Growth performance of *Acropora formosa* in natural reefs and coral nurseries for reef restoration

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Abstract. Coral reefs are highly valuable ecosystems and play crucial roles in marine ecosystem dynamics by providing food and shelters for many organisms. Unfortunately, coral reefs around the globe are declining, thus apart from marine protected areas, active conservation and restoration efforts are extremely crucial. In this study *Acropora formosa* nubbins were transplanted and their performance were monitored, with the main aim to evaluate their survivals and growth in comparison with natural reef. The extension growth, proto-branch generation, mortality and survivals were assessed for one year in Tioman Island, Malaysia. The *A. formosa* growth rates ranged from 0.59±0.07 to 1.20±0.03 cm mth^{-1} in the nursery and from 0.55±0.13 to 0.72±0.11 cm mth^{-1} in the natural reef. The transplanted corals exhibit higher growth rates particularly during early period of transplant, and moreover have significantly higher proto-branch generation rates compared with the natural colony. However, their survivals were significantly low, mostly due to predation by fish and other corallivores. Seasonal variations in coral growth were observed, with faster rates during the inter-monsoon period (March-April and October-November). This study for the first time, documented the success of *A. formosa* transplantation and its application in coral nurseries in Malaysian waters. Coral transplantation is highly beneficial for active coral reef restoration and conservation. Nevertheless, continuous long term, systematic monitoring are needed in order to have greater understanding of the *A. formosa* growth and dynamics in the tropical coral reef ecosystems.

Key Words: *Acropora formosa*, coral growth rates, coral nursery, reef restoration, coral transplant.

Introduction. Coral reefs are highly valuable ecosystems, and are well known for the variety of marine flora and fauna within. These reefs play crucial roles in marine ecology and coastline protection, and are also vital in providing food and other resources to coastal communities (Hoegh-Guldberg et al 2007; Burke et al 2011; Osinga et al 2011). Unfortunately, coral reefs around the globe have been declining rapidly. This degradation resulted from a combination of natural and anthropogenic factors, such as climate change (Baker et al 2008; Munday et al 2008; Ateweberhan et al 2013), pollution (Burke et al 2011; Feary et al 2012; Riegl & Purkis 2012), sedimentation (Wolanski et al 2004; Fabricius et al 2005; Wooldridge 2009), destructive fishing (Jackson et al 2001; Chabanet et al 2005; Fox et al 2005; Hughes et al 2007; Caras & Pasternak 2009) and coral mining (Caras & Pasternak 2009).

The decline in reef health has driven many studies to determine the effects of the natural and anthropogenic factors mentioned above. Research and publications on coral reefs has since dramatically increased, and with that more awareness are coming from the public as well as legislators. As a result, legislations and Marine Protected Areas (MPAs) have been introduced in some countries (Rinkevich 2005). However the annual loss of coral reefs in the Indo-Pacific still increased from 1% to 2% between 1997 and 2003 (Rinkevich 2005, 2008). Thus, the concept of active conservation and restoration was introduced in order to replenish and restore degraded reefs more quickly and more effectively. Example method is coral transplantation where corals were collected from a healthy donor reef and cultivated in 'nurseries' similar to the method in silviculture

(Rinkevich 2005, 2008). The cultivated corals were then transplanted back onto the degraded reef in order to restore their ecological properties (Yeemin et al 2006; Garrison & Ward 2008; Rinkevich 2008; Chou et al 2009; Forrester et al 2011; Ammar et al 2013). Therefore, good understanding of coral growth, development and interactions with their environmental is crucial in order to achieve effective reef restoration (Rinkevich 2005, 2008; Forrester et al 2011; Osinga et al 2011; Ammar et al 2013).

Recently, a coral reef transplantation programme has been launched in Tioman Island, Malaysia, utilizing *Acropora formosa* from the nearby Renggis Island (RCM 2012). In the present study the transplanted corals were assessed and monitored, with the main aim to evaluate their survivals and growth performances, in comparison with the natural colony at the donor site. Since this was the pioneer coral transplantation program in Malaysia, results from this study are therefore very important for future program in Malaysian coastal waters, as well as in other parts of the region.

