A COMPARATIVE STUDY OF GROWTH RATES AND YIELD OF THE SEAWEED, *Kappaphycus alvarezii (Doty),* USING VARIABLE SEEDLING DENSITIES AND CULTURE METHODS IN COASTAL KENYA.

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DECLARATION

DECLARATION BY THE CANDIDATE

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DEDICATION

I dedicate this project to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program and on His wings only have I soared. I also dedicate this work to my husband who has encouraged me all the way; who was patiently with the children when I was away for long and whose encouragement have made sure that I give it all it takes to finish that which I had started. To my children, who were affected in every way by my absence.

Thank you. My love for you all can never be quantified. God bless you.

ABSTRACT

Seaweed farming has been demonstrated to have significant socio-economic benefits to coastal communities and has the potential to reduce pressure on wild fishery stocks. This work was aimed at testing sustainable farming technique of the seaweed, *Kapapphycus alvarezii*, at two sites (Kibuyuni and Gazi) on the south coast of Kenya. Two culture methods (off-bottom and rafts) were tested for growth and yield of the species at five stocking densities (50g. 75g, 100g, 125g, and 150g) replicated three times. The density treatments for Rafts and Off bottom methods were sampled bi-weekly for growth and yield during the northeast (NEM) and southeast monsoon (SEM) seasons during March –July 2014 and November –April 2015. Physico-chemical parameters were measured bi-weekly at each site and related to growth and yield at sites. Data were analyzed using a combination of multivariate and univariate statistics. Results showed mean maximum growth rates (%/day ± SD) of 2.97±0.00 at Gazi at two weeks of culture during NEM season for the rafts, while rates of 2.86±0.10 were obtained at Kibuyuni during SEM season. The Off-bottom method yielded growth rates of 2.73±0.13 after a period of ten weeks of culture during the NEM season in Gazi while the method produced rates of 2.49±0.1 at Kibuyuni at nearly the same interval during the NEM season. At Gazi site,two –way ANOVA showed season and density to have significant effect on growth rate ($p<0.05$) while, method of culture had no significant effect. The result suggests that Gazi farmers may simply select any of the methods that provide highest growth rate at the shortest time. Season, method and density had significant effect on growth rate at Kibuyuni ($p< 0.05$) indicating all the variables are important to be considered when culturing the species at Kibuyuni. This implies that at Kibuyuni off-bottom method is desirable during SEM and raft method during NEM. The physico-chemical parameters had effects on growth and yield that varied between sites and seasons. These results are discussed in relation to other studies on the same species and recommendations are made based on the data and the constraints of the study.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Farming of seaweeds is a relatively young and robust form of aquaculture with great potential to support coastal livelihoods in Kenya. World seaweed production has been characterized by exponential growth during the last 50 years (Loureiro et al., 2015) and it tripled between 1997 and 2012, from 7 million tons to 24 million tons (Mt) (FAO, 2014). While 33 countries reported seaweed farming in 2012 for a total of 23.8 Mt, 98.7% of production came from eight Asian countries, with Zanzibar in Tanzania being the only prominent country in Africa at 0.65% of global production (FAO, 2014; FAOSTAT, 2015). Harvesting from the wild has remained stagnant at ~1 Mt/year for the last decade, with 1.1 Mt in 2012 or 4% of total global seaweed production (FAO, 2014; FAOSTAT, 2015).

Farmed *Kappaphycus alvarezii (Doty)*, is one of the economically important red algae, which yields carageenan, a commercially important polysaccharide (Ask et al, 2003). Carrageenans are used in a variety of commercial applications as gelling, thickening, and stabilizing agents, especially in food products. Besides, carrageenans are also used in pharmaceutical formulations, cosmetics and industrial applications such as mining (Parker, 1974).

Commercial cultivation of *K. alvarezii* originated in the Philippines in the year 1960 (Ask and

Azanza2002). Although the off-bottom method has been tried on the red algae in Kenya (Wakibia, 2006) and Tanzania (Msuya, 2006), the most optimum method yielding sustainable income to households requires determination and is likely to vary spatially (Wakibia, 2008) . It is generally known that *K. alvarezii* requires warm sea water, high light levels, nutrient-enriched water and a high degree of water motion for successful cultivation (Glenn and Doty, 1990). The factors that influence the growth and yield of seaweed generally vary with site and methods, and the success of each method varies among and within countries (Parker, 1974). The objective of this study was therefore to determine the optimum method of production with potential to provide maximum returns to farmers and, to describe the environmental factors that affect growth and yield of *K. alvarezii* in coastal Kenya.

1.2 Problem Statement

Development of alternative livelihoods has become a popular policy to uplift the socio-economic status of small-scale fishers and to reduce fishing pressure on overexploited fisheries. Different culture technologies and methods of farming have been practiced and found to be potential alternatives for livelihoods for coastal communities (Samonate *et al.* 1993). However, the seaweed farming technique in coastal East Africa has relied mostly on the off-bottom method of farming employing the lowest seedling density (Wakibia *et al.*, 2006). Although the off-bottom method of farming has given the farmers reasonable income, it does not represent the best option to improve overall household income from seaweed farming as the seedling densities used take long to reach the required size thus giving low yields (Wakibia *et al.*, 2006). Therefore, it’s important to explore alternative farming methods at appropriate seedling densities in order to come up with an optimal density and method that will give high yields within a reasonable period in order to sustain livelihoods. Although some studies have been conducted on the effects of environmental factors on seaweed (Neori *et al.*, 2007; Chopin, 2014; Radulovich *et al.*, 2015) there is little information on how these factors may affect performance of *K. alvarezii* growth in coastal areas of East Africa. Nonetheless, considering the importance of seaweeds to the food and pharmaceutical industries, establishing the optimum conditions for growth would help coastal communities maximize returns from seaweed farming.

1.3 Justification

Most coastal communities in East Africa majorly rely on artisanal fishing as an economic activity. Considering that world food production must increase by 70–100% by 2050 in order to sustain populations (Clay, 2011; Hisas, 2011; Tillman *et al.*, 2011,(Pickett *et al.*, 2008). however, the capacity of agriculture to satisfy all these needs seems to be insufficient considering growing shortages of adequate land, water, and fertilizer. Most of the required increases in food production must come from increases in productivity from existing agricultural land and only about 10% from adding new land (Clay, 2011; OECD-FAO, 2012; FAO, 2013b; Garnett *et al.*, 2013; Godfray and Garnett, 2014). New sources of supplementing food production need to be found. The fishing pressure on the already overexploited resources has led to environmental degradation and reduction on fish catches (McClanahan *et al.*, 2008) which cannot sustain the rapidly increasing population in Kenya, and hence other sources of livelihoods are required. Seaweed farming has been demonstrated to have significant economic benefits to the Kenyan (Wakibia *et al.*, 2006) and Tanzanian (Msuya 2006) coastal communities and a potential source of alternative livelihood on the Kenyan coast. However, in order for seaweed farming to be profitable, there is need to increase efficiency of the methods used to grow the main seaweed species and understand the ecological factors influencing the growth of the seaweeds in the main areas where they are grown at the Kenyan coast. Some fishermen are willing to give up fishing in favor of more lucrative economic opportunities and alternative livelihoods such as seaweed farming (Wakibia *et al.*, 2006), a move that will reduce pressure on fish stocks. This work aimed at describing suitable scientific invention with regard to the culture of *K. alvarezii* in coastal Kenya as an alternative livelihood to fishing in coastal communities.

1.4 Objectives

The general objective of the study was to determine the optimum growth rate and yield of the seaweed *Kappaphycus alvarezii* grown under different culture methods (in Raft and Off- bottom plots) and at different seedling densities on the south coast of Kenya.

1.5 Specific Objectives

The specific objectives of the study were:

i. To determine the spatial variation in growth rate and yield of *K.alvarezii* farmed under different stocking densities and two culture methods on the south coast of Kenya.

ii. To determine seasonal variation in the growth rate and yield of *K.alvarezii* farmed under different stocking densities and two culture methods within the lagoonal reefs on the south coast of Kenya.

iii. To determine the influence of physico-chemical parameters on the growth rates and yield of *K.alvarezii* on the south coast of Kenya.

1.6 Hypotheses

This study was guided by the following statistical hypotheses**:**

I. H_0: There is no significant difference in growth rate and yield of *K.alvarezii* cultivated using different stocking densities and two farming methods at two sites on the south coast of Kenya.

II. H_o: There is no significant seasonal variation in growth rate and yield of *K.alvarezii* under raft and off- bottom methods of farming within the lagoonal reefs on the south coast of Kenya.

III. H_o: There is no significant influence of physico-chemical parameters on the growth rate and yield of *K.alvarezii* on the south coast of Kenya.

CHAPTER TWO

LITERATURE REVIEW

Seaweeds, or marine microalgae, are plant-like organisms grouped into three phyla of red, brown, and green, with a total number of species estimated at between 8,000 and 10,500 (Lüning, 1990; Thomas, 2002; Hurd et al., 2014; Guiry, 2015). Seaweeds are ubiquitous in coastal areas, exhibiting extensive regional species richness and global diversity patterns (Abbott and Norris, 1985; Kerswell, 2006). Zemke-White and Ohno (1999) documented 145 species used for human consumption and 101 for hydrocolloid. The worldwide seaweed industry provides a wide variety of products for direct or indirect human uses that have an estimated total value of US$10 billion per year (Bixler and Porse2011; FAO 2013). Seaweed for human consumption constitute about 83 % of production (Craigie,2011), while the remainder is used as fertilizers and animal feed additives, medical applications (Zimmermann *et al*.,2005;Ehrhart*et al*.,2013), and biotechnological applications (McHugh,2003). Worldwide, microalgae production increases 5.7 % every year and more than 18 million tons of microalgae were produced from global capture and aquaculture in 2011 (FAO 2014). In 2011, 96 % of the global total production of microalgae came from aquaculture, with Asian countries dominating seaweed culture production (99.05 % by quantity and 99.36 % by value, FAO 2014).

Five genera (e.g., *Saccharina*, *Undaria*, *Porphyra*, *Eucheuma*/*Kappaphycus*, and *Gracilaria*) represent around 98 % of the world's cultivated seaweed production (Suo and Wang 1992,Pereira and Yarish2008).*Saccharina japonica* was the most cultivated algae in the world until 2010 when the production of *Eucheuma*/*Kappaphycus* reached over 5.5 million tons for a value over US$1.3 billion (Suo and Wang 1992; McHugh 2003; FAO 2014). *Saccharina* and *Eucheuma*/*Kappaphycus* are mostly produced as raw materials for the food and food polymer industries. Aquaculture of seaweed is scarce outside of Asia, which triggered a worldwide search for hitherto unexploited natural seaweed resources. In 2011, 786,466 t of seaweeds was commercially harvested in 28 countries, ranging from cold to tropical coastlines in both hemispheres, with over 55 % of the biomass harvested in Latin America and almost 32 % in Europe (FAO 2014). The top producers are Chile and Norway, respectively, accounting for 51.3 and 19.2 % of the global catches of natural seaweed (FAO 2014).

While 33 countries reported seaweed farming in 2012 for a total of 23.8 Mt, 98.7% of production came from eight Asian countries, in order of quantity: China (53.6%), Indonesia (27.4%), the Philippines, Republic of Korea, Japan, Korea DPR, Malaysia, and Vietnam (FAO, 2014; FAOSTAT, 2015). Zanzibar in Tanzania occupies the ninth place with 0.63% of world production. Thus, nine countries (four temperate and five tropical) produced 99.3% of farmed seaweed output. Harvesting from the wild has remained stagnant at ∼1 Million tones/year for the last decade, with 1.1 Mt in 2012 or 4% of total global seaweed production (FAO, 2014; FAOSTAT, 2015). Presumably, there is more seaweed harvesting from the wild with local, unreported use. Thus, total farmed and wild-harvested output of ∼25 Mt in 2012, though sizable, is still only ∼0.3% of the total plant food produced in 2012 through agriculture (Valderrama *et al.*, 2013, 2015). However, this growth is already evidence that a large expansion in seaweed farming is viable both technically and economically in various conditions. An economic analysis of seaweed cultivation around the tropical world has shown that in some countries, primarily Indonesia and the Philippines, *Kapppaphycus* farming is already a well-established industry, providing employment opportunities to thousands of coastal inhabitants who have reduced access to alternative livelihood sources (Valderrama *et al.*, 2013, 2015). Seaweed use by harvesting or collecting from the natural environment (wild harvest, including beach cast collection) is an ancient human practice in many regions of the world, like China (Tseng, 1981; Tseng and Chang, 1984; Xia and Abbott, 1987) and Europe (Kain and Dawes, 1987; Critchley and Ohno, 1998; Critchley *et al.*, 2006). There is evidence of seaweed use for food and medicine from over 14,000 years ago in southern Chile (Dillehay *et al.*, 2008). The most traditional uses of seaweed include both nonconsumptive and consumptive forms: as medicine, as inputs into industrial processes, as fertilizer and animal feed, and for other domestic purposes such as for building materials. Human consumptive uses include raw products, such as in salads, soups, and main dishes, including sushi, as well as in processed form such as flavorings in chips and snacks (Dillehay *et al.*, 2008).

