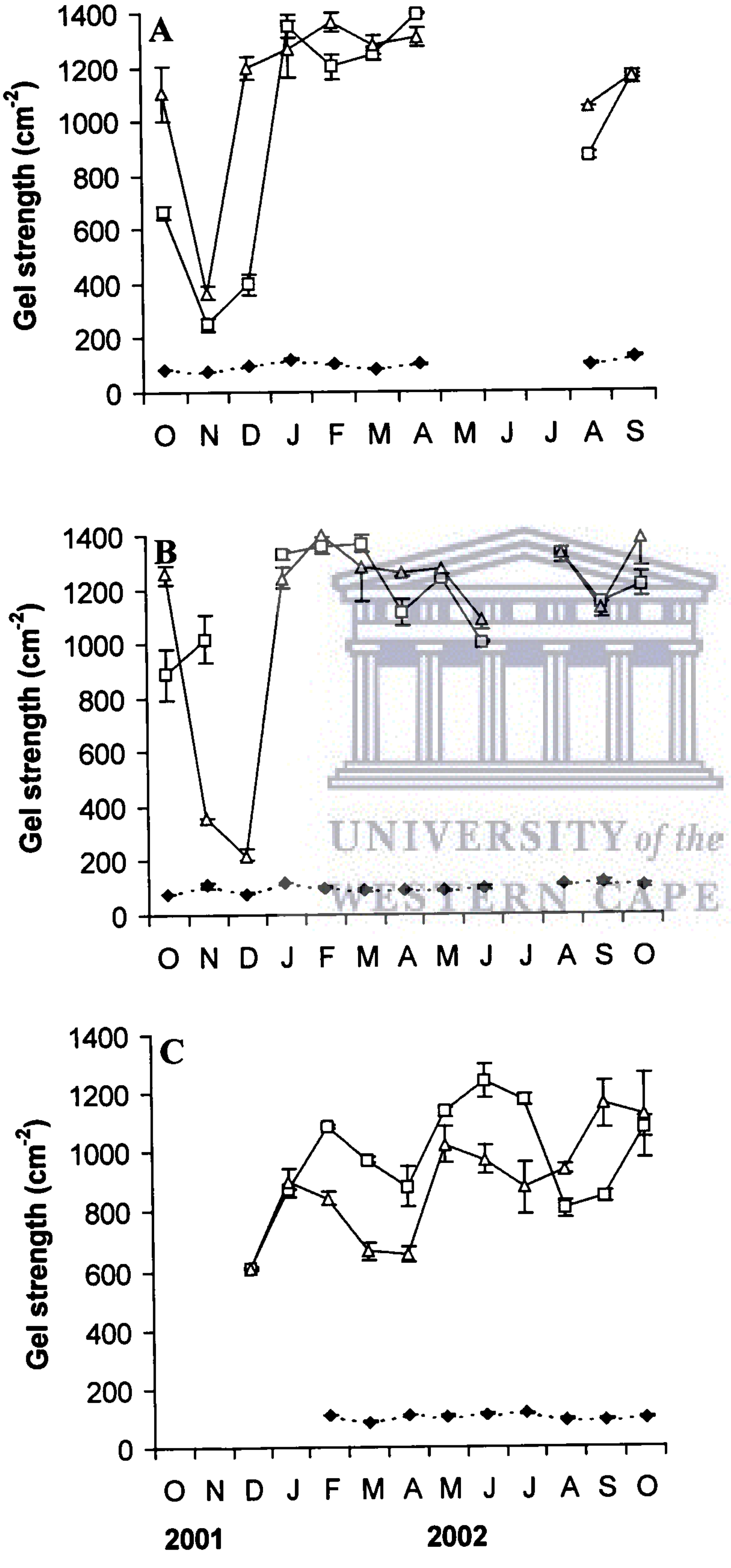


Figure 4.2 Wakibia



CHAPTER 5

ECONOMIC ANALYSIS OF EUCHEUMOID ALGAE FARMING IN SOUTHERN KENYA[5]

Abstract

Two eucheumoids (brown E. denticulatum and brown K. alvarezii) were grown in pilot farms of 0.1 ha for 6 weeks (42 days) at two sites (Gazi and Kibuyuni) in southern Kenya, to determine their net yield and economic viability. Sensitivity analysis was also done to determine the effects of decreased farm gate price and increased operating costs on the return of investment (ROI) and payment period in eucheumoid farming. The average net yield varied from 880 to 1209 kg dry wt for E. denticulatum and 600 to 1150 kg dry wt for K. alvarezii per crop. No significant difference in net yield was observed between the two morphotypes. However, a higher yield ($p<0.05$) was obtained for plants grown at Gazi (1071 ± 65 kg dry wt) than those at Kibuyuni (793 ± 93 kg dry wt). Total initial investment required for a 0.1 ha seaweed pilot farm (consisting of capital outlay and operating costs) for one crop was estimated at Kshs. 11 253 (Kshs. 75=1US$), with labour (both hired labour and family labour) accounting for about 52% of the total production cost. The average annual income per 0.1 ha farm was Kshs. 7549 and Kshs. 49 126 for E. denticulatum and K. alvarezii, respectively. The rate of return on investment in farming E. denticulatum ranged from 15 to 63%, while 122 to 380% for K. alvarezii. The pay back period was shorter for the latter (0.3 to 0.7 years) than the former (1.2 to 2.7 years). Economic sensitivity analysis showed that even if the farm gate price was decreased by 20% and operating cost was increased by 20%, K. alvarezii farming would still be a profitable and attractive venture in Kenya, but not E. denticulatum which resulted in negative economic indicators.

Key words: Cost and return analysis; sensitivity analysis; productivity; *Eucheuma*; *Kappaphycus*; eucheumoid; aquaculture; Kenya.

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5.1 Introduction

The economic importance of seaweeds and their dwindling supply led to the farming of commercial seaweeds, particularly Eucheuma denticulatum (Burman) Collins & Hervey and Kappaphycus alvarezii (Doty) Doty ex P. C. Silva in the late 1960s (Doty, 1987). Cultivation of these red seaweeds was pioneered in the Philippines to alleviate pressure on over harvested natural wild stock (Doty, 1987). Tropical Kappaphycus and Eucheuma seaweeds are farmed for their phycocolloid, carrageenan, used in food, pharmaceutical and cosmetic industries (McHugh, 2003). There is a great demand for carrageenans partly due to the growth in consumption of convenience foods and low-fat meat products which has opened up new markets for these phycocolloids (McHugh, 2003). Owing to the increasing global demand for carrageenans, the seaweed industry has encouraged the commercial cultivation of eucheumoids in certain tropical countries such as Indonesia, Fiji, Kiribati, Tanzania and Mozambique (Ask et al., 2003, McHugh, 2003). Kappaphycus alvarezii farming is at a pilot-scale stage in Brazil (Paula and Pereira, 2003) and Mexico (Muñoz et al., 2004), among other countries.

Commercial eucheumoid cultivation has become a major source of livelihood to thousands of coastal inhabitants in developing countries (Hurtado-Ponce et al., 2001; Ask et al., 2003). It is a high-yielding investment with a return ranging from 78% to over 100% per annum which is well above the opportunity cost of some activities such as fishing (Padilla and Lampe, 1989; Luxton and Luxton, 1999). An annual net income ranging from US$ 2662 (Samonte et al., 1993) to US$ 5948 (Firdausy and Tisdell, 1991) has been obtained from a one ha eucheumoid farm. It has been reported that the high income from eucheumoid farming has significantly contributed to an increased standard of living for the coastal families (Mshigeni, 1994; Hurtado-Ponce et al., 1996). The export of dried seaweeds is a source of foreign exchange for seaweed growing countries such as Indonesia (Firdausy and Tisdell, 1991), Tanzania (Lirasan and Twide, 1993; Mshigeni, 1994), Fiji and Kiribati (Luxton and Luxton, 1999), and the Philippines (Hurtado and Agabayani, 2002). Eucheumoid farming is deemed suitable for coastal communities because it is labour intensive and requires low capitalisation (Doty, 1987; Padilla and Lampe, 1989).

Despite the socio-economic importance of eucheumoid farming in developing countries, the economics from the farms are poorly known (Doty, 1987). There has been no economic investigation addressing the variability in yields and profits among and within seaweed farms (Smith, 1987). Few studies have investigated the economics of eucheumoid culture. For example, the costs and returns of Kappaphycus farming have been reported in the Southeast Asian region particularly in Indonesia (Firdausy and Tisdell, 1991) and the Philippines (Samonte et al., 1993; Hurtado-Ponce et al., 1996). However, most of these reports are based on data collected through interviews with practicing seaweed farmers which do not reflect the actual yields and production costs (Hurtado et al., 2001). Alih (1990) estimated the costs and returns from Eucheuma and Kappaphycus farming among farms in Tawi-Tawi, the Philippines, whereas Doty (1987) examined investment requirements for a one ha Eucheuma farm in Sabah, Malaysia. In Zanzibar, Tanzania, although eucheumoid farming has become well established since the early 1990s, only a few unpublished reports have been attempted on the cost and return analysis of this activity. The potential economic returns from seaweed farming vary from place to place (Doty, 1987), hence the operational economics in the western Indian Ocean areas such as Tanzania and Madagascar cannot be based upon the Southeast Asian case studies. The costs and returns of seaweed farming also vary according to the farming methods and the environmental conditions (Hurtado et al., 2001). The coastal communities in the western Indian Ocean region are also culturally and economically quite different from their counterparts in Asia. Thus each region and country must make its own estimates of costs and returns for eucheumoid farming (Smith, 1987).

