Overall growth rate of *Acropora sp.* at two dive sites on Koh Tao, Thailand

Research report

Linda Zijlstra

Leeuwarden, the Netherlands, May 2013

University of Applied Sciences
VAN HALL LARENSTEIN
PART OF WAGENINGEN UR

eco koh tao
Dive Enrich Preserve Discover

Overall growth rate of *Acropora sp.* at two dive sites on Koh Tao, Thailand

Research report

Supervisors: Dr. S. Chavanich
Mr. N. Cook
Mrs. J. Dowling
Mr. S. Dowling
Mr. B. van Wijk
Education: Animal management – Wildlife management

Linda Zijlstra 880728004
linda.zijlstra@wur.nl

Leeuwarden, the Netherlands, May 2013

Abstract

Coral reefs play a vital role in global ecosystem health and in many human economies: they provide habitat and act as nurseries for fish and aquatic invertebrates, provide barriers from storms and waves to protect sea coasts, breakdown excess nutrients and compounds, and help to regulate atmospheric gases. Yet, natural and anthropogenic threats such as pollution, run-off and tourism have led to an overall decline in live coral cover all over the world.

From October 2012 till January 2013, 50 fragments were measured on both Junkyard and Twins, two dive sites on the west coast of Koh Tao, Thailand. During weekly surveys, the coral fragments' length and health were measured, as well as the environmental parameters water temperature and horizontal visibility.

The obtained data from the coral length has been transformed to an overall growth rate with the use of the independent samples t-test. This resulted in the coral fragments of Junkyard, although smaller than those at Twins, have grown bigger than those at Twins, due to the fact that Junkyard has a higher – but not yet harmful amount of – nutrient input from sewage discharge, solid pollution, boat pollution and land run-off which causes the coral fragments to grow faster. When pollution at Junkyard will increase in the future however, this might lead to a change towards an algal dominated dive site which reduces light penetration and with that coral growth. Therefore it is recommended to stabilize or reduce pollution on Koh Tao.

Introduction

Coral reefs are one of the oldest, most diverse and most productive ecosystems on Earth, hosting 32 out of 34 animal phyla and a total of nine million species, while covering less than 0.2% of the ocean floor (Bryant et al, 2006; Reid et al, 2009) and less than three per cent of the Earth's surface (Kaiser et al, 2005). It has an annual primary production of $0.7PgCy^{-1}$, whereas rainforests, the most productive ecosystem on Earth with an annual primary production of $17.87PgCy^{-1}$, covers seven per cent of the Earth's surface but hosts only nine animal phyla. (Kaiser et al, 2005; Reid et al, 2009; Townsend et al, 2003)

"Coral reefs play a vital role in global ecosystem health and in many human economies: they provide habitat and act as nurseries for fish and aquatic invertebrates, provide barriers from storms and waves to protect sea coasts, breakdown excess nutrients and compounds, and help to regulate atmospheric gases" (Scott, 2008). Furthermore, more than 100 million people rely on coral reefs every day for their livelihoods in that it provides food, raw materials, medicines and activities that thrives economies, such as tourism (Scott, 2008; Brylske, 1999; Yeemin et al, 2006). It is estimated that the overall contribution of coral reefs to economies all over the world is approximately 375 Billion USD per year (West & Salm, 2003). This, however, has a major drawback: the first results of Reefcheck, presented in 2002 on the World Summit of Sustainable Development in Rio de Janeiro, indicated that from the more than 300 coral reefs surveyed in 31 countries, no single reef could be designated as pristine (Hodgson, 1999). Nowadays, reefs suffer from both natural and anthropogenic threats (Yeemin et al, 2006), with natural events causing most damage (Scott, 2008), but as they occur occasionally, reefs are capable of recovering from these disturbances (Reid et al, 2009; Scott, 2008). Anthropogenic threats in itself seem to have less impact, but as they occur on a daily basis, reefs are incapable of recovering and therefore suffer much more (Scott, 2008). Recent anthropogenic disturbances that have led to an overall decline in live coral cover are overfishing, bleaching events, pests & invasive species, tourism, pollution and run-off from rapid land-use change (Done et al, 2010; Garces, 1992; Reid et al, 2009; Weterings, 2011).

Coral growth

On Koh Tao, coral spawning takes place in March. Mature coral colonies, from about 10 centimetres in size – which corresponds to an age of approximately eight years – release their eggs, which have developed for six months, into the water where they ascend to the sea surface mixing with sperm and being fertilized. The planulae drift in the water column with the currents and tidal systems for a couple of hours to up to four weeks until they touch the reef where they settle on a suitable substrate, free from fleshy algae. Here it develops into a coral polyp. It is now that zooxanthellae come to live in symbiosis with the algae to gain maximum exposure to sunlight for photosynthesis. (Reid et al, 2009; Mann, 2000; Barnes & Hughes, 1999)

The coral polyps withdraw their tentacles during the day, so the zooxanthellae have maximum access to sunlight for photosynthesis as photosynthesis is required for the growth of corals, as illustrated by Goreau (1959) and Goreau and Goreau (1959): with experiments in the laboratory, growth rates of corals were much higher in the light than in the dark. Corals that were held in the dark expelled their zooxanthellae after a few weeks, although they remained healthy. If the corals were treated this way, they had much reduced growth rates of calcification, even in the light.