Farming techniques have undergone several innovations since it was first introduced. The growth rates are influenced by seasonal variations and nutrient levels in different sites (Rao and Mantri, 2005). In Southern Japan, daily growth rate has been measured for culture under different temperatures and pH in laboratory controlled conditions and at different depths in the sea using the floating raft culture method. It is generally accepted that *Kappaphycus* requires warm sea water, high light levels, nutrient enriched water and a high degree of water motion for successful cultivation (Glenn and Doty, 1990). Differences in their physiological characteristics including growth performance and photosynthesis have been reported from laboratory studies (Dawes *et al.*, 1994), however, in field studies or cultivation trials only one- or two-color strains (preferentially brown and green) have been studied so far (Ohno *et al.*, 1994; Hurtado *et al.*, 2001). The selected and cultivated varieties of *K. alvarezii* have been introduced to numerous parts of the world for the purpose of research or the development of a commercial method of farming of these seaweeds. The commercial mariculture of *Kappaphycus alvarezii* (Doty) and *Eucheuma denticulatum* (Solieriaceae, Gigartinales, Rhodophyta) in Zanzibar, Tanzania started in December 1989. At the experimental stage, both local Tanzanian and Philippines strains of *K. alvarezii, K. striatum* and *E. denticulatum* were used (Mtolera *et al.*, 1995a). The Tanzanian strains had lower growth rate than the Philippine strains and among the Philippines strains,*E. denticulatum* had a better growth rate than *K. alvarezii* and *K. striatum*, and therefore farmers preferred to cultivate the Philippines strain of *E. denticulatum* (Mtolera *et al.*, 1995a).

Although Kenya has similar environmental conditions as Tanzania (McClanahan, 1988) there is yet no commercial exploitation of farmed seaweeds using different methods. However, Wakibia *et al.*, (2006) reported on the factors that influence the growth rates and yield in Kenya.

Nursery procedures have been developed to produce clean and healthy seedlings at commercial scale, including sexual or asexual spore formation (Reddy *et al.*, 2008). Tip culture (vegetative micro propagation) is also growing as an advanced means for vegetative propagation. There are more than 85 species of seaweeds for which tissue culture has been reported. Laboratory produced spore seedlings attach themselves directly to ropes or nets or to strings that are then attached to ropes and nets and planted for the growing season (Reddy *et al.*, 2008). Nursery tanks are often necessary to keep a selected vegetative stock for reproduction and planting when seasonal changes do not allow continuous farming throughout the year, also reducing natural stands. An advantage of nursery or laboratory reproduction is that high quality and uniform seedlings from selected vigorous and healthy parental lines can be used, promoting higher yields and quality. However, when simple vegetative propagation is feasible, dependence on laboratories to supply seedlings may initially inhibit farming and increase costs until it becomes competitive with vegetative reproduction at the proper scale (Reddy *et al.*, 2008).

Although the use of vegetative seedlings obtained from the last seaweed crop is advantageous for production at a small scale and with low investment, if properly practiced (e.g., Breton, 2006), selecting, cutting, and attaching vegetative seedlings of 20–150 g each spaced 0.2–0.25 m apart to ropes or nets is very time consuming. Vegetative seedlings are attached either by tying them (tie–tie system) or inserting them in the rope fabric. Using vegetative seedlings also requires seaweed biomass in the order of one to several tons per hectare, up to one-fourth of the harvest, several times a year. Nonetheless, and depending on the scale of operation, as particularly determined for *K. alvarezii,* farming operations based on this method of reproduction and planting are financially viable (Valderrama *et al.*, 2015). When harvesting is partial (i.e., ropes and nets are left deployed with a portion of each plant left attached for regrowth) as is the case for many species, replanting costs are considerably reduced. After obtaining or producing seedlings, planting is done using the main cultivation techniques, which are variations in many ways determined by the species being farmed and the distance to the shore and to the sea floor. With some exceptions, cultivation techniques are mostly based on the use of ropes and nets (Valderrama *et al*., 2015). These techniques are by far the main ones in use at sea to date, including variations such as supporting nets with bamboo framing. After attaching the right number or density of seedlings of desired characteristics to ropes or nets (“seeding”), planting consists of placing these at sea at a given depth in a predetermined spatial arrangement based on an optimized density of number of plants per area. Density is determined for each species based on the expected size at harvest and other considerations, by establishing the number of plants within and between rows for ropes or the equivalent parameters for nets (Valderrama *et al*., 2015).

Seaweed farming is an extractive aquaculture whose very process of production of valuable biomass renders the sea’s various ecosystem services with ecological and economic values (Chopin *et al*., 2008, 2010; Neori *et al*., 2007; Radulovich *et al*., 2015). As compared to animal aquaculture, seaweed farming adds oxygen during photosynthesis and cleans seawater from excess nutrients (N, P, and others). Nutrient extraction, or uptake, cleans water effectively and thoroughly through a process known as bioremediation, with several practical applications (e.g., Forster, 2008; Neori, 2008). It has also been shown that farming seaweeds in coastal waters enhances biodiversity and fisheries (Radulovich *et al*., 2015). Seaweeds are carbon sinks that can reduce ocean acidification through the uptake of CO2 from water at a scale that depends on the scale of farming operations. It has been estimated that to stabilize atmospheric CO2 at 400 ppm, global carbon sequestration needs to be several hundred gigatons of carbon, and Hughes *et al*., (2012) analyzed the use of seaweeds for carbon negative fuel production. As a thought exercise and with estimated gross seaweed capture rate of

2000 t C/km2/year, it would take 5 million km2 (1.4% of the world's ocean area) to take up 10 Gt

C/year by ocean-grown seaweed, roughly the total yearly global carbon emission from use of fossil fuels (Landschützer *et al.*, 2014). This type of massive biomass production scheme could sustainably alleviate the world's food gap and provide a source of bioenergy (Branch *et al.*, 2013). Very large-scale seaweed farming can have both positive and negative impacts on biodiversity. Shading can and alkalization may harm and benefit different local biological activities, competing for instance with phytoplankton and therefore filter feeders, but at the same time aiding calcification of shellfish and corals, which suffer from ocean acidification (Branch *et al.*, 2013). The combination of large-scale extractive seaweed farming with the extractive farming of bivalves and the fed farming of fish in cages may allow an ecologically and functionally balanced development (Chopin *et al.*, 2008, 2010; Neori *et al.*, 2007), though limited in scale to areas surrounding fish farming operations.

The cultivation or farming of seaweeds can thus be defined as the optimized planting of seaweed crops in water for growth. This means optimizing for photosynthesis the interception of solar radiation mostly on an area basis and the interaction with water for the uptake of nutrients, gases, and water in a volumetric basis, also related to water movement (Ye *et al.*, 2011). From there on, during the grow-out phase, farming is mostly ensuring continued photosynthesis at the optimized rate until yield.

Though the availability of water, sunlight, and gases can usually be taken for granted in the selection of a location for seaweed farming, adequate supply of nutrients may be an important consideration (Ye *et al.*, 2011). In a successful farm, the capacity of seawater in the given locality to provide nutrients through motion or upwelling is matched with or surpasses the uptake potential of the cultivated seaweed. Excepting experiments and some commercial attempts that have not prospered, currently all worldwide seaweed production depends on nutrients from local seawater, which is often enriched by anthropogenic inputs (Ye *et al.*, 2011; Feng *et al.*, 2013). When analyzing marine aquaculture in general, this bio extractive nature of seaweed growth may complement and compares very favorably in economic and environmental terms with fed-fish farming, which, in contrast, requires massive inputs of feed, much of which ends up in the surrounding environment as feces or unused feed (Ye *et al.*, 2011; Feng *et al.*, 2013).

Fixation of atmospheric nitrogen by epiphytes growing on seaweeds (Head and Carpenter, 1975; Philips *et al.*, 1986) is an overlooked factor that may have great potential regarding seaweed nutrition, though this may be insufficient for very large farms further off-shore. The “dumping” of nutrients into the sea from anthropogenic sources is so large that extensive dead and hypoxic sea areas exist, estimated at ∼250,000 km2 and growing (Diaz and Rosenberg, 2008). Seaweed cultivation in such eutrophied areas would absorb excess nutrients and thus contribute to rebalancing local ecosystems, representing a clear opportunity for large-scale seaweed farming for products and services in these areas.

Understanding this duality of the nutrients issue at sea, ranging from their absence to their excess, is essential to expanding seaweed farming.

Furthermore, huge quantities of naturally occurring ocean nutrients can be artificially up welled for mid ocean farms, perhaps coupled with passive energy generation (Gao and McKinley, 1994;

Lovelock and Rapley, 2007; Maruyama et al., 2011).

There are three exceptions to the shallow water "benthic" nature of seaweeds that are relevant to farming. The first is that two species of *Sargassum* (*S. natans*and *S. fluitans*), a ubiquitous genus of brown seaweeds, live free-floating at the surface of the Sargasso Sea and nearby Atlantic areas, where they comprise millions of tons of biomass (Huffard *et al*., 2014; Lapointe *et al*., 2014). However, although *Sargassum* species abound around the world, only these two *Sargassum* species are holopelagic (i.e., have a completely pelagic life cycle) and, as far as it is known, inhabit only the Sargasso Sea and nearby areas. For example, free-floating *Sargassum* masses in the South China Sea have been shown to be detachments from benthic growth (Komatsu *et al*., 2008). Such free-floating, holopelagic growth, which is in many ways analogous to "green tides," may have applications for farming (Komatsu *et a*l., 2008). The second exception is the opportunistic growth that occurs when seaweed seedlings become attached to floating structures that provide a substrate (e.g., a drifting log or a buoy and its ropes). This ability of seaweeds to grow attached to floating objects is the basis of seaweed farming. Just about any seedling of any seaweed can be attached to ropes or nets and will grow as long as it receives adequate sunlight and its nutrient and gas requirements are satisfied, no matter how deep the sea is beneath it (Komatsu *et al*., 2008). The third exception is when seaweeds are grown without attachment in tanks or other confined spaces and provided with adequate circulation (Neori *et al*., 2004). This is often referred to as tumble culture. Therefore, it is clear that seaweeds are not at all obligate benthic organisms and can grow very well as epipelagic organisms, be it attached or freely floating at the surface or submerged in seawater of adequate temperature and salinity, as long as their requirements for water, sunlight, nutrients, oxygen, and carbon dioxide are adequately provided for (Neori *et al*., 2004).

Various abiotic stressors, which are often considered a more widely occurring limitation, perhaps due to their severity, are usually the product of adverse or non-optimal environmental conditions, often happening in a short time, such as very low or too high irradiance, water temperature, and salinity (Msuya and Porter; 2014). The effects of abiotic stressors can be direct, promoting a variety of undesirable responses, including complete disintegration of the crop, or indirect, by triggering or favoring pathogenicity, like with ice–ice, a bacterial disease favored by nonoptimal environmental conditions. Msuya and Porter (2014) describe the impact of negative environmental conditions, particularly high water temperature, to off-bottom seaweed farming in Tanzania. To date, the best procedure to deal with such stressors is prevention in the form of selecting the optimal site, seaweed species, cultivar and seedlings, and farming method for each environment. Cleaning the standing crop by hand (e.g., splashing in water) is useful in reducing some types of fouling. Importantly, both biotic and abiotic hazards, like sharks and rough seas, must also be considered regarding worker welfare (Msuya and Porter 2014).

Biotic stressors may also have positive effects. For example, cyanobacteria-fouling seaweeds may also fixate atmospheric nitrogen. Herbivory can also be beneficial when it enhances fisheries and nutrient recycling (e.g., Lapointe *et al*., 2014; Radulovich *et al*., 2015).

Control is essential in both agriculture and aquaculture, including seaweed farming. Although total control is not achievable even in the most sophisticated growth chambers and aquaria, there are significant control-based differences between farming and natural growth (Lin *et al*., 2008). As previously indicated, because of the overpowering nature of several of the variables involved, including biotic stressors and particularly variables related to water and climate, many of the control strategies must be imbedded in the seaweed farming system before it is established. In that sense, just as any successful agriculture is “climate- and soil-smart,” successful seaweed farming must be “climate- and water-smart.” For this, proper selection of site, seaweed species and propagation, and cultivation techniques are essential specific elements that determine control for each situation (Lin*et al*., 2008).

The capacity to produce seedlings of the desired species or cultivar in sufficient number and quality whenever required are key aspects for any farming operation (Lin *et al*., 2008). This is particularly important regarding some seaweed species or locations because abundant material for vegetative propagation is not always available, and sexual or asexual reproduction is often complex and requires expertise to be implemented (Lin *et al*., 2008). Due to adaptational behavior, many seaweed species naturally tend to disintegrate totally or mostly after reproduction or in response to seasonal or other drastic or rapid changes. As examples, confronting the cold of winter may damage the crop and the shortening of day length may trigger undesirable reproductive changes (Vásquez, 1995), and Russell (1986) described the process of selecting infertile plants of the red seaweed *Chondruscrispus*, which “tend to disintegrate when they reach reproductive maturity,” as the basis for developing cultivars for farming (Hurd *et al.*, 2014). If unaccounted for, this type of behavior may represent a hindrance to farming, not only for propagation but also in terms of obtaining yields. Based on this, for the main temperate zone seaweeds, *Saccharina*, *Undaria*, and *Pyropia*, propagation is through spore formation (Hurd *et al.*, 2014). For subtropical and tropical farmed species, fragments of thalli are often sufficient as vegetative seedlings.

Both ropes and nets provide adequate substrate for cultivation of seaweeds, though their success in this role often depends on the type of fabric being used (Valderrama *et al.*, 2015). They are a customizable component of farming infrastructure and their use allows for varying lengths and widths of plots for a variety of situations, both floating and submerged. They are also accessible, being generally available, low cost, and light yet durable and flexible – critical characteristics for withstanding deployment in the marine environment. The desired spatial arrangement of “seeded” ropes – or lines – and nets is obtained by holding them in place and depth through two main methods, depending on the depth to the floor or the bottom (Valderrama *et al.*, 2015). For shallow waters wooden pegs, posts, or poles buried in the sea floor are used. Pegs (e.g., 0.7 m long) are sufficient to hold off-bottom plantings (Hurd *et al.*, 2014).