Material and Method

Description of the study sites. This study was conducted at Tioman Island, Malaysia, about 30 nautical miles from the mainland. The Tioman Island archipelago comprises of Tioman, Tulai and Renggis and were gazetted as a Marine Park in 1994 under the Malaysian Fisheries Act 1985 (Amended 1993). The island can be easily accessed by flight from Kuala Lumpur and Singapore, apart from many boat services from the mainland. The island is highly influenced by the Northeast Monsoon during November to February, which brings heavy rainfall and storms (Wong 1993). Due to the increasing environmental pressures, climate change and deteriorating reef condition, a coral reef rehabilitation program was initiated by Reef Check Malaysia (RCM), with the installation of a coral nursery at Tekek in June 2011 (RCM 2012). Small nubbins of *A. formosa* were collected from a nearby donor reef at Renggis Island (Figure 1).

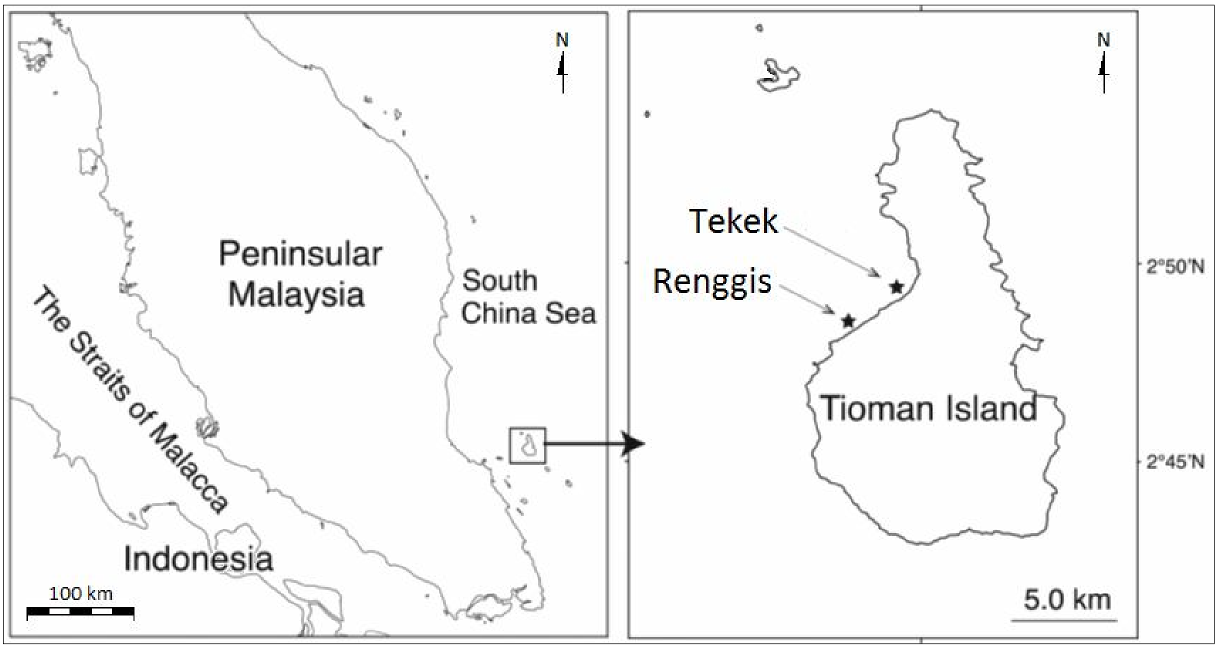

Figure 1. The location of Renggis reef and the coral nursery at Tekek, Tioman Island, Malaysia.