Several studies have suggested that eucheumoid farming could be developed in Kenyan waters (Yarish and Wamukoya, 1990; Lirasan and Twide, 1993; Chapter 2). Seaweed farming has also been reported to be a low capital investment venture with high rates of return (Smith, 1987, Hurtado-Ponce et al., 1996). However, the economic viability of seaweed farms needs to be studied and quantified before undertaking commercial seaweed farming in Kenya (Oyieke, 1998). A pilot farm is highly desirable for reasonably accurate estimates to be made, particularly the annual yield and income from sale of seaweed (Smith, 1987). Therefore, this study was performed to determine the economic viability of E. denticulatum and K. alvarezii farming at 0.1 ha pilot farms in southern Kenya.

5.2 Materials and methods

5.2.1 Study sites

The study was conducted at two coastal sites (Gazi Bay and Kibuyuni) in southern Kenya where there was an ongoing experiment on seaweed cultivation (see Chapter 2). The sites were chosen to represent a range of environmental conditions on the Kenyan coast. Gazi Bay (4°25′S, 39°30′E) is a shallow mangrove system which receives freshwater from nearby rivers. However, both a shoreward wind and tidal currents mix the water in the bay, leading to seawater with near oceanic salinity (Kitheka, 1996). The seaweed pilot farms were established on a sandy flat covered with about 20-30 cm of water at the lowest tide and 3.8 m at the highest tide. Kibuyuni (4°38′S, 39°20′E) is a large intertidal reef flat covered by a belt of the seagrass Thalassodendron ciliatum (Forsskål) den Hartog. The eucheumoids were planted on a reef-flat covered with 10 cm of seawater at the lowest tide and 3.2 m at the highest tide.

5.2.2 Culture technique and seaweed production

Two morphotypes from two species: brown Eucheuma denticulatum and brown Kappaphycus alvarezii collected from Zanzibar, originally from Bohol in the Philippines were used in this study. The fixed off-bottom rope technique as described by Lirasan and Twide (1993) was adopted to culture the two morphotypes (see chapter 2). At each site, two 0.1 ha pilot farms were established; each containing 420 polypropylene ropes (5 m long, 4 mm diameter) of each morphotype. The ropes were stocked with 25 healthy seaweed cuttings, each weighing about 100 g wet weight. The cuttings were tied to the rope using plastic straws ('tie-ties') at intervals of 25 cm. Once stocked, the ropes with cuttings were weighed and installed. The seaweed farms were maintained at least twice a week by removing epiphytes and tightening loose stakes, ropes and cuttings. After six weeks (42 days), the stocked ropes were untied, water drained by shaking for 30 seconds, and the fresh wt of the harvested material was determined. Net yield or production (fresh weight) was calculated as the difference between the initial weight (about 1045 kg for the 0.1 ha) and the final weight at the end of the culture period. The harvested plants were sun dried on mats for three days. About eight kg fresh wt of harvested materials yielded one kg of dry wt. The productivity study was conducted in February-March (period of low growth) and August-September (period of high growth) and the net yield values were averaged for each morphotype. The average wt was multiplied by 10 to get productivity values for one crop. Data on net yields (two duplicates, period of low and high growth) were analysed by General Linear Model Procedures (GLM) followed by determining differences among individual mean values by Least Significant Difference (LSD) test at $p<0.05$. Statistical analyses were performed using the SAS Program (SAS, 1999).

5.2.3 Economic analysis

A cost and return analysis was used to evaluate the economics of the two eucheumoids at the two coastal sites (Shang, 1990). The procedure involved estimation of the initial investment cost and revenue from the pilot farms. Data presented in this study are based upon the actual costs and production figures obtained in a 0.1 ha pilot farm and projected for one year with five crops. The total investment requirements (farming costs) were expressed in terms of capital assets (capital outlay) and operating costs (working capital). The capital outlay included: polyethylene ropes (4 mm), floating baskets, water proof sheets, gunny bags, a digging bar, a bull hammer, and a knife. The working capital consisted of cash expenses (seaweed cuttings, plastic straws, hired labour and miscellaneous expenses) and non-cash expenses such as family labour and annual depreciation. Family labour was treated as a non-cash expense computed by man-days devoted in the pilot farms at Kshs. 145 man-day^{-1} of 5 hours (average low tide working time day^{-1}). Since family labour was a non-cash expense, it was considered as equivalent to the opportunity cost of labour of the time spent for fishing or working in the agricultural farms. In the cost and return analysis, the straight-line method of annual depreciation (Shang, 1990) was used and capital assets were assumed to have no residual value at the end of their useful life.

The revenue from seaweed was based on the average yield obtained in the pilot farms during the low and high growth period for each morphotype at each site. The farm gate prices of seaweeds were pegged at Kshs. 20 (75 Kshs.=1US$, in 2002) and Kshs.10 kg^{-1} dry wt for K. alvarezii and E. denticulatum, respectively, based on the prevailing Tanzanian prices (D. Rogers, per. comm.). However, the prices were computed at a conservatively higher rates of 25% above the Tanzanian farm gate prices to cater for total investment costs incurred here, unlike in the former situation where seaweed farmers were provided with supplies and materials. The costs of equipment, materials, supplies and other inputs were based on market prices at Mombasa.

Standard economic indicators used to evaluate investment feasibility in this study were the payback period and return on investment (ROI) according to Shang (1990). The payback period is the time taken (years) to gain a financial return equal to the total initial investment. It is the most widely used project selection factor when risks involved are relatively high (Shang, 1990). The payback period was calculated by dividing the total initial investment by the sum of the annual net income of the pilot farm and annual depreciation (from capital assets). The return on investment is another popular investment appraisal technique that does look at the whole project. The ROI was calculated by dividing the annual net income from the pilot farm by the total initial investment. Economic sensitivity analysis was also performed to determine the ROI and payment period of both morphotypes at the two sites under two different situations: decrease in farm gate price by 20% and increase in operating costs by 20% according to Hurtado and Agabayani (2002). The currency used in the computations was the Kenyan shilling (Kshs. 75=US$1, in 2002).

5.3 Results

5.3.1 Production

The net yield and projected productivity values of the two commercial morphotypes grown in a 0.1 ha pilot farm are presented in Table 5.1. The average net yield varied from 880 to 1209 kg dry wt for E. denticulatum and 600 to 1150 kg dry wt for K. alvarezii. No significant difference in net yield was observed between the two morphotypes. However, higher yields were obtained for plants at Gazi (1071 ± 65 kg dry wt) than those at Kibuyuni (793 ± 93 kg dry wt) ($p<0.05$). The high yield at Gazi site resulted in a projected annual productivity of more than 50 t dry wt ha^{-1} yr^{-1} for both species while the same morphotypes had productivity values ranging from 32 to 47 t dry wt ha^{-1} yr^{-1} at Kibuyuni (Table 5.1).

5.3.2 Costs and returns

The total initial investment in a 0.1 ha seaweed pilot farm was estimated at Kshs. 19 553 (Table 5.2). This amount covered the capital outlay and the initial working capital (or operating cost) for the first cropping. The stakes were free as they were cut in a local forest. The annual depreciation was Kshs. 4493, computed by a straight-line method based on the estimated economic lives of the various supplies and materials. The same total initial investment was used for both sites because they are close to each other (about 10 km apart) and all supplies and materials were bought from the same city, Mombasa.

The comparative costs and returns of E. denticulatum and K. alvarezii grown at 0.1 ha pilot farms are presented in Table 5.3. The projected total operating cost was Kshs. 11 253 consisting of cash and non-cash expenses which was based on average obtained from two harvest periods (February-March (period of low growth) and August-September (period of high growth). Labour was the most important operating costs with the hired labour and family labour together accounting for 52% of production costs for the 0.1 ha seaweed farms. Labour costs included staking, tying seaweed cuttings, cleaning, harvesting and drying plants.

The annual net income per 0.1 ha farm was highest for K. alvarezii (Kshs. 74 388) grown at Gazi followed by K. alvarezii (Kshs. 23 864) at Kibuyuni, while the lowest value of Kshs. 2855 was obtained for E. denticulatum at the latter site (Table 5.3). The average annual income per 0.1 ha was Kshs. 7549 and Kshs. 49 126 for E. denticulatum and K. alvarezii, respectively. Consequently, the return on investment (ROI) followed the same trend. However, the trend was reversed for the payment period with the shortest payment time of 0.3 years observed for K. alvarezii at Gazi and the longest (2.7 years) for E. denticulatum from Kibuyuni (Table 5.3). The higher net income and return on investment for K. alvarezii than E. denticulatum was due to farm gate price differences with the former species fetching Kshs. 25 kg^{-1} whereas the latter species was worth Kshs. 12.50 kg^{-1}. However, both K. alvarezii and E. denticulatum at Gazi had a higher net income and ROI, and shorter payment period than their counterparts at Kibuyuni, probably due to differences in site characteristics. Although the net income and ROI for the two morphotypes at both sites were positive, the pilot farms planted with E. denticulatum registered low profitability levels, particularly the extremely low value of Kshs. 2855 obtained from plants grown at Kibuyuni.

