Western Indian Ocean J. Mar. Sci. Vol. 13. No. 1, pp. 11 - 22, 2014

Suitability of Selected Coral Species for Culture in the Ornamental Aquarium Trade

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Keywords: Ornamental coral culture, growth, survival, *Pocillopora*, *Acropora*, *Porites*, Kenya

Abstract — The culture of corals for the aquarium trade has been encouraged as a sustainable alternative to wild harvesting which has increasingly threatened coral reef ecosystems worldwide. A one-year experimental study was undertaken to assess the culture potential of seven scleractinian corals, *Pocillopora damicornis*, *Pocillopora verrucosa*, *Pocillopora eydouxi*, *Porites rus*, *Acropora humilis*, *Acropora selago* and *Acropora verwei*. Coral fragments obtained from the Mombasa Marine Reserve were transplanted onto artificial substrata placed in the Mombasa Marine Park, a no-take MPA. The fragments were monitored for survival and growth. The latter was measured in each fragment in terms of changes in linear extension of the main branch (axial growth) and branch width (radial growth). Survival after six months ranged from 91% (*A. humilis*), 88% (*P. eydouxi*), 80% (*P. rus*), 79% (*A. selago*), 62% (*P. damicornis*), 56% (*A. verwei*), and 29% (*P. verrucosa*). Survival increased with fragment size and a minimum size of 2cm in length proved optimum. Mean monthly growth (±SE) in axial length and branch width was highest in *A. selago* (29.6±4.1mm and 68.3±8.3mm respectively) and lowest for *P. damicornis* (13.5±4.7 mm and 33.8±7.7mm). This study demonstrated a low-tech method that can be used to establish parent stock for commercial ornamental coral culture.

INTRODUCTION

The value of the global trade in live aquarium organisms has been estimated to be US$ ~200-330 million p.a. (Grey *et al*., 2005; Wabnitz *et al*., 2003). The advent of home coral reef aquaria has led to a growing market for live coral (Delbeek, 2001;Wabnitz *et al*., 2003), involving more than 140 scleractinian coral species and a volume of 11-12 million fragments or colonies per year (Wabnitz *et al*., 2003). Popular coral genera traded include *Trachyphyllia*, *Euphyllia*, *Goniopora*, *Acropora*, *Plerogyra*, *Catalaphyllia*, *Favia*, *Lobophyllia*, *Porites*, *Turbinaria*, *Montipora* and *Heliofungia* (Wabnitz *et al*., 2003; Jones, 2008). According to the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) trade database, the top ornamental coral exporting countries are

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Indonesia (91%) and Fiji (8%), while the main importers are the USA (68%), European Union (24%), Japan (3%), Singapore (2%), Hong Kong (1%) and Canada (1%) (Jones, 2008). Kenya is a major supplier of marine ornamental species in the western Indian Ocean (Okemwa *et al*., 2009) and investors have shown keen interest in diversifying the trade to include cultured organisms to provide an alternative livelihood source for local fisher communities and reduce fishing pressure on the wild stocks.

Stony corals are listed in CITES Appendix II (vulnerable to overexploitation but not at risk of extinction).Their trade is permitted only if the specimens have been legally acquired and their export will not be detrimental to survival of the species or their role in the ecosystem. Culturing of stony corals has increasingly been cited as an alternative approach to reducing the impacts of harvesting on natural coral reefs in developing Indo-Pacific countries (Paletta, 1999). Cultured stony corals can be traded under CITES as long as the exporting country is satisfied that they have been grown from second generation cultured stock (Wells & Barzdo, 1991).

Interest in the culture of stony corals has grown tremendously (Arvedlund *et al*., 2003) with studies focusing on the development of both sexual and asexual culture techniques. Both farming techniques are encouraged as viable options to maintain a sustainable marine aquarium trade as well as to rehabilitate degraded reefs. Asexual culturing involves use of corals which have been fragmented either naturally or artificially. The coral fragments are cultured either in situ or in land-based aquaria (Delbeek, 2001; Arvedlund *et al*., 2003; Yap and Molina, 2003). Some costs and benefits may influence the choice of the culture environment. Although in situ culture systems may be more affordable, they may be compromised by predation and variable environmental conditions (Delbeek, 2001).On the other hand, the cost of propagating corals in *ex situ* systems is considerably higher due to the investment needed to recreate natural reef conditions in terms of water chemistry, nutrients, water flow and light intensity (Lindsay & Stanley, 2004).Comparisons between the two systems have revealed species-specific variations in survival and growth (Moothien Pillay *et al*., 2011)

Farming of corals in situ for the aquarium trade has been demonstrated to be economically viable in the Pacific region e.g. USA, Fiji, Solomon Islands, Philippines (Paletta, 1999; Delbeek, 2001; Herlan & Lirman, 2008; Lal & Kinch, 2005, Lindsay & Stanley, 2004). In the western Indian Ocean region, similar studies have been conducted at Mafia Island in Tanzania (Lindahl, 1998). Coral transplantation experiments have been conducted in Kenya, comparing growth and survival of coral fragments on natural and artificial substrata to assess their potential for reef rehabilitation in degraded areas (Tamelander *et al*., 2000). The aim of this study was to assess the suitability of potential ornamental coral species for the aquarium trade by comparing their survival and growth on artificial substrata in an in situ culture system.

