Western Indian Ocean J. Mar. Sci. Vol. 10, No. 1, pp. 59-71, 2011

Experimental Polyculture of Milkfish (*Chanos chanos*) and Mullet (*Mugil cephalus*) Using Earthen Ponds in Kenya

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Keywords: polyculture, milkfish, mullet, earthen ponds.

Abstract—Seasonal growth of milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) was studied in polyculture in six small earthen ponds in Mtwapa Creek and Gazi Bay, Kenya, between 2005 and 2006. The ponds were sited on sandy mangrove flats and were periodically connected with the sea providing water exchange during high spring tides. This inundation also filled mangrove pools and channels where fish fingerlings and juveniles were seined with push nets to establish their seasonal abundance and to stock the ponds. Fingerlings weighing 5-9 g were stocked at 4 fish/m^2 and a polyculture ratio of 5 milkfish: 1 mullet. The ponds were fertilized with dry chicken manure at 15 kg/pond every two weeks (0.595 g/m^2 per day). Fish were sampled monthly, basic water quality parameters (temperature and oxygen) were monitored weekly and nutrient analysis four times per crop. There were significant differences in milkfish and mullet abundance between months ($p < 0.05$). Milkfish growth rate was significantly different between the wet (0.52±0.18 g/day) and dry (1.21±1.0 g/day) seasons ($P < 0.05$), as was that of mullet (0.15±0.04 and 0.29±0.15 g/day, respectively; $P < 0.05$). The production of mullet fish was 160-380 kg/ha and milkfish 1 440–5 160 kg/ha. Fish survival varied between 81.4% in the wet season and 90.3 % in the dry for milkfish and 79.8–87.0 % for mullet. Water quality parameters fell within the culture requirements in both the wet and dry season, with chl-a, and salinity being significantly higher in the dry season, while phosphates and nitrites were significantly lower in the dry season ($p < 0.05$).

INTRODUCTION

The development of mariculture in Africa has suffered several setbacks, including a high cost of labour per unit output (Christensen, 1995); and the lack of documentation on possible impacts to the environment, appropriate technology, facilities, infrastructure and government policies. Despite this, the demand for marine fisheries production is increasing with the expansion of tourism and increasing human population (Anon, 1997).

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Mariculture in East Africa is still small in scale and undeveloped (Bryceson, 2002) compared to South East Asia where it forms the backbone of the economy. Finfish culture has focused on the culture of milkfish, mullet and rabbit fish, with the latter being less tolerant to sudden changes in environmental parameters (Mmochi & Mwandya, 2003). Milkfish and mullet always occur together in coastal wetlands; they consume similar food, mainly the abundant detritus, i.e. *lab-lab* (benthic algal mat) and lumut (filamentous algae) which create a complex community structure (Bagarinao, 1999).

Milkfish farming in East Africa and parts of Asia is quite extensive in small ponds 0.5-1.0 m deep depending on tidal water exchange, using natural food, a minimal use of fertilizers and a low stocking density (2-3 fish/m^2) (Mmochi & Mwandya, 2003; Bagarinao, 1999). Over the past few years in Kenya, milkfish and mullet culture has been practised in pens enclosing natural channels and pools (Mwaluma, 2003; Rasowo, 2004).

Milkfish and mullet polyculture constitutes a recent introduction (6 years) to maricultural research in Kenya, but it has a longer (10 years) history in Tanzania (Mwangamilo & Jiddawi, 2003). This polyculture is considered suitable for mariculture due to the tolerance of milkfish and mullet to varied levels of oxygen and salinity (Mmochi & Mwandya, 2003; Smith & Heemstra, 2003), a common characteristic in intertidal earthen ponds used for aquaculture where water exchange is dictated by the tidal regime.

In South-east Asia, milkfish have been grown in polyculture with mullet in marine coastal ponds due to their different feeding habits and habitat preferences (Joseph, 1982; Lutz, 2003). The underlying goal of milkfish and mullet polyculture involves increasing productivity, utilizing ecological resources within an aquatic environment more efficiently but with a reduction in risk; as mullet are susceptible to ectoparasites and scale loss (during handling) leading to secondary vibriosis, and mortalities (Tucker & Kennedy, 1998), in polyculture a farm is not dependent on this fish alone.

This study was conducted to determine how wild milkfish and mullet fare in pond culture systems subjected to tidal water exchange with minimal organic fertilization, thereby depending on their natural productivity. Additionally, this study explored the influence of season (wet/dry) on growth of milkfish and mullet, and the availability of fingerlings.