At night, coral polyps feed on plankton. This constant feeding allows corals to rapidly produce a hard calcium carbonate skeleton in the form of aragonite. (Kaiser et al, 2005; Reid et al, 2009) It can be assumed that the net expansion of coral is approximately 50% of the 10-100 kg $m^{-2}/year^{-1}$ $CaCO_3$ produced annually. In this case, coral grows 7-70mm $year^{-1}$ upwards every year. (Buddemeier & Smith, 1988) Zooxanthellae provide the required energy for this growth by the products of photosynthesis, i.e. Glucose ($C_6H_{12}O_6$) and oxygen (O_2). In return, the zooxanthellae obtain a safe home as well as nutrients from the waste created by the coral polyp. (Kaiser et al, 2005; Pinet, 2008; Reefcheck, 2012; Reid et al, 2009)

To get a better insight in coral growth rates of the coral reefs around Koh Tao, Surrathani, Thailand, this research involves measurements on the growth rates of *Acropora cervicornis* fragments over a four month time span on two dive sites on the west coast of the island Koh Tao: Junkyard and Twins. The main question to be answered during this research is:

What is the difference between overall Acropora growth rates on two different dive sites on Koh Tao – Junkyard and Twins – measured on coral growth per day and water quality?

For further explanation of influences on the growth rates at both Junkyard and Twins, the next research questions arise from the main research question:

- What are the water pollution problems that both dive sites have to deal with and how does this influence their water quality?
- How does the health of the coral fragments at both dive sites change from October 2012 till January 2013, measured on their colour intensity?
- What is the overall coral growth rate of *Acropora* on both dive sites?

Methods

Study site

Koh Tao is a well developing island in the western Gulf of Thailand that is a popular destination for scuba diving. The western side of the island has three main villages, whereas the eastern side is relatively unpopulated. Although the island occupies only $21km^2$ it has a population of approximately 1400 permanent residents and over 300,000 visitors annually, occupies over 40 dive schools and is responsible for 46% of all PADI (= Professional Association of Diving Instructors (PADI, 2013)) SCUBA (=Self Containing Underwater Breathing Apparatus (Reid et al,2009)) dive certifications in Thailand. It is located approximately 600 km south of Bangkok, 60km northwest of Koh Phangan and 70km from Chumphon province.

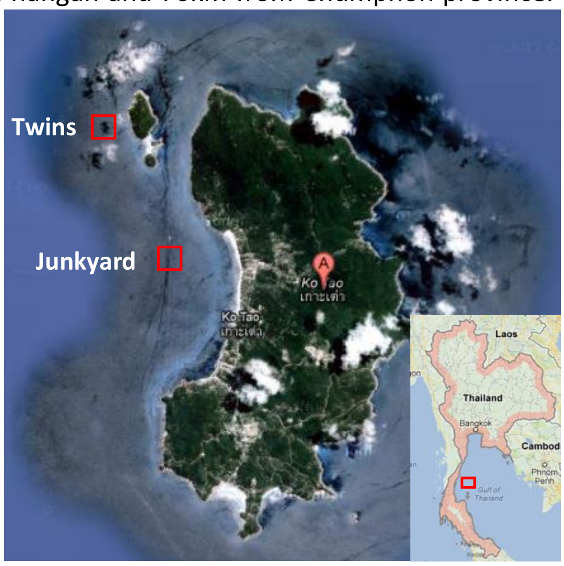

Figure 1. Study site. (Source: Google maps, 2012)

(Asiatika, 2012; Terlouw, 2012; Williams et al, 2012; Yeemin et al, 2006)

This research focuses on two out of 25 dive sites around Koh Tao: Junkyard (10°07’00.35”N & 99°48’43.18”E) and Twins (10°05’14.98”N & 99°49’23.41”E).

Junkyard is situated on the west coast of Koh Tao, approximately 500 metres from the coast of Mae Haad, the harbour of Koh Tao. It consists of a nursery and several junk structures that serve as artificial reefs and provide habitat and protection for fish and invertebrates. It is built with the purpose to train entry level divers and for courses with limited objectives requiring extensive natural reef environments. (Eco Koh Tao, 2012) (Figure 1. Study site)

“Twins is located off the west coast of the nearby Koh Nangyuan. A shallow fringing reef gives way to two to three large granite rock pinnacles aligned in an east to west formation. The site is also home to Buoyancy world, Koh Tao’s largest artificial reef and purpose built diver training site located north of the shallow pinnacle” (Scott, 2008).(Figure 1. Study site)

Research population

Corals are organically constructed, wave-resistant rock structures that are classified as animals and are created by coral polyps and zooxanthellae that depend on its own ability to produce its structure at or near sea level, i.e. till a maximum of approximately 42 metres deep. (Buddemeier & Smith, 1988; Drew, 1972; Pinet, 2008; Reid et al, 2009; Scott, 2008).

Acropora, a fast growing genus of hard coral (Wallace, 1999) present in Koh Tao’s waters in high numbers, dominates most undamaged shallow reef slopes across the Indo-Pacific region that offers intermediate to high water movement, high oxygen concentration, good light penetration and clear water (Done et al, 2010).