Donor reef and nursery setup. Four sampling sites at the donor reef in Renggis Island were randomly selected and marked by underwater buoyant markers. The *A. formosa* colony branches were then randomly selected and tagged using cable ties with numbered plastic tags (Figure 2). The distance between the cable tie and the tip of coral branch was maintained at approximately 3 cm (Charuchinda & Hylleberg 1984). A total of 92 coral branches at the four sites were tagged and their survivals, growth and proto-branch generations were monitored throughout this study.

In the coral transplant experiment, coral nubbins of 5-10 cm lengths were collected from Renggis Island reef by using pliers (Soong & Chen 2003). The nubbins were maintained submerged in a zip-lock plastic bag filled with sea water, and were transferred to the nursery site at Tekek within an hour. The nubbins were transplanted onto specially made substrates, comprised of rectangular frames made from 15 mm diameter PVC pipes. The PVC frame was approximately 80 cm x 70 cm, with four parallel pipes across, and the whole structure was elevated to about 35 cm from the bottom. The nubbins were tied vertically to the frames using plastic cable ties (Figure 3). There were 60 nursery frames installed at the Tekek nursery site, with a total of 1680 nubbins successfully transplanted. In this study the nubbins were randomly selected for observations.

Figure 2. The *Acropora formosa* colony at Renggis Island, Tioman Island, Malaysia. The coral branches were randomly selected and tagged for monitoring purposes.

Figure 3. The PVC frame used as substrate for the coral transplant at Tekek, Tioman Island, Malaysia.

Coral monitoring and observations. During the monitoring period, environmental parameters such as water depth, temperature, photosynthetic active radiation (PAR), visibility and secchi depth were taken at each site during each visit. Apart from that, continuous water temperature profiles were recorded using the Onset HOBO Pendant Temperature Data Logger (Onset Computer Corporation 2012). Four aspects of *A. formosa* growth were monitored i.e. extension growth, proto-branch generation, predation rates and survival rates, which were recorded every two months. The extension growths were measured using a flexible measuring tape, from the area marked by the cable tie up to the tip of the axial polyp (Charuchinda & Hylleberg 1984; Okubo et al 2005). Only the primary axial branch were measured, while the corals and nubbins with their tips missing due to predation or with bite marks were excluded. The protobranch generations were monitored by recording every secondary white-tipped axial branch that emerged from the area between the cable tie and the branch tip. The predation rates were defined as removal of the intact tip of coral branch or nubbins by corallivores (Jayewardene et al 2009), and were recorded as portion (lengths) of coral removed by corallivory fish. And finally the survival rates were determined by counting the number of dead nubbins, which defined as corals without any signed of living polyps present.

Statistical analysis. All data were tested for assumptions of normality and homoscedasticity by the Bartlett's test and were arcsine-transformed when required. Comparisons between the nursery site at Tekek and natural reef at Renggis were conducted using t-test. Variations between sampling months were compared using one-way ANOVA, followed by Tukey's post hoc test. Significance of differences was defined at $p < 0.05$. Statistical analyses were performed using MINITAB® software.

Results. The sites at natural reef of Renggis Island were significantly deeper compared with the transplanted corals at the nursery site in Tekek (Table 1, $p < 0.05$), with mean water depth of 7.20±0.07 m and 5.81±0.04 m respectively. The seawater temperature at both sites were relatively similar ($p > 0.05$), with annual range between 27ºC and 31ºC (Figure 4), and mean daily temperature of 28.89±0.70°C. Relatively higher temperatures were recorded during March-April and October-November period. The PAR values were significantly different between the two sites ($p < 0.05$), which ranged from 70 to 165 µmol m^{-2} s^{-1} in the nursery site and from 30 to 175 µmol m^{-2} s^{-1} in the natural reef. The different in PAR values was probably due to the different depth of the two sites, where there were significant negative correlation between PAR and water depth at both sites (Pearson correlations, $p < 0.05$). There was no significant different in secchi depth reading and underwater visibility between the two sites ($p > 0.05$), which indicated that the water quality (turbidity) and degree of transparency was quite similar between them.