Poles of varying lengths are used for plantings at midwater or at the surface. A modality in areas where tides fluctuate moderately is to take advantage of the fixed depth allowed by poles to subject the planting to varying depths of water to the point that at some hours of the day the whole planting is exposed to air. This does not usually affect the seaweed yet substantially decreases the load of fouling, parasites, and herbivores. In China, cultivation of *Pyropia* seeded on nets uses this technique, among others (Hurd *et al*., 2014). Off-bottom and midwater plantings (i.e., submerged from 3 m to 5 m) do not alter the seascape view and allow for other activities at the surface like navigation and recreation. For example, some off-bottom plantings allow for working on them during low tide and are surfing sites during high tide. However, off-bottom plantings affected by very low tides may suffer from high water temperature that combines with other hazards (Msuya, 2011; Msuya and Porter, 2014).

For deeper waters (varying from 3 m to 10 m or more during low tide), which represent the vast majority of the coastal environment and where farming will need to expand, spatial arrangement based on anchors and buoys is often necessary, though anchoring using pegs is also done in shallower sites (Msuya, 2011; Msuya and Porter, 2014). Anchors vary in cost and individual capacity from burlap sacks filled with sand to concrete blocks weighing a ton or more. Buoys vary from reused plastic bottles, jugs, and barrels to factory-sourced buoys. For floating rafts, the shape of the structure is given by the rigid frame (Msuya, 2011). The shape and tensional integrity of floating line plantings is obtained through the push–pull of the properly matched interactions between the sinking and buoyancy provided by water and the opposite effects from buoys and anchors (Msuya, 2011). The number and characteristics of the different types of anchors and buoys depend on various conditions for each operational unit. For example, small buoys are placed along lines and larger ones at key structural points. Currents play a significant role and, to the extent that distance to the bottom is varied, waves and tides require a “sagging” of extra length of rope from the structure or raft to anchoring. This sagging is particularly noticeable at low tides and tends to disfigure the spatial arrangement to an extent (Msuya, 2011).

Other cultivation techniques being developed or, to a point, used, include planting directly on the sea bottom in a manner similar to planting on land, such that farms resemble natural kelp forests and seaweed prairies (Chung *et al*., 2013). Given the distinct tendency of kelp-type seaweeds to grow several meters tall in temperate waters, the term “forest” is used to describe their occurrence; however, most seaweeds that cover extensive bottom surfaces are much shorter (e.g., beds of *Sargassum* reach ca. 1 m tall) and resemble prairies more than forests. While this approach is limited to shallow coastal waters where sufficient sunlight reaches the bottom, its proponents argue that cultivated seaweed forests and prairies can act as carbon sinks and provide additional ecosystem services (Chung *et al*., 2013). Other bottom-planting modalities include rock-based culture practiced with *Eucheuma spinosum*in western Indian Ocean coasts, tying seaweed cuttings with an elastic band to rocks, which after a few weeks establish their own fixation points (De San, 2012), and planting seaweed seedlings directly on the seabed or using artificial substrates placed on the floor, as has been described for *Gracilaria* farming in Chile (Hernandez Rodriguez *et al*., 2001).

Tank and pond seaweed culture, often considered small scale though intensive, can have largescale applications. Schemes for very large marine seaweed farms in deserts by the sea have been proposed (FAO, 2010,Garcia Reina, 2010; FAO, 2010,Shpigel, 2013). To take advantage of extensive ocean areas, it's considered useful for seaweed production on the open sea on a much larger scale. Large drift culture rafts for free-floating cultivation have been proposed (Notoya, 2010), whether resembling growth on the Sargasso Sea or using an unanchored structure that holds shape on its own with seaweeds seeded on ropes or nets. This can be implemented particularly in gyres, where the farms will be largely kept in place by currents, and/or to clean and recover hypoxic ocean areas. If structures that hold shape on their own are utilized, then single-point moorings can be used, possibly regardless of the depth to the bottom. Seaweed nutrition can be enhanced by artificial upwelling (e.g., as in Maruyama *et al*., 2011).

Harvesting cultivated seaweeds and bringing them to land is a key and relatively costly aspect of sea farming (Hurd *et al*., 2014). Depending on the scale of the operation, the methods employed vary substantially, from manually bringing in an armful load on foot from intertidal off-bottom plantings to mechanized harvesting of floating line plantings from large barges in deeper waters. In many ways, farmed seaweed harvesting is analogous to harvesting from agriculture operations – varying according to the crop being farmed and its intended use, scale of the operation, available technology, and sea and weather conditions (Hurd *et al*., 2014).

Depending on the crop being produced or the cultivation technique, harvesting may be total or partial.

Total harvests include ropes or nets together with the seaweed material, as is done with *Saccharina*, *Eucheuma*, and *Kappaphycus*. In partial harvests only new growth from the initial planting or the previous harvest is taken, leaving behind sufficient material from each plant for regrowth allowing for multiple harvests, as is done with several species including *Pyropia*(*Porphyra*), *Gracilaria*, and *Sargassum* (Hurd *et al.*, 2014). Differences in harvesting techniques occur for several reasons. A total harvest may be required at the end of the growing season, when maximum growth has been achieved and/or to avoid the crop suffering negative effects from seasonal changes. Another reason, as applied to *Eucheuma* and *Kappaphycus*, is that although harvesting may occur at 45–60-day intervals throughout the year, the highest accumulations of carrageenan are normally found in older tissue. In many cases, harvested lines holding these seaweeds are passed through a hole (line stripper) where all material is removed from the rope. Therefore, it makes sense to take the entire seaweed material, rather than just new growth, in order to obtain all the older tissue (Valderrama *et al*., 2013).

Partial harvest, in contrast, allows for several harvests (even up to 4 years with *Sargassum* (Redmond *et al.*, 2014a) without the need for replanting, which substantially decreases farming costs. Partial and frequent harvesting also allow farmers to count on several crops per year, avoiding complete losses of a single crop while also decreasing the compounding effects of epiphytic and epizootic fouling and other biotic stresses. Frequent harvests also allow farmers to take advantage of varying market conditions by managing supply of produce when demand is high, although seaweed maturity considerations are important (e.g.,Barta, 2008). When farming for food, tender tissue obtained by clipping off new growth often has better gastronomic characteristics than older tissue; "hard" seaweed pieces were a common negative comment from tasting panels trying different seaweed food recipes (Radulovich *et al.*, 2015).

Harvesting by hand produces the highest quality material, in part because of the opportunity the process provides for some degree of on-site removal of sea-borne contaminants (fouling, opportunistic animals and epiphytes, sea debris). Although machine harvesting is faster, it may require more careful off-site separation of undesired material from the harvested crop prior to use or processing. (Radulovich *et al.*, 2015).

While *Eucheuma denticulatum* is the most popular species being produced due to its ease of adaptation to the prevailing aquatic environmental conditions, it faces the marketing problem. On the other hand, *Kappaphycus alvarezii* which fetches higher gate price than *E. Denticulatum* has continued to register poor growth when cultured using the same culture techniques at similar environment. *Kappaphycus alvarezii* has been shown to be more vulnerable to the negative effects of the rising seawater temperature on cultivated seaweeds. These negative effects include infestation of plants by 'ice-ice'syndrome (whitish soft thallus tissue) and epiphytes and occur mostly on seaweeds cultivated under the popular off-bottom technique. On the other hand, bamboo wood used in constructed floating rafts for culture of *K.alvarezii* in deep water is reported to degrade fast leading to sometimes loss of plants and frequent uneconomical replacement.

As a strategy to improve the growth and production of this high value seaweed species, a newly innovated culture technique (Raft method) in deeper water was suggested as a remedy for 'ice-ice' challenges (Msuya *et al.*, 2014). Like in many seaweed cultivating countries Kenya is embracing this technology through research initiatives in mariculture,

Currently seaweed farming technology has been transferred to over 200 farmers at Kibuyuni, Mkwiro and Funzi in Kwale County who are now engaged in seaweed farming as a source of livelihood.

While all of *Eucheuma* and *Kappaphycu s*production is based on simple vegetative propagation obtained from the previous harvest (Teitelbaum, 2003; Valderrama *et al*., 2013), for *Gracilaria*and *Sargassum* vegetative propagation is the most common method, although they are also reproduced by spore formation (Redmond *et al*., 2014a,b).

The aim of the present study was to compare the growth rates and yield of *K. alvarezii* in two sites on the south coast of Kenya using the known techniques of floating raft and off- bottom culture systems treated with variable seedling densities. The work also assessed the influence of physico-chemical variables and seasonality on growth rates and yield of *K.alvarezii*.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Sites

The study was conducted at two sites (Gazi Bay and Kibuyuni) (Fig.1) on the southern coast of Kenya during March –July in 2014 and November 2014 – April 2015. The study compared two seaweed culture methods (Rafts vs. off-bottom plots) at different stocking densities at the two

sites.

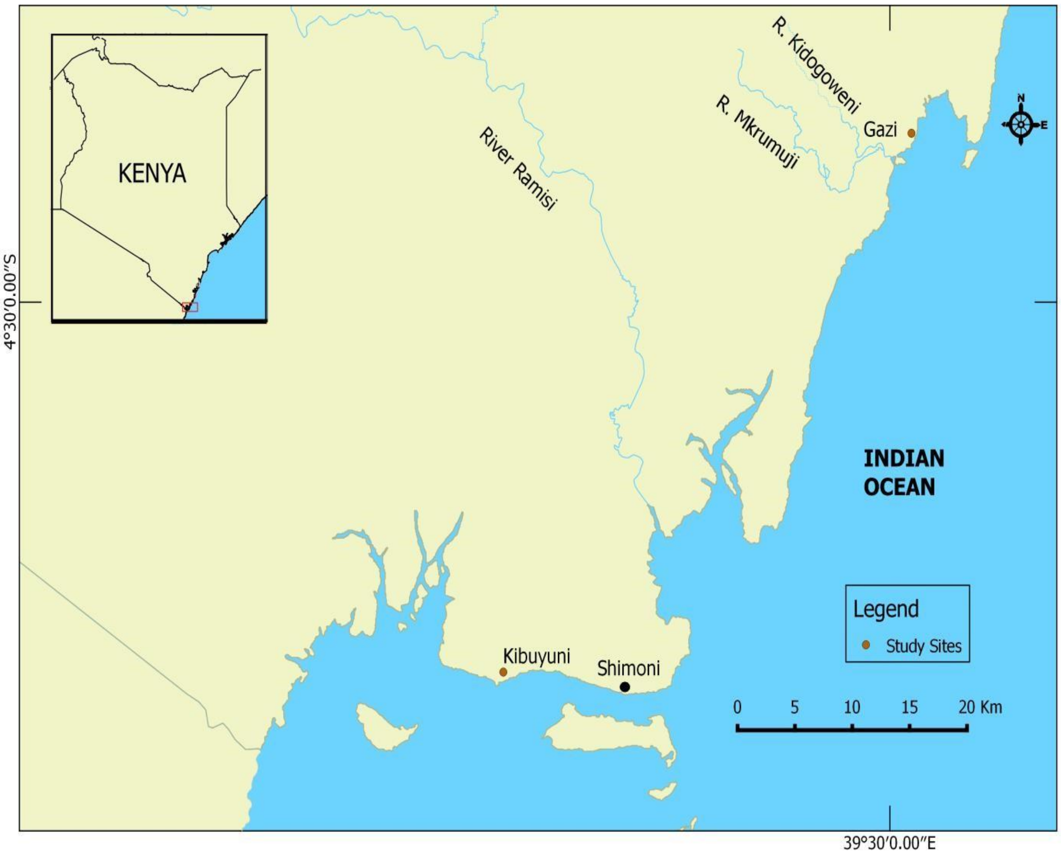

Figure 1. Amap of the Kenyan south coast showing Gazi and Kibuyuni study sites on the south coast where experimental farming of the seaweed was conducted. (Source : Author, 2017)

The two study sites were chosen to represent a range of environmental conditions on the Kenyan coast. Gazi Bay ((4°25 S, 39°30 E)) (Fig. 1) is a shallow mangrove system which receives freshwater from nearby rivers, Kidogoweni and Mkrumuji. Shoreward wind and tidal currents mix water in the bay leading to seawater with near oceanic salinity (brackish) (Kitheka, 1996).

The second site, Kibuyuni ((4°38 S, 39°20 E))is 20 km from Gazi and is a large intertidal reef flat covered by a belt of the sea grass *Thalassodendron ciliatum*. The seaweed experimental farms in this study were established on sandy flats covered with about 10-30 cm of water at the lowest tide and 3-4 m at the highest tide at both sites. Both sites (Gazi and Kibuyuni) are influenced by large-scale pressure systems of the Western Indian Ocean and monsoon winds (Southeast and Northeast monsoons). The southeast monsoon (SEM) extends from April to October and the northeast monsoon (NEM) from November to March (McClanahan, 1988). The southeast monsoon is associated with strong winds, low air and water temperatures, low solar radiation and heavy precipitation, and low salinity (McClanahan, 1988). During the northeast monsoons, these conditions are reversed with high solar radiation, high salinity and water temperatures.