As *Acropora* provides food and shelter for organisms living with it, its resilience – i.e. “the ability of reefs to absorb shocks, resist phase shifts and regenerate after natural and human induced disturbances” (Pusch, 2011) – is important for the long-term maintenance of reefs and their mega diversity. However, *Acropora* is highly susceptible to unpredictable events such as exposure to intense illumination, hurricanes, storms, and elevated sea temperatures, causing it to bleach and die over large areas. This high sensitivity to anthropogenic and natural disturbances come from their narrow physiological tolerance ranges for environmental conditions, the interactions between key reef species that are susceptible to stress from pollution and “the effects of toxic substances that may be enhanced at high water temperatures that are common in coral reef environments” (Pastorok & Bilyard, 1985).

When coral is damaged it needs time to recover, which usually takes between 10-50 years, “providing that there are ample sources of diversity in surrounding areas and that no new disturbances occur during this time” (Scott, 2008). Even when coral is capable of recovering from bleaching events such as those in 1998 and 2010 – where 50% of the coral cover in Koh Tao’s waters was lost, from 71.87 ± SE 1.54% to 20 ± SE 6.30% after the 2010 bleaching event (Chavanich et al, 2012) – or other anthropogenic or natural disturbances, reproductive output may be absent or greatly reduced in the following one to two spawning periods, although reproduction is fundamental for reef growth (Done et al, 2010; Wallace, 1999; Wilkinson, 1998). After three to eight years of growth, *Acropora* is capable of reproduction (Wallace, 1999), which occurs through on site asexual budding; detachment, where polyps are detached from the coral colony and float freely to a new place, usually only over short distances, where they settle; and sexual reproduction for long-distance dispersal. It is generally only after settlement and metamorphosis into sessile polyps that zooxanthellae are required for growth. (Kaiser et al, 2005)

When coral reefs are degraded due to disturbances, “recruitment of new individuals – larvae or fragments – is essential to rebuild coral cover and diversity” (Done et al, 2010).

Successful attempts have been done on Koh Tao at both Junkyard and Twins to grow coral fragments of the genus *Acropora* in coral nurseries as an attempt to restore its numbers to levels prior to the bleaching events in 1998 and 2010 during which *Acropora* suffered most (GCRMN, 2010; Wilkinson, 1998). It is recommended to use *Acropora* in nurseries in the Pacific because of its fast growth rate, – up to 12 cm per year (Tunnicliffe, 1981) – high survival rate (50%-100%) and ability to occupy large areas (Harriott & Fisk, 1988).

Data sampling

Figure 2a. *A cervicornis* in PVC. (Dowling, 2012)

Figure 2b. Coral nursery (Dowling, 2012)

The coral nurseries on Junkyard and Twins are used for growing fragments of the critically endangered (Aronson et al, 2008) staghorn coral (*Acropora cervicornis)* that is found on the sediment and otherwise would not have had a chance of survival as there is no substrate available to settle. These fragments were collected and fit in polyvinylchloride (pvc) pipes (figure 2a) after which they were put in the nurseries (figure 2b) in the same area and depth as they were collected, as coral is incapable of growing in other environmental circumstances than where it has grown (Harriott & Fisk, 1988). After growing in the nurseries for six months to one year (Harriott & Fisk, 1988; Herlan & Lirman, 2008), the fragments have grown to such as size that they outcompete each other for space and thus are ready for transplantation onto the purpose built metal artificial reef structures. During transplantation, the approximately 150 (70 for Junkyard and over 80 for Twins) *Acropora* fragments were taken off the nurseries one by one and put in a tray, which was then carried to the artificial reef structure at a depth between seven and ten (Junkyard) and ten and twelve meters (Twins) where the fragments were securely fit in seven centimetre long metal pipes, approximately fifteen centimetre apart, making sure that the fragment would touch the metal frame, to ensure easier settlement by the coral fragment.

After transplantation, pictures were taken with a Fujifilm finepix EXR F550 to compare the fragments' position with the photos to get to know how many fragments were actually transplanted. After that, a table of random numbers (Kumar, 2005) was used to obtain 50 random samples (n=50) for each structure.

The samples were measured on a weekly basis to obtain their length (in millimetres) from the settlement of the coral fragment to the longest tip of the branch (figure 3) using a 30 centimetre flexible plastic ruler. Besides this, water temperature was measured every week with the use of a Mares Icon HD dive computer. Furthermore, water clarity was measured during every survey with the use of a 100 m reel: diver 1 held the reel and diver 2 swam away holding the end of the reel. When diver 2 became invisible, diver 1 pulled the line to stop diver 2 from swimming, after which diver 1 measured the distance on the reel. The CoralWatch coral health chart was used during the first and every fourth dive after that to keep track of any changes in the health of the coral samples' by comparing the colour of the slate with the colour of the coral. (Siebeck et al, 2008). This data was collected from October 2012 till January 2013.

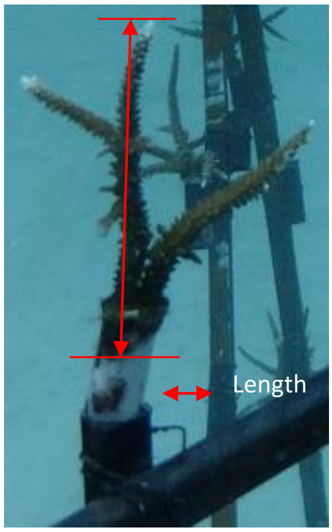

Figure 3. Coral measurements (Zijlstra, 2012)

Finally, a literature study was undertaken to obtain information about water quality. Results are obtained by the use of SPSS 20 where daily growth rate ± SE and independent samples t-test are calculated. To be able to execute these statistics, collected data has been transformed as can be seen in appendix 1.