MATERIAL AND METHODS

Study area

The study was conducted in intertidal earthen ponds in the mangroves of Mtwapa Creek and Gazi Bay, Kenya (Fig. 1), for 217 culture days. A total of six small earthen ponds (0.018 ha each) were constructed on the intertidal mangrove sand flats during the dry season in 2005 and wet season in 2006. The dry season, when there was little or no rainfall, was June-December in 2005, while the wet season when rainfall was heavy in 2006 fell between February-August. Three sites were selected for this study along the coast of Kenya and included the involvement of local communities: Kwetu Training Centre and Majaoni Youth Group at Mtwapa Creek and Makongeni Baraka Conservation Group in Gazi Bay (Fig. 1). Two ponds were used at each of the sites, their elevation varying between 0.5 and 1.1 meters above mean sea level. The ponds at Mtwapa Creek had *Avicennia marina* at the upper, landward site and a mixture of *Ceriops targal* and *Rhizophora mucronata* at the lower, seaward site, while those at Makongeni had *A.marina* at both sites. The Mtwapa Creek ponds were similarly located in an *A.marina* mangrove but the topography behind the ponds was relatively hilly relative to that at Makongeni where the topography had a gentler slope.

Pond Design and Fertilization

The culture ponds were constructed on sandy flats where seawater flow from the creek and bay could exchange up to 40% of the pond water every 10 days at high spring tide

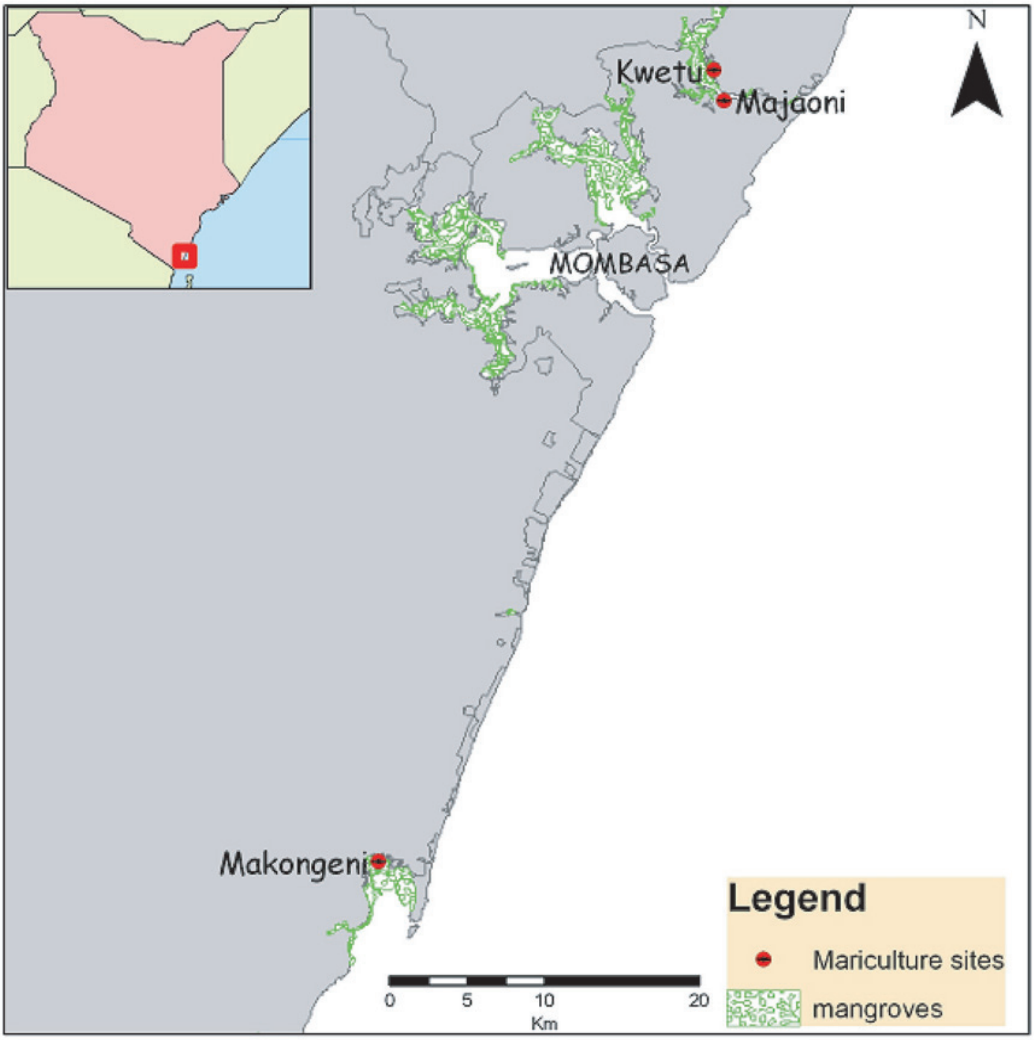

Figure 1. Map of Kenya coast showing the study sites where polyculture trials were undertaken.