3.2. Preparation of the experimental plots

3.3. Bamboo Rafts

The experiment on the growth and yield of *Kappaphycus alvarezii* were conducted in floating rafts and off- bottom plots at each of the two sites. Bamboo poles were used to construct the mainframes of the rafts (5 m × 2.5 m) with one support in the middle (Fig. 2, Plate 1). Each raft had four ropes of 6mm thickness tied across the frame as shown in Plate 1. The ropes were tied at interval of 0.5m. Each of the four ropes had 20 seedlings (80 seedlings per raft) and the spacing between seedlings on the rope was 20 cm apart (Plate 1). Seedling insertion in the rafts is described in part 3.1.4

Plate 1.A picture showing a typical raft in water at a study site during low tide. Notice the inserted seedlings on the ropes as explained in part 3.1.4.
(Source: Author, 2017)

3.4. Preparation of off- bottom Plots

The off-bottom plots were also 5×2.5m in dimension and were demarcated by wooden mangrove stakes of 1.5 m in height. Each off-bottom plot had also four ropes of 6 mm thickness tied from one end of the stake to the other (Plate 2). Spacing between each rope in the plot was 0.5m. Each rope had 20 seedlings (giving 80 seedlings per each off- bottom plot). Spacing between seedlings on each rope was 20cm apart per plot as was for the rafts.

At each of the two sites of Gazi and Kibuyuni (see Fig. 1 for locations), the rafts and off-bottom plots were located at the same general area in the lagoons and so experienced same environmental conditions. Each raft and plots at each site was applied to one of four seedling weights/densities of; 50g, 75g,100g, 125g and 150g. Each of the five densities was replicated three times (×3 for rafts and plots giving 15 rafts and 15 plots at each site). The replicated rafts and plots at each site were then stocked with seedlings of *Kappaphycus alvarezii* as below:

3.5 Seedling insertion in the rafts and plots

Healthy seedling materials of weights., 50g, 75g, 100g, 125g and 150g were obtained from the farmers at Kibuyuni and were applied to the raft or the off-bottom plots as experimental units. In the 50g raft treatment for example; each of the four ropes (see 3.4) had 20 seedlings each weighing 50g. Therefore one rope of 50g treatment had 1000g (20×50g) of seedlings giving 4000g for each plot. Similarly, a 75g treatment plot or raft had a total of 6000g seedling, while a treatment of 150g had a total seedling weight of 12000g. Each of the 5 seedling treatments (50g, 75g,100g,125g,150g) were replicated three times (× 3) for rafts and off- bottom plots at each of the sites.

Plate 2. Seaweed plants of *Kappaphycus alvarezii* suspended in the off-bottom plots at low tide. Notice the stakes. (Source: Author, 2017)

3.5.Sampling Design

The rafts and off- bottom plots were treated and sampled as follows;

The five different initial seedling densities; 50g, 75g,100g, 125g and 150g (see section 3.2.3) were tried for growth rate and yield comparisons. Fifteen rafts and fifteen plots of 5x 2.5m (3 replicates per treatment) were used at each of the two study sites of Gazi and Kibuyuni.

Sampling of the treatments was done fortnightly during the two seasons; southeast monsoon (March to July 2014) and northeast monsoon season (November 2014 to April 2015). The ropes containing the seedlings were initially weighed before being deployed in the rafts or the off- bottom plots. Sampling during the SEM season was done for eight weeks, while sampling for NEM season was done for12 weeks, at bi-weekly intervals. During each sampling day, seedlings in the ropes of the off- bottom plots and rafts were untied from the stakes (for plots) or bamboo poles (for rafts) and lifted out of the water one rope at a time. The whole rope was weighed with the seedlings using a portable digital balance and weight recorded to the nearest gram. The number of lost seedlings between sampling was also recorded. After weighing the ropes with the seedlings, the ropes were then tied back to the rafts or plots to continue growing the seedlings. After 6 weeks (3 sampling occasions), the seedlings were weighed with the ropes and harvesting was done by removing all the seedlings from the ropes, the ropes were washed to remove epiphytes and the seeds replanted using cuttings from the harvested plants for further monitoring. Initial experiments showed massive losses at harvesting beyond 6 weeks, so harvesting was majorly done at this period when the plant had attained maximum biomass. A great proportion of seedlings during NEM season weighing 100 g and after 3weeks of biomass increase were lost due to breakage, *ice ice* and herbivory (Replanting was done after the 6th week thus the reason for 6 sampling intervals during NEM period).

3.6. Physico-chemical parameter measurements

Physico-chemical parameters (D.O, pH, temperature, TDS, and salinity) were monitored *in situ* once monthly using a hydro lab and measurements covered the two seasons at both sites.

Turbidity at sites was measured using Secchi disc. Water samples for nutrients (phosphates, ammonia and nitrates) were collected randomly at each site using sample bottles and analyzed in the laboratory once a month. The phosphate-phosphorus was determined using the Denges Method (Lind, 1979) and following APHA (1985), while Nitrate-nitrogen was determined by phenol disulphonic acid method as described by Mackereth (1963). Ammonia was determined by the procedure of Parsons et al., (1984).

3.7. Data analyses

The Daily Growth rate (DGR) of *Kappaphycus alvarezii* was determined for the two sites and method as % increase in wet weight per day using the formulae (Dawes *et al.,* 1994):

DGR % =ln $[W_f / W_0]$ /t*100 DGR = [(Wt / Wo) 1-t – 1] x 100

Where:

W_0 = initial wet weight, W_f= weight after *t* days, t = time intervals (days).

The plant yield (Y) estimated in g/m^2 was determined for each method, treatment and site using the formula of Hurtado *et al.,* (2001) as;

$Y = (W_f/W_o)/A_t$

Where,

W_f= final fresh weight (g) at t day, W_o= initial fresh weight (g), A_t = Total area of the plot given as 5x 2.5m (12.5 m^2) for rafts and plots.

Factorial ANOVA was used to test for the effect of site, season and density treatments on growth rate and yield of *K. alvarezii.* Data were log (x+1) transformed before analysis in order to correct for heteroscedasticity of variance and to approximate normality of data. Canonical correspondence (CCA) analysis was used to determine the effect of water quality parameters on yield and growth rate of *K. alvarezii* at the sites under different culture methods and seasons.

CHAPTER FOUR

RESULTS

4.1. Daily growth rate and Yield of *Kappaphycus alvarezii* at sites during the Southeast monsoon season

4.2. Growth Rates

During the SEM season, the daily growth rate (% /day ± SD) in rafts at Gazi ranged from a low of 1.88 ± 0.21 in the 100g treatment on the 4th sampling period to a high of 2.95±0.15 in treatment 50g on the 6th week of sampling (Table 1). In the 50g treatment, growth was highest (2.95±0.15) during the 6th week of sampling and lowest on the 8th sampling week (2.59±0.24) (Table 1). In the 75g treatment, growth ranged from a high of 2.83±0.05 (2nd week) to a low of 2.27±0.2 on the 8th sampling week. For the100g treatment, growth ranged from a high of 2.72±0.06 (in the second week) to a low of 1.88±0.21during the 8th sampling week. In the 125g treatment, growth ranged from a high of 2.70±0.1 (in the second week) to a low of 2.10±0.20 on the 8th sampling period. In the 150g treatment growth ranged from a high of 2.75±0.07 (second week) to a low of 2.26±0.21 on the 8th week of sampling (Table 1)

One-way ANOVA analysis indicated significant difference within 100g treatment daily growth rate (F=3.87, P=0.025) and no significant differences within 50g, 75g, 125g and 150g treatments daily growth rates ($p>0.05$) among time intervals of sampling (Table 1). The Anova test indicated no significant differences in daily growth rates between all treatments during each of the weeks of sampling ($p>0.05$) (Table 1).

Table 1.Variation in mean daily growth rates (% /day ± SD) of *Kappaphycus alvarezii* in rafts at Gazi during the southeast monsoon season. Sampling occurred every two weeks.

Treatments (g)	**Sampling intervals (weeks)**					
	2	**4**	**6**	**8**	**F-value**	**P-value**
50	2.89±0.05	2.85±0.08	2.95±0.15	2.59±0.24	1.07	0.377
75	2.83±0.05	2.61±0.08	2.33±0.25	2.27±0.2	2.17	0.109
100	2.72±0.06	2.53±0.14	2.03±0.30	1.88±0.21	3.87	0.025
125	2.70±0.12	2.50±0.07	2.48±0.12	2.10±0.20	3.13	0.149
150	2.75±0.07	2.29±0.23	2.05±0.34	2.26±0.21	1.55	0.224
F-value	1.11	1.72	1.82	1.17		
P-value	0.371	0.172	0.152	0.344		

During the SEM season, the mean daily growth rate (% /day±SD) in off- bottom plots at Gazi ranged from a low of 1.60±0.09 in treatment 150g during 8th week of sampling to a high of 2.48 ± 0.03 in treatment 50g during the 2nd week of sampling (Table 2). In the 50g treatment, growth was highest (2.48±0.03) during the 2nd sampling week and lowest at 8th week of sampling at 2.28±0.07. In the 75g treatment, growth ranged from a high of 2.37±0.052 at the 2nd sampling week to a low of 1.90±0.29 on the 6th sampling week (Table 2). In the 100g treatment, growth rate ranged from a high of 2.4±0.016 (2nd week) to a low of1.81±0.08 during the 8th week of sampling. In the 125g treatment, growth ranged from a high of 2.31±0.05 (2nd week) to a low of 1.66±0.10 on the 8th sampling week. In the 150g treatment, growth ranged from a high of

2.39±0.02 (2nd week) to a low of1.60±0.09 during the 8th week of sampling (Table 2).

One–way ANOVA analysis indicated significant differences in daily growth rate within 100g, 125g and 150g treatments ($P<0.05$) and no significant differences within 50g and 75g treatments daily growth rates ($p>0.05$) (Table 2). Between weekly sampling, there was significant difference in the daily growth rate between treatments in daily growth rate in the 4th and 8th sampling weeks ($p<0.05$) and no significant differences in daily growth rate between treatments in the 2nd and 6th week of the sampling ($p>0.05$) (Table 2).

Table 2.Variation in mean daily growth rates (% /day ± SD) of *Kappaphycus alvarezii* in off-bottom plots at Gazi during the southeast monsoon season.

Treatments (g)	**Sampling intervals(weeks)**					
	2	**4**	**6**	**8**	**F- value**	**P-value**
50	**2.48±0.03**	2.47±0.18	2.30±0.04	2.28±0.07	1.05	0.393
75	2.37±0.052	2.13±0.04	1.90±0.29	1.96±0.059	1.8	0.173
100	2.4±0.016	2.16±0.030	2.07±0.03	1.81±0.08	22.62	0.001
125	2.31±0.05	2.02±0.06	1.68±0.16	1.66±0.10	8.49	0.001
150	2.39±0.02	1.76±0.18	1.85±0.09	1.60±0.09	8.93	0.001
F-value	2.32	3.56	1.79	9.49		
P-value	0.082	0.018	0.158	0.001		

Sampling occurred every two weeks.

At Kibuyuni during SEM season, the daily growth rate (% /day ± SD) in rafts ranged from a low of 0.69±0.05 in treatment 150g during 8th sampling week to a high of 2.86±0.14 in treatment

75g during the 2nd week of sampling (Table 3). In the 50g treatment, growth was highest

(2.49±0.10) in the 2nd week of sampling and lowest (1.98±0.09) in 8th week of sampling. In the

75g treatment, growth ranged from a high of 2.86±0.14 (2nd week) to a low of 1.83±0.17 on the 8th week of sampling. The 100g treatment was missing as the seedlings were carried away by the waves. In the 125g treatment, growth ranged from a high of 2.31±0.20 (2nd week) to a low of

1.45±0.35 on the 4th sampling interval. Growth rate in the 150g treatment ranged from a high of 1.79±0.18 (2nd week) to a low of 0.69±0.05 on the 8thweek of sampling. In general there was high growth in the second week of sampling that appeared to decline with time during the SEM season

One-way ANOVA analysis indicated significant differences in daily growth rate within 50g, 75g, and 150g treatments ($P<0.05$) with no significant differences within the 125g treatments ($p>0.05$). Between treatments, there was significant difference in daily growth rate in the 2nd and 8th week of sampling ($p<0.05$) and no significant differences in daily growth rates in the 4th and 6th week of sampling ($p>0.05$) (Table 3).

Table 3.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus alvarezii* in rafts at Kibuyuni during the southeast monsoon season. Sampling occurred every two weeks.

Treatments (g)	**Sampling intervals (weeks)**					
	2	**4**	**6**	**8**	**F-value**	**P-value**
50	2.49±0.10	2.08±0.14	2.23±0.14	1.98±0.09	3.26	0.043
75	2.86±0.14	1.90±0.05	2.29±0.01	1.83±0.17	16.18	0.011
125	2.31±0.20	2.15±0.24	1.95±0.33	1.45±0.35	1.66	0.253
150	1.79±0.18	1.76±0.02	1.41±0.13	0.69±0.05	18.78	0.008
F-value	4.32	1.37	2.26	6.64		
P-value	0.028	0.311	0.135	0.007		

For the off-bottom plots at Kibuyuni, the daily growth rate (% /day ± SD) during SEM season was highest at 2.42±0.02 on the treatment 150g during 2nd week of sampling (Table 4). In the 50g treatment, growth was highest (2.30±0.06) on 2nd week and lowest (1.49±0.11) in 8th week (Table 4). In the 75g treatment, growth ranged from a high of 2.36±0.04 (2nd week) to a low of

1.50±0.09 during the 8thweek. In the 125g treatment, growth rate ranged from a high of 2.41±0.04 (2nd week to a low of 1.52±0.17on the 8th sampling. In the 150g treatment, growth ranged from a high of 2.42±0.02 (2nd week) to a low of 1.32±0.11 on the 8th sampling week (Table 4).

One-way ANOVA analysis indicated significant differences in daily growth rates within all treatments ($P<0.05$) and no significant differences in daily growth rate between treatments.

($p>0.05$) (Table 4).