Table 5.4 presents sensitivity analysis of return on investment (ROI) and payback period (years) for two commercial eucheumoids under different situations. The economic indicators (ROI and payment period) for farming both morphotypes at the two sites would be responsive to fluctuations in decreased farm gate prices by 20% and increased operating costs by 20%. In the case of decreased farm gate prices, the return on investments (ROIs) would drop by 35% and 67% for K. alvarezii grown at Gazi and Kibuyuni, respectively, whereas at both sites E. denticulatum farming would register negative ROIs. Consequently, the payment period would increase by 0.9 and 5.2 years for K. alvarezii grown at Kibuyuni and E. denticulatum grown at Gazi, respectively. There would be little changes in the payment period for K. alvarezii grown at Gazi while negative values would be observed for E. denticulatum grown at Kibuyuni. In the second case if the operating cost were to increase by 20%, K. alvarezii at both Gazi and Kibuyuni would show higher ROI with a corresponding lower payback period than E. denticulatum at both sites. From the two scenarios, it would appear that eucheumoid farming at both sites would be more sensitive to decreased farm gate price than the increased operation costs. Therefore, at all pilot farms, an increase in operation costs by 20% with the exception of E. denticulatum grown at Kibuyuni, would still be profitable (Table 5.4).

5.4 Discussion

5.4.1 Productivity

The amount of seaweed produced in this study would scale up to an estimated annual yield of 32 to 55 t dry wt ha^{-1} yr^{-1} based on the mean weight per harvest and there are 5 harvests in one year (Table 5.1). This estimated yearly production was low in comparison to the extrapolated K. alvarezii production of about 100 to 110 t dry wt ha^{-1} yr^{-1} in Kiribati, central Pacific (Luxton and Luxton, 1999). The higher yield was due to the high density planting method that was used in Kiribati. The average seaweed production obtained in the present study was comparable to those reported by Braud and Perez (1978) in Djibouti waters (32 t dry wt ha^{-1} yr^{-1}) for E. denticulatum and 48 t dry wt ha^{-1} yr^{-1} for K. alvarezii (=E. cottonii) in Indonesia (Firdausy and Tisdell, 1991). However, the yield reported here was higher than the 10 to 30 t dry wt ha^{-1} yr^{-1} estimated for commercial eucheumoid farms (Doty, 1987; Alih, 1990). It was also higher than the projected yield of 27.9 t dry wt ha^{-1} yr^{-1} for K. alvarezii in the Philippines (Hurtado-Ponce et al., 1996) and 21 t dry wt ha^{-1} yr^{-1} in Hawaii (Glenn and Doty, 1990). However, the annual productivity data of eucheumoids reported in this investigation should be treated with caution as several authors have pointed out that scaling-up small experiments to estimate potential commercial yields could result in lowered values (Hanisak and Ryther, 1984; Doty, 1987).

The eucheumoid production obtained from Gazi pilot farms was significantly higher than that of plants farmed at Kibuyuni (see results). The differences in yields may be attributed to site characteristics, particularly the water motion, among other factors. The water motion was significantly higher at Gazi than at Kibuyuni (see Chapter 2). In addition, strong tidal currents reaching velocities up to 0.6 m s^{-1} were reported at Gazi Bay (Kitheka, 1996). A higher relative growth rate was also obtained at Gazi than at Kibuyuni (see Chapter 2). It seemed that the high water motion at Gazi supplied inorganic nutrients for the growth and production of eucheumoids. The high yield of 100 to 110 t dry wt ha^{-1} yr^{-1} for K. alvarezii at Kiritimati and south Tabuaeran farming areas in Kiribati was attributed to high water movement at both sites (Luxton and Luxton, 1999). Water motion has been recognised as a prime factor in eucheumoid growth and productivity (Doty, 1987; Glenn and Doty, 1992). Water motion is thought to increase seaweed growth rates and thus production, by decreasing the thickness of the unstirred layer of water around the algal surface, thereby enhancing greater availability of nutrients and more uniform conditions of irradiance, temperature and salinity (Doty, 1987). The low eucheumoid production at Kibuyuni was probably due to low water motion and also the presence of grazers and epiphytes which were observed to lower yield of K. alvarezii in the Philippines (Hurtado-Ponce et al., 2001).

5.4.2 Costs and returns

Eucheumoid farming required few supplies and materials (Table 5.2). The total initial investment required for a 0.1 ha seaweed pilot farm in this study was Kshs. 11 253 (US$ 260) and this would scale up to US$ 2600 ha^{-1}. Uan (1990) estimated a slightly lower investment requirement of US$ 1638 for a one ha K. alvarezii seaweed farm in Kiribati. However, the author did not include labour cost as working capital. The total investment required for a one ha eucheumoid farm in the Philippines varied from US$ 721 (Hurtado-Ponce et al., 1996) to US$ 1994 (Samonte et al., 1993). Doty (1987) reported that a capital investment of US$ 3285 was required for a one ha Eucheuma farm in Sabah, Malaysia. However, a higher investment of US$ 5247 was estimated for a one ha K. alvarezii farm in Indonesia (Firdausy and Tisdell, 1991). Among the operating costs, labour (both the hired labour and family labour) was the most important cost item, accounting for about 52% of total production cost (Table 5.2). The family labour input was valued at the hired labour wage rate. Labour accounted for 40% and 60% of the total cost of production in a one ha K. alvarezii farm in the Philippines (Hurtado et al., 2001) and Indonesia (Firdausy and Tisdell, 1991), respectively. Thus eucheumoid farming is a relatively labour-intensive activity suited to developing countries where labour is relatively abundant and cheap. In some studies (Alih, 1990; Uan, 1990), the operating costs were considered low since it was assumed that seaweed farmers use their own family members. However, labour is one of the most important considerations in economic analysis and should always be included as cost items in the cost and return calculations (Shang, 1990).

Eucheumoid farming is considered an attractive livelihood for coastal communities with high returns (Doty, 1987; Padilla and Lampe, 1989; Hurtado-Ponce et al., 1996; Hurtado-Ponce et al., 2001). In the present study, the net income from a 0.1 ha pilot farm would translate into an average annual income of Kshs. 75 490 and Kshs. 491 260 for E. denticulatum and K. alvarezii, respectively from a one ha seaweed farm. The average farm size would be about 0.5 ha because every household would depend on its members for labour and the investment required to start the venture could be accommodated with their limited financial resources. It would be expected that most households at the sites would manage a 0.5 ha pilot farm planted with both E. denticulatum and K. alvarezii. This would provide a yearly income of about Kshs. 283 375 (US$ 3778) or a monthly income of Kshs. 23 615 (US$ 315) for each household, which is more than twice the average monthly household income of Kshs. 9904 (US$ 132) they earned from fishing and other livelihoods (see Chapter 3). Luxton and Luxton (1999) reported a similar annual income of US$ 3726 for a family unit from a 900 to 1000 m^2 K. alvarezii farm in Kiribati. A lower annual income of US$ 2662 was obtained for a one ha K. alvarezii farm in the Philippines (Samonte et al., 1993). However, Firdausy and Tisdell (1991) reported a higher annual net income of US$ 5948 from a one ha of K. alvarezii in Indonesia. This investigation showed that eucheumoid farming has the potential of becoming a major source of income for the Indonesian coastal fishing communities.

In the present study, the return on investment (ROI) in farming K. alvarezii was higher than 100% with a payment period of less than a year, whereas those for E. denticulatum were less than 100% and more than a year, respectively (Table 5.3), implying that the culture of the former species was more profitable than the latter. It also took shorter time to recover the initial investments in farming K. alvarezii than E. denticulatum. In the Philippines, Alih (1990) obtained a payback period of 0.7 and 1.6 years, and return on investments of 150 and 61% for K. alvarezii and E. denticulatum, respectively. Results of the present study showed a higher ROI for K. alvarezii than the 243% and 150% ROIs obtained by Samonte et al. (1993) and Alih (1990), respectively in the Philippines, and the 123% ROI from K. alvarezii farming in Indonesia (Firdausy and Tisdell, 1991). However, the ROI for K. alvarezii obtained in this investigation was lower than the returns of investment reported for K. alvarezii in the Philippines (1002% ROI; Hurtado-Ponce et al., 1996) and in Kiribati (900% ROI; Luxton & Luxton, 1999).

The economic indicators (ROI and payment period) reported in this study should be regarded with caution because the costs and returns were calculated free of uncertainties and risks such as ‘ice-ice’ syndrome, El Niño phenomenon and farm gate price fluctuations, among other negative factors. For example, an El Niño weather pattern was observed to reduce K. alvarezii production by 60% in Kiribati (Luxton and Luxton, 1999), whereas farm gate price stability was reported to be a critical problem in eucheumoid production in the Philippines (Padilla and Lampe, 1989; Alih, 1990; Hurtado-Ponce et al., 1996). In 1998, an El Niño weather pattern was experienced in the western Indian Ocean region, including the Kenyan coast. Economic sensitivity analysis was done by reducing farm gate prices by 20% and increasing the operating costs by 20% in order to determine their effects on economic indicators (Table 5.4). A decrease in farm gate price would reduce the ROI of K. alvarezii farming by 35-67% and increase the payment period by 33 to 129%. The payment period and ROI for E. denticulatum at both sites would all be negative with the exception of the pilot farm at

Gazi (Table 5.4). The scenario of the increased operating costs by 20% would not be as severe as a reduction in farm gate prices though the ROI for E. denticulatum would deteriorate to a low or negative values (Table 5.4). The farming of E. denticulatum, particularly at Kibuyuni would be more prone to a decrease in farm gate price and increase in operating costs than that of K. alvarezii (Table 5.4).