through pond PVC overflow pipes (Fig. 2). Community aquaculture ponds in Kenya are only constructed on sand flats with minimal or no cutting of mangrove trees and no pumping systems for water exchange, unlike ponds in Southeast Asia where mangroves are often cut to create room for fishponds (Primavera, 2005). The PVC overflow pipes were covered with screen nets on both sides to filter incoming and out flowing water and prevent entry of predatory fish. They were fixed in the pond dykes one meter above the pond bottom to ensure retention of a minimum water depth of 0.75 m in the ponds at all times. The incoming tide enriched the culture ponds with plankton and nutrients from the ocean, aiding the development of the *lab-lab* (benthic algal mat) as a food source for the milkfish and mullet. Supplementary organic manure was used to fertilize the ponds at neap tide every fortnight. Dry chicken manure was obtained from local villages at $1 (70 kshs) per 30 kg sack. The manure was applied to the ponds at the rate of 15 kg per pond/2wks (0.595 g/m^2/day). It was floated in sacks at the opposite corners of the ponds to enable slow release of the nutrients, thus promoting primary production while avoiding oxygen depletion. Old manure sacks were removed and replaced with new ones bi-weekly (Knud-Hansen, 1998).

Figure 2. A pond at Majaoni showing the PVC standpipe to drain the pond and the overflow pipe that allowed water exchange at spring high tides and maintained the water level.

Water Quality Sampling and Analysis

Salinity, dissolved oxygen, temperature and pH were measured in situ in each of the six research fishponds weekly, in the morning between 08.00-09.00 a.m. and in the afternoon between 14.00-15.00 p.m. using a hand-held refractometer, oxygen meter and pH meter respectively. Samples for chl-a, ammonia, nitrite, phosphate, particulate organic matter and total suspended matter were collected monthly at three points in each pond in a plastic cylinder, mixed and then subsampled to obtain a representative sample for laboratory analysis. The samples were stored in cooler boxes with ice and transported to the laboratory at the Kenya Marine and Fisheries Research Institute (KMFRI) within three hours where analysis was done by titration. All water quality analyses were undertaken following guidelines outlined by Eaton *et al.*, (1995) and Boyd and Tucker (1992).

Stocking and Sampling

Milkfish and mullet fingerlings were collected to stock the ponds using push nets constructed with mosquito netting. Fingerlings were collected in mangrove channels and pools at low tide in the Mtwapa Creek and Gazi Bay. They were transported to the culture ponds in half-filled buckets with a 99% survival rate. The opportunistic capture of fingerlings in intertidal pools at low tide with hand nets also proved possible. Fish were corralled for 24 hours in a *hapa* (mosquito) net staked in the pond to enable their measurement (weight and total length) before stocking. The fish were weighed using a digital electronic balance and their length with a 30 cm ruler. Fingerling collection continued daily on average for 20 days to reach the required stocking density. A total of 392 milkfish and 124 mullet were stocked per pond during each culture cycle, ranging between 2-8 cm in length and 5-9 g in weight.