Table 4.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus alvarezii* in off-bottom at Kibuyuni during the southeast monsoon season. Sampling occurred every two weeks.

Treatments (g)	**Sampling intervals (weeks)**					
	246	**8**	**F- value**	**P-value**		
50	2.30±0.06	1.79±0.01	1.57±0.16	1.49±0.11	9.82	0
75 0.001	2.36±0.04	1.80±0.08	1.46±0.10	1.50±0.09	23.8	
125 0.001	2.41±0.04	1.86±0.05	1.44±0.10	1.52±0.17	16.12	
150 0.001	**2.42±0.02**	1.74±0.12	1.45±0.10	1.32±0.11	28.55	
F-value	0.87	0.15	0.27	0.73		
P-value	0.464	0.928	0.845	0.543		

4.3. Variation of Yield between treatments and methods during southeast monsoon season

For the off-bottom plots at Gazi during the SEM season, the mean yield (g/m^2±SD) at Gazi calculated during the 6th week of sampling ranged from a low of 189.72±4.72 to a high of

670.3±27.8 in the 150g treatment (Fig. 2).In the 75g treatment, yield ranged from a high of

449.7±68.3 (6th week of sampling) to a low of 232.0±10.9 on the 2nd week of sampling .The 100g treatment yield ranged from a high of 585.5±23.6 on the 6th week to a low of 287.87±3.19 on the 2nd week of sampling (Fig. 2). The 125g treatment yield ranged from a high of 503.6±68.7 (6th week of sampling) to a low of 310.4±17.9 on the 2nd week. In the 150g treatment, yield ranged from a high of 670.3±27.8 (6th week of sampling) to a low of 382.8±7.12 on the 2nd week (Fig. 2).

For the rafts at Gazi during SEM season (Fig. 2), the 50g treatment yield ranged from a low of 194.4±65.4 in the 4th sampling interval to a high of 391.1±32.5 on the 4th week of sampling or the second sampling interval. In the 75g treatment, yield ranged from a high of 437.9±47.5 (4th week) to a low of 237.5±48.9 on the 8th week. In the 100g treatment yield ranged from a high of 538.9±74.0 during the 4th week of sampling to a low of 177±80.5 on the 8th week. The 125g treatment yield ranged from a high of 554.5±43.8 (4th week) to a low of 137.7±70.8 on the 8th week of sampling. 150g treatment yield ranged from a high of 499.7±23.7 (4th week of sampling) to a low of 230.1±69.4 on 8th week (Fig. 2).

One- way ANOVA indicated mean bi-weekly yield differed significantly between treatments in Gazi for both the raft and off-bottom culture methods (Rafts, F=19.16, p= 0.001; off-bottom, F=69.31, p=0.001).

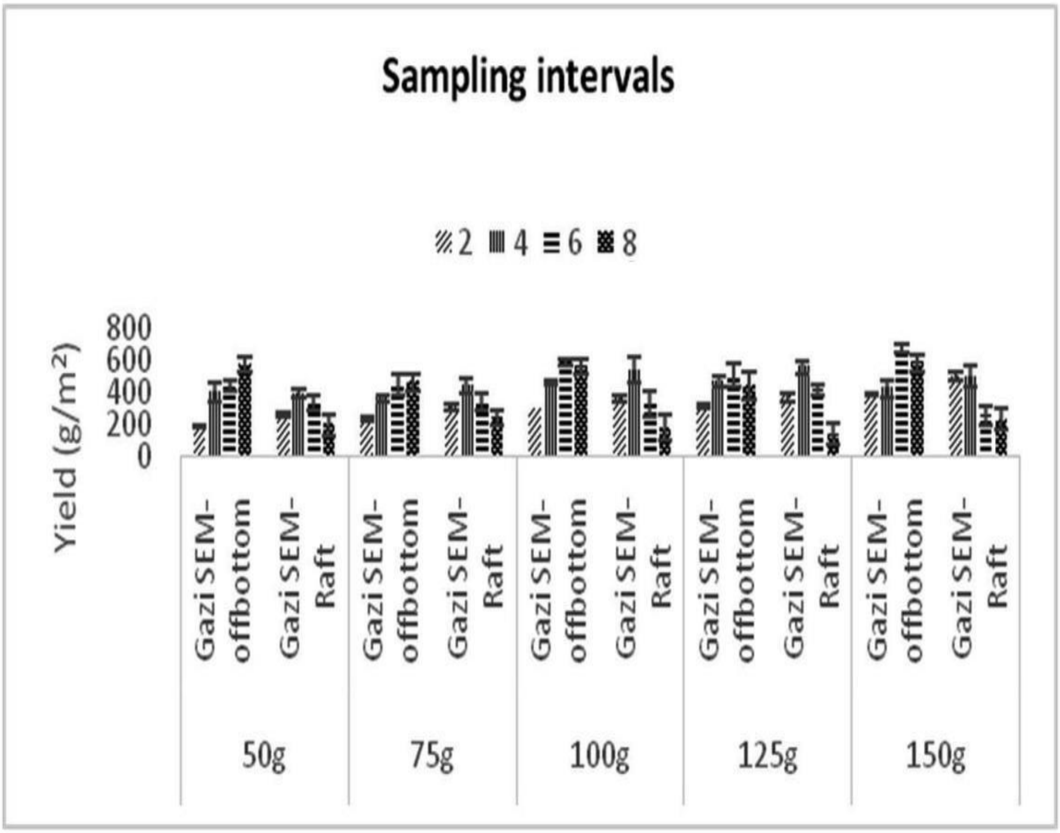

Figure 2.Bi weekly yield of *Kappaphycus alvarezi* during SEM season in Gazi under different seed densities and culture methods.

For the Kibuyuni off-bottom plots (Fig.3), the 50g treatment yield ranged from a high of 188.8±20 during the 8th week of sampling to a low of 139.17±7.3on the 2nd week of sampling. In the 75g treatment, yield ranged from a high of 300.9±28 (8th sampling) to a low of 228.1±117.1 on the 2nd week of sampling. The 100g treatment is missing from the results as the seedlings were lost from the ropes due to turbulence of sea waves. The 125g treatment yield ranged from a high of 449.0.±62.8 (8th sampling) to a low of 315.6±12.3 on the 2nd sampling. The 150g treatment yield ranged from a high of 447.2±44.2 (8th sampling) to a low of 379.6±8.3 on the 2nd sampling interval (Fig. 3).

For rafts at Kibuyuni during the SEM season (Fig. 4), the mean yield (g/m^2±SD) at Kibuyuni in the 50g treatment ranged from a high of 118.9±40.9 on the 8th sampling week to a low of 72.1±11.8 on the 4th week of sampling. In the 75g treatment, yield ranged from a high of 158.8±2.8 (2nd sampling) to a low of 111.8±10.6 during the 4th sampling period. The 125g treatment yield ranged from a high of 179.6±60.4 (4th week) to a low of 69.5±16.8 on the 8th sampling interval. The 150g treatment yield ranged from a high of 115.6±20.8 (4th week) to a low of 52.4±10.0 on the 8th sampling interval.

One-way ANOVA analysis indicated mean yield was not significantly different between treatments in Kibuyuni for the raft culture method (F=0.85, p= 0.509) with significant difference between treatments for the off-bottom culture method (F=68.03, p=0.001).

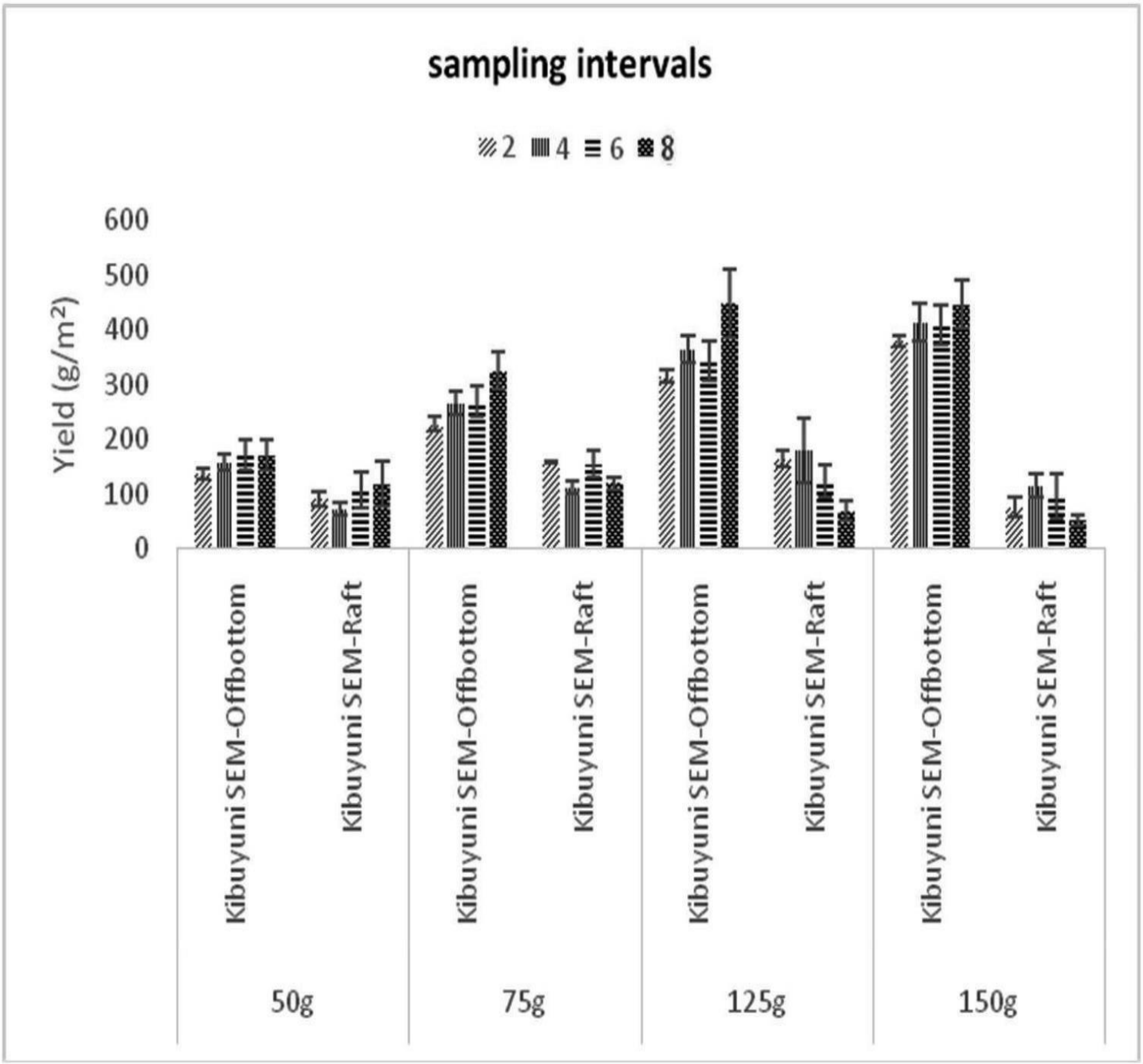

Figure 3.Bi - weekly yield of *Kappaphycus alvarezii* during SEM season in Kibuyuni under different seed densities and culture methods.

4.4. Daily growth rate and yield of *Kappaphycus alvarezii* at sites during Northeast monsoon season

4.5. Growth Rate

For rafts at Gazi during the NEM season, the mean daily growth rate (% /day ± SD) ranged from a low of 0.84±0.26 in treatment 125g during the 6th week of sampling to a high of 2.97±0.00 in treatment 50g during 2nd week of sampling (Table 5). In the 50g treatment, growth was highest (2.97±0.00) on the 2nd week and lowest (1.17±0.59) in the 4th week of sampling (Table 5). In the 75g treatment growth ranged from a high of 2.78±0.09 (8th week) to a low of 1.23±0.29 during the 10th week of sampling.

Growth rate in the 100g treatment ranged from a high of 2.80±0.04 during the 8th week to a low of 1.41±0.24 on the 10th week, while for the 125g treatment growth ranged from a high of 2.66±0.10 (8th week) to a low of 0.84±0.26 on the 6th week. Growth rate in the 150g treatment ranged from a high of 2.68 ± 0.08 (2nd week) to a low of 1.05±0.07 on the 12th week (Table 5).

One-way ANOVA analysis indicated weekly significant differences within 75g, 100g, 125g and

150g treatments daily growth rates ($P<0.05$) and no significant weekly differences within the 50g treatment daily growth rates ($p>0.05$). Between treatments, there was significant difference in daily growth rate in the 2nd, 4th 6th, 8th and 12th weeks of sampling ($p<0.05$) and no significant differences in daily growth rates in the 10th sampling week ($p>0.05$) (Table 5).

Table 5.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus* *alvarezii* in rafts at Gazi during the northeast monsoon season.

Sampling occurred every two weeks.