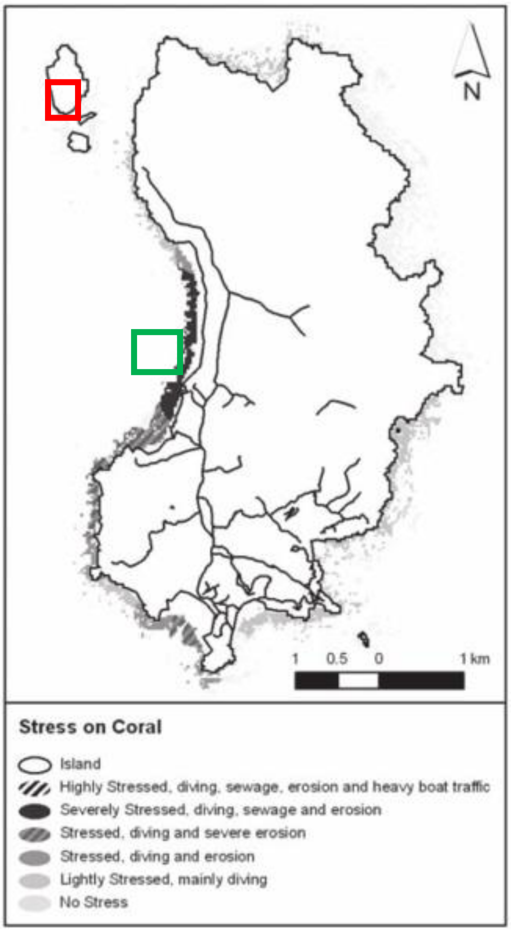

Figure 4. Stress faced by coral reefs on Twins (red box) and Junkyard (green box) (Weterings, 2011).

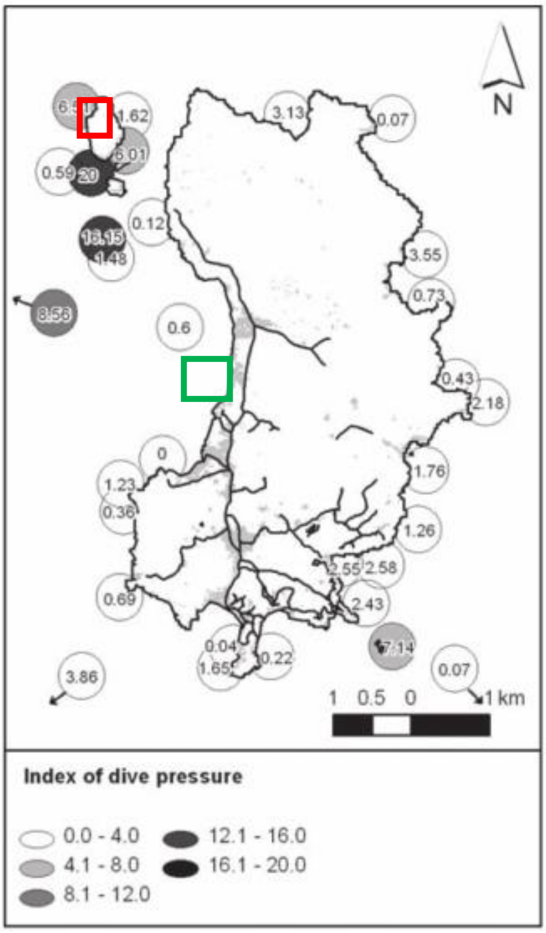

Figure 5. Dive pressure on Twins (red box) and Junkyard (green box) (Weterings, 2011).

Results

Water quality

Coral reef degradation is a major issue in Ban Don Bay – which includes Koh Samui, Koh Phangan and Koh Tao – for several decades and is mainly caused by recreation, deforestation, overfishing, global warming and pollution (Garces, 1992; Weterings, 2011). A study by Weterings (2011), showed that coral reefs of Mae Haad face high stress due to sewage discharge, scuba diving, erosion and high boat pressure (figure 4), whereas the coral reefs of Twins face highest diving pressure of the entire island (figure 5). These types of pollution lead to additional pollution of coastal waters, affecting coral reefs and its growth (Weterings, 2011).

Although sewage pollution does not seem to be a major problem in most areas (Hodgson, 1999), it plays a vital role in coral reef health in Southeast Asia (Edinger et al, 2000), including Koh Tao. Sewage pollution plays a major role here as well as in other provinces of Thailand as there is no proper sewage system and sewage is therefore discarded directly into the sea, affecting shorelines, coastal waters and coral reefs (Chou et al, 2002; Wong, 1998; Yeemin et al, 2006). Water pollution due to sewage discharge usually leads to an increase in the amount of nutrients on a reef and with that a shift in the benthic community towards an algal community occurs (Pastorok & Bilyard, 1985; Wong, 1998), which influences coral growth, reproduction and survival and thus their fitness (Quan-Young & Espinoza-Avalos, 2006).