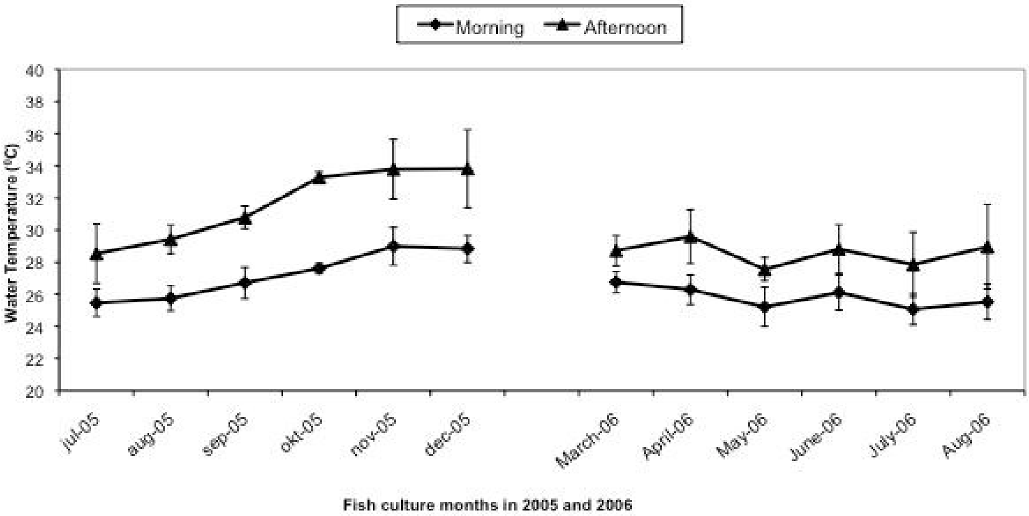

Figure 3. Morning (08.00-09.00) and afternoon (14.00-15.00) variations in temperature in the fish culture ponds during the wet (long rains-2006) and dry (short rains-2005) seasons.

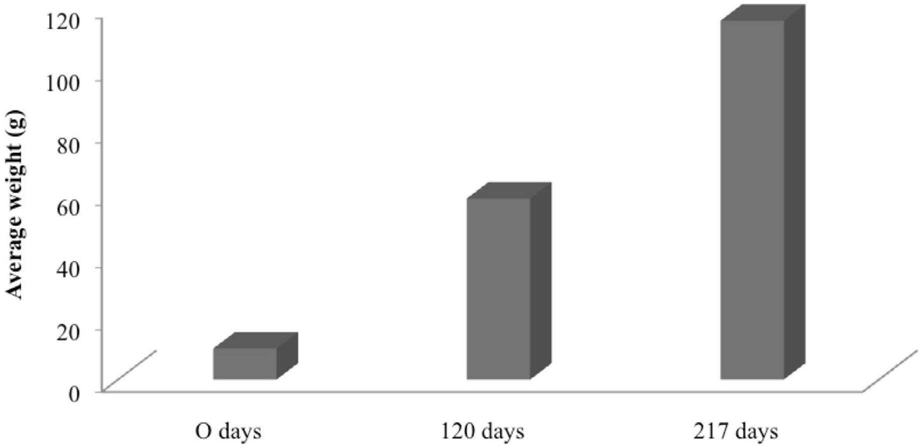

Figure 4. Growth of milkfish in coastal earthen ponds in Kenya during the wet season in 2006. Average growth rate was 0.53 g/day.

Pond fish were sampled using seine nets once a month to measure their growth in both length and weight, sampling ~10 % of the total milkfish and mullet or 40 fish per pond. Harvesting took place after 217 days by draining all the water from the ponds through the outlet PVC pipes. Harvested fish were grouped into species and then into size classes before measuring their total length and wet weight. The harvest was sold to the local people at customary prices to create awareness of the importance of mangrove conservation in providing livelihood opportunities such as fish culture.