Results of this study indicate that seaweed farming would be more prone to farm price fluctuations than the costs of inputs, suggesting that seaweed buyers should stop the tendency of supplying farming materials such as ropes and tie-ties to farmers while paying low prices for dried seaweeds as is practiced in Tanzania (pers. obser.). Rather, the seaweed processors should devise a way of increasing farm gate prices while the seaweed farmers buy their own inputs. This could promote entrepreneurship in seaweed farming as only interested farmers would take up the activity. It would be better to have a few active members rather than a whole village where most of the members are not committed to seaweed farming. For example, in Tabuaeran Island, Kiribati, eleven seaweed farmers accounted for about 17% of the Island's K. alvarezii production (Luxton and Luxton, 1999). In Zanzibar, some fishermen are supplied with farming inputs, particularly the monoline cultivation ropes but they instead use them for fishing purposes (pers. obs.). The interested villagers may have a problem to raise capital investment to start farming, but in this scenario the seaweed buyers could provide a credit facility to be paid back from the delivered dried seaweeds. In addition, the sensitivity analysis showed that the culture of K. alvarezii was still profitable even after the two adverse scenarios, as it appears to absorb the farm gate price and operating cost shocks. To develop seaweed farming in the region may be difficult because the seaweed price is never enough to cover the real operational costs. In fact, the labour effort is never calculated when pegging farm gate prices. Therefore, seaweed buyers and processors should base their farm gate prices on the minimum daily wage for the region and total production costs, including labour expenses, to encourage villagers to focus on eucheumoid cultivation.

In conclusion, eucheumoid cultivation, particularly that of K. alvarezii, appears to be a potentially viable aquaculture venture at both sites and could provide a good source of livelihood for the poor coastal communities. Seaweed farming, however, needs attention from the Kenyan government and the local and international community to promote a sustainable seaweed industry which should be economically and ecologically suited to the coastal areas of Kenya.

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Table 5.1 Net yield (kg dry wt) and projected annual productivity (t dry wt ha^{-1} yr^{-1}) of two commercial eucheumoids grown in a 0.1 ha pilot farm at two sites in southern Kenya.

	Site and morphotype			
	Gazi		Kibuyuni	
Period (2002)	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
February-March (yield)	983	940	880	600
August-September (yield)	1209	1150	1010	682
Mean yield	1096	1045	945	641
Productivity	54.8	52.3	47.2	32.1

Table 5.2 Initial investment and annual depreciation for a 0.1 ha pilot farm of commercial eucheumoids in southern Kenya (Kshs. 75=1US$ in 2002).

Item	Quantity	Unit cost	Total cost	Economic life (years)	Annual depreciation
Capital outlay					
Polyethylene rope (4mm)	12	475	5700	3	1900
Floating basket	2	200	400	0.5	800
Water proof sheet (m^2)	20	50	1000	1	1000
Gunny bag	20	15	300	0.5	600
Digging iron bar	1	400	400	5	80
Bull hammer	1	400	400	5	80
Knife	2	50	100	3	33
Subtotal			8300		4493
Working capital (1 crop)			11 253		
Total initial investment			19 553		

Table 5.3 Comparative cost and return analysis of two eucheumoids grown at two sites in southern Kenya. (Kshs. 75=1US$ in 2002).

Item	Site and morphotype			
	Gazi		Kibuyuni	
	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
Quantity (kg dry wt)	1096	1045	946	641
Revenue (Kshs.)[a]	13 702	26 131	11 824	16 026
Operating costs				
Cash expenses				
Seaweed cuttings (1050 kg)	2100	2100	2100	2100
Plastic straws (7 rolls)	1750	1750	1750	1750
Hired labour				
Staking (10 man-days)	1450	1450	1450	1450
Tying cutting (12man-days	1740	1740	1740	1740
Miscellaneous (10%)[b]	704	704	704	704
Subtotal	7744	7744	7744	7744
Non-cash expenses				
Family labour(18 man-days	2610	2610	2610	2610
Depreciation	899	899	899	899
Subtotal	3509	3509	3509	3509
Total production cost	11 253	11 253	11 253	11 253
Net income (average 1 crop)	2449	14 878	571	4773
Net income (5 crops year^{-1})	12 243	74 388	2855	23 864
Return on investment (%)	63	380	15	122
Payment period (years)	1.2	0.3	2.7	0.7

[a] Estimated farm gate prices for I kg of dried *Eucheuma denticulatum* and *Kappaphycus alvarezii* were Kshs. 12.50 and Kshs. 25.00, respectively.

[b] 10% of Seaweed cuttings, plastic straws ('tie-ties') and hired labour.

Table 5.4 Sensitivity analysis of return on investment (ROI) and payback period (years) for two commercial eucheumoids grown at two sites in southern Kenya.

Case	Site and morphotype			
	Gazi		Kibuyuni	
	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
No change (0%)				
Return on investment (%)	63.0	380.0	15.0	122.0
Payback period (years)	1.2	0.3	2.7	0.7
Decrease in farm gate price by 20%:				
Return on investment (%)	-7.0	247.0	-46.0	40.0
Payback period (years)	6.4	0.4	-4.4	1.6
Increase in operating costs by 20%:				
Return on investment (%)	5.0	323.0	-43.0	64.0
Payback period (years)	3.6	0.4	-5.0	1.1

CHAPTER 6

CROSS-SECTORAL POLICY IMPLICATIONS FOR THE INTRODUCTION AND DEVELOPMENT OF COMMERCIAL EUCHEUMOID CULTIVATION IN KENYA[6]

Abstract

Commercial eucheumoid cultivation has been introduced in several tropical countries in Southeast Asia, the Pacific and the western Indian Ocean. The attractive economic opportunities of seaweed farming in Zanzibar have generated a considerable interest for the exploitation of commercial eucheumoids (*Eucheuma denticulatum* and *Kappaphycus alvarezii*) in Kenya. However, there are no suitable natural sources of *Eucheuma* and *Kappaphycus* in Kenya, and utilisation of eucheumoids could only be realised by mariculture. A cross-sectoral policy analysis regarding legislation and policy relevant to the introduction and development of eucheumoid cultivation in Kenya, with particular reference to Kenyan legislation was conducted. Several research and policy interventions are recommended to facilitate the development of an environmentally acceptable eucheumoid mariculture, including the introduction and quarantine procedures. The establishment of a national mariculture development programme in Kenya is proposed as a means to develop and manage the farming of marine resources, including seaweeds.

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6.1 Introduction

Commercial eucheumoid cultivation is one of the most important sources of livelihood among the coastal villagers in several tropical countries such as Indonesia, the Philippines and Tanzania (Doty, 1987). Eucheumoid farming is a labour intensive activity which thus provides employment to coastal populations. For example, over 500 000 people in the Philippines (Trono et al., 2000) and about 16 000 in Zanzibar (Lirasan & Twide, 1993) benefit directly from *Eucheuma* and *Kappaphycus* farming. Several authors have reported that the communities and families involved in seaweed farming have improved standards of living (Alih, 1990; Hurtado-Ponce et al., 1996). Eucheumoid farming has also contributed significantly to foreign exchange earnings of the producing countries (Doty, 1987; Lirasan & Twide, 1993; Luxton & Luxton, 1999). In addition, seaweed farming is reported to increase productivity at the farm sites with increased fish catch for the coastal village communities (Mtolera et al., 1992). It has also been reported that increased economic prosperity in the coastal communities due to seaweed farming could reduce the destructive fishing practises as fisherfolk would be involved in the farming activity (Mshigeni, 1983; Alih, 1990).

As a way of broadening the livelihoods for coastal inhabitants, several countries such as Indonesia, Tanzania, Kiribati, Fiji and Madagascar (Ask et al., 2003) have introduced eucheumoid farming in their coastal waters. In Mozambique, commercial quantities of eucheumoids are currently being produced (R. Piezas, pers. comm.). Experimental cultivation of commercial eucheumoids has also been carried out in other countries such as India (Mairh et al., 1995), Vietnam (Ohno et al., 1996), Brazil (Paula et al., 1999), and Mexico (Muñoz et al., 2004). However, there has been an increasing concern over the introductions of exotic seaweed species to coastal waters due to their potential ecological impacts (Mtolera et al., 1992; Boudouresque et al., 1995; Rodgers & Cox, 1999). Other potential issues of eucheumoid farming relate to conflicts with other users of the coastal zone, marketing problems and uncoordinated expansion (Alih, 1990; Phillips, 1990; Msuya, 1993). The effects of the eucheumoid farming on the local fauna and flora have not yet been determined in many areas such as Tanzania (Johnstone & Olafsson, 1995). Numerous studies have been carried out on the socio-economic impacts of eucheumoid cultivation (Alih, 1990; Msuya, 1993; Hurtado-Ponce et al., 1996, Ask, 1999), but only a few investigations on its possible ecological effects (Ask et al., 2003; Oliveira & Paula, 2003).