METHODS

Study Site

The study was carried out in the Mombasa Marine National Park (MMNP) between April 2010 and April 2011 (Fig. 1). The MMNP was established in 1988 and, while all forms of resource extraction are prohibited in the park (McClanahan & Kaunda-Arara, 1996; Cros & McClanahan, 2003), it is surrounded by an adjacent reserve where traditional fishing activities are allowed. This reserve, which extends approximately 1km to the north and 12 km to the south, served as the donor site for the collection of coral colonies for the experiment. The area is covered by seagrass patches, scattered coral bommies and bare sand. The MMNP and reserve have a similar reef structure, bottom topography and depth range, but differ slightly with respect to reef cover (Cros & McClanahan, 2003). The coast is enclosed by a fringing reef approximately 2 km offshore with a deep channel in the

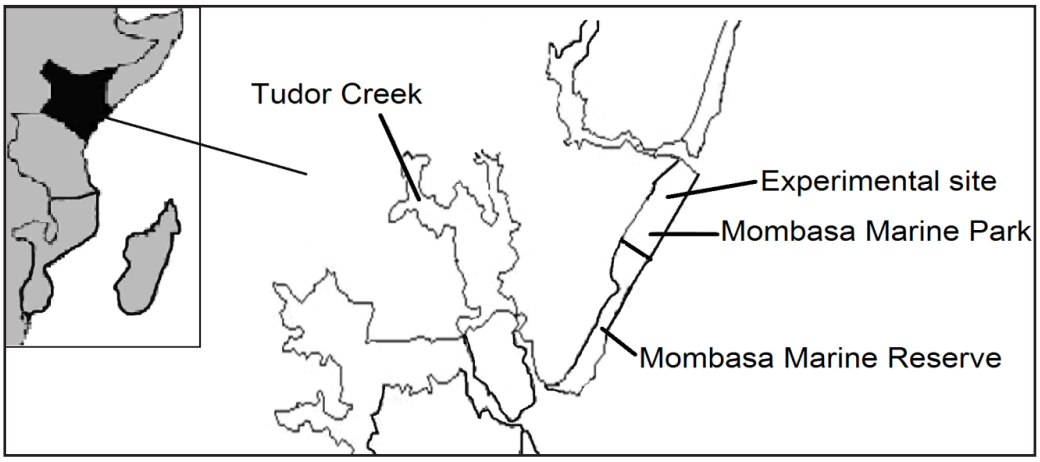

Figure 1. Location of the experimental site within Mombasa Marine Park.

south, and experiences a maximum tidal range of 4 m (Cros & McClanahan, 2003; Kirugara *et al*., 1998). The area is influenced by cyclic meteorological and oceanographic patterns caused by seasonal changes in the Inter-Tropical Convergence Zone (ITCZ) zone. These changes create two distinct seasons, the southeast monsoon (SEM) and northeast monsoon (NEM) that control many ecological processes. The SEM (April to October) is characterized by high cloud cover, rainfall, river discharge, wind energy, lower temperatures and reduced salinity, resulting in high water-column mixing, fast currents and wave energy. These parameters are reversed during the NEM (November to March). Sea surface temperatures range between 25°C and 31°C all year round.

Construction of culture tables and artificial substrate

Four 2.4 m x 1.2 m table frames were constructed using 20mm diameter round-bar metal rods (Fig. 2a). The table frames were deployed in situ and the legs were secured on concrete blocks to enhance stability. Artificial coral substrata were manufactured using a 50:50 sand-cement mixture. Palm-sized balls of the mixture were hand-pressed into circular disks with a small thumb depression on the centre and two small holes punctured on opposite sides, the design being adapted from similar studies elsewhere (e.g. Clark & Edwards, 1995; Edwards & Clark,1998; Franklin *et al*., 1998; Yap *et al*., 1998; Lindahl &Stanley, 2004; Soong & Chen, 2003; Quinn & Kojis, 2006). A set of four 2ft x 4 ft wire mesh grids served as table tops for each table frame. A piece of nylon monofilament was threaded through the two holes of each dried cement disk and tied onto a wire mesh grid. Fifty cement disks were tied onto each wire mesh grid and labelled using Dymo tape® (Fig 2b).