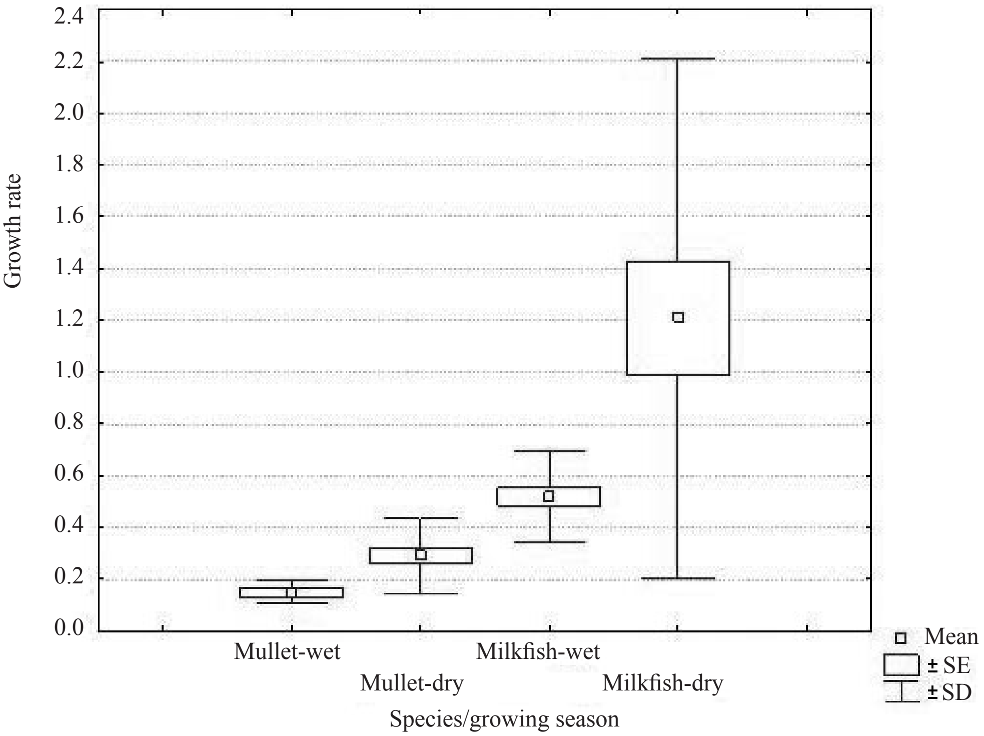

Figure 5. Growth rate (g/day) of milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) in coastal earthen ponds in Kenya in the wet and dry seasons.

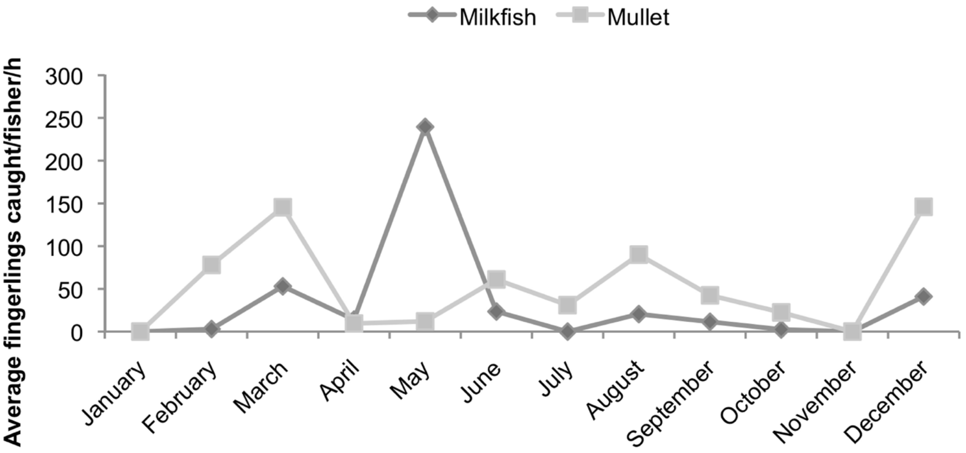

Figure 6. Annual abundance of milkfish and mullet fingerlings in Mtwapa Creek in Kenya during 2005-2006.

Fingerling occurrence survey

Fingerling collection was based on the findings of Kumagai *et al.* (1985) who established that the occurrence of juvenile milkfish in natural mangrove nursery grounds (pools and channels) varied with the food supply, size of habitat and connection with the sea. Fingerling surveys were thus conducted twice a month in Mtwapa Creek during spring high tides. The fingerlings were collected in push and seine nets in the mangrove pools and channels that were connected with the sea during spring high tides. A crew of two undertook the sampling for a period of one hour in each sampling day. The fingerlings were identified and measured in the field and transferred to ponds if needed for culture or released back to the sea.

Statistical Data Analysis

Arithmetic means and standard deviations were determined for the samples. One way ANOVA was used to assess the effects of seasonality in fish growth for pooled data in the wet and dry seasons, while repeated measures ANOVA was used to analyse monthly milkfish and mullet fingerling abundance. To determine if there was any significant difference in milkfish and mullet occurrence, data were pooled for all months and analysed using ANOVA. Differences in water quality between seasons and sites were tested with one way ANOVA. The wet period was from February to August in 2006, while the dry period was June to December 2005.

RESULTS

Water quality

Salinity varied significantly between seasons, being <30 in some months and having a mean of 28.4 in the wet season, while other readings were >40 in the dry months with a mean of 41.7 ($p < 0.05$, Table 1). However, there were no significant differences in salinity between sites. Temperature, pH and oxygen concentration did not differ significantly between seasons (Fig. 3, Table 1) or sites. The mean morning temperature, oxygen concentration and pH values were 25.8^{o}C, 2.7 mg/l and 7.05. Afternoon means for oxygen in the dry and wet season were 5.8 mg/l and 6.6 mg/l respectively and their monthly fluctuations ranged between 4.5 mg/l to 9.8 mg/l; afternoon pH values were between 7.3 and 8.6.

Chlorophyll-*a* in the dry season was almost double that recorded in the wet season but phosphates and nitrites were significantly higher in the wet season. Levels of suspended organic matter, particulate organic matter and ammonia nitrogen in the ponds were low, with no significant difference between seasons (Table 1).