A major challenge facing the Kenyan government is how to generate employment opportunities to absorb the unemployed population, particularly the youth, curb environmental degradation and reduce poverty levels in Kenya, including the coastal communities (GOK, 2003). In order to help Kenyan coastal fisherfolk rise above their poverty and reduce pressure on coastal and marine resources, sustainable livelihood interventions are required. Poverty reduction strategies must be formulated not only to rely on higher economic growth but should also incorporate and target pro-poor, marine-based programmes and projects. The interventions should also be environmentally friendly. Such intervention strategies could include promotion of offshore fishing, deployment of artificial reefs and introduction of technology for seaweed mariculture. According to Ask et al. (2003), commercial eucheumoid cultivation is a very attractive livelihood for coastal communities, with several environmental, social, economic and political benefits.

There is a considerable potential and interest for commercial eucheumoid farming in Kenya, as a source of livelihood for the coastal fishing communities (Yarish & Wamukoya, 1990; Oyieke, 1998). The sustainable livelihoods (SL) approach is one of the most innovative approaches which has been developed in response to poverty reduction and sustainable human development (Singh & Gilman, 2000). The SL approach includes a defined methodology for implementation. The SL methodology for measuring the components of the SL system consists of four channels (adaptive strategies, policy strategies, technology strategies, and investment strategies) (Keats, 1998; Singh & Gilman, 2000).

Having considered that SL approach is an integrated set of policy, technology and investment strategies, this study has considered the development of seaweed farming from within a sustainable livelihoods framework by applying three of the four channels. A participatory assessment of the assets, activities and coping and adaptive strategies of households was conducted at three coastal villages (see Chapter 3), while the technical feasibility of seaweed farming was determined using the fixed off-bottom farming technology (see Chapter 2). The micro finance and credit facilities to support seaweed farming were not determined in this study because seaweed cultivation projects are normally promoted by the international seaweed processors who also purchase the seaweed produced. However, there are no cross sectoral studies on policies and regulations regarding the introduction and development of eucheumoid cultivation in Kenya. Policy studies could provide a solid basis for policy formulation and implementation which would ensure sustainable development and equitable distribution of benefits from seaweed resources. A policy framework is also essential for adequate seaweed mariculture. Therefore this study was carried out to determine what changes in policy will be required to promote the ecologically safe commercial cultivation of commercial eucheumoids (*Eucheuma denticulatum* and *Kappaphycus alvarezii*) in Kenya.

6.2 Materials and methods

The primary means of data collection was literature review; informal interviews with Kenyan government officials; informal interviews with seaweed farmers and seaweed companies in Zanzibar; observation of water space use activities, and a brief analysis of published government legislation and policies. Relevant information was collected from government organisations mandated to develop and manage marine resources in Kenya, the private sector, and fisherfolk groups. In addition, the author visited various villages in Zanzibar where seaweed is grown (Paje, Jambiani, Chwaka Bay, Uroa and Fundo Island) where information was obtained through informal interviews with the seaweed farmers and seaweed companies. Information on farming activities was obtained through observaton in these villages.

6.3 Results and discussion

Several policy issues pertaining to seaweed farming have been identified as requiring attention if the commercial eucheumoid cultivation is to be started in Kenya for the benefit of the coastal communities and the carrageenan industry. However, since no seaweed farming exists in Kenya, the following discussion is based on studies and experiences from other eucheumoid growing countries. Table 6.1 presents the number of Kenyan statutes and government organisations which might impinge directly or indirectly on the development of mariculture activities, including seaweed cultivation.

6.3.1 Permit requirement

There is no exploitation of seaweeds in Kenya but just like any marine business, anybody planning to start eucheumoid cultivation would be required to apply for a permit or some form of legal concessions as done in other countries. For example in the Philippines, the practice of seaweed farming involved applying for a permit to farm from the Department of Agriculture-Fisheries (Technopak, 1988). The farmer identifies a suitable farming area while the local government makes site recommendations before the farmer can apply for a permit. The maximum area allowable for a single person (family) was one ha, and 30 ha for a co-operative society or company (Technopak, 1988). The situation is different in Tanzania where seaweed companies apply for permits to farm rather than the seaweed farmers. The interested company surveys and identifies suitable areas and applies for concessions to farm the sites. A concession to cultivate seaweeds is approved by the Fisheries Department and covers a whole village rather than the size of the area as in the Philippines (A. Juma, Fisheries Department, Zanzibar; pers. comm.).

In Kenya, since seaweed cultivation does not exist no agency has been mandated to issue permits for eucheumoid cultivation. However, it appears that the Department of Fisheries would be the most likely government agency to issue permits to start eucheumoid cultivation, because according to the Fisheries Act (Cap 378 of laws of Kenya), this agency is mandated to develop, manage, exploit, utilise and conserve fisheries in Kenyan fishery waters. For example, according to section 14 (1) of the Fisheries Act, no person should collect or culture oyster unless they have a valid licence issued by the Department of Fisheries (Table 6.1), implying that the same section could probably regulate seaweed cultivation. However, the Fisheries Act does not empower the department to specifically give permits for seaweed farming. The risk of the administrative obstruction and confusion on issuing seaweed farming permits appears to be a problem and, to combat this danger, a legislation empowering the Department of Fisheries to issue permits for seaweed mariculture needs to be introduced in Kenya. This could be done by amending the Fisheries Act to include permits for seaweed farming. Such legislation should consider the conflicts with fisherfolk and tourism development along the Kenyan coast, and whether the seaweed farmer or a seaweed company will apply for the permit. The revision of the Fisheries Act should be subject to a public participation process through meetings and workshops.

6.3.2 Zoning policy

The rapid development of seaweed cultivation has raised concern on how this activity may interfere with other ways of utilising the coastal zone (Phillips, 1990). The large areas required for an economically viable seaweed culture in some countries has resulted in conflicts with users over visual impact and access to water space. For example, the eucheumoid farms on the east coast of Zanzibar have taken up considerable space and in Paje village, the entire area between the low tide mark and the outer reef is being farmed (pers. obs.) leaving no space for other coastal activities such as tourism and fishing. Conflicts with tourism development have been reported on the other areas where eucheumoid cultivation is intensive (Msuya, 1993). In the Philippines, Phillips (1990) reported a conflict over the development of seaweed farming on Tubbataha Reef over aesthetic values in establishing a National Marine Park. According to Phillips (1990) the potential water space needed for seaweed culture may become a constraint to development of this activity in some tropical areas due to competition for coastal and near-shore utilisation.

If commercial eucheumoid cultivation is to be considered in Kenya, the government would have to grant concessions within the sea to interested local and international business communities. However, legal and sociological considerations would appear to be a potential hindrance to seaweed farming in Kenya because there is no legislation on allocation of coastal waters for mariculture, particularly on the inshore reef areas where there are interested stakeholders (fisherfolk, aquarium fish collectors, dive operators, and hoteliers).

Population pressures and tourism development has already led to conflicts over access to sea, land and water use in the north coast of Kenya (UNEP, 1998). The establishment of marine parks and reserves by the Kenya Wildlife Service as mandated by the Wildlife (Conservation and Management Act) (Cap 376) of 1985 has also reduced available areas for seaweed cultivation (Coppejans, 1989). The classic problem of access to sea surface area has become acute along the Kenyan coast, particularly in areas with high tourism activities due to uncontrolled construction of hotels, cottages, villas, apartments and guest houses (UNEP, 1998). As land is being converted for hotel and residential development along the shorefront, traditional fishing villages are being displaced. The original fishing villages are being moved from the seafront to hinterland locations, some as far as 12 km away (ICAM, 1996). Fishermen have also lost access to the beach. The land-based seaweed operations such as the drying of harvested seaweeds also need the land adjacent to shoreline for construction of drying tables.

The relevant statute for regulating land development is the Land Planning Act (Cap 303) of 1970 administered by the Department of Land and Physical Planning (Table 6.1) but it is ill-equipped to deal with conflict resolution and mariculture.

A suitable site is an important factor in the sustainability of mariculture, thus the government should identify appropriate areas for the various types of mariculture, including seaweed cultivation. The water space conflicts and identification of suitable sites for mariculture could be resolved by a balanced approach to management and development of marine resources on the basis of sound scientific data on impacts and strategic planning. For example, developing a large-scale inventory of water spaces as well as an oceanographic atlas for the Kenyan coast using Geographical Position System (GPS) and Geographic Information System (GIS) techniques would serve as data input for a water space use management plan. Such studies could identify potential mariculture areas and nodes along the Kenyan coast.

A zoning scheme and rules for water use activities in the coastal areas could then be developed after incorporating the input from the government agencies which may be involved in marine resources, mariculture industry representatives, local NGOs, boat owners, hoteliers, fisherfolk organisations, and the local communities. The Kenyan agencies and statutes in Table 6.1 should be involved in any zoning activities to avoid water space conflicts along the coast. This scheme could consider zoning specific areas for specific activities such as fishing, tourism development, marine parks and reserves, mariculture (fisheries and seaweed), etc. The Department of Tourism should also regulate tourist enterprises by licensing only those that are constructed in the designated zones. In terms of the Land Planning Act (Cap 303) of 1970, the Department of Land and Physical Planning could also influence development adjacent to the shoreline by enforcing the legally mandated 100-foot (33.7 m) setback limit along the shorelines. This free area would enable the seaweed farmers to access their farms and construct their drying tables. It is recommended that the Coast Development Authority should be the lead agency for the implementation of the zoning policies because it is mandated by Coast Development Authority Act (Cap 449) to plan and co-ordinate of development projects along the coastline, including fishing and marine activities. The Kenya Marine & Fisheries Research Institute could also act as the repository for the data input because it is the manager of the Kenya Geographic Information System for the Eastern African Coastal and Marine Environment Resources Database (UNEP, 1998).