Collection of the corals and the propagation of coral fragments

Seven coral species were selected for the experiment on the basis of appeal and availability at the collection and experimental sites. These were *Acropora humilis*, *Acropora selago*, *Acropora verwei*, *Pocillopora damicornis*, *P. eydouxi*, *P. verrucosa* and *Porites rus*. Healthy (free of disease and bleaching) donor coral colonies were randomly selected and detached from the natural substratum using a hammer and chisel in the Mombasa Marine Reserve. The colonies ranged in size from 15 to 30 cm in diameter and were transported by boat to the experimental site in Mombasa Marine Park in 20 litre plastic buckets filled with sea water. The experimental site in the park was selected to minimise vandalism and interactions with

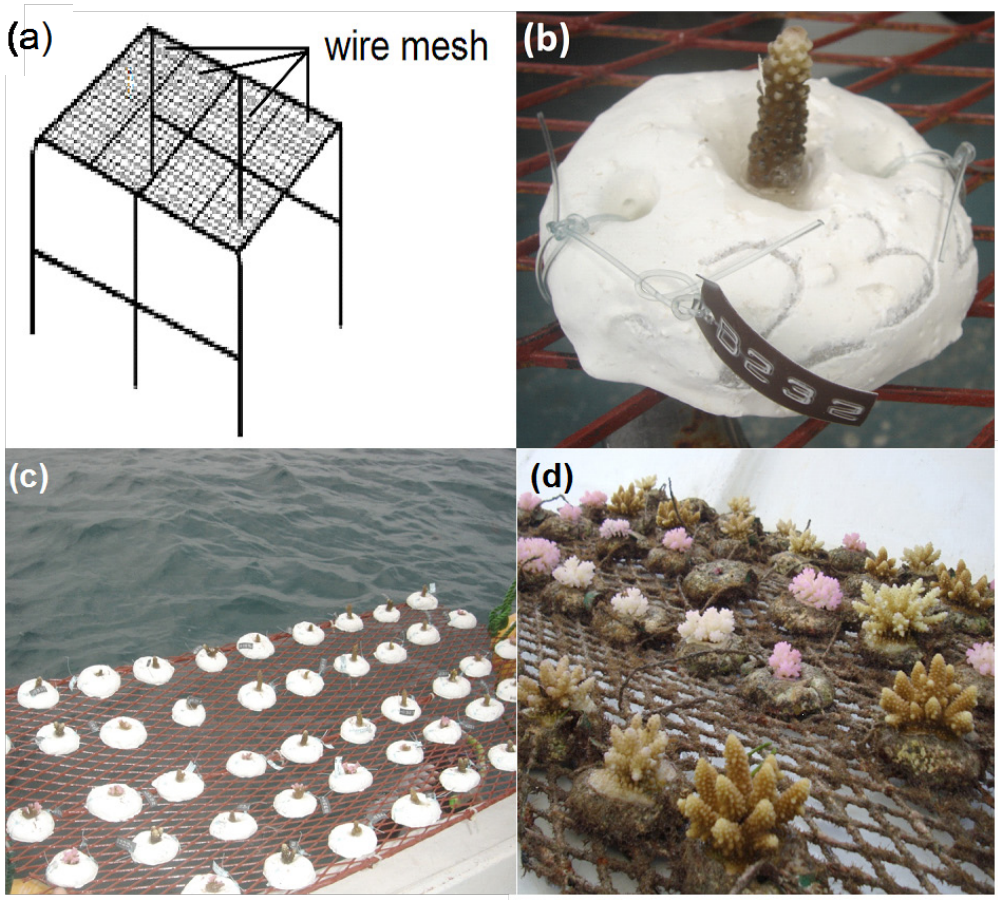

Figure 2. a) Diagram of a culture table, b) coral fragment attached to a labelled cement disk and secured to the wire mesh grid with nylon monofilament, c) fragments prior to deployment and d) at the end of the experiment.

fishing activities which occur in the reserve. The coral heads were left in situ overnight at the site, after which the tips of the branches were clipped off in fragments ranging from 1-4 cm in length. Excess water was removed from each fragment using a paper towel and the fragment was then glued using epoxy resin onto the cement discs already attached on the wire mesh (Fig. 2b and c). The glued fragments were left to set for approximately five minutes, after which each wire mesh grid was gently lowered onto the table frame and secured using plastic cable ties. Coral propagation was implemented in two trials during the SEM and NEM to compare seasonal variation in growth and survival. The SEM trial was initiated on 9 April 2010, while the NEM trial was initiated on 18 November 2010. In total, 800 coral fragments were propagated as shown in Table 1. The cement disks were gently cleaned every four weeks of all fouling organisms. A sample photo of the propagated fragments at the end of the experimental period is shown in Fig. 2d.