Table 1. Water quality parameters (mean ± sd) recorded in coastal earthen ponds in Kenya in the wet and dry seasons. Significance of results was tested by ANOVA.

Water quality parameters	Pond water		Statistical
	Wet season	Dry season	p-value
Chlorophyll-a (mg/l)	0.93±0.74	1.73±0.58	<0.05
Total suspended matter(g/l)	0.04±0.004	0.039±0.004	0.857
Particulate organic matter(g/l)	0.03±0.004	0.04±0.003	0.834
Dissolved oxygen(mg/l) - afternoon	5.75±2.53	6.59±3.58	0.296
Salinity	28.38±0.12	41.66±3.27	<0.05
pH - afternoon	8.08±0.07	7.45±0.02	0.253
Ammonia-N (g/l)	1.24±0.78	0.53±0.09	0.245
Phosphate (mg/l)	1.72±0.14	0.04±0.008	<0.05
Nitrite-N (g/l)	0.07±0.034	0.02±0.003	<0.05

Growth rate and production

Milkfish grew from an average stocking weight of 10 g to an average of 115.4 g after 217 days during the wet season (Fig. 4) but their growth was roughly double this figure in the dry season (Fig. 5). Mullet grew slower throughout the culture period, attaining a significantly lower mean growth ($p < 0.05$) and much lower final weight. The dry season yielded a significantly higher growth rate for both milkfish (1.21g/day) and mullet (0.29 g/day) compared to the wet season ($p < 0.05$; Fig. 5), with significantly higher weights at harvest ($p < 0.05$; Table 2). Their maximum weights varied in both the wet and dry seasons but they attained larger sizes in the dry season. Both milkfish and mullet were observed to feed intensively during mid-afternoon on hot sunny days when lab-lab started peeling off the pond bottom to float, fostering active surface feeding by the fish. Once milkfish reached a total length of ~14 cm, they tended to respond to the incoming high tide by swimming against the current and aggregating in front of the pond gate. Fish survival of both species was ≥79%.

Fingerling occurrence

The bimonthly survey undertaken during 2005-2006 indicated that milkfish fingerlings occur twice a year (March–June with a peak in May and October-December, and a relatively small peak in December); they were minimal in the periods in between (Fig. 6). Their peak abundance coincided with a period of rainfall along the Kenyan coast. Mullet fingerlings were available throughout the year, with smaller peaks compared to the milkfish. However, mullet were limited in abundance between April and June and in November. The incidence and abundance of both species varied between months though the differences were not significant ($p=0.089$).

DISCUSSION

Culture species and fingerling collection

Milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) tolerate a range of water quality parameters, manifest simplicity in their diet and adaptability to crowding, these being attributes tapped in the current study. Their tendency to aggregate, noted in the literature (Rice & Devera, 1998), aided in their capture. These attributes proved of benefit in the small-scale aquaculture here, confirming the viewpoint of Swift (1985) that it is best to select species like milkfish and mullet that are tolerant to fluctuations and extremes of water quality for this purpose.

Table 2. Seasonal survival (%), harvesting size (mean ± sd), maximum size attained (g) and production (kg/ m^2) of both milkfish and mullet in coastal earthen ponds in Kenya during 2005-2006. (Superscript letters indicate significant ANOVA at $p<0.05$.)

Parameter	Milkfish		Mullet	
Season	Wet	Dry	Wet	Dry
Survival	81.4%	90.3%	79.8%	87%
Average size at harvesting	81.3 ± 28.1^a	262.5 ± 218.1^b	28.7 ± 6.9^c	62.9 ± 31.9^d
Maximum size at harvest	117.8	650.5	30.4	150.2
Anticipated production @ 100% survival	0.177	0.572	0.020	0.043
Actual production	0.144	0.516	0.016	0.038

The seed stocks were obtained from the wild by netting in mangrove pools and channels. Lack of hatchery facilities necessitated dependency on their wild capture and it was not possible to get seed stock of the same size for the research trials. However, even in South East Asia where hatchery technology is highly developed (Lee & Liao, 1985), most of the culture of this species is based on the collection of larval and juvenile fish from the wild (Villaluz, 1986). Mosquito nets are cheap, available locally and easy to employ for seining in spring high tides.

Water Quality

Temperatures in the experimental ponds varied between 24-34°C in the wet and dry seasons respectively. According to Villaluz and Unggui (1983), milkfish can tolerate a temperature range of 20-43°C and temperature was thus not a limiting factor in their growth but would have been a growth-inducing factor according to Rice (2003). Similarly, although salinity was significantly higher in the dry season (mean 42) than the wet season (mean 28), Crear (1980) noted that milkfish and mullet tolerate salinities between 0 -158 making them suitable for culture (see also Lee & Liao, 1985).