Research by Schwieder (2012) indicates that, of three islands investigated, Koh Tao has the highest amount of dead coral covered with algae (35.09 ± 5.92%) and lowest live coral cover (39.14 ± 8.30%). Although other water quality parameters such as dissolved oxygen (6.39 ± 0.06 mg l^{-1}) and total suspended solids (11.02 ± 0.14 l^{-1}) seem to be in the normal range of values – i.e. 6.39 mg l^{-1} (saltaquarium, 2012) and 5-80 mg l^{-1} resp. (Delta, 2012) – values from particulate Nitrogen appear to be at the upper limit of the normal value range: 37.48 ± 2.10 µg l^{-1}, with normal values ranging between 0-45 µg l^{-1} (Coralshop, 2012). (Schwieder, 2012; Börder, 2012; Bennecke,

2012) They also conclude that "Koh Tao, although densely populated and visited by many tourists, profits from strong currents, masking the actual amount of pollution by tourism-generated sewage waters. Mae-Haad, a very broad bay with adjoining connections to neighbouring bays is better flushed and discharged nutrients are thus carried away more quickly. Hence, measured values are likely too low and not reflecting the actual degree of anthropogenic disturbance of reef waters" (Schwieder, 2012; Börder, 2012; Bennecke, 2012). It can therefore be assumed that – taking into account the high dead coral covered with algae and low live coral cover, indicating a phase shift – water quality around Mae Haad, where Junkyard is situated, is low when compared to other bays around Koh Tao, including Twins.

Finally, fishermen are slowly replacing their fishing boats by dive boats, but a general lack of knowledge and poorly managed tourism activities still leads to anchor damage and diver damage on the dive sites. Pollution and damage to coral reefs has already led to a 17% decline of live coral cover in a 5-year time span on Koh Tao. (Yeemin et al, 2006)

Coral health

Coral health in this research is indicated by the use of a CoralWatch coral health slate. This slate consists of colours that can be compared with colours of the coral fragments. The darker the colour, the healthier the coral fragment is, with a score of three or higher indicating a healthy coral fragment because the intensity of the colour indicates the amount of algae present in the coral fragment. (Coralwatch, 2012)

Figure 6 shows that corals investigated on Junkyard have undergone a change in colour intensity from 3 to 4 in the lightest colour whereas the fragments at Twins have undergone a negative change from 4 to 3. Figure 7 indicates that Junkyard again has undergone a positive change in coral health from 3/4 till 4/5. In the darkest colour, Twins has undergone a positive change as well, from 4 to 6, the maximum score a fragment can get.

Overall, the health of the fragments has increased, indicating that the transplantation of

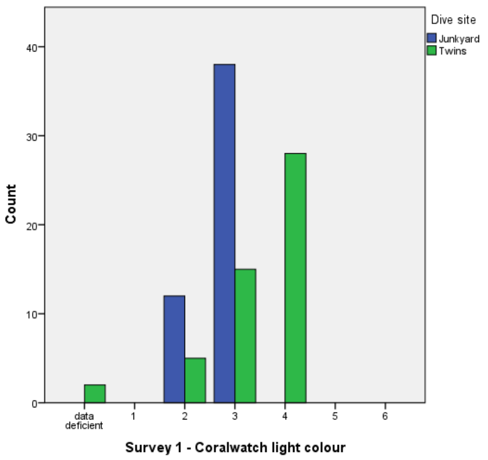

Figure 2a. First survey CoralWatch Light colour

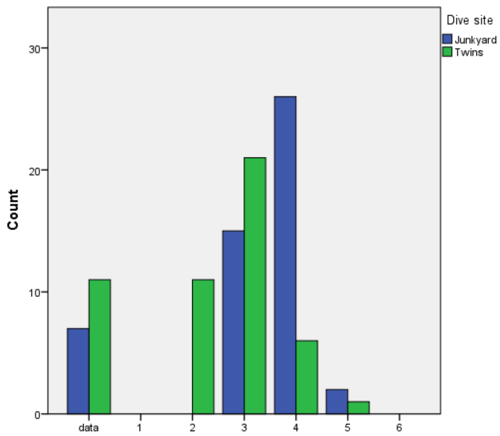

Figure 6b. Final survey CoralWatch light colour

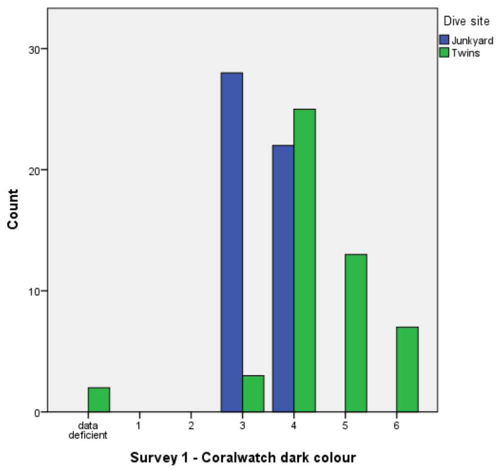

Figure 7a. First survey CoralWatch dark colour

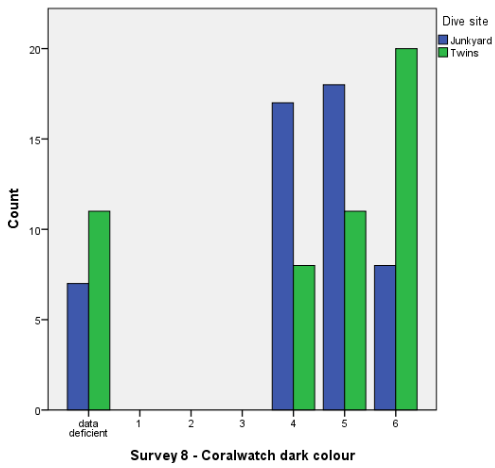

Figure 7b. Final survey CoralWatch dark colour

the coral fragments from the nurseries onto the artificial reef structures has been profitable for the coral fragments.