Table 1

The environmental parameters (mean±standard error) at Renggis reef and coral nursery at Tekek, measured at noon between 13:00 to 14:00 h

	Nursery site	*Natural reef*	*Statistics*
Depth (m)	5.81±0.04	7.20±0.07	t-test: -17.90, p < 0.05, df = 411
Temperature (ºC)	28.24±0.06	28.22±0.06	t-test: 0.19, p > 0.05, df = 516
PAR (µmol m^{-2} s^{-1})	114.00±2.80	95.10±2.70	t-test: 4.82, p < 0.05, df = 275
Visibility (m)	9.17±1.60	9.33±1.50	t-test: 0.07, p > 0.05, df = 9
Secchi reading (m)	5.12±0.09	5.50±0.16	t-test: 2.11, p > 0.05, df = 6

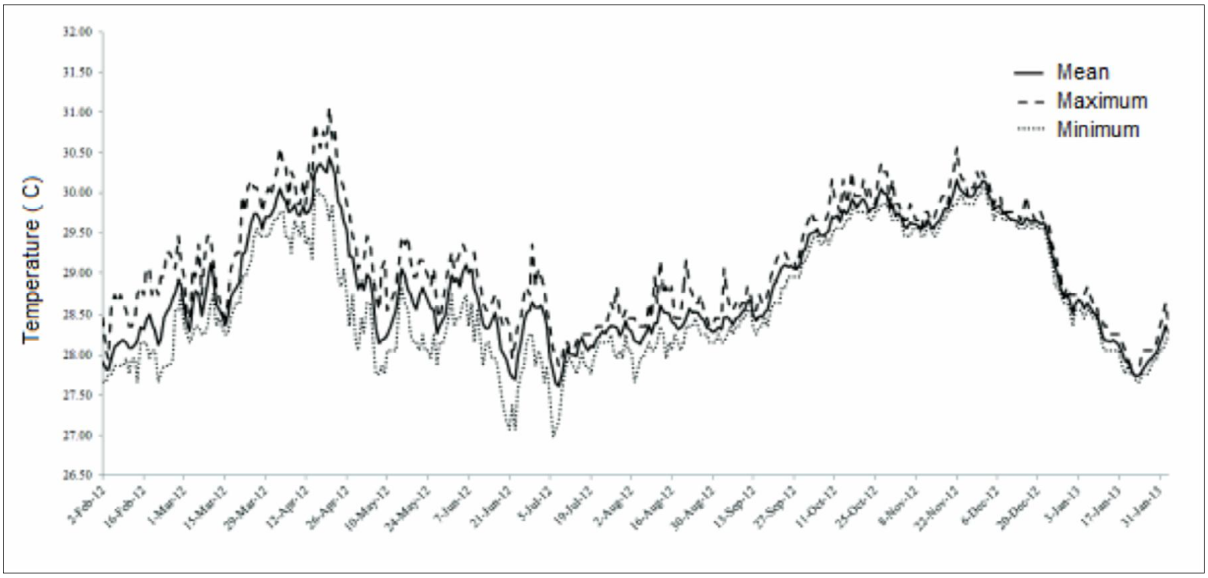

Figure 4. Daily water temperatures recorded throughout the study period.