Although they increased slightly during the day, pH (7.0 to 8.5) fell within acceptable levels (Rice, 2003; Bagarinao and Lantin-Olaguer, 1998) but was higher in the dry (8.07) rather than the wet (7.4) season. Milkfish and other fish survive normally in a pH range of 5.0-9.0 (Rice, 2003; Bagarinao and Lantin-Olaguer, 1998). The slight increase in pH from morning to evening was probably attributable to photosynthesis (Boyd, 1992). However, afternoon levels were low when compared with those recorded by Mirera (2000) in Tilapia ponds where artificial fertilizers were applied.

Chlorophyll-*a* was lower during the wet season (0.93 mg/l) compared to the dry season (1.73 mg/l). The levels were higher than those recorded by Mirera (2000) at Sagana in his studies of pond fertilization, where a high correlation was observed between fish standing crop and chl-a, but lower than those recorded by Boyd (1992) in experiments conducted at Auburn University.

Dissolved oxygen levels observed in this study ranged between 5.75 mg/l in the wet season to 6.59 mg/l in the dry season. However, morning values were, on rare occasions, <1 mg/l following days of heavy rainfall and windless conditions, leading to oxygen depletion. As noted by Rice (2003), the fish were then forced to gulp for air on the surface in the early morning. Higher variations in dissolved oxygen appeared to be associated with variations in pond productivity (wet season, morning, 2.85-4.1 mg/l; afternoon, 7.5-8.3 mg/l; dry season, morning, 3.25-3.75 mg/l; afternoon, 8.6–11.15 mg/l).

Levels of nitrite in the culture ponds were relatively low (0.0196-0.0723 g/l) compared to culture ponds in the Philippines (0–1 mg/l; Bagarinao, 1999) and the maximum that fish can tolerate over a 48 hour period (Almendras, 1987). Nitrite values were probably low because no artificial feeds were used in the experiment.

Total ammonia nitrogen (TAN) recorded in this study ranged between 0.53–1.24 g/l, far below the 96 h toxicity limit (21 mg/l) published by Cruz (1981). The source of ammonia in this study was probably from fish excreta, bacterial decomposition of organic matter (Kaushik and Cowey, 1991).

Phosphates were observed to be significantly higher during the wet season (1.72 mg/l) than the dry season (0.038 mg/l), possibly due to limited uptake by phytoplankton, the senescence of phytoplankton and the release of phosphates from the sediments (Welch, 1980). The phosphate concentration supports the findings of Mmochi and Mwandya (2003) in Makoba fishponds. The phosphate levels available in the current study were above the values required for earthen culture ponds (0.001-0.05 ppm; Knud-Hansen, 1998). Total suspended solids and particulate organic matter were low in both the dry and wet season (0.03 g/l and 0.05 g/l, respectively).

Dynamics of fish growth

Milkfish and mullet growth rates were significantly higher during the dry season compared to the wet season, these findings being similar to those of Guanzon *et al.* (2004). Growth rates observed in this study were higher than those reported by Mwangamilo and Jiddawi (2003) in their laboratory experiment on milkfish fingerlings after 64 days in plastic tanks (0.12 g/fish/day), signifying the potential of earthen pond culture systems. The earthen ponds provide conditions that promote growth of *lab-lab* and lumut that form the main feed for milkfish and mullet in earthen ponds. *Lab-lab* (a complex mat of blue green algae, diatoms and associated invertebrates) and *lumut* (mainly filamentous green algae) and associated micro-and meio-fauna form the main food source for pond-reared milkfish and mullet (Blaber, 1980). *Lab-lab* is prevalent in the dry season with its high temperature, salinity and chlorophyll-*a* and has a positive influence on fish growth and productivity. Its build-up during the dry season has been observed elsewhere and it is considered equivalent to benthic algae (FAO, 1987), leading to high milkfish production relative to the other food sources (*lumut* and plankton). *Lumut* is prevalent during the rainy season and yields <400 kg fish/ha, while *lab-lab* yields 1000-2000 kg fish/ha, explaining why milkfish and mullet growth in the present study were higher in the dry season than in the rainy season. During the rainy season, *lab-lab* disintegrates while lumut and/or plankton become the prominent food source, limiting fish growth (Banno, 1980).