Coral growth

Although the coral fragments of Twins are significantly (sig = 0.026) bigger (251.66 ± 48.093 mm) than those at Junkyard (225.26 ± 66.989 mm), the coral fragments of Junkyard have grown more than those at Twins. The coral fragments at Junkyard have grown non-significantly (sig = 0.119) with 1.1110 ± 0.80697 mm per day whereas the fragments at Twins have grown an average of 0.8906 ± 0.57496 mm per day (figure 8).

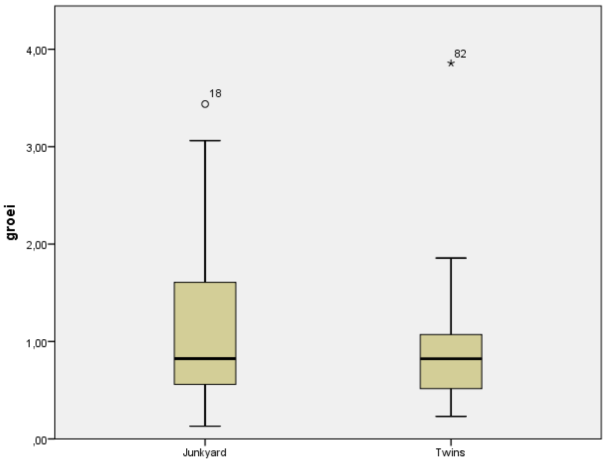

Figure 8. Coral growth

Discussion

“Originally, coral growth rates were studied by measuring selected coral heads and then re-measuring them at times ranging from annually to over a score of years later. Now, it is more common to measure coral growth rates by staining techniques or by measuring annual density variations revealed by x-radiography”. (Highsmith, 1979) Other studies, such as (Done et al, 2010), have made use of the space-for-time substitution by (Pickett, 1989) for long term research; or by estimating the skeletal weight of the coral from its buoyant weight in seawater whose density had been accurately determined (Davies, 1989), to obtain short term data with less than 24h time interval; whereas other studies are carried out in a laboratory under favoured conditions (Renegar & Riegl, 2005). Most studies that aim to understand the calcification mechanism to obtain growth rates, however, have followed the technique of (Goreau, 1959), which involves measuring the rate of incorporating Calcium into the skeleton (Davies, 1989). As neither the techniques nor the time is not available for this research, this research has measured the length of the coral fragments on a weekly basis.

Research by Edinger et al (2000) states that because of corals ability to consume terrigenous matter – corals are capable of removing sediment up to a rate of 150-250 mg cm-^{2}d^{-1} with a maximum speed of 14 mg cm-^{2}d^{-1}, mainly done by relatively low-cost polyp extension by uptake of water through the stodeum or tentacular movement instead of the more weak and high-cost ciliary action and mucus production (Pastorok & Bilyard, 1985) – it is capable of dealing with intermediate disturbance that can even increase its growth rates. This is consistent with the results of this research, where the coral fragments of Junkyard, which is more polluted due to a high sewage-, pollution- and erosion pressure, have grown more on a daily basis than did the fragments on Twins, which is not as polluted.
Other research however indicates that small changes in preferred parameters (high light intensity, stable sea surface temperatures, intermediate water movement and nutrient poor conditions) can cause significant changes (up to 50%) in growth rates: “High energy rates and high sedimentation can reduce growth, while changes in temperature, salinity and sedimentation can influence not only growth, but also diversity and abundance of corals” (Crabbe & Smith, 2005). Furthermore, Pastorok & Bilyard (1985) state that increased nutrient load on a reef leads to a shift in species dominance towards algae, which affects corals in two ways. At first, algae reduce light penetration and thereby affect coral nutrition, - growth and - survival as zooxanthellae are incapable of photosynthesizing. Secondly, increased production by algae often leads to an increase in benthic filter-feeders which outcompete corals for space.
Besides a reduction in growth rates, pollution can also lead to a major decline in the socio-economic value of a coral reef and its communities due to the loss of ecological services

(e.g. coastal protection), reef aesthetics (e.g. scuba diving and snorkelling) and it may lead to a permanent change in fishermen's lives due to a decline in fish catch. (Hernández-Delgado et al, 2008)

Conclusion and recommendations

Even though the waters around Mae Haad, where Junkyard is situated, are more polluted than those at Twins, the coral fragments of Junkyard have a bigger daily growth rate than the fragments of Twins. One reason for that is the increase of nutrients in the water that give the coral fragments the possibility to feed more and thus grow better. As research by Pastorok & Bilyard (1985) indicates that extensive pollution leads to a decrease in coral growth rates, and the goal of transplanting coral fragments is to preserve and restore the coral reefs around Koh Tao, it is recommended to give best efforts to stabilize or reduce the amount of pollution in Mae Haad bay in the future. With a future increase in nutrient input in these waters, it might be impossible to deal with coral reef conservation in this bay in the future if nothing is done.