Extension growth and protobranch generations. The mean extension growth of *A. formosa* nubbins at coral nursery in Tekek and natural reef in Renggis is presented in Figure 5. The growth rates ranged from 0.59±0.07 to 1.20±0.03 cm mth^{-1} in Tekek nursery, and from 0.55±0.13 to 0.72±0.11 cm mth^{-1} in Renggis reef. The growth rates at the nursery were generally higher compared with the natural reef. The difference appeared probably due to higher PAR values in nursery areas, which was located at much shallower waters. However, they were only significantly different during the first four months of the study ($p < 0.05$), with highest growth rate recorded, at 1.44±0.12 cm mth^{-1}. No significant difference was detected for the following months ($p > 0.05$). Throughout the monitoring period, the variations in growth rates appeared relatively similar between the nursery and the natural reefs. There was also quite similar pattern of variations between growth rates and mean daily temperature throughout the study (Figure 5). However, low correlations were detected between the temperature and the growth rates in Tekek (Pearson correlation = 0.14, $p > 0.05$), and Renggis (Pearson correlation = 0.67, $p > 0.05$). The proto-branch generation rates also showed higher values in the nursery site compared with the natural colony throughout the study (Figure 6). There were significantly higher proto-branch recorded in the nursery during the earlier phase (March to July 2012) and final phase of the monitoring (January 2013) ($p < 0.05$). Again, this might be due to higher PAR values recorded in Tekek nursery area.

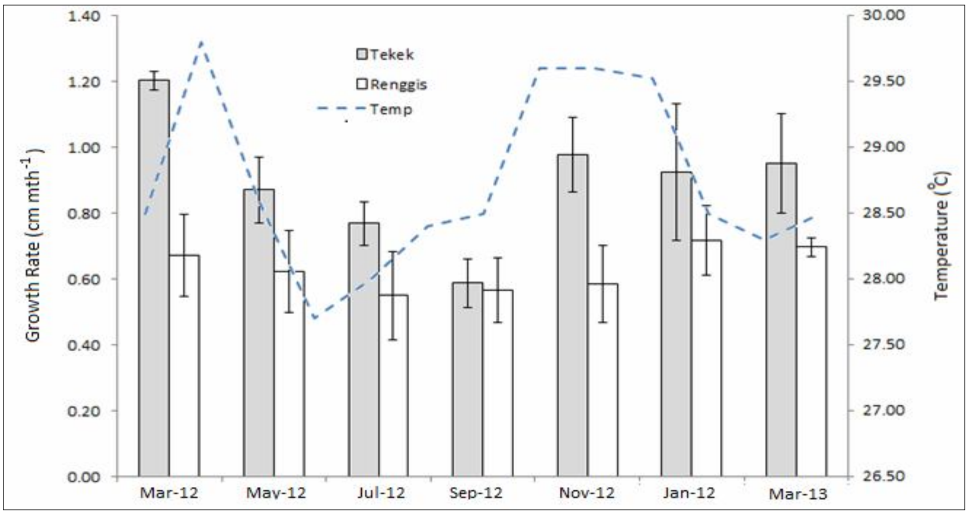

Figure 5. Growth rates (extension growth) of *Acropora formosa* and variations in seawater temperature from March 2012 to March 2013.