Environmental parameters

Sea surface temperature and salinity were measured monthly around midday using a mercury thermometer and a hand-held refractometer for three consecutive days at the experimental site. The data were later compared with remotely sensed satellite data for the same period obtained from www.worldseatemp.com/en/Kenya/Bamburi. In addition, three replicate samples of sea water were collected and

Table 1.The number of coral fragments used during the SEM and NEM phases of the study.

Coral species	SEM	NEM
Acropora humilis	133	43
Acropora selago	36	46
Acropora verwei	197	48
Pocillopora damicornis	161	46
Pocillopora eydouxi	17	8
Pocillopora verrucosa	46	0
Porites rus	10	9
	600	200

transported to the KMFRI laboratory where they were filtered through a 5µ GFF filter and dried at 60°C in a muffle oven to constant weight, after which they were reweighed to determine total suspended matter.

Measurement of fragment growth and survival

Fragment growth was monitored by measuring the change in linear extension of the main branch of each fragment (L: the total length to the apical tip) and its branch width (W: the widest diameter perpendicular to the axial length). The first measurements were taken using a metal vernier calliper one month after fragment deployment in May 2010 to allow for acclimatization. Measurements were thereafter recorded in July, September and December 2010 and April 2011. Survival rate was calculated as the percentage of the originally transplanted fragments still living at each measuring interval.

Statistical analyses

The linear measurements of the coral fragments were standardized to mm/month to compare growth rates between the coral species and seasons. Fragments that had lesions, or manifested negative growth, were excluded from the calculations. The data obtained between May and September 2010 for four species (*A. humilis*, *A. selago*, *A. verwei* and *P. damicornis*) were compared with data obtained for these species between September and April 2011 to determine variations in growth rate between the SEM and NEM. The number of healthy fragments used in the analyses ranged between 30 and 40 for each species. Linear regression analysis of the final L and W values was undertaken for five species (*A. humilis*, *A. selago*, *A. verwe*i, *P. damicornis* and *P. verrucosa*) to determine the relationship between these dimensions. Mean growth rates for each species were then compared using one way ANOVA and Tukey's Honest Significant Difference test within STATISTICA 6.0. The difference between the mean size of surviving and dead fragments during the first twelve-week period was tested using Student's t-test. Variance in the sea surface temperatures and total suspended matter were compared between the NEM and SEM using Student's t test. Correlation between in situ temperature and satellite temperature data was tested by linear regression.

RESULTS

Environmental parameters

Trends in the in situ mean temperature data correlated well with the satellite data (R^2 = 0.74), although the in situ temperature were slightly higher (Fig. 3). This difference was expected as the study area is isolated from the open ocean during low tide, causing temperatures to rise above that of the open sea during the NEM (McClanahan *et al*., 2007). Temperature was lowest in June and July (~26°C) and highest in March (29°C). Salinity was lowest in August and September (29) and highest between November and February (35-36). Temperature during the NEM (November to March) was significantly higher than during the SEM (April to October), the salinity was significantly higher during the NEM, and total suspended matter was significantly higher during the SEM (Table 2).

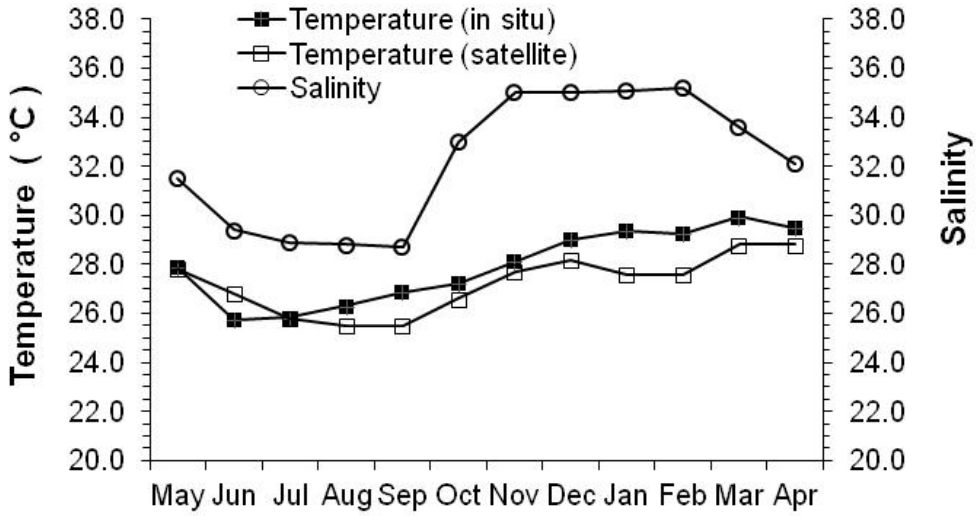

Figure 3.Mean monthly variation of temperature and salinity measured at the coral culture site and remotely sensed monthly sea surface temperature for Bamburi, Kenya (www.worldseatemp.com/en/Kenya/Bamburi).