Projections of the present results suggest that a polyculture system should be able to produce 0.3 kg/m^2 milkfish and 0.036 kg/m^2 mullet in the wet season, and 1.01 kg/m^2 and 0.24 kg/m^2 respectively in the dry season, assuming 100% fingerling survival (Table 2). The results suggest that improved survival of milkfish and mullet in polyculture would be more profitable through increased yield per square meter. Though the highest production would be realised during the dry season because of abundant lab-lab production, lumut would still support diminished fish growth in the wet season.

The intensive feeding observed in the Kenyan ponds during hot sunny afternoons was also observed by Kumagai *et al.*, (1985) and Chiu *et al.*, (1986) “Feeding activity peaks at midday and in the afternoon when dissolved oxygen, water temperature and digestive enzyme activity are highest”. The tendency of milkfish >14 cm to respond to the incoming high tide by swimming against the current and aggregating in front of the pond gate in an effort to get out was a behaviour also noted by Schuster (1960).

Studies undertaken in Asia suggest that harvesting of milkfish takes place when fish have reached a size of 300-800 g body weight with pond yields of 50-500 kg/ha/year (Bardach *et al.*, 1972). Gandhi *et al.*, (1988) recorded a production in polyculture of 872 kg/ha but with relatively lower survival compared to the current study. The theoretical production in the present study was 1 440 kg/ha in the wet season and 5 160 kg/ha in the dry. Harvested milkfish averaged 82 g in weight in the wet season and 263 g in the dry, with some individuals weighing up to 650 g, concurring well with the studies of Mwaluma (2003) and Gandhi *et al.* (1988). Mullet production was lower (160 -380 kg/ha) and the average fish weight was 29 g and 63 g during the wet and dry seasons respectively. The growth of milkfish and mullet in the current study was similar to that recorded by James *et al.* (1984) over a culture period of 270 - 300 days. Growth of milkfish and mullet during the wet and dry seasons was uniform, suggesting that feed availability and water quality parameters similarly did not vary.

The survival of both species was ≥79% and similar to that recorded by Gandhi *et al.* (1988) in earthen ponds under mono- and polyculture, but lower than that recorded by Mwangamilo and Jiddawi (2003) under laboratory conditions.Growth in the present study under natural pond conditions undoubtedly exposed the fish to a more natural variety of food available and environmental conditions. This productivity would be beneficial to local farmers since their expenses would be limited to the purchase of chicken manure and labour to collect seed stock.

Fingerling abundance

In the Philippines, milkfish were observed to enter a mangrove lagoon fortnightly with the high tides of spring tide periods where they grew into juveniles before leaving the area with the high tides (Kumagai *et al.*, 1985). These observations concur with those of Kumagai (1984) that fry are available during the new and/or full moon period because intense spawning occurs during the quarter moon periods. However, fry availability does fluctuate due to climatic factors and fishing effort. The present survey indicated that milkfish could reliably be collected twice a year between March and June, with a peak in May, and again in December. Mullet could be collected throughout the year but were limited in abundance between April and June when milkfish were most abundant. These observation are similar to those recorded in the Philippines, which indicate that milkfish fry occur practically throughout the year with peaks in abundance in April-July and October-November (Villaluz, 1986), while Indonesia has two milkfish fry seasons: April-June and September–December (Chong *et al.*, 1984). In addition, FAO records corroborate the findings of the current study along the Kenyan coast (FAO, 1987). The abundance of milkfish and mullet is associated with the spawning cycle, which varies seasonally according to locality (Kumagai, 1984). Based on the annual abundance patterns of milkfish fry, their breeding season appears to be protracted near the equator, diminishing progressively to a single peak at higher latitudes in the northern hemisphere.

In conclusion, fish culture can be accomplished within earthen ponds on intertidal mangrove sand flats in Kenya. Milkfish grow fast, reaching market size earlier compared to mullet under polyculture, although they both have a high survival rate. The present results suggest that polyculture during the dry season has a high productivity due to the availability of *lab-lab* as fish food. However, milkfish farming is best undertaken during periods of peak fingerling abundance. Milkfish and mullet are tolerant of variable environmental conditions, making them good candidates for earthen pond culture. However, research is needed to establish the cheapest supplementary feed that will promote faster growth with minimal environmental impacts.

Acknowledgments–I acknowledge funding from CORDIO East Africa, which enabled implementation of the project, and Kwetu Training Centre. My sincere gratitude is extended to Elgin Arriesgado, Renson Washe and Abdallah Mtile who made time available for the project activities. I am also obliged to the community members of Majaoni and Makongeni for their support, many of whom were directly or indirectly involved in project implementation.

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