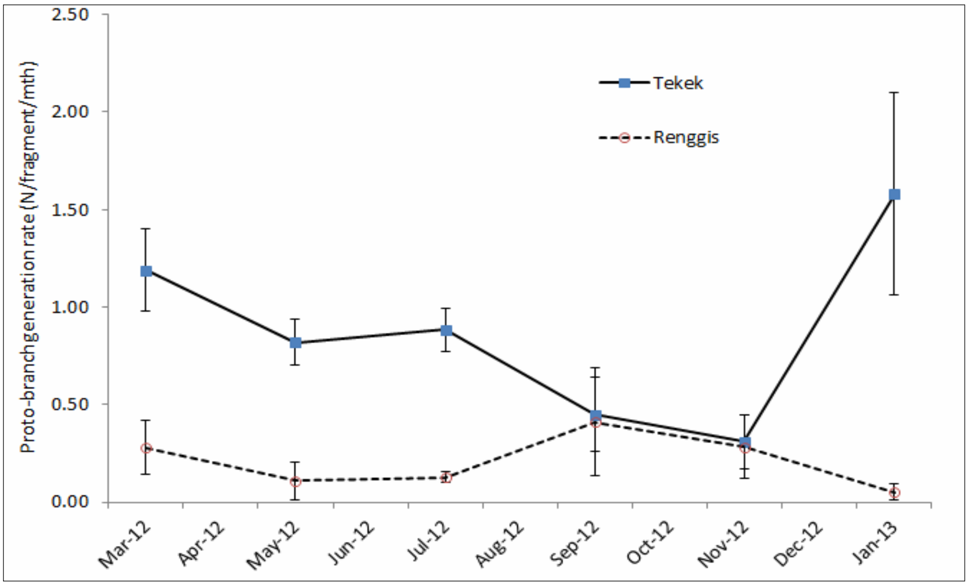

Figure 6. *Acropora formosa* proto-branch generation rates recorded throughout the study period at Tioman island, Malaysia.

Mortality, predation rates and survivals. The survival rates of *A. formosa* in the natural reef was significantly higher than the coral nurseries ($p < 0.05$) (Figure 7). All tagged coral branches at the natural reef were survived and remained healthy throughout the monitoring period. The transplanted coral nubbins were also performing well and healthy during the first six months, with mean survival rates of 94.64±1.03%. There was no significant difference in survivals between both sites during this period ($p > 0.05$). However, the survival rate in the nursery site decreased sharply between July to September 2012 ($p < 0.05$), before gradually become more constant in the following months ($p > 0.05$).

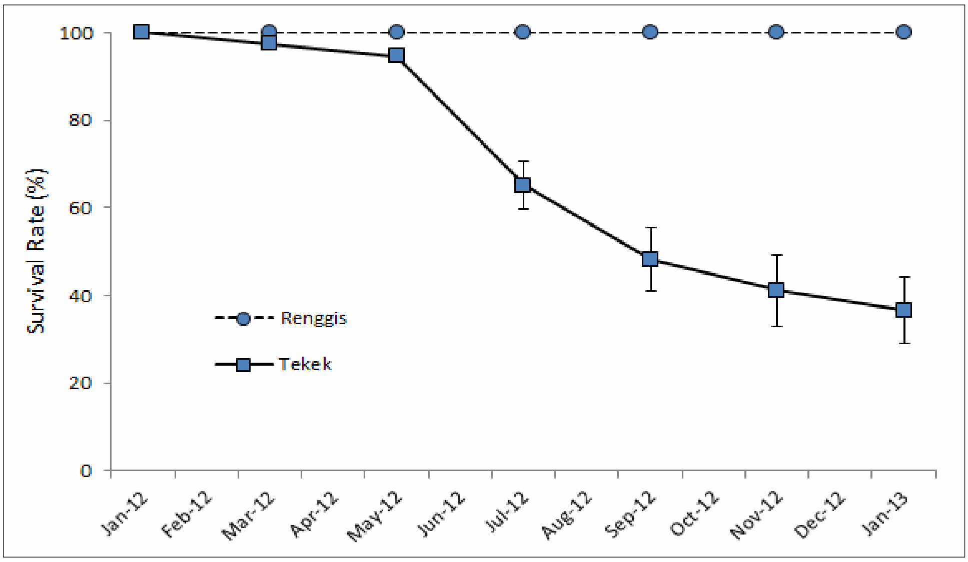

Figure 7. The survival rates of *Acropora formosa* nubbins at Tekek nursery and natural reef at Renggis, Tioman Island, Malaysia.

The higher mortalities recorded at the nursery site were mainly due to predation by fish and other corallivores. Majority of the dead corals are either totally gone or partly broken with bite marks. There were high variations in predation rates at the nursery site, while in the natural reef the rates were more constant (Figure 8). The difference probaby due to the low density of corals in the nursery, thus they were more exposed to predators compared with the dense and complex structure of the natural reef. Although there was no significant difference in predation rates between the nursery and the natural reef during the first two months ($p > 0.05$), the predation rates in the nursery increased sharply after that ($p < 0.05$). The predation rates were then gradually decreased to a level similar to the natural reef at the end of experiment ($p > 0.05$).