Treatments (g)	**Sampling intervals(weeks)**							
	2	**4**	**6**	**8**	**10**	**12**	**F-value**	**P-value**
50	**2.97±0.00**	1.17±0.59	1.28±0.96	2.47±0.05	1.41±0.76	1.49±0.19	1.72	0.
75	2.69±0.07	1.8±0.14	1.7±0.33	2.78±0.09	1.23±0.29	1.61±0.03	13.55	0.001
100	2.66±0.04	1.95±0.03	1.62±0.22	2.80±0.04	1.41±0.24	1.50±0.04	18.53	0.001
125	2.58±0.05	1.93±0.07	0.84±0.26	2.66±0.10	1.02±0.20	1.48±0.03	26.7	0.001
150	2.68±0.08	1.76±0.05	1.38±0.09	2.17±0.15	1.37±0.18	1.05±0.07	27.73	0.001
F-value	3.15	4.31	3.11	8.34	0.33	15.47		
P-value	0.033	0.01	0.035	0.001	0.853	0.001		

At Gazi during NEM season (Table 6), the mean daily growth rate (% /day ± SD) in the off- bottom plots ranged from a low of 1.26 ± 0.05 in the 125g treatment on the 12th sampling week to a high of 2.73 ± 0.13in treatment 50g during 10thweek of sampling. In the 50g treatment, growth was lowest (2.11±0.20) during the 6th week, while in the 75g treatment it ranged from a high of 2.46±0.05 (8th sampling) to a low of 1.36 ± 0.07 on the 12th sampling week (Table 6).In the 100g treatment growth ranged from a high of 2.42 ± 0.0 (8th sampling) to a low of 1.32 ± 0.07 during the 12th sampling week (Table 6).Mean daily growth rate in the 125g treatment ranged from 2.43±0.02 (8th week) to 1.26 ± 0.05 on the 12th week (Table 6). The 150g treatment growth rate ranged from a high of 2.40 ± 0.02 (2nd week) to 1.35 ± 0.04 on the 12th week.

One-way ANOVA analysis indicated significant differences in mean daily growth within all the treatments (Table 6). Between treatments, there was significant difference in mean daily growth rate ($p<0.05$) in all the treatments except during the 6th week and a marginal value during the 2nd week (Table 6).

Table 6.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus alvarezii* in off-bottom at Gazi during the northeast monsoon season. Sampling occurred every two weeks.

Treatment (g)	Sampling intervals (weeks)							
	2	4	6	8	10	12	F-value	P-value
50	2.50±0.02	2.51±0.14	2.11±0.20	2.56±0.04	**2.73±0.13**	2.12±0.04	4.52	0.002
75	2.41±0.05	2.15±0.09	2.01±0.09	2.46±0.05	2.33±0.10	1.36±0.07	24.45	0.001
100	2.41±0.01	2.17±0.06	1.91±0.08	2.42±0.01	2.20±0.11	1.32±0.07	33.48	0.001
125	2.36±0.03	1.97±0.08	1.86±0.08	2.43±0.02	2.19±0.09	1.26±0.05	38.51	0.001
150	2.40±0.02	1.55±0.15	1.70±0.11	2.29±0.06	1.81±0.22	1.35±0.04	11.04	0.001
F-value	2.43	9.16	1.56	4.06	5.32	35.91		
P-value	0.062	0.001	0.202	0.007	0.001	0.001		

At Kibuyuni during NEM season (Table 7), the daily growth rate (% /day ± SD) in the rafts ranged from a low of 0.34±0.00 in the 100g treatment on the 6th week to a high of 2.49 ± 0.10 in

50g treatment during 8thsampling week (Table 7). In the 50g treatment, growth was highest

(2.49±0.1) on 8th sampling week and lowest (1.45±0.67) on the 10th week. Growth rate in the 75g treatment ranged from a high of 2.07±0.14 (2nd week) to a low of 1.38±0.20 on the 4th sampling week (Table 7). The 100g treatment growth rate ranged from a low of 0.34±0.00 (6th week) to a high of 1.62±0.00 on the 8th week. In the 125g treatment, growth rate ranged from a high of 1.98 ± 0.03 (2nd week) to a low of 0.47±0.01 during the 10th sampling week. The 150g treatment growth rate ranged from a high of 2.29±0.56 (12th week) to a low of 1.15±0.35 during the 6th sampling week (Table 7).

One-way ANOVA analysis indicated significant differences within 100g and 125g treatments daily growth rates ($P<0.05$) and no significant differences between treatments daily growth rates within 50g,75g and 150g ($p>0.05$) (Table 7). Between treatments, there was no significant difference in daily growth rate during the 4th, 8th and 12th sampling weeks ($p>0.05$) (Table 7).

Table 7.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus alvarezii* in rafts at Kibuyuni during the northeast monsoon season. Sampling occurred every two weeks

Treatments (g)	Sampling intervals (weeks)						F-value	P-value
	2	4	6	8	10	12		
50	2.34±0.26	1.58±0.34	1.46±0.33	**2.49±0.1**	1.45±0.67	2.04±0.26	1.53	0.253
75	2.07±0.14	1.38±0.20	1.60±0.21	1.91±0.1	1.78±0.30	1.68±0.12	1.35	0.266
100	1.56±0.00	0.93±0.00	0.34±0.00	1.62±0.00	0.79±0.00	1.59±0.00	19.03	0.001
125	1.98±0.03	0.92±0.3	0.55±0.07	1.55±0.39	0.47±0.01	1.65±0.00	9.46	0.008
150	1.35±0.07	1.53±0.31	1.15±0.35	1.68±0.41	1.61±0.21	2.29±0.56	1.18	0.375
F-value	4.35	2.25	3.9	1.7	2.48	1.04		
P-value	0.019	0.12	0.027	0.21	0.096	0.425		

For the off-bottom plots at Kibuyuni during NEM (Table 8); the mean daily growth rate (% /day ± SD) ranged from a low of 0.59±0.03 in treatment 150g during the 12th sampling week to a high of 2.54 ± 0.01in treatment 50g during the 8th sampling week (Table 8).The 50g treatment, growth was highest (2.54±0.01) on the 8th sampling week and lowest (1.45±0.29) during the 6th sampling week. Growth ranged from 2.49±0.03 (2nd week) to 1.85±0.08 on the 12th sampling week in the 75g treatment (Table 8). In the 100g treatment, growth rate ranged from a high of 2.45±0.05 (8th week) to a low of 1.62±0.08on the 6th sampling week. For the 125g treatment, growth ranged from a high of 2.51±0.03 (2nd week) to a low of1.50±0.11 on the 6th sampling week. In the 150g treatment, growth ranged from2.37±0.05 (2nd week) to0.59±0.03 during the 12th sampling week (Table 8).

One-way ANOVA analysis indicated significant differences within all the treatments daily growth rates ($P<0.05$) (Table 8). Between treatments, there was significant difference in daily growth rate in the 8th, 10th, and 12th weeks ($p<0.05$) and no significant differences in daily growth rates in the 2nd, 4th and 6th weeks ($p>0.05$) (Table 8).

Table 8.Variation in mean daily growth rates (% /day±SD) of *Kappaphycus alvarezii* in off-bottom at Kibuyuni during the northeast monsoon season. Sampling occurred every two weeks.

Treatments (g)	**Sampling intervals**							
	2	**4**	**6**	**8**	**10**	**12**	**F-value**	**P-value**
50	2.31±0.13	1.94±0.37	1.45±0.29	2.54±0.01	1.99±0.24	2.00±0.08	2.61	0.08
75	2.49±0.03	1.77±0.10	1.59±0.13	2.52±0.04	2.13±0.13	1.85±0.08	15.79	0.001
100	2.38±0.05	1.81±0.06	1.62±0.08	2.45±0.05	2.29±0.10	1.69±0.05	25.63	0.001
125	2.37±0.03	1.80±0.11	1.50±0.11	2.51±0.03	2.09±0.11	1.73±0.04	26.7	0.001
150	2.37±0.05	1.91±0.04	1.24±0.08	2.32±0.05	1.54±0.15	0.59±0.03	71.71	0.001
F-value	1.17	0.38	1.91	2.98	5.08	98.38		
P-value	0.342	0.825	0.129	0.032	0.002	0.001		

4.6. Yields of *Kappaphycus alvarezii* at sites during the northeast monsoon season

During the NEM season at Gazi site off-bottom plots, (Fig. 4), the highest mean yield (Mean±SD) in the 50g during the experiment ranged from a high of 496.5±52.6 on the 10th week of sampling to a low of 187.68±4.60 in the 2nd sampling week. In the 75g treatment; yield ranged from a high of 479.2±32.0 (6th week of sampling) to a low of 247.4±10.5 on the 8th week. The 100g treatment yield ranged from a high of 535.6±39.9 on the 6th week to a low of 289.38±5.12 during the 8th week (Fig.4). The 125g treatment yield ranged from a high of 607.3±41.7 (6th week of sampling) to a low of 328.0±16.5 on 12th week. In the off-bottom plots, yield ranged from a high of 580.3±52.5 (6th week) to a low of 350.7±20.7 on the 8th week of sampling.

For the rafts (Fig. 5), mean yield (g/m^2±SD) at Gazi calculated during the experiment for 50g rafts ranged from a high of 287.0±23.0 during the 2nd week to a low of 149.2±88.4 during the 10th week (Fig. 4). In the rafts, yield ranged from a high of 424.6±40.9 (6th week of sampling) to a low of 182.8 ±78.5 in the 10th week (Fig.5 while. the 100g yield ranged from a high of 420.1±73.1 in the 6th sampling week to a low of 241.7±56.5 on the 10th week. In the 125g treatment, yield ranged from a high of 422.0±34.1 (8th week) to a low of 201.1±48.6 during the 6th week (Fig.4). The 150g treatment yield ranged from a high of 493.4±31.7 (2nd week of sampling) to a low of 273.4±44.1 during the 10th week of sampling (Fig. 4).

One-way ANOVA analysis indicated significant mean bi-weekly yield differences between treatments in Gazi both for the raft and off-bottom culture methods (F = 8.99, p = 0.01; F = 120.4, p = 0.01, respectively).

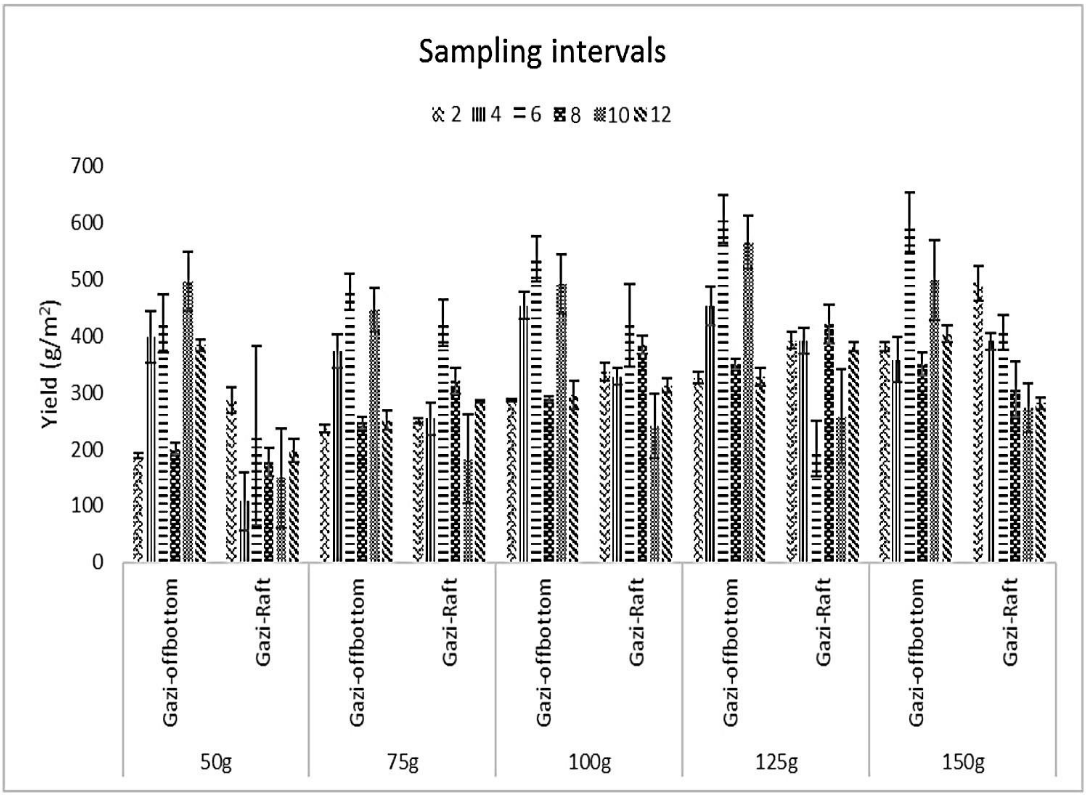

Figure 4.Bi-weekly yield of *Kappaphycus alvarezii* during NEM season in Gazi under different seed densities and culture methods.

At Kibuyuni during NEM season off-bottom plots (Fig. 5), mean yield (Mean±SD) in the 50g plots ranged from a high of 254.7±14.8 during the 12th week to a low of 130.9±16.4 on the 2nd week of sampling. (Fig.5). In the 75g plots yield ranged from a high of 351.8±21.5 on the 12th week of sampling to a low of 219.35 ±7.50 on the 2nd week (Fig.5). Yield in the 100g treatment was highest at 482.6±46.1 on the 10th week to a low of 258.2±13.2 on the 2nd week of sampling. Yield for 125g treatment ranged from a high of 464.6±50.0 in the 10th sampling week to a low of 306.27±9.71 on the 2nd week. In the 150g treatment, yield was highest at 466.7.± 20.6 (4th week) and lowest at 184.54±4.81 on the 12th week of sampling.

For the rafts at Kibuyuni, the mean yield (Mean±SD) ranged from a high of 212.7±18.4 in the 50g treatment during 12th week to a low of 102.3±20.1 in the 4thweek of sampling. The 75g treatment yield ranged from a high of 263.4±16.1 (12th week) to a low of 115.5±15.0 on the 8th sampling week while the 100g treatment yield ranged from a high of 280.00±0 (12th week) to a low of 80.0±0 on the 6th week. Yield for the 125g rafts was highest at 402.80±4.80 (12th week of sampling) to a low of 82.52±0.680 on the 10th week (Fig. 6). In the 150g treatment, yield ranged from a high of 245.1±10.9 (12th week) to a low of 69.3±27.9 during the8th week of sampling (Fig.5).