Literature

Aronson, R., Bruckner, A., Moore, J., Precht, B., & Weil, E. (2008). *Acropora cervicornis.* IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. *[internet]* Available from*:* www.iucn.org (Accessed on October 22, 2012)

Asiatika (2012). Information about Koh Tao. Asiatika travel service Co, 2010-2012. *[internet]* Available from: *http://www.kohsamui-thailand.org/koh-tao.html* (Accessed on October 4, 2012):

Barnes, R.S.K., & Hughes, R.N. (1999). An introduction to marine ecology. *[book].* 255 pages. Blackwell Science, 1999. Third edition.

Bennecke, S., (2012). Effects of tourism on pelagic-benthic coupling and sedimentary properties in coral reefs in the Gulf of Thailand. Universität Bremen. (Unpublished master thesis).

Börder, K. (2012). Influence of tourism on organic matter concentrations, microbial activity and O2 availability in coral reefs in the Gulf of Thailand. (Unpublished Masterthesis)

Brown, B.E. (1996). Coral Bleaching: causes and consequences. Coral Reefs (1997) 16. Suppl.: S129-S138. Department of Marine Sciences and Coastal Management, University of Newcastle.

Bryant, D., Burke, L., McManus, J., & Spalding, M. (2006). Reefs at Risk. *[book]* 59 pages. World Resources Institute, Washington D.C. 2006.

Brylske, A.F. (1999). Marine Resource Management for Dive Professionals. PADI international, 1999.

Buddemeier, R.W. & Smith, S.V. (1988). Coral reef growth in an era of rapidly rising sea level: predictions and suggestions for long-term research. Coral Reefs 7. Pp. 51-56. Springer Verlag

Chavanich, S., Viyakarn, V., Adams, P., Klammer, J & Cook, N. (2012). Reef communities after the 2010 mass coral bleaching at Racha Yai island in the Andaman Sea and Koh Tao in the Gulf of Thailand. Phuket mar.biol.Cent.Res.Bull. 71. Pp. 103-110.

Chou, L.M., Tuan, V.S., Reefs, P., Yeemin, T., Cabanban, A., Suharsono., and Kessna, I. (2002). 7. Status of Southeast Asia coral reefs. In: Status of Coral reefs of the world. Pp. 123-152.

Cook, N. (2011). Photo coral nursery measurement. March, 2013.

Coralshop, (2012). Normal values Particulate Nitrogen *[internet].* Available from: *http://www.coral-shop.com/news.php?id=90*. (Accessed on December 13, 2012)

Coralwatch, (2012). Project AWARE specialty. Educational dvd. Retrieved on September 8, 2012

Crabbe, M.J.C. & Smith, D.J. (2005). Sediment impacts on growth rates of *Acropora* and *Porites* corals from fringing reefs of Sulawesi, Indonesia. Coral reefs, 2005. 5 pages.

Delta, (2012). Normal values Total suspended solids *[internet].* Available from: *http://www.deltaenvironmental.com.au/management/Lab_methods/suspended_solids.htm* (Accessed on December 13, 2012).

Done, T.J., DeVantier, L.M., Turak, E., Fisk, D.A., Wakeford, M., & van Woesik, R. (2010). Coral growth on three reefs: development of recovery benchmarks using a space for time approach. Coral Reefs (2010). 29:815-833

Dowling, S. (2012). Photos coral nurseries at Twins. February 2012

Drew, E.A. (1972). The biology and physiology of alga-invertebratesymbioses. II. The density of symbiotic algal cells in a number of hermatypic hard corals and alcyonarians from various depths. Journal of Experimental marine biology and ecology. Volume 9. Issue 1. Pp. 71-75

Eco Koh Tao, (2012). Use of Junkyard artificial reef. [internet]. Available from: *http://www.ecokohtao.com/proart.html* (Accessed on February 22, 2013)

Edinger, E.N., Limmon, G.V., Jompa, J., Widjatmoko, W., Heikoop, J.M., & Risk, M.J. (2000). Normal Coral Growth Rates on Dying Reefs: Are Coral Growth Rates Good Indicators of Reef Health? Marine pollution bulletin. Vol.40. No.5, Pp. 404-425.

Garces, L.R. (1992). Coral reef management in Thailand. ICLARM no. 891; also extracted from the Integrated Management Plan for Ban Don Bay and Phangnga Bay, Thailand (ONEBMSTE 1992).

GCRMN, (2010). Status of Coral Reefs in East Asian Seas Region: 2010. Global Coral Reef Monitoring Network, Ministry of the Environment & Japan Wildlife Center.

Google maps, (2012). Koh Tao, Thailand. *[internet]* Available from: http://www.google.nl/maps (Accessed on October 12, 2012)

Goreau, T.F. (1959). The physiology of skeleton formation in corals. 1. A method for measuring the rate of calcium deposition by corals under different conditions. Biol. Bull. Mar. Lab. Woods Hole 117. Pp.239-250.

Goreau, T.F., & Goreau, N.I. (1959). The physiology of skeleton formation in corals. 2. Calcium deposition by hermatypic corals under various conditions in the reef. Biol. Bull. Mar. Lab. Woods Hole 116. Pp. 59-75.

Harriott, V.J., & Fisk, D.A. (1988). Coral transplantation as a reef management option. Proceedings of the 6th international Coral Reef Symposium, Australia, 1988, Vol. 2, Pp. 375-379.