Some aspects of water space conflict between seaweed cultivation and other users could also be resolved by the use of culture techniques designed to allow multiple uses (Philips, 1990). For example developing raft methods of farming eucheumoid in suitable mangrove bays in Kenya could reduce conflicts with tourism activities which are mostly based on the reef areas. However, the mangroves are managed by the Department of Forestry and any allocation of water space in mangrove bays by another agency could lead to a conflict with the Forests Act (Cap 385). A system of coordinated management and institutional oversight would be needed. This could be accomplished by the Department of Forestry collaborating with other sectors such as the Department of Fisheries and those concerned with navigation such as the Department of Transport and Kenya Ports Authority (Table 6.1). Floating methods are also reported to promote high growth in eucheumoids and disturb the benthic environment minimally compared to the fixed off-bottom method (Doty, 1987).

6.3.3 Environmental policy

There is an increasing concern over the ecological effects of seaweed farming activities on the environment (Johnstone & Olafsson, 1995; FAO, 1996; Ask et al., 2003). Some eucheumoid farming activities have effects on the substratum and may potentially damage stands of mangroves and terrestrial shrubs. Reduced species diversity in eucheumoid farms has been reported due to clearing of seagrasses and removal of macrobenthic organisms such as sea urchins and starfishes (Mtolera et al., 1992). It has also been speculated that stressed eucheumoids (due to grazing, high photon rates, high temperature, low water motion water, epiphytes or seagrasses) produce halogenated compounds which might be toxic to the algae themselves and nearby organisms (Collen et al., 1995; Mtolera et al., 1995). On the other hand, the eucheumoids and farm structures (such as stakes, ropes, buoys, and rafts) may increase species diversity by providing space and shelters as well as foraging sites for invertebrate and vertebrate feeders (Doty, 1987; Phillips, 1990).

The most common type of farming technique is the fixed off-bottom method which uses ropes and stakes (poles) either from mangrove forests or terrestrial shrubs. In Zanzibar, seaweed farmers prefer mangrove stakes because they have an economic life of about six months; they do not rot as quickly as other wood. The seaweed farming activity, among others, has caused a serious depletion of mangrove poles in some areas in Zanzibar (Mtolera et al., 1992). In Chapter 5 of this study, 630 mangrove stakes (each with diameter-4 cm, length-80 cm, and weighing-2 kg) were used for a 0.1 ha, translating into wood material weighing 1260 kg in one crop and 25 t for a one ha per year. In 1991, about 200 ha in Zanzibar were under *E. denticulatum* crop (Lirasan & Twide, 1993) and based on values from the current study, this would translate into 5000 t of wood material per year which is quite a substantial amount of wood regardless of whether the stakes used were mangroves or terrestrial shrubs.

The environmental aspect is a major component that needs to be integrated into eucheumoid cultivation. Mariculture impact assessment is a process that can be used to improve decision-making and ensure that the development options under consideration are ecologically, socially and ecologically sustainable. The identification or prediction, evaluation or analysis and mitigation measures of potential implications of mariculture development are the main focus of the Environmental Impact Assessment (EIA) process (UNEP, 1998). Although EIA is a critical management tool for mariculture development, including seaweed cultivation, no EIA is required for potential mariculture activities in Kenya. However, according to section 58(1) of the Environmental Management and Co-ordination Act of 1999, commercial projects involving the exploitation of natural fauna and flora may be required by the National Environment Management Authority to apply for an EIA Licence. The proponent of the project should undertake or cause to be undertaken at his own expense an EIA study and prepare a report. The EIA study and report required under this Act should be conducted by individual experts or a firm of experts authorised by the authority. It is recommended that EIA guidelines and procedures for mariculture activities, including seaweed farming be formulated and enacted in the Parliament with the National Environment Management Authority being the lead agency. It is also recommended that public consultation should play a major role in the formulation of these EIA guidelines.

6.3.4 Introduction of exotic species policy

Introductions of non-indigenous species might have a positive or negative impact on the environment and the people. For example, introduced commercial eucheumoids are important sources of livelihood to thousands of coastal villages and provide foreign currency to seaweed growing countries. On the other hand, some exotic seaweeds introduced either accidentally or deliberately have had negative impacts. Their impacts may be negative either directly, for example, where they compete with and displace indigenous species or indirectly as a result of habitat alteration or disruption of community structure (Oliveira & Paula, 2003). The documented cases of seaweeds demonstrating invasive characteristics, with drastic effects on ecosystems, have been accidental introductions. For example, the invasive *Caulerpa taxifolia* (Vahl) C. Ag., an accidental introduction from a marine aquarium, has reduced the species diversity in photophilic algal communities due to the loss of some species in the Mediterranean region (Boudouresque et al., 1995). Further, *Sargassum muticum* which was accidentally introduced with the oyster spat has become established in areas normally occupied by the seagrass *Zostera marina* (Druehl, 1973).

Despite the widespread introduction of eucheumoids (Table 6.2), there have only been a few studies that have investigated their ecological effects on the environment (Mtolera et al., 1992; Johnstone & Olafsson, 1995; Ask et al., 2003). Ask et al. (2003) observed that there are no serious negative ecological impact associated with the introduction of eucheumoids but other authors have suggested otherwise. Russell (1983) observed that coral heads covered by *K. striatus* (F. Schmitz) Doty ex P.C. Silva in Hawaii died after 74 days, presumably due to shading. Similarly, Woo et al. (2000) reported that *K. striatus* covered and killed several coral heads in the same area. However, eucheumoid farms in Zanzibar are sited on the intertidal lagoons (Msuya, 1993), where there are probably no live coral heads, and hence no cases of dead corals have been reported.

Another potential problem with the introduction of commercial eucheumoids is the potential for simultaneous introduction of additional species. For example, four unwanted algal species (*Acanthophora spicifera* (Vahl) Boerg., *Dictyota acutiloba* J. Ag., *Hypnea musciformis* (Wulfen) Lamour. and *Ulva reticulata* Forsskål) were accidentally introduced in Kiribati when transplanting eucheumoids from Hawaii (Russell, 1982). Lirasan and Twide (1993) also reported that the introduction of *E. denticulatum* and *K. alvarezii* to Zanzibar from the Philippines resulted in an outbreak of the epiphytic red algal genus *Polysiphonia* (Mtolera, 2003). The epiphyte mainly attacked the latter species but it is unclear whether it was introduced together with the seaweed cuttings.

In Kenya, there are few scattered natural stocks of eucheumoids along the coast, and hence to promote seaweed farming, exotic cultivated morphotypes of *Kappaphycus* and *Eucheuma* ought to be introduced. Any person wishing to import plant material into Kenya must first obtain a permit from the Ministry of Agriculture, Kenya Plant Health Inspectorate Service (KEPHIS) according to the Plant Protection Act (Cap. 324) of 1979. In accordance with section 8 (2) (1) of the Act, plants shall be imported after obtaining a permit from the Director of Agriculture. Unfortunately, the list of plants requiring an importation permit does not include seaweeds. However, according to section 51(e) of the Environmental Management and Co-ordination Act of 1999, the National Environment Management Authority is empowered to issue guidelines for prohibiting and controlling the introduction of alien species into natural habitats in Kenya. In addition, section 5 (1) (a) of the Fisheries Act (Cap 378) empowers the Director of Fisheries Department to impose the control of introduction into, or harvesting or removal from, any Kenya fishery waters of any aquatic plant, including seaweeds. It appears that there are no clear policies regarding the importation of exotic algal species for mariculture.

It is recommended that a permit requirement for importation of fresh or dry seaweed material be enacted in the Parliament with Kenya Marine and Fisheries Research Institute being the lead agency as it has quarantine facilities and trained personnel (See Chapter 2). The introduced species should be managed carefully to reduce any negative impact to the environment. Such management options should follow the introduction and quarantine procedures proposed by Ask et al. (2003) and the FAO-Technical Guidelines for Responsible Fisheries (FAO, 1996).

6.3.5 Marketing policy

Despite the proven technical and economic feasibility of eucheumoid farming in several countries, the seaweed industry is beset with problems such as marketing and quality control of dried plants that requires government and industrial intervention. Various authors have expressed concern that despite the benefits being reaped by seaweed processors due to the increasing demand of carrageenan in the world market, local seaweed farmers continue to be exploited and live on subsistence levels in Zanzibar and other eucheumoid growing regions (Alih, 1990; Msuya, 1993). Leaders in Zanzibar have complained that the seaweed buyers (agents for carrageenan industries) exploit farmers by fixing the price of seaweeds among themselves, at Tsh 80 and Tsh 100 kg^{-1} dry wt for *E. denticulatum* and *K. alvarezii*, respectively (Tsh 1200=1US$). According to Rönnbäck et al. (2002) a potential threat to the commercial eucheumoid business in Zanzibar is the marketing aspect which is controlled by the international seaweed processors. The marketing issue in Tanzania is worsened by the current farming conditions where seaweed farmers depend on the seaweed buyers for their seaweed cuttings and cultivation ropes, while the latter set farm gate prices according to their initial investments (Sobo, 2004). It appears that the monopoly control of seaweed prices in Zanzibar by international processors may not be an optimal model and does not argue well for the seaweed farmers.