One-way ANOVA analysis indicated mean bi-weekly yield was not significantly different between treatments in Kibuyuni for the raft culture method (F=0.85, p= 0.509) but significantly different between treatments for the off-bottom culture method (F=68.03, p=0.001) (Fig.5).

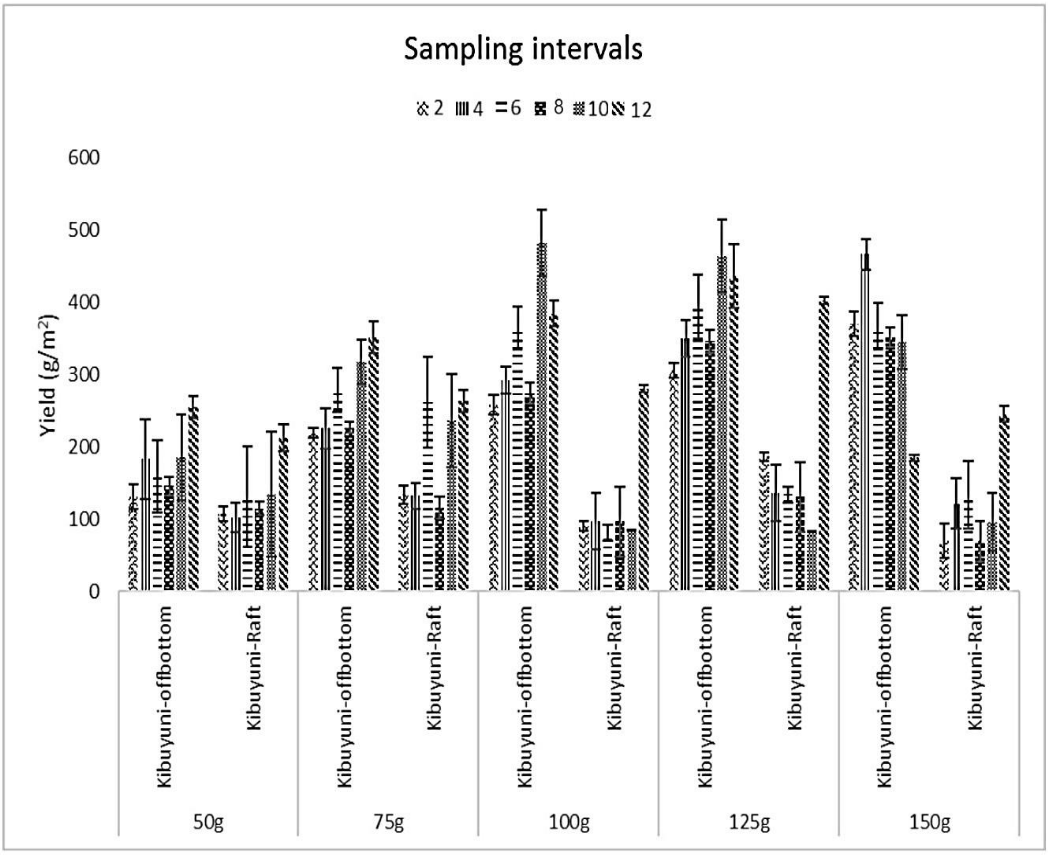

Figure 5.Bi-weekly yield of *Kappaphycus alvarezii* during the NEM season at Kibuyuni under different seed densities and culture methods.

4.7. Effect of season, method and treatment on growth rate and yield

The General Linear Model applied to the results indicated that season and density had significant effect on growth rate ($p<0.05$) while, method had no significant effect at Gazi ($p>0.05$) (Table 9). However, at Kibuyuni, the General Linear model indicated that season, method and density had significant effect on growth rates ($p< 0.05$) indicating all the variables are important at Kibuyuni (Table 10). In terms of yields, the GLM analysis indicated that season, method and density had significant effects at Gazi ($p< 0.05$) signifying all the variables are important at Gazi site in influencing yield (Table 11). Season had no significant effect on yield ($p>0.05$), however, method and density had significant effect on yield at Kibuyuni ($p< 0.05$) implying that the variables are important at Kibuyuni (Table 12).

Table 9.General linear Model testing the effect of season, method and density on growth rate (%/day) of *Kappaphycus alvarezii* at Gazi.

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Season	**1**	**376.0**	**376.012**	**20.32**	**0.000**
Method	**1**	**0.1**	**0.083**	**0.00**	**0.947**
Density	**4**	**926.9**	**231.735**	**12.52**	**0.000**
Error	**629**	**11638.5**	**18.503**		
Lack-of-Fit	**13**	**132.2**	**10.167**	**0.54**	**0.897**
Pure Error	**616**	**11506.3**	**18.679**		
Total	**635**	**12862.2**			

Table 10.General linear Model testing the effect of season, method and density on growth rate (%/day) of *Kappaphycus alvarezii* at Kibuyuni.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Season_1	**1**	**506.1**	**506.12**	**51.15**	**0.000**
Method_1	**1**	**1910.6**	**1910.57**	**193.08**	**0.000**
Density_1	**4**	**160.4**	**40.09**	**4.05**	**0.003**
Error	**565**	**5590.7**	**9.90**		
Lack-of-Fit	**12**	**249.5**	**20.80**	**2.15**	**0.013**
Pure Error	**553**	**5341.1**	**9.66**		
Total	**571**	**8244.0**			

Table 11.General linear Model testing the effect of season, method and density on yield of *Kappaphycus alvarezii* at Gazi.

Source	DF	AdjSS	Adj MS	F-Value	P-Value
Season	1	260967	260967	11.51	0.001
Method	1	708505	708505	31.26	0.000
Density	4	1224152	306038	13.50	0.000
Error	629	14257728	22667		
Lack-of-Fit	13	396346	30488	1.35	0.177
Pure Error	616	13861382	22502		
Total	635	16309480			

Table 12.General linear Model testing the effect of season, method and density on yield of *Kappaphycus alvarezii* at Kibuyuni.

Source	DF	Adj SS	AdjMS	F-Value	P-Value
Season_1	1	513	513	0.05	0.815
Method_1	1	4805901	4805901	513.91	0.000
Density_1	4	1090779	272695	29.16	0.000
Error	565	5283643	9352		
Lack-of-Fit	12	1168275	97356	13.08	0.000
Pure Error	553	4115367	7442		
Total	571	11651396			

4.8. Seasonal variation in physico-chemical parameters at sites

The mean physico-chemical variables at Gazi and Kibuyuni during the NEM and SEM seasons are shown in Table 13. During SEM season, there was no significant difference in Temperature, DO, Conductivity, Salinity, pH and Phosphates between Gazi and Kibuyuni ($p > 0.05$). During NEM season, there was no significant difference in Conductivity, TDS and salinity between the two sites (Table 13). The mean water temperature was significantly higher in Gazi (30.96^0C ±0.46) compared to Kibuyuni (29.28^0C ±0.25) during NEM season. However, mean water temperature was significantly lower in Gazi (30.93^oC ±0.22) compared to Kibuyuni (31.02^0C ±0.18) during SEM season. There was no significant difference in dissolved oxygen (mg/l) between Gazi and Kibuyuni during both NEM and SEM season (Table 13). Salinity (ppt) was higher at Kibuyuni (35.34±0.55) and Gazi (33.03±0.78) during NEM than SEM Kibuyuni (28.76±0.46) and Gazi (27.54±2.38) (Table 13). There were no significant differences in pH at both sites during NEM and SEM season. There were significant differences in nitrates at both sites in both seasons while ammonia was significantly higher at Gazi than Kibuyuni during both seasons with higher values at both sites during the NEM (Table 13).

Table 13. Seasonal comparison of water quality parameters between southeast monsoon (SEM) and northeast monsoon (NEM) seasons at Gazi and Kibuyuni experimental sites

Variables	SEM		t-test		NEM		t-test	
	Gazi	Kibuyuni	t	P	Gazi	Kibuyuni	t	P
Temp (⁰C)	30.9±0.22	31.0±0.18	-0.30	0.76	30.96±0.46	29.2±0.2	2.22	0.032
DO (mg/l)	6.03±0.19	5.39±0.34	1.60	0.133	4.30±0.27	3.3±0.24	1.98	0.055
Conductivity (mS/cm)	49.3±0.56	47.7±0.92	1.42	0.178	57.9±1.92	59.0±0.6	0.11	0.911
TDS (mg/l)	30258±251	28600.12±696.6	2.24	0.047	32736.4±541.4	35021.87±410.8	-0.34	0.738
Salinity (ppt)	27.54±2.3	28.76±0.4	-0.05	0.628	33.03±0.78	35.34±0.55	-1.10	0.281
pH	7.48±0.01	7.48±0.09	-0.03	0.981	7.28±=0.06	7.6±0.01	2.80	0.008
Phosphates (mg/l)	0.06±0.00	0.11±0.02	-1.65	0.131	0.80±0.14	0.07±0.03	3.06	0.006
Nitrate (mg/l)	0.37±0.01	0.46±0.01	-5.61	0.05	0.35±0.01	0.45±0.0	-6.33	0.05
Ammonia (mg/l)	1.28±0.02	1.03±0.04	5.11	0.05	0.63±=0.09	0.30±0.03	2.34	0.025

4.9. Relationship between physico-chemical variables and growth rate

Canonical Correspondence Analysis (CCA) indicated axis 1 explained more (83.39%) of the variance in growth rate of *alvarezii* in rafts at both sites (Fig.6). During SEM season, Ammonia, DO and Temperature influenced growth rate at Gazi irrespective of the stocking density in the rafts (Fig.6). During NEM season, the parameters; TDS, Conductivity and Phosphate appear to influence growth rate at Gazi and specifically for the 125g and 100g treatments. Salinity and Nitrates seemed to influence growth of the 75g treatment at Kibuyuni in both seasons. CCA analysis showed pH not to be associated with site or seasonal influence of growth rates at both sites (Fig.6). Canonical Correspondence Analysis indicated that axis 2 explained more (87.03%) of the variance between the variables in the growth rate of *K.alvarezii* in the off-bottom plots at both sites (Fig.7). During SEM season, Ammonia, DO, Temperature Nitrates and pH seemed to influence growth rate at Kibuyuni irrespective of the stocking density in the plots (Fig.7).

During NEM season, Salinity, TDS and Conductivity influenced growth rate at Kibuyuni. Nitrate appeared to influence growth rate for treatments 75g, 125g and 150g irrespective of the season (Fig. 7). CCA analysis showed pH again not to be associated with site or seasonal influence of growth rates at both sites (Fig.7).

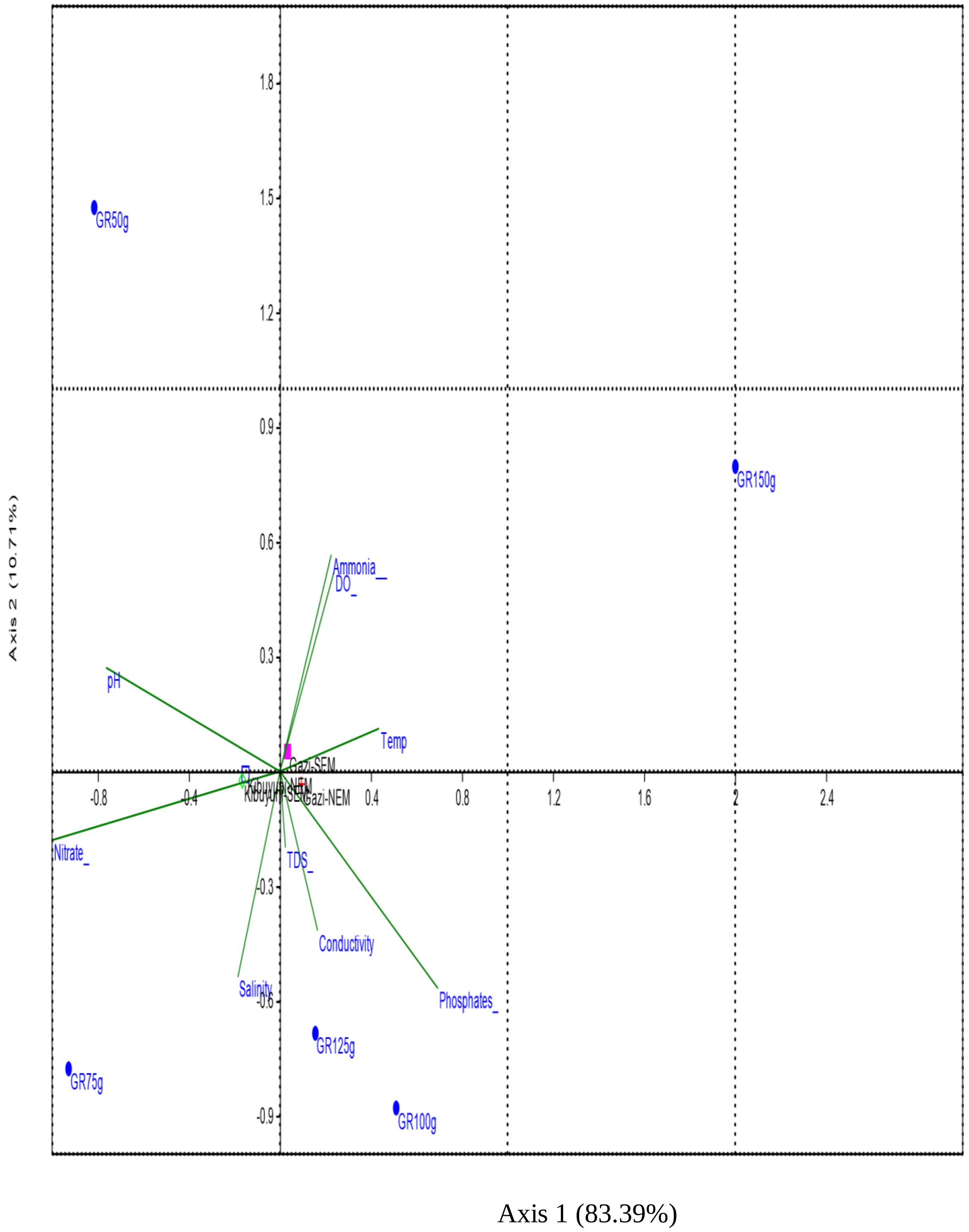

Figure 6.Canonical Correspondence Analysis relating physico-chemical variables with growth rate of *Kappaphycus alvarezii* at different treatments (GR) at Kibuyuni and Gazi during NEM and SEM season using the raft method