Herlan, J., & Lirman, D. (2008). Development of a coral nursery program for the threatened coral *Acropora cervicornis* in Florida. Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008. Session number 24. Pp. 1244-1247

Hernández-Delgado, E.A., Sandoz, G., Bonkosky, M., Norat-Ramírez, J., & Mattei, H. (2008). Impacts of non-point source sewage pollution on Elkhorn Coral, *Acropora palmate* (Lamarck), assemblages of the southwester Puerto Rico shelf. Proceedings of the 11th International Coral Reef Symposium, Ft.Lauderdale, Florida, 7-11 July 2008. Session number 18. Pp. 747-751

Hodgson, G. (1999). A global assessment of human effects on coral reefs. Marine pollution bulletin. Vol. 38. No5. Pp.345-355. Elsevier Science, 1999

Kaiser, M.J., Attrill, M.J., Jennings, S., Thomas, D.N., Barnes, D.K.A.,Brierly, A.S., Polunin, N.V.C., Raffaelli, D.G., & Williams, P.J.B. (2005). Marine ecology – Processes, systems and impacts. *[book]* 513 pages. Oxford university press, 2005.

Kumar, R. (2005). Research methodology – a step by step guide for beginners. *[book].* 322 pages. Table 12.3 (pp. 172). Sage Publications, London. 2nd edition.

Mann, K.H. (2000). Ecology of coastal waters with implications for management. *[book].* 355 pages. Blackwell Science, Inc, 2000. Second edition.

PADI, (2013). Professional Association of Diving Instructors. [internet] Available from *https://www.padi.com/scuba/about-padi/default.aspx* (Accessed on February 22, 2013)

Pastorok, R.A., & Bilyard, G.R. (1985). Effects of sewage pollution on coral-reef communities. Marine ecology – progress series. Vol.21. Pp 175-189.

Pinet, P. (2008). Invitation to Oceanography. *[book]* 626 pages, Jones and Bartlett Publishers, Boston. Fifth edition

Pusch, S. (2011). Effects of Tourism on herbivore community composition in coral reefs in the Gulf of Thailand. Ludwig-Maximilians Universität München (unpublished master thesis)

Quan-young, L.I., & Espinoza-Avalos, J. (2006). Reduction of zooxanthellae density, chlorophyll *a* concentration, and tissue thickness of the coral *Montastraea faveolata* (scleractinia) when competing with mixed turf algae. Limnol.Oceanogr. 51. Pp. 1159-1166.

Reefcheck, (2012). Eco diver intro. Educational dvd. Retrieved on September 4, 2012

Reid, C., Marshal, J., Logan, D., & Kleine, D. (2009). Coral reefs and climate change. The guide for education and awareness. *[book]* 256 pages. CoralWatch, the University of Queensland, Brisbane, 2009, PB,

Saltaquarium, (2012). Normal values dissolved oxygen content sea water *[internet].* Available from: http://saltaquarium.about.com/od/aquariummaintenancecare/a/Importance-Of-Dissolved-Oxygen-Levels-In-Your-Marine-Aquarium.htm (Accessed on December 13, 2012).

Schwieder, H., (2012). The effects of tourism on inorganic nutrient availability and benthic coral reef community composition in the Gulf of Thailand. Universität Bremen. (unpublished master thesis).

Scott, C. (2008). Koh Tao ecological monitoring program. *[book].* 107 pages. Save Koh Tao Community Group, 2008.

Siebeck, U.E., Logan, D., & Marshall, N.J. (2008). CoralWatch – a flexible coral bleaching monitoring tool for you and your group. Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008. Session number 16. Pp. 549-553.

Terlouw, G. (2012). Coral reef rehabilitation on Koh Tao, Thailand. Internship report. Vrije universiteit Amsterdam (2012).

Townsend, C.R., Begon, M., & Harper, J.L. (2003) Essentials of ecology, 2nd edition. *[book]*. 510 pages. Blackwell Publishing, Oxford, Uk.

Tunnicliffe, V., (1981). Breakage and propagation of the stony coral *Acropora cervicornis*. Ecology. Vol.78, No.4, Pp. 2427-2431. Proc.Natl.Acad.Sci. USA. April 1981

Wallace, C.C., (1999). Staghorn Corals of the World. A revision of the genus *Acropora*. *[book]*. 438 pages. CSIRO, 1999, Australia.

West, J.M., & Salm, R.V. (2003). Resistance and resilience to coral bleaching: implications for coral reef conservation and management. Conservation Biology. Vol. 17. Nr4. Pp. 956-957

Weterings, R. (2011). A GIS-based assessment of threats to the natural environment on Koh Tao, Thailand. Kasetsart J. (Nat.Sci.) 45. Pp. 743-755.

Wilkinson, C. (1998). The 1997-1998 mass bleaching event around the world. Ocean docs, 1998.

Williams, C., Beales, M., Bewer, T., Brash, C., Bush, A., Murphy, A., & Presser, B. (2012). Thailand. Lonely planet. 14th edition, published: February 2012. 814 pages.

Wong, (1998). Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean & Coastal Management 38. Pp. 89-109

Yeemin, T., Suthacheep, M., & Pettongma, R. (2006). Coral reef restoration projects in Thailand. Ocean and Coastal management 49 (2006). Pp. 562-575.

Zijlstra (2012). Photo coral measurements. Taken on October 24, 2012