In Indonesia and the Philippines, price fluctuation was reported to be one of the most serious problems in eucheumoid cultivation (Alih, 1990; Luxton, 1993). The problem was due to unstable buying policies of exporters who raised prices to grab their annual needs early in the year, and then abruptly stopped buying after getting their stock. The period of rising prices stimulated farmers to produce more, but in the end, the market was over supplied resulting in the lowered prices. This situation contributed to the 'boom-and bust' cycle of production of the seaweed (Alih, 1990). Though the use and market value of carrageenan is increasing (McHugh, 2003), the seaweed farmers feel that the processors are squeezing the seaweed buyers to lower the prices of seaweed (Rönnbäck et al. 2002). According to Ronnback et al. (2002) the monopoly control of seaweed prices in the eastern Africa and the Islands of the western Indian Ocean region by multinational corporations ensures their super-profits and yet abject poverty for coastal villagers.

If eucheumoid cultivation were to be developed in Kenya, similar market issues would be encountered. However, Kenya could learn from the various suggestions that been put forward to solve the marketing problem in eucheumoid producing countries. For example, to provide protection for farmers against fluctuating price cycles associated with changes in world supply and demand, the central Pacific nations such as Kiribati have entered into contract farming (Luxton & Luxton, 1999). In contract farming, the seaweed farmers and seaweed buyers enter into buying arrangements where the company buyers or traders extend 'cash advances' to the farmer in return for the produce and they agree on a fixed farm gate price if the supply is assured (McHugh, 2003). In Tanzania, the government, seaweed industry and NGOs are also preparing to institutionalise contract farming as a means to expand *K. alvarezii* cultivation and production (Ask, 2004; Sobo 2004). The supply contract with a foreign processor guarantees the sale of product at no marketing cost and provides the stability and continuity to sustain both the farmers and the export company (Luxton & Luxton, 1999).

The organisation of seaweed farmers into co-operatives has also been suggested, which would serve as a forum to strengthen their bargaining power for a higher price for their produce. In addition, the organised farmers could enable the channelling of government and NGOs efforts to help them to be more effective. Through the group organisations, the farmers could also control the cultivation by programming their production periods in order to get the highest possible price for their produce, and also source their farming inputs (rope, floats) from a society store as practised in Kiribati (Luxton & Luxton, 1999). In recognition of potential problems in seaweed marketing, some countries such as the Philippines have also diversified into farming other economic seaweed species such as *Gracilaria* species as raw material for agar manufacture and *Caulerpa lentillifera* for human consumption (Trono et al., 2000). It would be necessary to conduct a market survey to determine the world prices before embarking on seaweed cultivation in Kenya. It is also recommended that Kenya Marine Fisheries Research Institute could conduct market studies on eucheumoid through its socio-economic department, while the Department of Co-operative Development could organise seaweed farmers into co-operative societies and enhance management of co-operatives via audits and training on management skills as mandated in the Co-operative Societies Act (Cap 490) of 1972.

6.3.6 National Mariculture Development Programme

Mariculture is recognised as offering great potential as a form of economic development for coastal areas. Its development should be accorded consideration for allocation of adequate resources in national and sectoral plans. There is no seaweed exploitation in Kenya and thus there are no regulations governing the development and management of these marine resources. However, as already mentioned, the Department of Fisheries is the government institution responsible for the development and management of seaweed resources in Kenya. The Department of Fisheries personnel are managers of fishery resources and they need research results and information to manage these resources. Within the structure of the Department of Fisheries, however, there is no provision or dedicated section to deal with mariculture, including seaweed cultivation (Deputy Director, Fisheries Department, pers. comm.). In fact the Department of Fisheries does not have the phycological capacities to conduct seaweed research as there is no seaweed scientist in the institution.

Research on seaweed in Kenya is carried out by the Kenya Marine & Fisheries Research Institute (KMFRI) which is mandated by the Science and Technology Act (Cap 250) to conduct research and survey work on various aspects of marine and freshwater fisheries. The institute also investigates and promotes mariculture and carries out socio-economic research on topics related to fisheries and aquaculture. However, the KMFRI does not have the mandates to develop marine resources, including seaweeds. If seaweed farming was to be developed in mangrove bays, the Laws of Kenya are not clear whether the Department of Fisheries or Forestry would be responsible for seaweed activity as the latter agency is in charge of mangrove forests. It appears that the government agencies mandated to develop and manage marine resources, do not have all the necessary mandates and do not have the phycological capacity to develop and manage seaweed farming in Kenya. The lack of a lead agency in the development and management of these resources is one of the reasons why there is no development of seaweed farming in Kenya.

A legal framework is essential for adequate mariculture development and management. However, there is no legislation that deals specifically with mariculture in Kenya. Considering the potential of mariculture and that no single institution in Kenya currently has the mandate to adequately address all mariculture issues in an integrated manner, an institutional mechanism is needed and it is suggested that a National Mariculture Development Programme should be established in Kenya. The function of the programme would be to develop and manage relevant aquatic resources, including seaweeds, in Kenya. The government should also create a specific agency with jurisdiction over all aspects of mariculture and tasked with promoting, co-ordinating and facilitating aquaculture development in Kenya. The agency should also be responsible for identification of appropriate sites for mariculture development (mariculture development zones), education, training, information systems and legislation needs, and development of demonstration pilot farms. However, the agency should work closely with the relevant government departments and the private sector in organising and developing mariculture and ensuring that the strategies are within the national development priorities.

A legal framework would be essential for the formation of the programme and for vesting the agency with powers to co-ordinate the programme. It is suggested that the Kenyan parliament should adopt a new and more embracing Coastal Zone Management Act which would empower the agency and regulate the varied activities which occur in the coastal zone, including mariculture. Currently there is no legislation that deals specifically with coastal area management and mariculture in Kenya.

In conclusion, eucheumoid cultivation is becoming a rapidly growing activity in tropical countries with suitable coastal areas and is a source of livelihoods for coastal communities. In Kenya, non-indigenous algal species may be introduced for mariculture purposes but only after careful consideration of possible damaging effects and the proper quarantine procedures are followed. However, eucheumoid introductions should not be hampered by bureaucratic complexities of government departments, rather these agencies should co-ordinate and promote seaweed farming jointly with the private sector as part of their rural development programme.

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Table 6.1 The roles of Kenyan statutes and the lead agencies with regard to mariculture.

Statute	Role	Agency
Fisheries Act (Cap 378)	To issue permits for oyster collection and culture To control the introduction and harvesting of seaweeds	Department of Fisheries
Wildlife (Conservation and Management Act) (Cap 376)	To establish and protect marine parks and reserves	Kenya Wildlife Service
Land Planning Act (Cap 303)	To plan the use and development of land in the coastal zone	Department of Land and Physical Planning
Tourist Industry Licensing Act (Cap 381)	To license and regulate the tourist industry	Department of Tourism
Coast Development Authority Act (Cap 449)	To co-ordinate fishing and marine projects	Coast Development Authority
Forests Act (Cap 385)	To control and regulate mangrove forests and bays	Department of Forestry
Merchant Shipping Act (Cap 389)	To regulate navigation in Kenya's territorial waters	Department of Transport
Kenya Ports Authority Act (Cap 391)	To construct and maintain navigational aids	Kenya Ports Authority
Environmental Management and Co-ordination Act, 1999.	To issue Environmental Impact Assessment licence To control the introduction of alien species	National Environment Management Authority
Plant Protection Act (Cap 324)	To control of diseases destructive to plants To control the importation and exportation of plants	Kenya Plant Health Inspectorate Service
Co-operative Societies Act (Cap 490)	To manage co-operative societies and marketing	Department of Co-operative Development
Science and Technology Act (Cap 250)	To conduct fisheries and aquaculture research	Kenya Marine Fisheries Research Institute

Table 6.2 Deliberate introductions of eucheumoids (*Eucheuma denticulatum* and *Kappaphycus alvarezii*) for experimental (Expt) or commercial (Com) purposes in various countries.