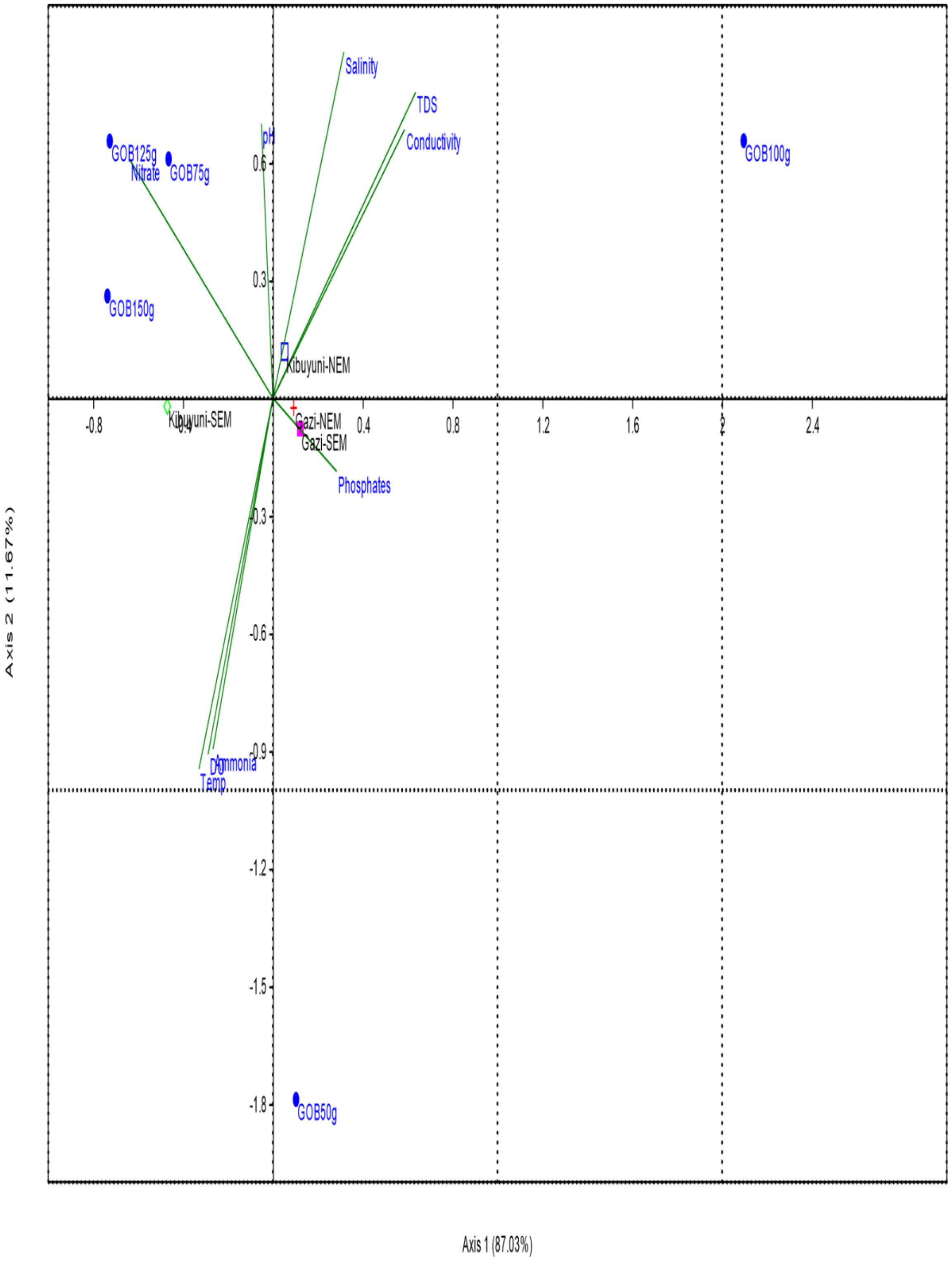

Figure 7.Canonical Correspondence Analysis relating physico-chemical variables with growth rate of *Kappaphycus alvarezii*at different treatments (GR) at Kibuyuni and Gazi during NEM and SEM season using the off-bottom method

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion

In this study, maximum growth rates (%/day) of 2.97±0.00 were obtained in the NEM season for the rafts method after two weeks at Gazi site. Kibuyuni also showed nearly equal maximum growth rates of 2.86±0.10 during the SEM season at two weeks of culture. Maximum growth rates of 2.73±0.13 were obtained in the NEM season for the off-bottom method after ten weeks at Gazi site. The off-bottom plots at Kibuyunishowed maximum growth rates of 2.49±0.1 during the NEM season at eight weeks for the off-bottom plots. At Gazi site, season and density had significant effect on growth rate ($p<0.05$) while, method of culture had no significant effect. The result suggests that at Gazi farmers may simply select methods that provide highest growth rate at the shortest time which happens to be the raft method. Season, method and density had significant effect on growth rate at Kibuyuni ($p< 0.05$) indicating all the variables are important to be considered when culturing *K alvarezii* at Kibuyuni. The two methods of farming showed maximum growth rates similar to the results obtained in subtropical waters of Brazil where growth rates of 2.6% were reported (Paula and Pereira, 2003). Nevertheless, results observed at Kibuyuni and Gazi were slightly lower than those reported by Luxton et al., (1987) in the south Pacific Islands at 3.5–3.7%/day. Season, method and density had significant effect on total yield at Gazi ($p< 0.05$) signifying all the variables are important at Gazi in affecting yield.

Differences between the two sites could be attributed to the differences in habitats between Gazi (more sheltered bay) compared to Kibuyuni (more open lagoon). There were significant differences in the growth rates between the two methods of farming in this study, which is similar to the results for green and brown strains of algae cultured in Northern Bohol (Trono and Ohno, 1989) using the raft method.

Dawes et al., (1994) and Hurtado (1995) reported slightly higher growth rates for the raft method (4.4–8.9%) when compared to off- bottom (4.68%) in laboratory and field studies.

In this study,season had no significant effect on yield at Kibuyuni, however, method and density had significant effect on yield at this site ($p< 0.05$) unlike for growth rates.

In Kibuyuni, growth rates of *K. alvarezii* decreased progressively with time in the raft method during the SEM season. This observation attributed to plant breakage as a result of the rough seas during this season. Biomass losses of up to 50% were observed during the experiment including total loss of the 100g treatment attributed to the roughness of the sea in this season and the size of the seedlings. Growth rates were higher during the NEM season for Gazi unlike Kibuyuni where growth rate were e higher during the SEM season. This disparity is likely due to differences in habitat structure between the sites.

In the present study, temperature, ammonia, and dissolved oxygen influenced growth rate at

Gazi irrespective of the stocking density in the rafts. Total Dissolved Solids, Conductivity and Phosphate influenced growth rate at Gazi and specifically for the 125g and 100g treatments during the NEM season. Salinity and Nitrates seemed to influence growth of the 75g treatment at Kibuyuni in both seasons. pH appeared not to be associated with site or seasonal influence of growth rates at both sites. A positive correlation between temperature and growth rate of *K. alvarezii* has also been reported elsewhere (Glenn & Doty 1992; Muñoz et *al.*, 2004), and likewise with salinity (Hung *et al.*, 2009) apparently consistent with the positive correlation between temperature and salinity with growth rates in this study. For the off-bottom plots at both sites during the SEM season, Ammonia, dissolved Oxygen, temperature nitrates and pH seemed to influence growth rate at Kibuyuni and specifically for the 125g treatment, 75g and 150g irrespective of the stocking density in the plots. During NEM season, salinity, Total Dissolved Solids and Conductivity influenced growth rate at Kibuyuni and Gazi and had no influence on the growth rates specifically for the 50g and 100g treatments. pH appeared again not to be associated with site or seasonal influence of growth rates at both sites. According to the site fertility theory (Santelices, 1999), seaweed growth is coordinated by a complex interaction of irradiance, temperature, nutrients and water movement. Thus, in environments with low or erratic nutrient supply, surge ammonium uptake has been described for *K.alvarezii* as a strategy to avoid nitrogen limitation of growth (Dy and Yap, 2001). Temperature, salinity and nutrients are believed to be the most important factors affecting *K.alvarezii* growth (Glenn and Doty, 1990). In another study, Glenn and Doty (1992) demonstrated that water motion accounted for 81–98% of the variation in growth rate, although they found an inverse significant relationship between maximum temperature and growth. Further, they report that photosynthetic temperature response for *K. alvarezii* increased up to 32:8^{0}Cthen sharply declined. In this study temperature seems to be only important in affecting growth at Kibuyuni perhaps due to the open nature of this site leading to wider temperature variation between seasons.

Similar to growth rate, *Kappaphycus* yield was highest during the NEM season that coincided with the months of calm but hot weather conditions especially at Gazi. This time is also a season of high salinity (McClanahan,1988). Decrease in yield during the SEM season was attributed to roughness of the sea leading to high biomass loss. Drifting of the rafts during this time led to the breakages of the bamboo poles and consequent loss of the seedlings. Maximum *Kappaphycus* yield of 5807.3±41.7Mean ±SD was obtained when water temperature and salinity was high especially at Gazi since it's a sheltered bay. On the other hand, the period of minimal *Kappaphycus* yield of 69.3±27.9 Mean ±SD during the SEM season corresponded to the highest amount of inorganic phosphate and dissolved oxygen. The strong water movement during the southeast monsoon increased hydrodynamics and roughness and consequently decreased growth and yield in the sampling sites. Phosphorus has been recognized as a nutrient that, together with nitrates, has an important role in algal growth and carrageenan content (Lapointe, 1987, Chopin et al., 1990). In this study, a significant positive correlation of phosphate and *Kappaphycus* yield was observed especially in Gazi Bay and in both seasons (Fig. 8). The maximum *Kappaphycus* yield (607.3±41.7Mean±SD)was therefore obtained during the period of highest nutrient supply in NEM season. A comparable positive nutrient-growth interaction has been observed in *Eucheuma isiforme*from Yucatán, Mexico (Robledo 2006) and in Tanzanian farms (Msuya,2006).

5.2. Conclusions

The raft method is potentially the best method of farming the species if proper anchorage is done to avoid drifting and site selection is maximized to avoid water turbulence especially during the SEM season. As reported by Ask and Azanza (2002), growth rates above 3.5%/day are considered adequate for commercial farming, this indicates that the highest growth rate of 2.9%/day in this study suggest less than optimal growth, however, there is likely to be geographical differences in growth potential and so the Ask or Azanza results cannot be generalized. During the NEM season, good growth was observed at both sites. Therefore, during this season *Kappaphycus* cultivation could be proposed as an alternative or complimentary livelihood source for fishermen, self help groups and coastal people with potential to reduce pressure on wild fish stocks. If cultivation of *K. alvarezii* is intended during the cold and rough SEM season (March to July) in the Gazi Bay and Kibuyuni sites,then the off-bottom method is preferable especially in the more open lagoons.. It was also noted that Kibuyuni site had the highest growth rates of *Kappaphycus alvarezii* within all the treatments and between treatments for the off-bottom culture method during the northeast monsoon season.

Gazi indicated highest mean weekly yield of *Kappaphycus alvarezii* between treatments for both the raft and off-bottom culture methods during the northeast monsoon season.

5.3. Recommendations

Following the results of this work, its recommended that *Kappaphycus alvarezii* cultivation could be proposed as an alternative livelihood for fishermen during the northeast monsoon season at Gazi using the raft method and a seedling density of 50g, while at Kibuyuni a seedling density of 125g (402.80± 4.80Mean±SD) is suitable using the raft method of farming during SEM season. *Kappaphycus alvarezii* production obtained at Gazi was significantly higher during NEM (580.3±41.7Mean±SD) and the differences in growth rate and yields at sites may be attributed to site characteristics, particularly the water motion, among other factors.

The greater water movement at Gazi supplied inorganic nutrients for the growth and production of *Kappaphycus*. During this season the sea is very calm, there is no drifting of the rafts and thus the breakage rate is minimal thus the highest biomass are attained. This is because Gazi is more sheltered than Kibuyuni thus making it a better growth performer.

For higher growth rates, the seedling density of 50g is the most appropriate in the off-bottom method during NEM season. This is because as this species is susceptible to environmental fluctuations, the biomass that remains after breakage continues to grow to maximum size within a short time.

Raft method of farming is recommended especially at Gazi with fluctuating water levels so that the plants could still get substantial sunlight during low tides. This system is also suited for Kibuyuni during NEM season since it’s an open sea and water movements are stronger. Similarly, the grazing of fishes, sea urchins and other aquatic animals could be minimized in the raft method through the frequent movement of the support system holding the seedlings.

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