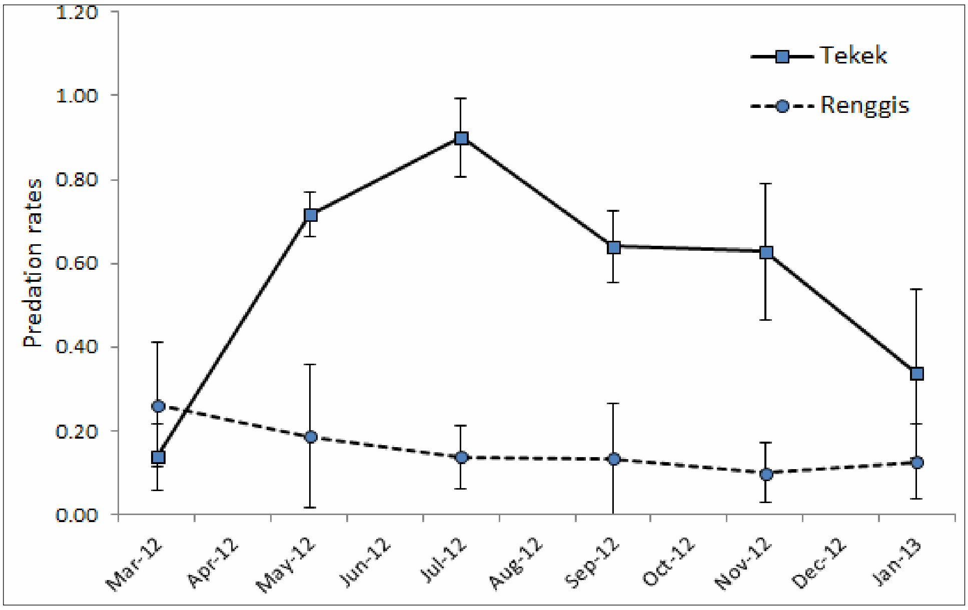

Figure 8. The predation rates of *Acropora formosa* recorded throughout the study period at Tekek nursery and Renggis reef, Tioman Island, Malaysia.

Discussion. The *A. formosa* growth rates recorded from the natural reef at Renggis was within the values reported from other studies (Table 2), indicating a healthy reef condition. The nursery site, however recorded maximum growth rates of 1.45±0.09 cm mth^{-1}, which was greater compared with the natural reefs in Renggis (this study), as well as other studies (Charuchinda & Hylleberg 1984; Gladfelter et al 1978; Harriot 1998; Crabbe & Smith 2002; Lirman et al 2010). *A. formosa* at both the nursery and natural reefs showed higher growth rates in March and November 2012, when the mean daily water temperature was also high. According to Hubbard (1997), the optimum range of water temperature for corals to grow is around 26-28°C. However, there was low correlation between temperature and growth rates.

Table 2

The *Acropora* sp. growth rates reported in other studies

Location	*Species*	*Growth rates (cm mth^{-1})*	*Source*
Tekek, Tioman, Malaysia	*Acropora formosa*	0.68±0.13 to 1.45±0.09	Present study
Renggis, Tioman, Malaysia	*Acropora formosa*	0.55±0.13 to 0.72±0.11	Present study
Salmon Bay, Australia	*Acropora yongei*	0.43±0.04	Ross et al (2015)
Virgin Island, USA	*Acropora cervicornis* *Acropora prolifera*	0.59±0.05 0.68±0.03	Gladfelter et al (1978)
Phuket, Thailand	*Acropora formosa*	0.51±0.15	Charuchinda & Hylleberg (1984)
Western Australia	*Acropora formosa*	0.44±0.16 to 0.66±0.13	Harriot (1998)
Sulawesi, Indonesia	*Acropora valenciennesi*	0.55±0.13 to 1.00±0.17	Crabbe & Smith (2002)
Okinawa, Japan	*Acropora formosa*	0.39±0.13 to 0.69±0.20	Okubo et al (2005)
Florida, USA	*Acropora cervicornis*	0.63±0.29	Lirman et al (2010)

Results from this study suggest that *A. formosa* in Renggis reef were not growing at their full potential. Since there was no significant drop survivals at Renggis reef, they could possibly be suffering from chronic or long term stress that suppressed their growth performance. Considering that Tioman Island is visited by almost 200,000 tourists annually (CCC 2005), the tourism pressure might have affected the health of Tioman's reefs. This could be an alarming message to the local authority to take necessary actions in the marine protected area of Tioman Island (Abelson 2006; RCM 2008; Rinkevich 2008).