Influence of initial fragment size on survival

The survival of fragments >2 cm (87.1%) was higher than that of fragments <2cm (73.4%). When grouped by size class (Fig. 4), fragments <1cm had the lowest survival rate, while those>3 cm had the highest. A significant difference between the mean size of surviving (2.5 cm ± 5.73) and dead fragments (1.65 ± 5.46) was observed during the first twelve-week period ($p< 0.05$, t -test).

Survival of the coral fragments

Survival of the coral fragments was high overall (mean 94%) after the first month but declined by the third month in July (Fig. 5). Six months after transplantation, 66% of the transplants had survived. *Acropora* species manifested higher survival (75%) than *Pocillopora* species (60%). At the species level, *A. humilis* exhibited the highest survival (91% after 6 months) followed by *P. eydouxi* (88.2% after 6 months), but the lowest survival occurred in *P. verrucosa* (29% after 6 months). After twelve months, *A. humilis* still exhibited the highest survival (86.6%) followed by *A. selago* (72.7%) and *P. damicornis* (43.3%). After twelve months, *P. eydouxi* and *Porites rus* had the poorest survival among all the species studied.

Growth of the coral fragments

No differences in mean monthly axial growth were observed among the species between the three tables deployed during the SEM, except for *A. humilis* on two of the tables ($p=0.0004$); therefore, the growth rate data for the three tables were pooled for further analysis. The linear relationship between L and W was significant for all species except *P. verrucosa*, for which the sample size was

Table 2. Mean (±SE) temperature, salinity and total suspended matter at the coral culture site in the Mombasa Marine Park.

Environmental Factors	SEM	NEM	Test Statistic	P	Annual mean
Temperature	27.0±1.39	29.1±1.25	Z=6.30	<<0.05	28.2±1.65
Salinity	30.5±3.73	33.9±4.55	Z=2.65	<0.007	32.4±4.53
Total suspended matter	0.07±0.017	0.04±0.047	Z=3.79	<<0.05	0.061±0.039

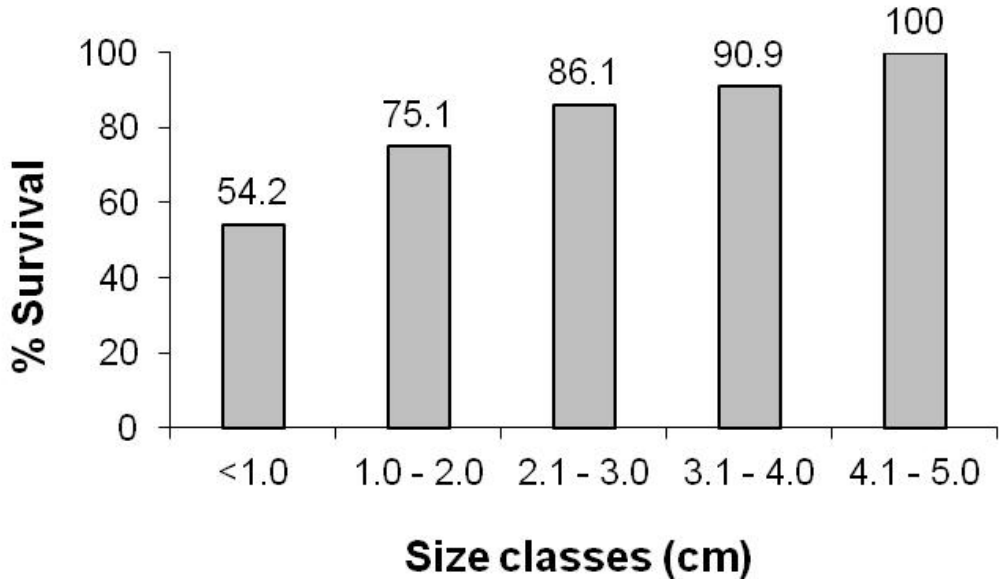

Figure 4. Percentage survival of the size classes of coral fragments grown out in the Mombasa Marine Park.

low (Table 3). The mean initial and final sizes and the percentage growth in both L and W are presented for May 2010 and April 2011 in Table 4. *Acropora* species realised the highest growth rates after 329 days, their W increasing by 260-310% and their L by~100%; *Pocillopora* species grew the least with an increase in W of 65-113% and in L of 24-100%; *Porites rus* yielded medium growth rates of 133% (W) and 88% (L).