Location	Species	Year of introduction	Purpose	Reference
Brazil	*K. alvarezii*	1995	Expt	Oliveira & Paula, 2003
Cuba	*K. alvarezii*	1991	Expt	Smith, 1998
Djibouti	*E. denticulatum*	1973	Expt	Braud & Perez, 1978
Fiji	*K. alvarezii*	1984	Com	Luxton & Luxton, 1999
Hawaii	*E. denticulatum* *K. alvarezii*	1971	Expt	Russell, 1982
India	*K. alvarezii*	1989	Expt	Mairh et al., 1995
Indonesia	*E. denticulatum* *K. alvarezii*	1984	Com	Adnan & Porse, 1987
Japan	*K. alvarezii*	1991	Expt	Ohno et al., 1994
Kenya	*E. denticulatum*	1992	Expt	Wamukoya, pers. comm.
	E. denticulatum *K. alvarezii*	2001	Expt	This study
Kiribati	*E. denticulatum* *K. alvarezii*	1977	Com	Russell, 1982
Madagascar	*K. alvarezii*	1998	Com	Ask et al., 2003
Malaysia	*K. alvarezii*	1978	Com	Doty, 1980
Mexico	*K. alvarezii*	1999	Expt	Muñoz et al., 2004
Mozambique	*E. denticulatum* *K. alvarezii*	1996	Com	R. Piezas, pers. comm.
Tanzania	*E. denticulatum* *K. alvarezii*	1989	Com	Lirasan & Twide, 1993
Venezuela	*E. denticulatum* *K. alvarezii*	1996	Expt	Rincones & Rubio, 1999
Vietnam	*K. alvarezii*	1993	Expt	Ohno et al., 1996

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Although commercial cultivation of eucheumoids have been developed in some countries in the western Indian Ocean region, the seaweed as a resource in Kenya has not been exploited, and this may be attributed to lack of knowledge of the potential value in these plants. The present study thus sheds light on the view that eucheumoid cultivation may be a potential source of employment opportunities and income for coastal communities in Kenya.

In this study, the average relative growth rates obtained for three exotic eucheumoids (brown *Eucheuma denticulatum*, brown and green *Kappaphycus alvarezii*) from Tanzania, were all above the commercial value of 3.5% day^{-1}; demonstrating that eucheumoid cultivation is feasible in suitable sites along the Kenyan coast. However, there are no figures available of suitable areas for seaweed cultivation along the coast. It is therefore recommended that a study should be carried out to identify all the potential areas for eucheumoid cultivation. The Geographical Position System (GPS) and Geographic Information System (GIS) techniques could be useful tools in mapping farmable areas.

During the current study, both brown *E. denticulatum* and brown *K. alvarezii* were observed to be more susceptible to epiphytes and 'ice-ice' syndrome, particularly during the period of high temperature and salinity than the green *K. alvarezii*. In Kenya, there are six eucheumoids growing along the coast, but the natural stock could not sustain commercial harvesting. Further research should therefore pay attention to strain selection so as to isolate those varieties with carrageenan of high properties, resistant to 'ice-ice' syndrome and epiphytes, and high growth rate under the Kenyan environmental conditions. However, genetic modification, other than by traditional selection methods, to enhance disease resistance or to select specific properties in commercial eucheumoids should be avoided so that the material farmed would be acceptable to the international community.

The results of the present work have demonstrated that the different eucheumoids show variations in yield and properties of carrageenans. It was evident that the culture site also influenced these properties depending on the prevailing ecological conditions; carrageenans of low gel strengths were obtained from plants farmed under growth promoting conditions and the reverse for slow growing plants. However, this should be investigated further by using several sites with markedly different ecological conditions. Nevertheless, from a mariculture point of view, it is apparent that information on ecological conditions of farming areas is important in siting eucheumoid farms to obtain carrageenan of high quality. The carrageenans extracted from the three morphotypes were of high industrial standards and comparable to Sigma commercial carrageenans, implying that some areas in Kenya might produce crops yielding high quality carrageenans. It is recommended that carrageenan processors should be basing their eucheumoid farm gate prices on the quality of dried seaweeds rather than their current methods of the quantity of dried material. Seaweed farmers in locations with slow growing conditions for eucheumoids are more likely to produce low biomass but of high quality than their counterparts in areas with growth promoting conditions. Hence, it would necessary to offer higher prices to farmers with high quality carrageenan containing material.

There are some basic factors to be considered before establishing eucheumoid farms in a village. One of these factors is to obtain information on the socio-economic conditions of the villagers. In the present investigation, the household socio-economic characteristics varied among the three coastal villages studied. This emphasises the need to investigate these aspects as part of baseline studies whenever a development project, including seaweed cultivation, is planned. The information on household size, age distribution, education level, gender of household head, sources of livelihoods, poverty level, skills, and coping strategies furnished by this study gave an insight on what might be some of the factors to be considered in developing eucheumoid cultivation in Kenya. Since this study identified socio-economic factors in only three coastal villages, it is recommended that more socio-economic surveys be carried in other villages along the Kenyan coast to explore the factors that are likely to influence the adoption and success of seaweed farming. It might be worthwhile finding out how the individual factors interact in influencing the adoption of government and donor projects and programmes, including seaweed farming and to rank the factors in order of importance. The latter might vary from one village to the other.

The present study showed that eucheumoid cultivation could be an attractive source of income and employment for the coastal communities. Eucheumoid cultivation was observed to be a labour-intensive operation with cost of labour accounting for over 50% of the total operating expenses. However, the profit was also high. A small size farm (0.5 ha) was estimated to provide a monthly net income of Kshs. 23 615 (US$ 315) for each household which is more than twice the average monthly income of Kshs. 9904 (US$ 132) earned from fishing and other livelihoods. However, the above economic returns must be regarded as above normal because they were based on economic data extrapolated from experimental pilot farms with favourable conditions. Furthermore, returns were calculated free of uncertainties and risks such as El Niño phenomena and farm gate price fluctuations. It is recommended that one hectare farms be established and maintained for one year in several locations to estimate costs of production and economic indicators. Results of the present cultivation trials showed that eucheumoid farming could be a profitable household industry requiring little capital investment, while offering high returns. Furthermore, the activity is suited to accessible shallow water reef flats, and the product has a market. Consequently, it is clear that eucheumoid farming could be a highly beneficial family activity along the coast, while conserving the marine resources. The relative non-perishability of eucheumoids is a particular advantage of the venture compared to many other mariculture activities. Eucheumoid cultivation does not also require imported inputs such as fertilizers and chemicals.

This study has demonstrated that eucheumoid cultivation has a social and economic potential for coastal communities. However, at the moment eucheumoid cultivation is non-existent although potentially suitable areas and labour are available. A cross sectoral policy analysis regarding legislation and policy relevant to the development of eucheumoid cultivation in Kenya has revealed that these policies are fragmented and in some cases subject to different interpretations. The roles of different government agencies are often conflicting and not always clearly defined. Thus, there is a need for the government to start the process which could lead to the formulation of effective policies relating to coastal mariculture, including seaweed cultivation. However, the formulation of enabling legislation on development and management of mariculture activities must have the public participation of all marine resources users and stakeholders. It should be recognized that an appropriate legal framework for coastal mariculture might effectively contribute to the implementation of sustainable livelihoods programmes, such as eucheumoid cultivation, to alleviate poverty among the poor coastal communities in Kenya.

APPENDIX I: Household interview guide

IOI-EA SEAWEED MARICULTURE PROJECT
Kenya Marine & Fisheries Research Institute, Mombasa

HOUSEHOLD INTERVIEW GUIDE

Name of village: ______________________.

1. COMPOSITION OF HOUSEHOLD

a) How many people live in the household, including yourself?

Name	**Position in the family**	**Sex**	**Age**	**Marital status**	**Education level**	**Main occupation**
1						
2						
3						
4						
5						
6						
7						

b) How many people live outside the household but still consider your house their home?

Name	**Position in the family**	**Sex**	**Age**	**Marital status**	**Education level**	**Main occupation**
1						
2						
3						
4						
5						

2. ECONOMIC ACTIVITIES

a) What is your main source of income? How much do you earn per week/month?

b) How does the main source of income vary with season?

c) What are your other sources of income? How much do you earn per week/month?

3. ASSETS

a) Is land owned or leased and if owned, how did you acquire it?

b) What is the size of land and do you have a title deed?

c) What are the types of livestock owned and how many? When are they sold / why?

d) What are the types of gears and boats owned? How much did they cost?

e) What are the types of farming tools owned and how did you acquire them?

f) Household amenity ownership: (Quantity and values (Kshs.)

1. Radio
2. Radio Cassette
3. Television set
4. Refrigerator
5. Sewing machine
6. Watch
7. Sofa set
8. Bed/chair
9. Other carpented furniture
10. Lamp (pressure, tin-can, kerosene)

4. TECHNOLOGIES

a) What technologies and skills are available in the household?

b) How were the technologies and skills learnt?

5. MICRO-FINANCE AND ALTERNATIVE OPPORTUNITIES

a) If you need to borrow money, where do you go? How is it repaid?

b) Do you save money? If so, where do you save it?

c) Are there micro-credit facilities and traditional practise in the village? If so, how do they operate?

d) What are the risks, problems and issues faced by the family/community now? How do you solve them?

e) What are the past, exiting and /or planned development activities in the household/village?

6. GENERAL HEALTH

a) What are the main diseases experienced by the household members? How do these vary by season?

b) What are the strategies adapted to dealing with these health problems?

c) Do the family members attend family planning and clinics services?

d) What are the sources of drinking water?

7. SOCIAL-POLITICAL STATUS

a) What are your ethnic make up and your religion?

b) What are the traditional belief systems outside the religion?

c) How prevalent is witchcraft in the household/village?

d) What cultural values are upheld in the household?

e) Do the household members belong to any organisation/group? If so, which organisations/groups?

8. HOUSEHOLD CONSUMPTION AND EXPENDITURE

a) What are the goods mainly consumed: vegetables, fruits, staple, fish and meat?

b) How much does the household spend on food per day/week/month?

c) How many meals do you eat a day? How does diet vary by seasons?

d) What are the hunger months? How long does this last?

e) How do you cope with food shortages?