The capacity of *A. formosa* to generate proto-branches showed almost similar pattern of variations as the extension growths. The generation and fast growth of proto-branches are essential for *Acropora* to form a branching reef. The three dimensional structure of the branching corals benefited the ecosystem by reducing wave actions and buffering the hydrodynamic impacts, thus preventing erosion (Madin & Connolly 2006). The geometry of branching *Acropora* colonies is capable of protecting the colony itself against excessive light in shallow waters by modulating light levels on the reef (Kaniewska et al 2008). In addition the complex reef structure also brings advantage for other reef inhabitants by providing shade and various types of micro-habitats. A high rate of proto-branch generation would also indicate high asexual reproduction through coral fragmentation, which is crucial for colony expansion (Lirman 2000) and for regeneration after storm destruction (Garrison & Ward 2008). Fragments of these broken proto-branches could then be beneficially utilized for coral transplantation (Soong & Chen 2003; Garrison & Ward 2008).

Results from this study may suggest that growth trend of *A. formosa* was possibly related to the annual monsoon seasons in Malaysia. *A. formosa* in Tioman Island recorded faster growth during March-April and October-November periods, where both were inter-monsoon seasons. During this period higher seawater temperature was recorded (Figures 2 and 3) and perhaps might have some influence on the coral growth. Results also showed decreased growth from May to September 2012 (Figure 3), which was within the Southwest monsoon period. The growth rates were increased again during the Northeast monsoon, from November 2012 to February 2013. Seasonal variations in extension growth and calcification of *A. formosa* have also been reported in other studies in Australia (Crossland 1981, 1984; Ross et al 2015), which also correlated with seawater temperatures. Thus it is important that coral transplant be conducted at times with optimum potential for their growth.

Although the transplanted coral recorded remarkable extension growth rate at 1.44 ± 0.68 cm mth^{-1} and demonstrated good growth potential, the survival rates at the end of experiment were significantly low. In addition, previous studies also recorded low survival rates of transplanted *Acropora* corals, with results showing that less than half of transplants managed to survived (Yap et al 1992; Okubo et al 2005). The higher mortalities recorded at the nursery site during this study were mainly due to predation by fish and other corallivores. Corallivorous fish such as the parrotfish (Scaridae) and butterflyfishes (Chaetodontidae) were commonly observed during the field survey. Previous studies have indicated that predation can limit the growth rate, competitive ability, and distribution of corals (Cox 1986; Pratchett 2005; Cole et al 2008; Francini-Filho et al 2008; Jayewardene et al 2009). The raised platform used in the present experiment has successfully deterred the creepy and crawling obligate coral predators such as the crown-of-thorns. However the setup cannot deter the highly mobile corallivorous fish, which should be considered in future coral transplant experiments.

Conclusions. This study has successfully documented the baseline data for *A. formosa* growth and its application in coral nurseries. *A. formosa* has excellent proto-branch regeneration and fast growth rates, thus can be suggested as a reef health indicator around Malaysia. The coral nursery work reported in this study was the first in Malaysia, which was managed by Reef Check Malaysia. With the current trend of increasing pressures on reef ecosystems, coral transplant is indeed an excellent method for active reef conservation and restoration. Nevertheless, continuous long term, systematic monitoring are needed in order to have greater understanding of the *A. formosa* growth and dynamics in the tropical coral reef ecosystems.

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