Mean axial growth in *A. verwei*, *A. humilis* and *A. selago* was lowest during May-July and highest during December-April (Fig. 6). Axial growth of *P. damicornis*, on the other hand, was lowest during September–December and highest during July-September. *Acropora selago* manifested higher mean growth in branch width than the other species. Growth in branch width was lowest in all the species during the May-July period except *P. damicornis*, in which this parameter was lowest in July-September and September-December. Growth in L and W was thus similar in pattern for all species except *P. damicornis*. Growth overall was higher in the NEM than the SEM except for *P. damicornis* and *A. selago* (Fig. 7). The former manifested little change in growth between the monsoon seasons, the latter lower growth in axial length but higher growth in branch width in the SEM.

Table 3. Results of linear regressions of axial and branch width growth of five coral species propagated in the Mombasa Marine Park.

Species	Regression formula	R	DF	p
Acropora humilis	W=28.9+0.915L	0.618	90	>0.001
Acropora selago	W=23.6+1.220L	0.730	20	>0.001
Acropora verwei	W=35.8+0.823L	0.579	63	>0.001
Pocillopora verrucosa	W=12.1+0.822L	0.607	5	0.147
Pocillopora damicornis	W=10.7+0.402L	0.723	55	>0.001

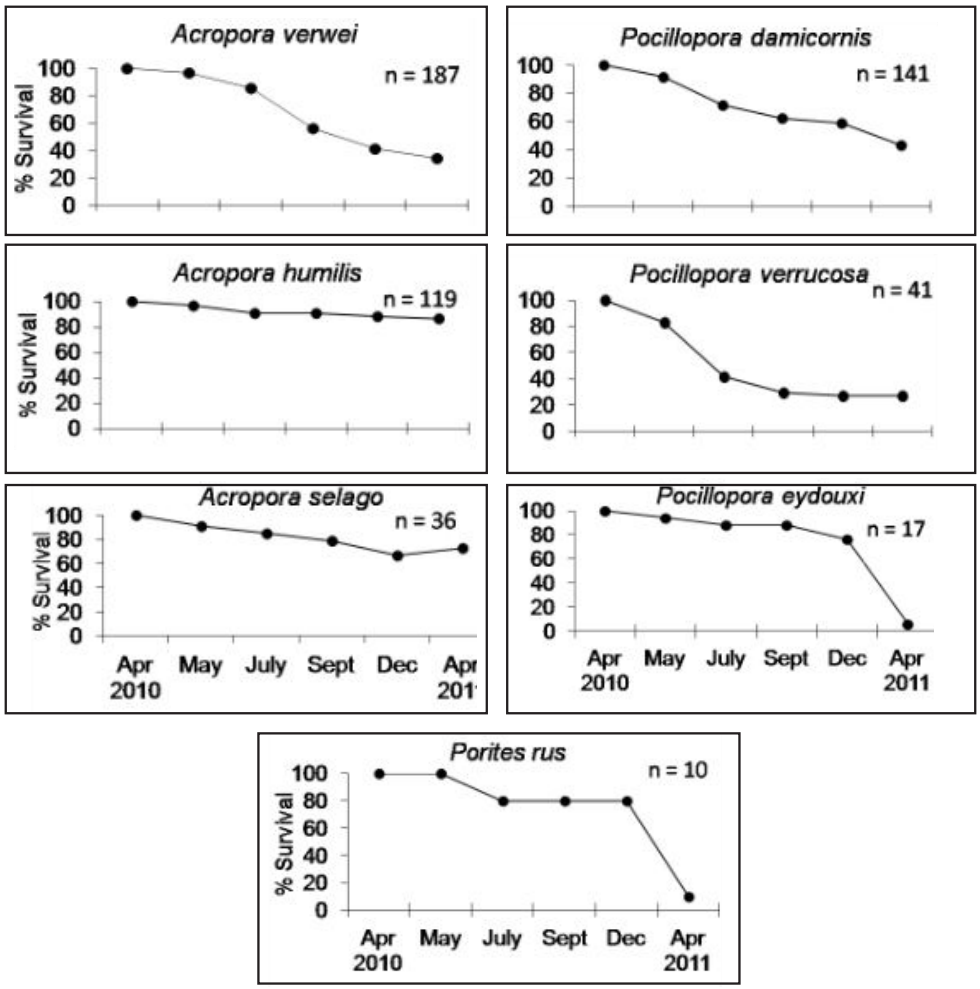

Figure 5. Percentage survival of seven species of corals transplanted to the experimental culture tables for grow-out in the Mombasa Marine Park during April 2010-April 2011. N = the initial number of fragments that were transplanted.

Table 4. Mean (±SE) initial, final and percentage increase in axial length and branch width of *Acropora humilis, A. selago*, *A. verwei, Pocillopora damicornis*, *P. verrucosa* and *P. eydouxi* fragments (after 329 days), and *Porites rus* fragments (after 208 days).

	Axial length			Branching width		
Species	Initial (mm)	Final	% increase	Initial	Final	% increase
Acropora verwei	19.0±5.4	37.9±9.3	99	15.5±6.7	60.2±16.3	287
Pocillopora damicornis	14.5±4.2	29.4±7.2	102	20.4±7.1	43.5±16.6	113
Acropora humilis	19.6±6.0	36.7±12.4	82	13.3±3.9	48.8±18.8	266
Pocillopora verrucosa	19.5±3.3	26.7±8.7	36	25.2±7.6	47.1±8.0	86
Acropora selago	18.2±4.6	39.5±13.6	116	12.2±4.2	58.3±21.9	374
Pocillopora eydouxi	24.0±6.9	29.8±8.3	24	18.4±6.9	30.5±8.9	65
Porites rus	16.8±2.9	31.6±6.1	88	15.0±1.4	35.5±11.2	133

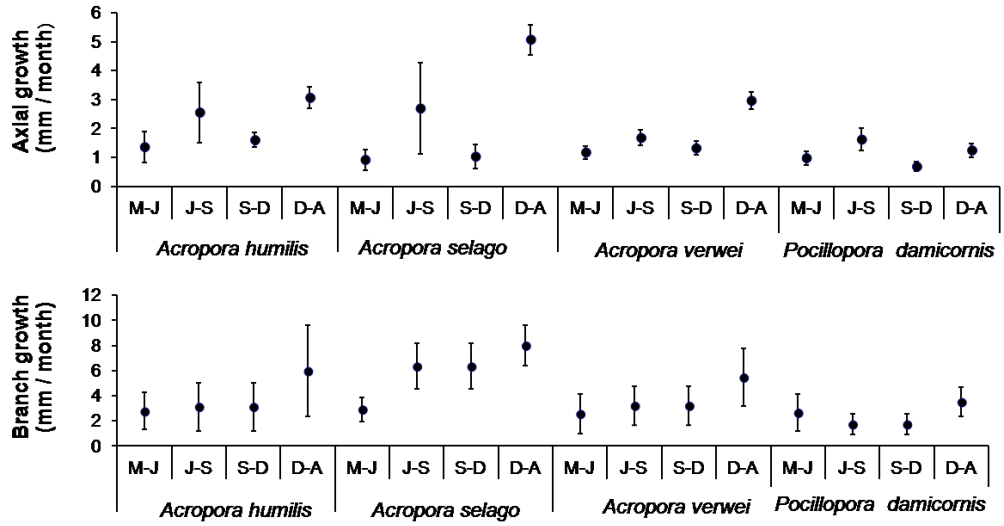

Figure 6. Mean axial and branch width growth in *Acropora humilis*, *A. selago*, *A. verwei* and *Pocillopora damicornis* during the measurement intervals of May-July, July-September, September-December and December-April.

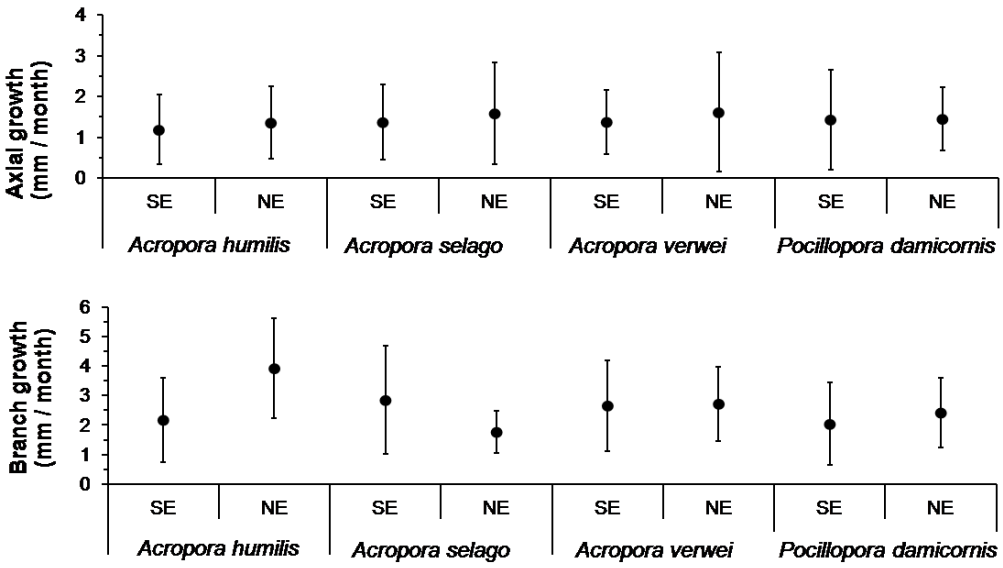

Figure 7. Mean monthly axial and branch width growth in *Acropora humilis*, *A. selago*, *A. verwei* and *P. damicornis* during the NEM and SEM.

DISCUSSION

High survival rates (up to 100%) were recorded for three species of *Acropora* and *Pocillopora damicornis* in a coral culture system in a Mauritian lagoon until high temperatures dramatically reduced their survival (Moothien Pillay, *et al*., 2011). High survival rates, ranging from 75.3% to 87%, have also been recorded for *A. grandis* and *A. muricata* in a mid-water nursery in Thailand (Putchim *et al.*, 2008).The high survival rates obtained in this study, particularly amongst the *Acropora* species, is thus not surprising.

Survival of the fragments was influenced by their initial size. While survival amongst fragments >4cm approached 100%, fragments <2cm experienced high mortality. Similar results have been obtained in other studies which have demonstrated that the survival of coral fragments is size-dependent, large fragments having a greater chance of survival (Lindahl, 1998, Tamelander *et al*., 2000, Herlan & Lirman, 2008). Forsman *et al*., (2006) found further evidence of size-specific mortality in an in situ *Porites* nursery where fragments <3cm^2 had a low survival rate, but those in an closed nursery system did not undergo size-specific mortality where factors such as sedimentation, grazing, predation and competition were limited. Thus, larger coral fragments should be used in coral culture systems to obtain a high survival rate

Apart from *Pocillopora verrucosa*, regression analysis revealed a close relationship between the axial growth and branch width expansion in the coral species investigated in this study, indicating that either parameter is suitable for monitoring early growth in coral fragments in culture systems. Overall, *Acropora* species grew faster than *Pocillopora* species, similar to findings from other studies (Yap & Gomez, 1981, 1985). The axial growth rates recorded for *P. damicornis* (~18 mm/year) in this study were nevertheless of the same order of magnitude to those measured in Australia (Harriott, 1999) Mauritius (Moothien Pillay, et. al., 2011) and India (Guzman & Cortes, 1989).The axial extension of *Acropora* species doubled and their branch width increased threefold over the 329 days that the experiment was conducted. Branch width increased faster than axial length in all species due to the formation of new branches. *A. humilis* and *A. selago* achieved the highest growth rates.

Generally, fragment growth was higher during the NEM than the SEM, although the differences were not statistically significant. Studies elsewhere in the Indian Ocean (e.g. Suresh & Mathew,1993, 1995) have similarly yielded no significant differences in the seasonal skeletal extension rates of *Acropora* species (e.g. *A. formosa* and *A. aspera*), indicating that seasonal environmental factors such as temperature appear to have a minimal influence on coral growth in coral culture systems. On the other hand, skeletal extension was inversely correlated with currents, suspended matter and sedimentation in the aforementioned studies. In the present study, suspended matter was higher during the SEM, while salinity was lower, which may explain the lower growth rates perceived during this season.

Coral culture for ornamental purposes is clearly viable in Kenya using simple and relatively low-cost techniques. Three species were found to have a high potential for culture: *A. humilis*, *A. selago* and *P. damicornis*. The latter has been found to be an ideal culture candidate for the ornamental market due to its colouration, survival and growth potential (Borneman, 2009). This species also has relatively high recruitment rates in Kenya (Tamelander *et al*., 2000). The methods used in this study provide low-tech means of establishing mother colonies as a source for second generation seed for ornamental coral culture. However, before this technology can be adopted commercially, a protocol on standards and requirements should be developed. It will be important to ensure traceability of cultured corals from those harvested from the wild. More experimental studies should be conducted to assess the suitability of other ornamental species for culture to enhance the long-term sustainability of the marine ornamental trade in Kenya.

Acknowledgements – This study was conducted with financial support from the Kenya National Council of Science and Technology (NACOSTI). We thank the Kenya Marine and Fisheries Research Institute for logistical support. The Kenya Wildlife Service allowed us to conduct the study within the Mombasa Marine Park and provided logistical support during field work. We thank Mr Rene Jorgensen of Kenya Tropical Sea Life for his valuable support during the conceptualisation and initiation of the study. We acknowledge Masudi Juma, Brenda Obath and Tonny Nzioka for field assistance. Finally, we thank the anonymous reviewers whose criticism helped us to improve the manuscript.

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